08284

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Offshore Nuclear Powerplants A CEQ/Interagency Task Force Study

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1975

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PB 253 987

OFFSHORE NUCLEAR POWERPLANTS

A CEQ/Interagency Task Force Study

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U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET

1. Report No.

2.

3. Recipient's Accession No. 151416

4. Title and Subtitle
OFFSHORE NUCLEAR POWERPLANTS
A CEQ/Interagency Task Force Study

5. Report Date 1975

6.

7. Author(s)
CEQ/Interagency Task Force

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Council on Environmental Quality
722 Jackson Pl. N.W.
Washington, D.C. 20006

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

The major issues and considerations in a decision to deploy nuclear powerplants offshore in single and multiple units, including those that are unresolved.

17. Key Words and Document Analysis. 17a. Descriptors
Floating nuclear powerplants
Offshore powerplants
Energy

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement
NTIS

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page
UNCLASSIFIED

21. No. of Pages

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

PREFACE

The events of the past two years have sharply focused the attention of the United States on a whole array of difficult questions about our future quality of life and a prime ingredient -- energy: how much energy is essential to the economic viability of our Nation? How should we choose to supply this energy? What costs, particularly those involving environmental quality, are we prepared to bear? In the context of rising prices and constrained availability of energy and as self-sufficiency becomes a firmer policy target, the choice of feasible and attractive energy-producing technologies has expanded rapidly.

This rapid expansion accentuates a further question: what should be the Federal role during this period of technology development? A number of options are available, many very controversial, but certainly one is indisputable. The Federal Government has a mandate to collect, analyze, and disseminate information. Here, as in all areas of public policy, an informed citizenry is essential. Over the last several years, the Council on Environmental Quality in conjunction with several other Federal agencies has been engaged in several study efforts in response to these issues. This report is the culmination of one such study.

The siting of nuclear powerplants offshore has emerged as one of the promising yet disturbing technologies prime for implementation in the not-too-distant future. Offshore siting conceivably could overcome many of the economic and environmental difficulties of onshore siting, but for many it simultaneously raises the specter of safety hazards and severe environmental degradation.

In accordance with the concept that the involvement of Federal agencies with the development of new technologies should be "proactive" rather than reactive, this study was initiated in May 1973 as it became apparent that offshore nuclear powerplants were emerging as a serious candidate technology. All concerned Federal agencies gathered and formed working groups coordinated by CEQ to identify issues and associated information needs and availability. These working groups evolved a study outline for which Federal agencies were then assigned lead and/or support roles to best employ their expertise and concern for the issues identified. From this structure a draft report emerged which has been reviewed iteratively by these Federal agencies -- resulting in this final report.

That this report does not present a forum for totally informed decisions for the deployment of specific offshore nuclear powerplants at specific sites is not surprising and

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in fact is appropriate. The intent was to identify the major issues and considerations as the technology emerged -- thus the report herein. This report is not, nor was it ever intended to be, a statement of environmental impacts of offshore nuclear powerplants -- that, quite correctly, will result from the regulatory process for specific deployment applications. Rather, this report serves to typify the pervasive issues related to the decision to deploy nuclear powerplants offshore not only in the case of a single facility but also in the context of multiple deployment. It is not the intent of this study to condemn or applaud this new energy concept. This will be done in other forums. This study will have fulfilled its purpose if it simply points out to the public the major issues and considerations of offshore nuclear powerplants, including those that are as yet unresolved.

It hardly need be mentioned here that conditions in the energy sector have changed rapidly and dramatically since this study was undertaken two years ago. Considerable effort was made to keep the results up-to-date, but that may be impossible in the current environment. One important change has been the increasing uncertainty of future plans for offshore nuclear facilities. The schedule for the Public Service Electric and Gas Atlantic Generating Station has slipped several years further into the future while other customers for floating plants have failed to materialize.

Another important change at the Federal level has been the dissolution of the Atomic Energy Commission and the rebirth of its major components as the Nuclear Regulatory Commission (NRC) and the Energy Research and Development Administration (ERDA). This report maintains the old Atomic Energy Commission (AEC) designation. Readers, however, can generally substitute NRC for AEC within the report with no loss in accuracy.

The scope of the study is broad and the coverage is deep. For those persons interested only in acquainting themselves with the rudiments of offshore nuclear powerplants, Chapter I may be sufficient. For those interested in pursuing particular points more thoroughly, the body of the report and its appendices will be useful.

Chapters II and III, based upon significant inputs from the Federal Power Commission, the Department of the Interior (Bureau of Mines), and the AEC, present the role of offshore nuclear powerplants in the perspective of national energy supply and demand projections and economic feasibility. In Chapter IV and Appendices A and B the AEC describes one candidate offshore nuclear powerplant concept in considerable detail, including not only the construction and operation of these illustrative facilities but also the issues of safety and decommissioning. In Appendix C the National Oceanic and Atmospheric Administration (Environmental Data Service) presents a comparative discussion of the environment of the four coastal areas of the United States and a more thorough discussion of the environment in four East Coast regions that have been identified as a candidate for early deployment of offshore nuclear powerplants. Chapter V and Appendix E, based on significant contributions from the National Oceanic and Atmospheric Administration (National Marine Fisheries Service), the Environmental Protection Agency, and a contractor, Mathematica, Inc., present a detailed description of the direct environmental effects of this concept throughout its life cycle. Appendix C discusses the direct environmental effects of alternative technological concepts. Chapter VI and Appendix F, based upon work by Mathematica and the Department of Commerce (Bureau of Economic Analysis), present a discussion of the indirect environmental and economic effects of the floating nuclear plant concept throughout its life cycle. Chapter VIII discusses the interaction between offshore siting and other potential uses of the outer continental shelf and coastal regions. In Chapter VIII, based upon contributions of several Federal agencies (most notably the AEC and the Department of State) and Mathematica, the legal and institutional issues associated with the deployment of offshore nuclear powerplants are discussed in the context of various levels of governmental and public concerns. And last, but by all means of major importance, Chapter IX summarizes the current uncertainties relevant to the deployment of offshore nuclear powerplants and makes recommendations for future research.

In addition to the agencies mentioned above, several others have played an important role in this study: Department of Defense (Corps of Engineers), U.S. Coast Guard, Department of the Interior, Department of Commerce (Bureau of Economic Analysis), Department of Justice, and Federal Aviation Administration. Moreover, the participation of all of these agencies has been pervasive throughout the study and not limited to the above summary.

Russell W. Peterson, Chairman
Council on Environmental Quality

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APPENDICES

CHAPTER I

SUMMARY

Scope and Purpose

The purpose of this report is to explore the state of knowledge regarding the individual and multiple deployment of nuclear powerplants offshore and to point out where current understanding needs strengthening. The scope of the report is limited in several ways. First of all, the focus is primarily upon the interaction between the siting of nuclear plants offshore and the environment vis-a-vis onshore siting. Investigations of future nuclear power demands, the economics of offshore siting and safety have also been undertaken, but largely as a means for providing a framework from which environmental effects can be viewed.

Secondly, the report emphasizes a single offshore technology -- the floating nuclear plant (FNP)/fixed breakwater configuration -- and concentrates on a single geographical region, the Atlantic coast. Although there appear to be other feasible offshore technologies, the information presently available is insufficient to permit meaningful comparison. And while FNPs might in the future become economically attractive for the Pacific and Gulf coasts and for the Great Lakes, the Atlantic coast appears to be the most likely candidate for early deployment.

Perhaps the most serious limitation is the fact that while this report is generic in nature, the issues surrounding deployment of any single FNP facility are highly site-specific. Only after a particular site has been chosen can most issues be meaningfully addressed in the necessary detail. Issues not apparently important from a generic viewpoint could be central in specific instances and vice versa.

Thus it should not be inferred from any of the following discussions that deployment of individual FNPs must await resolution of any or all of the questions raised. Equally important, omission of a question or issue here does not imply that implementation should proceed without its consideration. In general, offshore siting decisions will be made on the basis of a broader view of the balance of economic, social and environmental costs and benefits than is portrayed here. This report shou not be interpreted as a universal evaluation of the offshore concept.

Overview

Examination of individual floating nuclear powerplants and their potential impacts on man and the environment leads the Council on Environmental Quality to the conclusion that there is reason for guarded optimism about their overall benefit. This optimism arises from the comparison of nuclear powerplants sited offshore with those sited onshore. An offshore nuclear powerplant is by no means a net benefit to the ocean environment, nor should it be expected to be. Compared to onshore plants, there appears, on the basis of currently available information, to be little significant difference in overall environmental acceptability.

This is not to say that the offshore concept can be recommended without qualification or reservation. For example, while it is possible to estimate the environmental, economic, and safety consequences of a single FNP facility, only the most rudimentary guesses can be made about the effects of a cluster or string of several facilities. The importance of clarifying our understanding of this question is apparent: substantial differences in the effects of limited versus large-scale deployment of FNPs would indicate a need for additional emphasis on longer range and more coordinated planning.

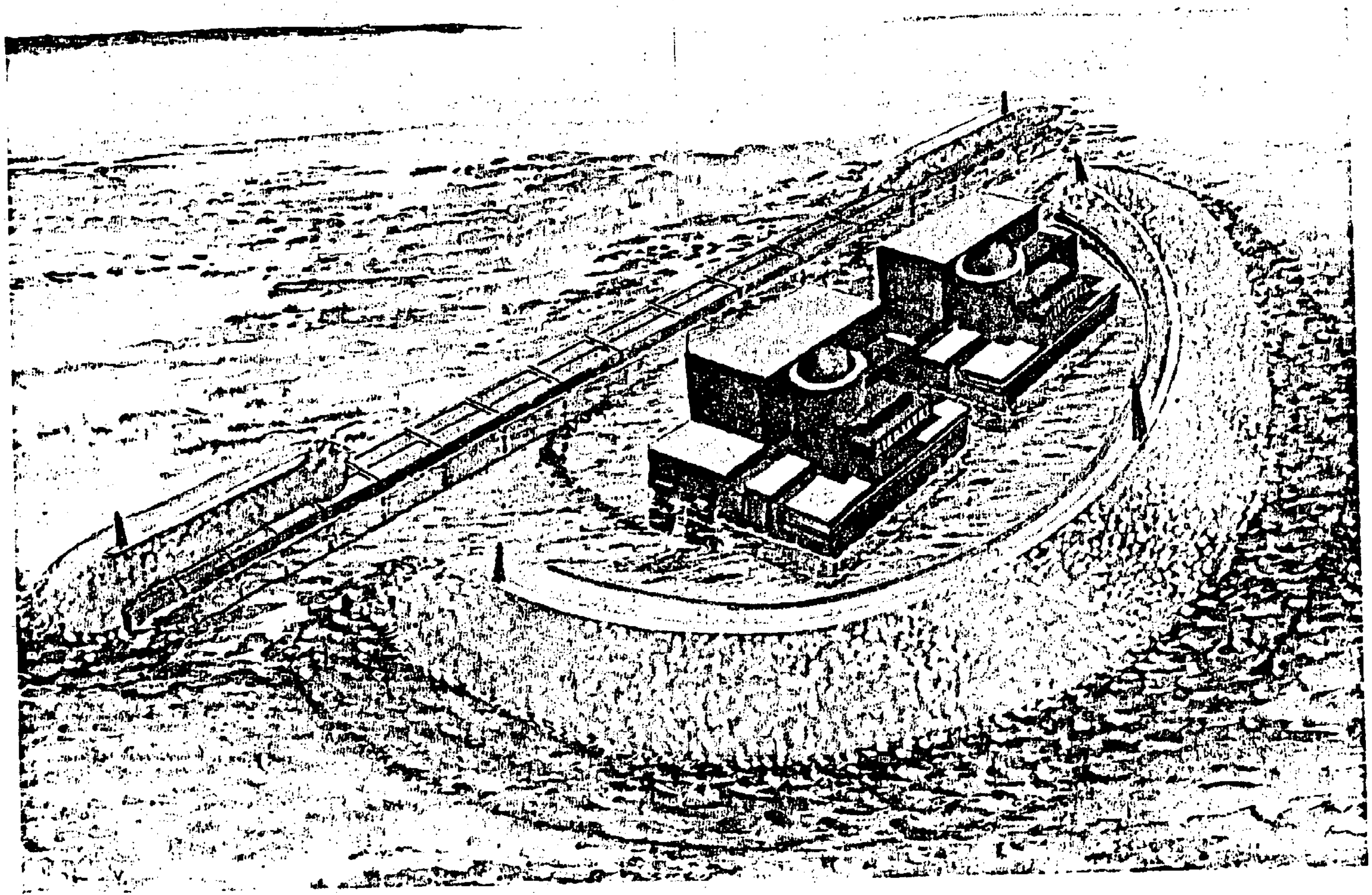
FNP Illustrated

Although several designs have been advanced for offshore nuclear power facilities, only one has been thoroughly developed and analyzed. The FNP has been designed by Offshore Power Systems and Public Service Electric and Gas Company for installation near Atlantic City, N.J. It is used for illustrative purposes throughout the report.

The PSE&G proposal (see Figure I-1) has the following components:

- A massive D-shaped breakwater
- Two barge-mounted 1,150-megawatt electric plants
- A five-cable transmission system
- An onshore construction and maintenance facility.

The breakwater (as designed for a water depth of 45 feet) would be the largest structure every placed in the ocean.



Atlantic Generating Station

Public Service Electric and Gas Company

Figure 1

- The breakwater itself would cover 15 acres of ocean bottom
- The perimeter of the breakwater would enclose an area at the mean low water level of roughly 0.12 square miles, 700 yards by 500 yards
- The breakwater would contain 6.5 million tons of aggregate, stone, and reinforced concrete, roughly the amount required for Hoover Dam
- Two FNPs in the breakwater would each generate 1,150 megawatts of electricity, enough to supply the 1972 power consumption of a city the size of Baltimore or of a state with a population as large as Maine's
- The steel barge hulls would be 378 feet by 400 feet by 44 feet high
- The reactor building would rise 174 feet and would be protected by a 34-foot steel wave shield
- Located 3 miles offshore, plants and breakwater would appear to be the same size as a 1,000-foot ocean liner viewed from 1/2 mile away.

The following sections very briefly summarize the content and findings of the chapters which follow.

Perspective: The Overall Nuclear Power Outlook

No matter what view one takes of future energy consumption -- high growth or low growth -- one is led to the conclusion that electric power consumption will continue to grow rapidly and that nuclear power will become an increasingly important source of electricity. The most conservative estimates show electricity growing from 25 percent of total energy consumption to well over one-third and electric energy generated by nuclear powerplants growing from 2 percent to over 50 percent of electric energy in the year 2000.

In absolute terms, the thermal energy generated by nuclear powerplants will grow (under moderate assumptions) from 0.4 quadrillion Btus in 1971 to around 40 quadrillion Btus in 2000 -- a one hundredfold increase. This growth translates into a need for 300 to 400 new nuclear powerplants of 1,150 MWe capacity. It is anticipated that nearly 40 percent of the growth (120 to 160 plants) will serve a strip 200 miles wide along the Atlantic coast. Roughly half of these are likely to serve the area from Maine through Pennsylvania, the other half south from Pennsylvania to Florida.

Why Offshore?

These energy estimates are not self-fulfilling. Nuclear power generation has consistently lagged behind projections. The principal reasons for these deployment lags have been siting problems and technical difficulties in construction and operation. Indeed, the difficulties are expected to grow because a higher rate of construction will dilute the existing pool of trained personnel and because relatively uncontroversial plant sites will become increasingly scarce.

Both of these factors are now causing utility executives to look seaward. Nuclear plants that can be mass-produced and then towed to offshore sites may mitigate the technical problems associated with on-site construction of onshore plants, even if present efforts to standardize onshore plants are successful. Perhaps most important, if offshore locations are less controversial than onshore, nuclear plants could be built nearer load centers and with less delay than usual.

It is difficult to compare directly the cost of an offshore facility with its onshore counterpart because in both cases costs are highly site-specific and relative costs can be expected to change significantly over the time it takes to actually emplace such a facility. At any given offshore site cost is a function of several factors: the region in which it is located (labor and transportation costs differ significantly), plant configuration (number of plants within a breakwater), water depth and design wave heights, distance from shore, composition of seabed, etc.

Despite the difficulty in making a comparison, total offshore costs appear to be perhaps 20 percent higher under current conditions (see Chapter III), but this amount could be pared significantly if manufacturing facilities where standardized FNPs will be produced reach full production volume, if the large uncertainty factor presently built into anticipated breakwater costs were reduced, and if cooling systems necessary to meet new EPA effluent guidelines for onshore plants proved more expensive.

Even today it appears that offshore plants would be competitive in the Northeast region. Combined with severe siting difficulties in that area, the relative costs suggest that offshore siting will be an economically viable alternative.

Given the need for electrical power, and the potential economic viability of the FNP concept, it is necessary to examine other considerations -- safety, environmental effects, other uses of the offshore areas, and the legal and institutional implications of offshore deployment.

FNP Safety

Although generalizations are presently difficult or even impossible, important observations related to offshore plant safety can be made.

The potential for accidents arising from events internal to the FNP is not much different from an onshore nuclear plant with one exception. Barge-mounted plants are subject to wave and tidal motion which, although limited by the breakwater and the mooring system, could affect the performance and reliability of important plant elements. Further, the FNP is located in a corrosive environment. Although the probability is low, these factors conceivably could combine to initiate equipment failure and exacerbate otherwise minor accidents.

A more important difference in safety is the potential for accidents initiated external to the FNP. Proper siting and barge and breakwater design can probably accommodate storms and waves safely and can offer protection against collision with large vessels -- even vessels containing hazardous cargo. The likelihood and effects of accidents which are unique to offshore locations are largely unexplored, however, and need to be more fully addressed. Simply lack of experience suggests that even more caution than is usually exercised with regard to the licensing of nuclear powerplants be applied to FNPs.

While severe meteorological conditions could require full or partial plant shutdown, the major question in these instances concern electric grid reliability rather than human health or ecological damage. Reliability becomes increasingly important with multiple deployment and could be a key factor in multiple deployment decisions. Security against military attack, sabotage, and acts of terrorism also becomes an increasingly important factor as multiple deployment proceeds offshore.

Environmental Effects

It is difficult to conclude definitively whether offshore plants are environmentally more or less desirable than onshore plants. To a large degree, the difficulty is due to site-specific variations. FNPs offer some environmental benefits relative to similar onshore plants in terms of land availability and heat dissipation, but they also present some unique environmental problems in terms of disturbance of the marine ecology. Offshore siting, however, offers an advantage over onshore in that it provides many additional feasible sites and thereby more flexibility to accommodate adjustments that can reduce environmental impacts and land use conflicts. A disadvantage is that the consequences of accidental releases, radioactive or chemical, are difficult to assess because of the complexity of the ocean and the offshore atmosphere as transport media.

The major indirect environmental effect of FNP deployment is probably the disturbance caused by large-scale granite quarrying and its transport. The local effects of quarrying could be magnified by clustering several FNPs in the same general area. With this possible exception, the indirect environmental effects of FNPs do not appear significant. Since offshore plants are unlikely to be a source of inexpensive energy, they are unlikely to induce rapid onshore industrialization.

Specific findings are contained in Chapters V and VI. Tables I-1 and I-2 list environmental effects in summary fashion. The tables do not attach relative magnitudes to the effects and thus cannot be used as a measure of relative impact. It should also be noted that in most cases, Federal and state regulatory programs will limit or prevent adverse environmental impacts.

Other Uses of Offshore Areas

The ocean along the coast is a valuable resource. Any use that forecloses other uses represents an additional cost to society -- an opportunity cost, in economic terms. Chapter VII discusses other uses and points out those that may be competitive. Table I-3 summarizes the findings and categorizes potential conflicts with other uses of the offshore areas. FNP site selection decisions should recognize these potentially competing uses. This is another consideration that becomes more important with multiple FNP deployment -- as well as with increasing use of offshore areas for other purposes. As the number and density

Table 3-1 A Summary of Direct Environmental Effects* (Onshore and Offshore) of FNPs

	Construction Phase		Operations Phase		Decommissioning Phase	
	Onshore Effects	Offshore Effects	Onshore Effects	Offshore Effects	Onshore Effects	Offshore Effects
NORMAL OPERATIONS	1. Damage to coastal and intertidal lands. 2. Temporary interruption of species migration. 3. Chemical effluents from materials prodcution and transportation. 4. Local noise pollution and aesthetic impacts. 5. Pressure for additional heavy duty roads or rail lines. 6. Water requirements for materials processes 7. Air pollution from dust and materials handling operations.	1. Dredging for transmission cable and site preparation may cause turbid conditions in the water, suspend toxic materials, bury benthic species, and result in siltation and disruption of the water column. 2. Emplacement of breakwater removes existing benthic habitat but provides new habitat causing change in local species mix. 3. Chemical effluents from the materials' emplacement. 4. Interaction of currents with the breakwater may lead to bottom scouring, current deflection and refraction leading in turn to: beach erosion, changes in species migration, nutrient composition, etc.	1. Maintenance dredging will have effects previously stated 2. Possible aesthetic effects from semi-permanent site including transmission lines and switching yard. 3. Loss of land for other uses.	1. Entrapment, impingement and entrainment of species in the cooling water intake systems reduces organisms' ability to sustain normal life processing. 2. Thermal effluents can lead to gas embolism and increased metabolic and respiration rates in marine species. Discharge velocities, and bottom scouring can lead to mechanical damage. 3. Discharge from the waste heat dissipation system may induce current patterns and modify water column characteristics, interfering with fish migration, etc. 4. Normal radioactive and chemical effluents. 5. The presence of the plant may have aesthetic impacts. 6. Though concentrating local biomass, the plant may interfere with commercial and sport fishing. 7. Maintenance dredging and breakwater repairs affect the biota.	1. Permanent layup of the FNP would result in loss of land and possible radioactive releases. 2. Mothballing would require dedication of dry or wet berthing space 3. Decommissioned landside facility may have alternative uses. 4. Long-term storage of radioactive materials presents environmental challenges.	1. Maintaining breakwater has effects previously discussed. 2. Dismantling or "filling-in" the breakwater could have effects that exceed its original construction. 3. Dismantling or removing the FNP will have environmental effects. 4. Permanent loss of thermal plume could damage attracted species. 5. Sinking the FNP would affect the environment.
ACCIDENTS	1. Chemical releases affecting the environment.	1. Chemical releases affecting the environment.	1. Fire or chemical releases affecting the environment. 2. Transportation accidents could involve sensitive inshore areas.	1. Release of radioactive materials affecting public health and safety and the environment. 2. Fires or chemical releases from inplant accidents or ship collisions with the breakwater. 3. Chemical releases associated with transmission cable accidents.	1. Radioactive releases from stored materials.	1. Radioactive chemical released during decommissioning or subsequent storage of FNPs.

*In many cases, impacts will be mitigated by existing Federal, State or local environmental standards or controls.

Manufacturing Facility		Breakwater	FNP
Construction	Operation	Construction	Operation
1. Transient pressure on local infrastructure -- schools, sewer and water, roads, etc.	1. Generation of air and water pollution and solid waste. Caustic and acid water effluents of particular importance.	1. Transient economic impact on adjacent shoreside communities. Probably of little consequence.	1. Attraction of energy intensive industries principal issue. Since FNP unlikely to be source of cheap power, probably unlikely to present problem.
2. Dredging and construction disrupts marine and wildlife habitats	2. Applies development pressures on local community but smaller in magnitude and more gradual than construction phase.	2. Raw materials production is the major environmental challenge, especially in case of granite quarrying. Cement and limestone generally less of a problem.	2. Onshore facility necessary much smaller than during the construction phase. Probably little or no impact.
3. Alternative land uses foreclosed on and off site due to subsidiary construction and aesthetic deterioration.		3. Construction and maintenance of inshore facility has little lasting impact.	
		4. Transportation of quarried materials may stress existing systems and require construction of additional transportation networks.	

Table I-3 POSSIBLE CONFLICTS BETWEEN FNPs AND OTHER USES OF OFFSHORE AND COASTAL REGIONS

Energy Resource Development	Recreation	Other Commercial Uses
1. Oil and Gas Production - Direct conflict between sites unlikely on Atlantic OCS - Possible conflict between FNP sites and vessel traffic and pipeline routing for oil and gas production. 2. Deepwater Ports - Direct conflict between sites unlikely - Possible conflict between FNP sites and port-to-shore oil transfer	1. Swimming - Effect of FNPs dependent on public perception of that threat to the beaches. 2. Tourism - Uncertain effect. FNP could become tourist attraction. 3. Fishing - Breakwater will concentrate sport fish, but exclusion area may prevent access. 4. Boating - Area of permissible operation will be limited by exclusion area.	1. Coastal Transportation - Probably little conflict with existing water transportation patterns, but might foreclose future shifts, particularly in the case of hazardous cargo. 2. Sand and Gravel - Possible conflicts in transportation. Dredging must avoid area of submerged transmission cables. 3. Manganese Mining - No conflict with deepwater mining operations. 4. Fishing - Exclusion areas may prevent access to fish concentrations near breakwater. Contamination of fish as a result of accident would have severe impact.

of various uses grow, "noncompetitive" sites become scarcer and siting becomes more difficult.

Legal and Institutional Considerations

As shown in Chapter VIII, the Federal process for licensing FNPs in coastal waters involves several agencies, each with separate responsibilities. This process is in need of streamlining to eliminate unnecessary duplicative efforts and Federal action is being taken to accomplish this. For all their present complexity, present Federal and state regulatory procedures provide many opportunities for interested parties to participate in the consideration of environmental, economic, and social questions. Any changes in regulatory procedure must retain this feature.

As for questions of international law, the United States clearly may deploy an FNP in its territorial sea (0 to 3 miles out). Further offshore on the high seas, an FNP would have to be constructed and operated with reasonable regard for other uses of the sea, and must not involve an assertion of sovereignty.

In Fine

Although this report is on balance guardedly optimistic about the overall benefit of FNPs, the acceptability of future FNP deployment will depend critically upon public appreciation of their relative merit. Thus, efforts in response to the information inadequacies noted in this report must provide answers to the satisfaction of the public in general -- not just the technician. Further, subsequent findings and the concerns of the public could introduce important issues for future consideration not identified in this report.

CHAPTER II

NATIONAL ENERGY OUTLOOK

During the 25 years from 1949 to 1974, U.S. energy consumption increased in all but three years. It increased from 31.5 quadrillion Btus to 73.2 quadrillion Btus -- a 3.2 percent annual rate -- while per capita energy usage rose at a 1.6 percent annual rate.

Experience over the 25-year period masks the accelerated growth in energy consumption during the more recent past, as shown in Table II-1. On both a total and a per capita basis, the 1965-70 growth rates far exceed those of earlier periods.

There are several reasons for the high growth rate of the sixties. In particular, 1961 to 1969 was the most prolonged period of economic prosperity of this century. The rapid rise in GNP during this period obviously contributed to the high rate of energy consumption. In addition, fuel prices declined relative to other prices. Fossil fuel per million Btus was priced at 35.0 cents

Table II-1

Energy Production and Consumption, 5-Year Intervals

	Energy Production		Energy Capita	
Year	Gross BTUs (quadrillions)	Average annual growth rate for 5-year periods	Gross BTUs (millions)	Average annual growth rate for 5-year periods
1950	34.0	-	223.2	
1955	39.7	3.1%	239.3	1.4%
1960	44.6	2.3	246.8	0.6
1965	53.3	3.6	274.4	2.1
1970	67.4	4.8	329.1	3.7

Source: Dupree, Walter G., Jr., and James A. West, <u>United States Energy Through the Year 2000</u>, U.S. Department of the Interior, December 1972.

in 1950, 33.3 cents in 1960, and 31.6 in 1970. These prices are in 1967 cents weighted by consumption. Two factors -- increasing income and declining relative prices -- account for much of the growth of energy consumption during the past decade.

Projections of Energy Consumption

Although understanding past energy supply and demand is essential to projections, these relationships are becoming less reliable as the basis for prediction.

Many new uncertainties have recently entered the energy picture as a result of the emergence of oil as an international political weapon, the rise of energy prices beyond experience, massive Federal expenditures and incentives for energy research and development, growing awareness of energy conservation, and, perhaps more important, an avowed national goal of energy self-sufficiency. The net effect of these factors is to invalidate previous energy projections and make current projections extremely uncertain.

Given the uncertainty implicit in any energy projections, three scenarios representing a wide range of possibilities are presented here:

- a "high" rate of growth, which assumes continuation of trends of the years prior to the 1973 Arab oil embargo.
- a "medium" rate of growth, reflecting recent increases in fuel prices but little or no change in Federal energy policies.
- a "low" rate of growth, which assumes large-scale conservation of energy and improvement of energy conversion efficiencies.

The three levels of demand are shown by consuming sector in Table II-2. The fuels required are shown in Table II-3. Because the projections are ranked in the order of total demand, individual components of the "low" cases are not always the lowest figures of the three levels, the "high" figures are not always the highest, and the "medium" do not always fall between the two.

Electric Power Projections

The preceding energy projections all foresee tremendous growth both in the generation and in the use of electricity, particularly electricity produced through nuclear power.

Table II-2

U.S. Energy Demand Projections, 1985 and 2000 1/ by Consuming Sector

(quadrillion Btus)

	1974	1985			2000		
	Actual	High	Medium	Low	High	Medium	Low
Household and commercial	14.6	19.0	14.3	12.9	21.9	19.9	16.7
Industrial	21.3	27.5	24.0	23.2	39.3	43.1	37.7
Transportation	17.7	27.1	22.8	20.7	42.6	32.3	25.6
Electric generation	19.6	40.4	44.7	38.7	80.4	68.7	40.8
Other 2/	--	2.6	--	--	7.7	--	--
TOTAL	73.2	116.6	105.8	95.5	191.9	164.0	121.0

1/ The "high" case is the same as in Department of the Interior, United States Energy Through the Year 2000, Department of the Interior, December 1972. The "medium" and "low" cases are Scenarios 0 and I as described in A National Plan for Energy Research Development and Demonstration: Creating Energy Choices for the Future. U.S. Energy Research and Development Administration, June 1975.

2/ Mainly synthetic natural gas.

Table II-3

U.S. Energy Demand Projections 1/ by Fuel

(quadrillion Btus)

	1974	1985			2000		
	Actual	High	Medium	Low	High	Medium	Low
Petroleum	33.8	50.7	47.1	34.6	71.4	70.5	40.3
Natural gas	22.3	28.4	24.0	26.5	34.0	15.4	22.8
Coal	13.0	21.5	19.6	17.0	31.4	32.4	21.4
Hydropower	2.9	4.3	3.4	3.4	5.9	3.7	3.7
Nuclear power	1.2	11.7	10.9	10.9	49.2	40.5	20.4
Geothermal	---	---	0.7	0.9	----	1.4	2.4
Other	---	----	0.1	2.2	----	0.1	10.0
TOTAL	73.2	116.6	105.8	95.5	191.9	164.0	121.0

1/ See note 1/ Table II-2 above

2/ Includes small amounts of shale oil

3/ Includes synthetic oil and gas

Since the 1880's, electric power loads have been growing at an average annual rate of about 7 percent, a rate that about doubles demands every 10 years. The growth is related both to population growth of about 1.3 percent each year and mounting per capita use. The relatively low cost of electric energy and the convenience, cleanliness, versatility, and reliability of electric equipment have been major influences on the continued increase in consumption.

Table II-4 details energy use for electric power generation for the three energy consumption levels. Although there is a wide range in terms of consumption, there is much less difference when consumption of electricity is seen in relation to total energy. In each case electricity composes from 34 to 42 percent of the total in 2000, compared to 27 percent in 1974. Even the low

Table II-4

Energy Resource Inputs for Electric Power Generation
(quadrillion Btus)

	1974	2000		
	Actual	High	Medium	Low
Coal	8.7	17.5	17.0	13.1
Petroleum	3.4	5.0	4.1	2.2
Natural Gas	3.4	2.6	2.0	---
Hydropower	2.9	6.0	3.7	3.7
Nuclear	1.2	49.2	40.5	20.4
Geothermal	---	---	1.4	1.4
	19.6	80.3	68.7	40.8
Electricity as a percentage of total energy	26.8	41.8%	41.9%	33.7%
Nuclear energy as a percentage of total energy	1.6%	25.6%	24.7%	16.9%
Annual growth rates of electricity 1971 to 200		5.4%	5.1%	3.8%
Nuclear power growth rates		18.0%	18.0%	16.8%

case, which aims at national self-sufficiency, and assumes very high levels of conservation, shows a high rate of electrification.

Note the large increases in consumption of electricity despite declines in projected electricity growth rates below historical levels. A decline in the growth rate of electricity consumption seems probable, particularly in light of recent price increases and the likelihood of further rises. It should be noted that the many authoritative forecasts of electric power made since 1970 have almost unanimously erred by overestimating future growth rates.

Table II-5 translates the electric energy consumption projections into estimates of electric generating capacity. Here, as in the previous table, the projected growth of nuclear power stands out. Even under the most restrictive scenario, nuclear generating capacity increases 20 times from 1974 to 2000. If the typical power facility of the next quarter century has a capacity of 2,300 megawatts, nearly 170 new nuclear facilities would have to come on line by 2000 at the low demand projection and over 400 at the high level.

At the national and regional levels, increasing reliance on electric energy is independent of the particular consumption level. Table II-6 shows regional requirements under assumptions of high overall energy growth rates. However, although the growth in generating capacity of all types is projected to be fairly uniform across the Nation, nearly 40 percent of new nuclear capacity added by 2000 is likely to serve a 200-mile wide strip along the Alantic Coast. Under any forecast level of total energy consumption, this projection translates into more than 100 nuclear generating stations. Half will probably be needed for Maine through Pennsylvania and the other half south through Florida.

Supply Constraints

The growing importance of nuclear power is a direct result of constraints on the use of other fuels -- relative price increases, environmental regulations, and availability of land and of the resources themselves. Table II-7 summarizes use factors for each major resource.

Table II-5

Installed Generating Capacity
(megawatts)

Plant	1973 Actual	2000 High	2000 Medium	2000 Low
Fossil Fuel[1]	339,000	720,000	584,000	387,000
Nuclear	20,000	960,000	864,000	403,000
Hydropower[2] & Geothermal	65,000	200,000	170,000	170,000
	424,000	1,880,000	1,618,000	960,000

---

[1] Includes steam, internal combustion, and gas turbine plants.

[2] Includes pumped storage.

Table II-6

Electric Utility Energy Requirements by Power Survey Regions
(thousand megawatts)

Power Survey Regions	1970	2000	Annual Growth Rate
Northeast	52.9	282.0	5.7%
East Central	44.0	249.0	5.9
Southeast	52.9	367.0	6.7
West Central	35.7	231.0	6.4
South Central	40.6	330.0	7.2
West	49.6	398.0	7.2
TOTAL [1]	275.7	1,857.0	6.6

---

[1] The totals are nearly identical to the Department of the Interior's "high" forecast.

Source: National Power Survey, Federal Power Commission, 1972.

Constraints on Use of Primary Resources for Electricity Generation

	Availability	Technology	Cost	Land Requirements	Environmental
Coal	Most abundant indigenous fossil fuel but frequently high in sulfur content.	Stack gas cleaning not yet accepted commercially.	Western low-sulfur deposits distant from Eastern demand centers.	Amount of land increases proportionally with generating capacity because of coal storage and ash disposal.	Use of high-sulfur coal limited by air quality regulations for sulfur and particulates
	Most reserves must be deep-mined.	Gasification, liquefaction, and solvent refining not yet developed commercially.	Eastern low-sulfur coal in demand for metalurgical use.	Mine-mouth locations necessitate large amounts of land for transmission line rights-of-way.	Strip-mining environmentally objectionable and reclamation costly.
					Acid drainage from mines must be controlled.
					Tall stack and bulk fuel handling facilities visually displeasing.
					Ash disposal becoming solid waste problem.
					Conversion to other forms of fuel transfers environmental problems from point of use to point of processing.

Table II-7 (cont'd)

	Availability	Technology	Cost	Land Requirements	Environmental
atural Gas	Very limited supplies	No problems	Low prices will rise rapidly.	Delivered by pipeline; no bulk handling facilities or ash disposal.	No problems.
	Imports disruptable		Imports expensive	Imports must be stored in tanks.	
	Earmarked for residential use				
ydro	Few remaining development sites.	No problems	Generally inexpensive	Water containment requires flooding large area.	Damming rivers or developing pumped storage sites often unacceptable.
	Pumped storage meets only peaking needs, net loss of energy.			Remote locations require large amounts of land for transmission line rights-of-way.	
uclear	Limited only by future availability of uranium. No problem at present.	Operational problems not completely resolved.	High capital costs, low operational costs.	Need exclusion area with suggested radius of 4 miles.	Disposal of wastes not resolved.
		Fuel cycle technology largely unproven			Large thermal effluents. Less visual impact than fossil fuel plants.

Coal

The most abundant and widespread indigenous fossil fuel, coal is potentially the most versatile. It can be converted to liquid and gas as well as to electricity. But coal is becoming more costly because of health and safety regulations and the remoteness of new deposits. Significant additional production appears several years away, and competition over current production has made it very difficult to secure future coal contracts. Further, storage of the coal and ash handling involve significant land and aesthetic costs.

Oil

When all geological forms -- shale and tar sands -- are considered, oil is potentially abundant. Nonfuel uses and environmental safeguards limit the domestic oil available at moderate prices, and reliance on international supplies involves national security issues. The technologies to develop some domestic supplies (shale and tar sands) are not fully developed and will surely lead to significant environmental challenges. Local storage facilities use large amounts of land and tend to be aesthetically displeasing.

Natural Gas

Available in larger quantities than in generally perceived under the current suppressed price situation, proven supplies of natural gas are limited domestically Reliance on international supplies raises national security questions. Content of sulfur and ash is ideal for meeting emission standards, but its natural volatility raises health and safety concerns in transport and use.

Hydropower

Hydropower is inexpensive and clean form of energy. However, additional domestic sites are few, and development may present significant environmental problems. But beyond that, hydropower in the form of pumped storage for peaking requirements is only about 65 percent efficient.

Nuclear

Supplies of nuclear fuel are currently viewed as secure, and nuclear energy produces little air pollution under normal operations. With recent and anticipated cost increases for the primary resources, nuclear fuel will become relatively cheap, particularly along the East coast. On the other hand, thermal water emissions are expensive to control. The issues of fuel reprocessing, long-range waste disposal, and nuclear safety present land-use, environmental, and health and safety problems. Further, capital costs are very high, and construction times have been long.

In general terms, the above factors -- or more correctly, their economic implications -- strongly influence the consumption projections that are presented. Nuclear power is an attractive solution to many current energy problems, not the least of which are of fuel availability and reliability. Several of the negative factors for nuclear power may be mitigated by offshore locations.

CHAPTER III

ECONOMIC ASSESSMENT OF OFFSHORE NUCLEAR POWERPLANTS

Although the ultimate decision to deploy a technology depends upon relative economic factors -- and the generalization certainly is true for offshore nuclear powerplants -- the possible "costs" must be weighed against possible "benefits." The evaluation must include not only the classical costs of capital operation and maintenance that accrue directly to the owner but also the costs that rarely take monetary form and most often accrue to society as a whole when left uncontrolled. Ecological and aesthetic considerations are prime examples.

This chapter addresses the conventional economics of the proposed floating nuclear plant, briefly compares costs of FNPs and onshore plants, and demonstrates how location offshore is constrained by the economics of water depth, distance offshore, meteorological conditions, etc.

Several concepts have been proposed for the offshore nuclear plant: artificial islands, bottom-seated plants with floating breakwaters, submerged and semisubmerged plants among them. (See Appendix D.) Many appear quite promising, but the one that has received extensive attention and is progressing twoard the implementation stage was proposed by Offshore Power Systems (OPS) and Public Service Electric and Gas (PSE&G) of New Jersey.

OPS has proposed barge-mounted nuclear powerplants moored permanently inside a massive breakwater or other barrier. PSE&G's proposed generating station consists of two OPS powerplants within a breakwater located north of Atlantic City about 3 miles out. It is depicted in Figure I-1. The floating nuclear powerplant (FNP) will be a complete electric generating station of standardized design built on a floating platform in a shipyard-like facility. Plant components and systems will be nearly identical to the recently licensed pressurized water reactor (PWR) nuclear powerplants'. The supporting platform will be a specially designed barge.

The breakwater discussed in this study is the one initially proposed by PSE&G for the Atlantic Generating Station (see Appendix A). It is roughly D-shaped, covers about 100 acres, and contains about 6.5 million tons of sand, gravel, rock, and concrete. The curved portion faces open ocean; it is about 3,000 feet long, 300 feet thick at the base, and 30 feet thick at the top and extends 64 feet above mean lower water (mean Low Water for the Atlantic Generating Station is approximately 45 feet). The straight section of the breakwater is approximately 2,140 feet long and is partially constructed of removable caissons to permit entry or exit of the FNPs. Both ends of the straight section are constructed of sand, rock, and dolosse. These dolosse are very large precast concrete forms (tetrapods) whose shape was selected to provide interlocking which minimizes their motion under severe wave attack.

The powerplants will have multiple high-voltage cables which will connect to the onshore electrical grid at a switching yard. In addition to the switching facility, the plant will also require a small area for materials and personnel, about 15 acres. Further, for the handling and processing of breakwater construction materials, a landside site of as much as 100 acres, with access to the ocean is required.

PSE&G has begun preliminary applications to site an OPS station about 3 miles out from Atlantic City. OPS has applied for a license to manufacture the barge-mounted plants at a facility on Blount Island, near Jacksonville.

Capital Costs

The capital costs presented here are based on the current concept proposed by OPS in accordance with the "Guide for Economic Evaluation of Nuclear Reactor Plant Design in the U.S." 531, NUS Corporation, January 1969. The figures were provided by the Oak Ridge National Laboratory CONCEPT code. The capital costs derive from the barge-mounted powerplant, the breakwater and mooring system, transmission lines, and shore facilities.

The Barge-Mounted Powerplant

The analysis assumes an FNP consisting of a barge-mounted pressurized water reactor powerplant of conventional design having a net electrical output of 1,150 megawatts, and using seawater for once-through flow of condenser cooling. Except for installation of the nuclear fuel, the FNP is assembled and functionally tested in a facility similar to a shipyard. The owners of the manufacturing facility are assumed responsible for designing, engineering, manufacturing, testing (without fuel), and preparing the plant for shipment. The overall capital cost of one barge-mounted powerplant is approximately $368 million. Component costs are presented in Table III-1.

Breakwater and Mooring System

An offshore breakwater large enough to protect a two-unit nuclear powerplant has never been built. The estimated costs were extrapolated from existing data on lesser enterprises.

Construction of the breakwater is estimated at about $180 million, as shown in Table III-2. The cost includes a 33% allowance for uncertainties in offshore construction costs. It consists primarily of the purchase, transportation, and placement of 5 million tons of rock at an upper limit of $18 per ton, including a 400- mile barge haul. and of 705,000 tons of reinforced concrete structures at about $100 per cubic yard (or $50 per ton), including materials and labor of onshore construction, transportation, and emplacement at the offshore site. Hauling the rock over 400 miles increases costs at a rate of $3 million per 100 miles.

Several mooring systems have been proposed for limiting horizontal movement of the FNP. The estimated cost is about $10 million per FNP, or $20 million for a two-unit station.

Transmission Lines

The most reliable, safe, and esthetic method of transmitting power to shore from an offshore station is by cable buried in the ocean floor. Buried cables are unaffected by violent storms, protected from collision with vessels, and hidden from view.

It is likely that each FNP will be required to have two independent three-phase circuits leading to an onshore switching station. A third circuit would be required for emergency use in case of damage or malfunction to one or the other cables.

Table III-1

Summary of estimated direct and indirect costs (F.O.B.)
of the floating nuclear powerplant (FNP)
(In millions of 1973 dollars)

Description of Equipment	Equipment and Materials	Labor	Total
Direct Costs:			
Structures and Barge	21.0	33.0	54.0
Reactor Plant Equipment	65.0	10.0	75.0
Turbine Plant Equipment	60.0	15.0	75.0
Electric Plant Equipment	17.0	9.0	26.0
Miscellaneous Plant Equipment	4.0	4.0	8.0
Total Direct Costs	167.0	71.0	238.0
Indirect Costs			
Contingency (10% of Direct Costs)			23.7
Factory Charges (20% of Direct Costs)			47.4
Engineering-Management (25% of Direct Costs)			59.3
Total Indirect Cost (55% of Direct Costs)			130.4

Table III-2

Estimated Construction Costs of 109 Foot Breakwater
for a Mean Low Water Level of 45 Feet*

Item	Cost (in millions of 1973 dollars)
Caisson	$ 7
Rock	98
Dolosse (armor)	30
Contingency	45
Subtotal	$ 180
Mooring Facilities	20
TOTAL	$ 200

*See Figure VI-7 for materials breakdown.

The two-unit station would require five three-phase cables. Buried cables in bays and alongshore are estimated at $1,325,000 per three-phase circuit-mile and underground at about $855,000 per circuit-mile. For 8 miles underwater and 3 miles underground installation, the total cost is about $66 million. (Although the OPS-PSE&G plant would be 3 miles offshore, cables are not routed to the nearest shore point.) An allowance of $1 million is made for each of five flexible connections at the FNP. As is customary for powerplant cost summaries, costs were not included for switchyard facilities and a step-up transformer. Thus the total estimated cost of transmitting power from offshore to the onshore switchyard is over $71 million.

Shore Facilities

A shore facility serving as a link for distribution of material and labor is needed during the construction and operational life of the plant. It may include a dock, service and supply vessels, storage yards and warehouses, concrete batch plant, offices, housing, and parking. Here the concrete caissons and breakwater armor (dolosse) will probably be made and the material, equipment, and personnel transported to the offshore site. Land costs, assuming 100 acres with 2,000 feet of ocean front at $1,000 per front foot, would be about $2 million. For development of the shore facility to support construction of the two-unit stations, a total of $6 million is estimated. Total capital costs for the two-unit station and support facilities are presented in Table III-3.

Table III-3

Estimated Capital Costs of a 2-Unit Floating Nuclear Generating Station

Item	Cost (millions of 1973 dollars)
Nuclear plants	$ 736.8
Breakwater and Mooring	200.0
Transmission cables	71.0
Onshore facilities	8.0
	$1,015.8

Parametric Variations in Capital Costs

The above costs assume a location 3 miles offshore, a depth of 45 feet, and a given transmission route, etc. These assumptions are clearly site specific. Sea bottom slope, population constraints on radiation dosages, design wave parameters, aesthetic considerations, alternative site uses, etc. all enter into selection of an FNP location. Consideration of the variables may result in requirements for higher breakwaters and longer transmission lines. The implications on capital costs are briefly discussed below.

What wave the breakwater must be designed to withstand depends on exposure of the site to storm-induced surges, to tsunamis, and to nonbreaking, breaking, or broke waves. These variables, in turn, depend on other factors.

Water depth at an offshore breakwater has a major influence on structural design because of the influence of depth on wave height. It also determines the convergence or divergence of wave energy and affects water currents. The breakwater must be designed to withstand the most destructive wave possible at the site. The relatively shallow water of the continental shelf directly limits maximum wave height.

Should the breakwater be constructed in deeper water and/or where the maximum wave height is increased, costs would, of course, rise. They are shown in Table III-4 for a breakwater of two heights. The cost of rock more than doubles,

Table III-4

Estimated Construction Costs of 109-Foot and 134-Foot
High Breakwaters at 45 Feet Mean Low Water Level
(millions of 1973 dollars)

Item	109 Ft.	134 Ft.
Caisson	$ 7	$ 10
Rock	98	206
Dolosse (armor)	30	37
Contingency	45	84
Subtotal	180	337
Mooring facilities	20	30
TOTAL	$200	$367

the reinforced concrete structure costs increase by $10 million, and mooring costs are half again as much. Including a 33% contingency factor, the breakwater cost increases to about $367 million. Thus a 23% increase in height raises construction costs by nearly 84%, suggesting that breakwater costs can vary by more than the breakwater height raised to the second power.

Height significantly affects cost because the volume of material and labor increases by more than the square of the height. Other factors that affect the bulk of the breakwater are the plane and vertical shape and slope of the sides. The shape is determined when the effect of wave attack is minimized, the configuration requirements of the contained floating nuclear powerplant are met, and the breakwater can withstand large vessel collisions. The side slopes are simply a function of size and density of armor units and construction methods.

There is a general trend toward increased use of dolosse instead of quarry stone. Dolosse can be uniformly produced in a given size, whereas it is difficult to quarry equally large stones of nearly uniform size. Dolosse have better stability characteristics than quarry stone; this means that lighter-weight armor units may be used or that side slopes of the breakwater may be steepened. Steepening the side slopes reduces the volume of material required for a given structure (hence, its cost) and reduces the required reach of handling equipment, for example, the floating cranes. Development of denser concrete may further reduce armor unit size and total weight, which would reduce the required capacity of handling equipment.

Bottom material at a proposed offshore breakwater site is also significant in determining the breakwater design. Soft bottom materials may not adequately support a breakwater unless a sufficient filter blanket is provided, and granular bottom materials may be eroded or scoured by strong water currents.

Assuming a constant water depth, the major cost resulting from varying offshore distances is the cost of the plant-to-shore electrical transmission system. Although the distance from shore may be less than the 3 miles assumed here, it is likely that public or regulatory interests may require longer plant-to-shore distances. Technologically, the limit for underground alternating current high-voltage power transmission without intermediate equipment stations is about 20 miles. This represents an additional 9 miles of sea floor installation for each of the five cables discussed above. The additional 45 miles of three-phase circuits for a two-unit station costs about $60 million, or $26.1 per kilowatt (electric).

Figure III-1 illustrates the relationship of distance from shore with total capital cost per kilowatt (electric).

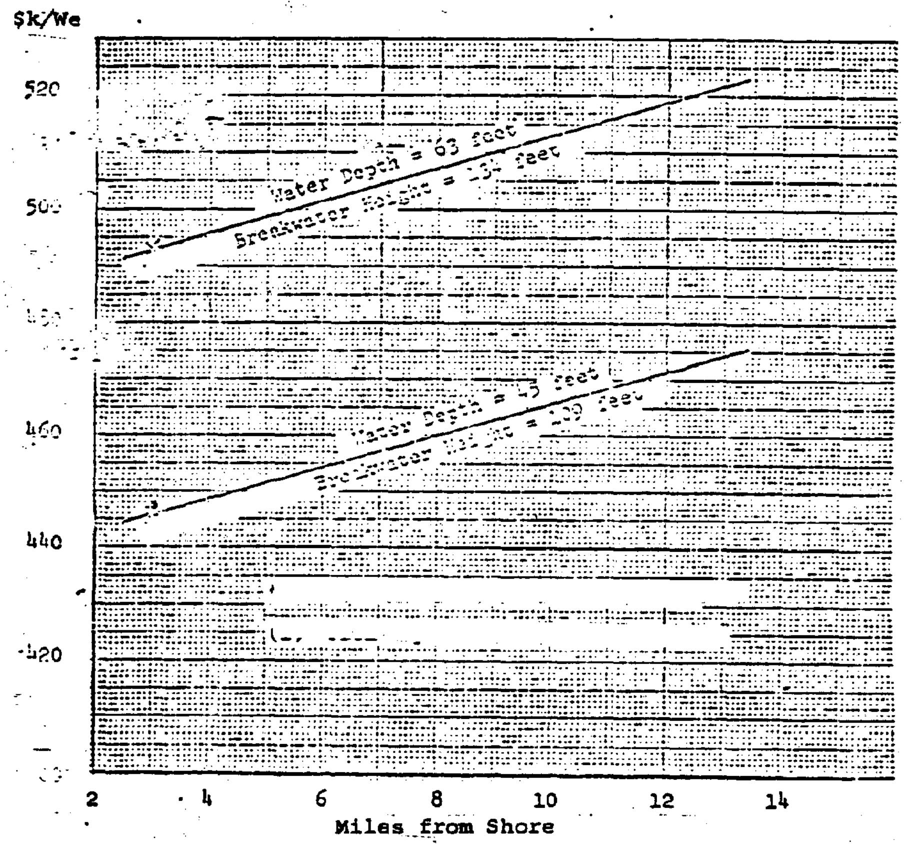


Figure III-1. Capital Costs of a 2-Unit Floating Nuclear Generating Station as a Function of Distance Offshore.

Offshore versus Onshore Capital Costs

Relative Plant Construction Costs

Floating nuclear powerplants are economically attractive from several viewpoints. One of the most favorable aspects is the ability to build FNPs in a facility similar to a shipyard. The cost savings are similar to those generally found for any item of mass production.

Onshore powerplants have always been constructed as custom, one-of-a-kind entities. For each facility, different laborers and craftsmen were recruited, trained, and organized to carry out the construction peculiar to the plant and site. The problem is particularly acute in construction of nuclear powerplants where construction must meet very stringent standards and specific site characteristics. Wages and turnover are generally higher in the construction industry than elsewhere and productivity lower. These problems have been reflected in the long slippages experienced in nuclear plant construction schedules and in the operating difficulties frequently experienced after a plant is brought on line.

The FNP avoids many of these problems and costs. Current planning is that powerplants will be built on shallow-draft floating platforms using assembly line procedures. Construction of FNPs would be amenable to the construction techniques of shipyards, where there is a permanent base of shops, equipment, and materials. A fixed construction site using a mass production approach is expected to stabilize the skilled labor force and increase efficiency as individual craftsmen learn from repetition.

Construction of power stations in a factory setting should improve quality of workmanship. Recent delays in bringing land-based power stations into full commercial operation have been found to result from poor quality work and inadequate inspection during construction. Quality control in the factory setting can be more rigorously and effectively administered than at a field construction site.

In addition, the reduced labor requirements and use of a well-equipped manufacturing plant at a site having a favorable climate for a year-round activity should permit more rapid completion of an operable floating power station than for current land-based construction. Moreover, shorter construction time will result in lower capital costs because of reduced cost escalation due to inflation, reduced total interest charges on borrowed money, and earlier revenue from operations. With inflation and interest each at about 8 to 10%, even modest reductions in construction time could significantly reduce total capital costs.

According to the AEC, efficiency in a shipyard is equal to a reduction of 2 man-hours per man-day in a typical construction situation. Shipyard efficiency for two barge units, then, would save $52 million if 1 man-hour per kilowatt (electric) costs $13 million. In addition, when manufacturing operations reach the planned output level of eight FNPs per year, this efficiency will shorten elapsed construction time by at least 1 year. At that level the capital investment in two units would decrease by about 10% of the direct costs, or around $50 million. Thus an assembly line approach to plant construction could save $100 million for a 2,300 megawatt facility.

Relative Cost of Thermal Emissions Control

In a nuclear powerplant only about 31 percent of the heat released in the boiler is converted into electrical energy. The unused heat energy is discharged through the turbine condenser cooling water.

Condenser cooling water has often been handled on a "once through" basis -- in other words it is drawn from a nearby water body, pumped through the condenser, and then discharged directly to its source. Large volumes of water are involved -- about 1,550 cubic feet per second in a modern 1,000-megawatt fossil fuel plant -- and the discharge stream is from 6° to 17°C warmer than the inlet stream. This temperature differential combined with a high flow rate is generally injurious to life in the receiving inland water body.

Because of the increasing difficulty in finding natural bodies of water that can accept waste heat, new generation facilities are using cooling ponds and cooling towers. Further, EPA requires closed-cycle cooling systems for all powerplants, unless a specific exemption is granted. Thus by 1980 the great majority of new inland generating facilities will employ some form of closed-cycle cooling system.

Siting an offshore powerplant is a way of using the heat assimilation capacity of the ocean and its subsequent heat rejection capability. Theoretically, the cooling capacity of the ocean over the continental shelf is several orders of magnitude greater than the total waste heat load expected to result from all electricity generation in the United States over the next century. And although complete and instant mixing obviously cannot be achieved, the much larger heat sink provided by the oceans will mitigate the plant's thermal discharge.

The thermal capacity of the ocean is distinctly valuable because offshore plants may not have to install cooling towers or acquire costly land for cooling ponds. For the proposed two-unit station off New Jersey, the savings on cooling towers alone range from $30 to $120 million ($13 to $52 per kilowatt electric, depending on the type of tower. The higher costs in this range apply to water-deficient areas where dry cooling towers are required.

Relative Land Costs

As discussed in Chapter II, a nuclear generating station requires 300 to 350 acres of land for the generating facilities and additional land for the exclusion zone. If the acreage does not front on a waterway, considerably more land must be added for cooling ponds. Often the same general features that make a large site ideal for a generating plant also make it well suited for other types of industry. Large industrial facilities ususally require similar acreage with provision for future expansion near highway, railroad, or barge transportation. Acquisition of potential generating plant sites is growing more competitive and expensive. The rising demand for recreational use of the waterfront has increased competition among recreation project, industrial, and powerplant developers for the same space.

Nuclear powerplants are generally remote from the population centers that they serve. Although distance tended to reduce land costs somewhat at the generating site, additional land had to be acquired for transmission line rights-of-way. Thus, lower per acre costs for the plant was negated by higher acreage requirements for the longer transmission distance. With projected population increases along the coasts and waterways, competition for sites with available water supplies at acceptable distances from load centers is expected to boost land costs for future inland nuclear powerplants.

Offshore plants are not nearly as constrained by land availability and cost. A landside support area of about 100 acres is necessary during the breakwater construction phase, only about 15 acres permanently. Thus there is roughly a 300-acre land advantage that accrues to offshore plants. If the price of land is assumed to be $20,000 per acre, the savings is $6 million.

Relative Safety Costs

The cost disadvantages of offshore siting are associated with the need to protect the powerplants from hazards not experienced on land and with the uncertainties generally associated with application of new technologies. The most obvious and largest single additional cost is for the breakwater and the mooring system.

The problems inherent to transporting large volumes of quarried rock and scheduling placement of materials to take advantage of acceptable weather conditions appear one of the major challenges of breakwater construction. Construction in open waters involves greater difficulties than the relatively straightforward site preparation work at a land-based plant. The contingency allowance of 33% is very conservative in view of the risks and uncertainties in offshore construction.

Before the FNP is emplaced inside the protective breakwater, it must be towed through open seas. During this trip from the manufacturing plant, it is vulnerable to a number of hazards. The risk takes economic form in insurance premiums and added design features to make it seaworthy. Other features are added to protect the FNP after emplacement. Special security and protective measures must be developed to cope with the potential threat of sabotage, for example, and these costs must all be included.

One of the least quantifiable disadvantages of offshore siting is the uncertainty of transmitting power ashore. High voltage (345 KV) submarine cables would be buried under the ocean floor. Considerable research has been performed on submerged high voltage cable, but the only directly applicable experience is a connection across New York Harbor between PSE&G in Jersey City and Consolidated Edison Co. in Brooklyn. The length of the tie is 6 3/4 miles; 6,600 feet uses copper conductors in an oil-filled pipe for the harbor crossing.

The pipe was trenched into the river bottom and back-filled with sand. However, the fact remains that such high-voltage lines have not yet been completely proven. The risk and additional development must also be considered costs of offshore siting.

The technological uncertainty may be offset somewhat by the fact that offshore nuclear powerplants will probably be permitted to locate nearer the load centers than would onshore plants. Based primarily upon population dosages, a recent study[1/] suggests that land-based reactors may have to be sited 30 to 50 miles from very large population centers while offshore locations may satisfy remoteness requirements only 15 to 20 miles from population centers (see Chapter IV). Proximity will probably cut costs for onshore transmission, at least partially offsetting the additional costs of offshore transmission.

Overall Comparison

Construction costs were estimated for onshore nuclear powerplants using once-through cooling in four industrial areas: Philadelphia, Atlanta, New Orleans, and Dallas. The estimates are based on costs of materials and labor over the past few years in order to show a typical plant completed in 1973. Labor productivity at each location was averaged out at 8 man-hours per kilowatt (electric). The 1973 costs of a single-unit, 1,150-MWe pressurized water reactor station near Philadelphia are compared to a single-unit FNP in Table III-5. The only significant difference is the 45% higher labor cost associated with wage and fringe benefits available in field construction.

Table III-5

Capital Costs of 1,150 MWe Nuclear Powerplant
Onshore and Offshore
(in thousands of 1973 dollars)

	Equipment		Labor		Total	
	Onshore	Offshore	Onshore	Offshore	Onshore	Offshore
Direct costs						
Containment structure and facilities	$22,087	$21,000	$34,763	$33,000	$56,850	$54,000
Reactor plant equipment	65,541	65,000	23,909	10,000	89,450	75,000
Turbine plant equipment	61,516	60,000	25,397	15,000	86,913	75,000
Electric plant equipment	14,196	17,000	16,577	9,000	30,773	26,000
Miscellaneous plant equipment	2,881	4,000	2,802	4,000	5,683	800
Subtotal	$166,221	$167,000	$103,448	$71,000	$269,679	$238,000
Indirect costs						
Contingency					18,656	23,700
Engineering and Management					51,057	59,300
Interest and Other					99,662	47,400
Subtotal					169,375	130,400
Total					439,054	368,400

For a two-unit land-based power station with once-through cooling, the second unit would cost about 85% of the first unit, assuming concurrent construction. Total costs are compared for fully operational 2-unit stations in Table III-6. Recent experience with escalating wage rates and evidence of decreasing construction productivity may be more severe than shown, particularly in the Northeast. Up to 12 man-hours/kWe has been reported in the Philadelphia area, and it may be that 10 man-hours/kWe is a more realistic average in other regions.

When the number of man-hours per kilowatt (electric) rises from 8 to 10, the cost of a two-unit onshore nuclear powerplant goes up about $80 million. Further declines in productivity could increase the onshore powerplant capital costs as much as $110 milion -- $48 per KWe.

The cost ranges of the on- and offshore stations are given in Table III-7. Although initially the offshore station may have higher capital investment costs, offshore unit costs are expected to decrease and onshore unit costs to continue to increase. The cost ranges reflect the uncertainties of labor costs and site-specific requirements.

No serious effort was made to fix the capital costs in terms of future dollars. However, assuming a continuation of current trends in material and labor costs, escalation of construction costs for onshore powerplants in Philadelphia and the Northeast as a whole would lead to a more favorable capital cost position for FNPs in that part of the country. At the present time, it appears that escalation would not affect relative capital costs for the Gulf coast and the southern Atlantic.

Table III-6

Total Costs of 2,300 MWe Nuclear Power Stations Onshore and Offshore
(in thousands of 1973 dollars)

	Onshore	Offshore
Total nuclear powerplant	$ 812,250	$ 736,800
Towing and insurance	-	9,200
Breakwater and mooring	-	200,000
Transmission cable	[1] -	71,000
Land and shore facilities	6,000	[2] 8,000
Thermal cooling system	[3] 30,000	-
Total	$ 848,000	$1,025,000

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[1] If an onshore plant must be located farther from the load center than an offshore plant, there would be offsetting transmission costs.

[2] Most of the land can be liquidated after construction.

[3] Lowest value of range discussed in text.

Table III-7

Capital Costs of an Offshore and Selected Onshore Nuclear Powerplants

(in 1973 dollars)

Location	Total cost (millions of dollars)	Unit cost (dollars/kWe)
Offshore	900 - 1,025	390 - 446
Philadelphia	826 - 936	359 - 407
Atlanta	752 - 862	327 - 375
New Orleans	719 - 829	313 - 361
Dallas	725 - 835	315 - 363

OPERATING AND MAINTENANCE COSTS

While capital costs vary substantially according to location offshore or onshore, operating costs appear not to.

Transporting staff and supplies over water is a cost disadvantage of offshore sites; experience in other industries shows that costs are not generally excessive. Radioactive fuel elements will have to be shipped from the FNP to reprocessing plants onshore, entailing both longer transport distances and increased handling as transport modes are changed. Again, it is doubtful that the costs would be critical.

Operating and maintenance costs for nuclear powerplants (excluding charges and nuclear insurance) typically amount to about 5% of annual plant operating cost. Personnel probably accounts for about one-half of this 5%. If wages, overtime pay, and personnel transportation costs at an offshore station were 50% higher than at a land-based plant, these would still amount to only 1.5% of annual costs.

With respect to maintenance, the FNP is readily accessible for barge shipment of bulky spare parts, but this accessibility is probably offset by the difficulty of installing large components on site due to lack of suitable handling equipment. Without dry dock maintenance facilities, hulls will be maintained in place using cofferdams to provide dry working areas -- a relatively costly procedure. The expense can be minimized, however, with effective hull corrosion prevention.

Another added operational cost of offshore plants is periodic dredging within the breakwater and under the barges. Periodic soundings will ascertain when hydraulic dredging is necessary to eliminate possible contact of the barge with the bottom. Although deposition of solids within the breakwater is generally a function of storm frequency and severity, sand deposition will be site - and design dependent, and dredging is not expected to be a large cost. For example, the deposition of 3 feet of sand over 15 acres with dredging costs of $5 per cubic yard, would result in an annual cost of $360,000 -- about 0.4 percent of the total annual cost. If 30 feet were deposited, the figure would only be 4 percent.

Repairs on the breakwater will generally result from storm damage. It is not uncommon for storm waves to remove heavy stone or dolosse from the face of breakwaters. Spare dolosse will have to be on hand and heavy barge equipment readily available to undertake repairs. Annual storm damage could require replacement of about 100 dolosse each weighing 40 tons each, at a cost of about $200,000 including placement, or 0.2 percent of annual costs.

Maintenance of buried transmission cables is not expected to be an important disadvantage of offshore powerplants. Routine maintenance is not expected, and possible cable damage by boat anchors or fish trawling can be minimized by adequate burial depth and prudent location.

Operating costs may be about 50 percent higher offshore than onshore. But the total is about one-half the cost of some mechanical draft wet cooling towers. Further, the entire increment amounts to just 2.0 to 2.5 percent of total annual costs.

DECOMMISSIONING COSTS

Any nuclear powerplant is licensed for 40 years at most. Then the operator must renew or apply for termination of the license and for authority to decommission the facility. (He may apply for decommissioning authority earlier if circumstances warrant.)

The methods of decommissioning vary with conditions and objectives. However, experience with first-time efforts for relatively small reactors (all less than 100Mwe, though indicating ready accomplishment and the variety of practical methods available, does not contribute much to estimating costs of decommissioning reactors in the 1,150Mwe category. The major difference is that the PWRs considered here have a much longer intended life and larger neutron flux, and differences in pressure vessel materials, mass, and design.

Table III-8 presents cost estimates of decommissioning a 1,150-MWe PWR plant comparable to an FNP. Because these costs were developed from experience with small reactors, as mentioned above, there is considerable uncertainty about actual costs. To provide firmer figures, a detailed analysis is being prepared as part of a "Light Water Reactor Decommissioning Study" sponsored by the Atomic Industrial Forum. This study is expected to be completed in late 1974.

Decommissioning Activities and Estimated Cost of Breakdowns for a Land-Based 1150-WMe PWR Nuclear Power Plant

Activity	Description of Activity	Percentage of Cost Entombment	Est'd Percent of Total Cost of Complete Removal
Calculation of radioactive inventories	Using operating history, reactor flux levels, samples obtained from piping, equipment, and biological shield, calculate inventories of all plant equipment and components.	4.0%	1.0%
Development of overall decommissioning concept	Develop overall sequence and methods to be used in removing (or entombing) the reactor, equipment and buildings.	1.6%	0.5%
Preparation and submittal of plan of action and environmental report	Prepare and submit a decommissioning plan and an environmental report describing planned activities, their potential environmental impact, and a cost-benefit analysis of the proposed actions.	8.7%	2.0%
Application for termination of operating license and authorization to dismantle (or entomb) facility	Prepare and submit necessary documents, including plant status and technical specifications to change from an operating license to a "possession only" license.	1.6%	0.5%
Prepare facility for decommissioning	Make building modification necessary to allow decommissioning to proceed. Includes setting up office space, change areas, temporary storage facilities for contaminated equipment; building modifications include access hatches, contamination control envelopes, ventilation and filtration systems expansion, shoring of floors.	7.6%	2.2%
Removal of equipment and piping from plant	Equipment and piping must be removed from the plant (or placed in entombment structure) in such a manner that nothing is removed before it is needed in decommissioning activities.	56.8%	17.0%
Removal of pressure vessel internals	All internals must be removed from the reactor pressure vessel and prepared for shipment. [Not performed in entombment procedure.]	n.a.	10.0%
Removal of pressure vessel	Remove pressure vessel from biological shield; prepare for shipment. [Not performed in entombment procedure.]	n.a	8.7%
Seal pressure vessel in biological shield	Seal vessel in shield in such a way as to prevent escape of any radioactivity and to deny access during entombment lifetime (or until residual radioactivity is so small as to not be hazardous). [Not performed in complete removal procedure.]	11.2%	n.a.

TABLE III-8 (Continued)

Activity	Description of Activity	Percentage of Cost Entombment	Est'd Percent of Total Cost Complete Remov
Removal of biological shield	Remove all radioactive concrete from the biological shield. [Not performed in entombment procedure.]	n.a.	2.0%
Removal of buildings	Remove all (nonradioactive) remaining buildings using standard demolition techniques. [Not performed in entombment procedure.]	n.a.	26.0%
Waste shipment, disposal, burial	Prepare for shipment and ship all radioactive and nonradioactive materials resulting from decommissioning.	4.3%	28.0%
Ground improvement and cleanup		1.6%	0.5%
Terminate license	Prepare and submit necessary documents to terminate the "possession only" license. [Not performed in entombment procedure.]	n.a.	0.5%
Radiation protection equipment	Required for personnel protection during decommissioning.	2.6%	1.1%
	SUBTOTAL	100%	100%

Source: Data from Gulf United Nuclear Corp., GU-5295, January 1973.

In a discussion of the costs of decommissioning offshore FNP generating stations, it is important to realize that the breakwater and support facilities may have to be decommissioned.

Cost uncertainties in decommissioning onshore facilities are compounded offshore. However, it seems clear that the costs of constructing the breakwater and support facilities are such that the facilities may be very attractive for other uses after the FNPs have been removed. Further, costs to remove the breakwater or even to maintain it as a safe structure (estimated at over $200,000 per year, including navigation aids, etc.) reinforce its attractiveness for other uses. The cost of maintaining it ($500,000 per year) to protect decontaminated FNPs stored within seem prohibitive.

The costs of decommissioning alternatives for FNPs are comparable to similar alternatives for onshore 1,150-MWe PWRs. Of great importance economically is the point that future decommissioning costs may not be significant in relation to total costs. For example, if the life of the FNP were 40 years and the discount rate were 10 percent, the present value of a decommissioning cost of $100 million would be only $2.2 million.

The time involved, discount rates, technological innovations, future development of coastal and offshore regions, etc. lead to the conclusion that discussion beyond possible alternatives and feasibility based upon experience is not particularly productive. It seems clear that capital expenditures for decommissioning may not be the determining factor either in FNP deployment or in decommissioning methods choosen in the future. Rather, they may depend upon social and environmental costs.

OVERALL ASSESSMENT

Floating nuclear ractors at offshore sites may become increasing economical as onshore construction costs continue to soar, particularly along the north Atlantic. However, even though this offshore concept could become less costly with experience, it will probably never be a source of low-priced electricity in any absolute sense.

There are means of reducing costs. It is clear that the breakwater controls the economics of offshore generating stations. Shared use of the breakwater by two generating plants is what makes the OPS proposal economically realistic. For a single-unit stations, the breakwater costs would lessen by about $36 million, resulting in a unit cost of about $492 per kilowatt (electric), which is about 10 percent higher than for a two-unit plant.

Indeed, the planned D-shaped breakwater appears to lend itself to four units by increasing the perimeter of the breakwater 1,000 feet to accomodate a square array of FNPs. Discounting potential technical and environmental limitations of this configuration, the additional 1,000 linear feet would add $80 million to site-related costs. Mooring facilities and transmission costs would double, but onshore costs would be relatively unaffected. As a result, the capital investment for an offshore station with four FNP units would be about $1,925 million. The unit cost of $418 per kilowatt (electric) is a decrease of $21 per kilowatt (electric), or about 6 percent below the two-unit costs.

Further savings could conceivably be realized by clustering stations. Two or more breakwaters served by the same shore facility would save some costs. Most important, however, breakwater construction sites in close proximity could benefit from the experience of the labor force and continued relationships with vendors. Thus, it appears that the pressures of economics will be in the direction of larger generating stations than those presently proposed and probably toward clustering when feasible.

Where the offshore generating station with two FNPs is economically competitive with an onshore facility in the northeastern United States, the anticipated higher onshore construction costs are expected to move the competitive regions farther south. Moreover, the potential economies of scale may extend the coastal regions in which FNPs are competitive.

It is clear that for at least some portion of the Atlantic coast the proposed FNP is today competitve with onshore nuclear powerplants. It is possible that the social costs -- direct environmental effects, safety, and indirect economic or environmental effects -- will be critical to deployment of the FNP.

REFERENCES

1/ O.H. Klepper and T.D. Anderson, "Future Siting Requirements for Offshore Nuclear Energy Stations," Trans. Am. Nucl. Soc., 16(1), 1973.

CHAPTER IV

POSSIBLE ACCIDENTS

The safety of a nuclear powerplant proposed for a given site will be evaluated in terms of the response of the plant and all of its subsystems to postulated disturbances in process variables, to potential external natural and manmade stresses (e.g., earthquakes, floods, explosions, aircraft impact at the site) and to postulated malfunctions or failures of equipment. The proposed design will be analyzed with respect to its capability to control or accommodate these situations. Often these safety, or accident, analyses identify limitations in expected performance of a plant at a site and thereby influence site selection and plant design.

Basic Concepts of Nuclear Powerplant Safety

The characteristic of today's nuclear powerplants that impose overriding safety precautions is their capability of generating and accumulating large quantities of radioactive materials. In the event of an accident to the reactor, basically two objectives must be achieved: stopping the rapid generation of heat and preventing release of accumulated radioactivity. The powerplants are designed to have the capability to shut down the reactor and to maintain it in a safe shutdown condition - the former to stop the nuclear chain reaction and associated generation of radioactivity and the latter to prevent resumption of the generation of radioactivity and to contain and control the inventory of radioactive materials within the reactor. Containment and control are accomplished by assuring the integrity of the reactor primary system where almost all the radioactive materials are located. To protect against the unlikely accident, such as the remote possibility that the primary system may be breached, nuclear powerplants have numerous engineered safety features.

FNPs will be regulated primarily by the Atomic Energy Commission. Licenses are issued only for facilities that meet prescribed safety standards and criteria. Provisions for conservative design and operating margins and for redundancy of components and systems compensate for the fact that uncertainties and risks cannot be reduced to zero. Thus, the AEC requires applicants and licensees to take actions necessary to assure that risks are reduced to acceptable levels and that the likelihood of severe accidents is extremely remote.

Regulation is based upon a philosophy of three levels of safety. The first concerns prevention of accidents. Each plant must be soundly designed, constructed of quality materials, tested, operated, and maintained in accordance with high standards and engineering practices and with a high degree of freedom from faults and errors. The basic nuclear plant design must be inherently stable and have a large tolerance (e.g., fail-safe features) for off-normal conditions. The second level of safety is based on the premise that accidents occur in spite of care in design, construction, and operation. Safety systems that consist of reliable protection devices and systems designed to prevent, arrest, or safely accommodate accidents are incorporated into the plant to protect the operators and the public and to prevent or minimize damage when accidents occur. The third level supplements the first two by providing safety systems to handle situations in which some protective systems are assumed to fail simultaneously with occurrence of the accident that they are designed to control. For each proposed plant several accident sequences are postulated as a basis for design and incorporation of plant features and equipment. These sequences are called Design-Basis Accidents (DBA). A nuclear plant is so designed that little or no radioactive release would be expected as a result of DBA specified for the particular site and that the resultant offsite radiation doses would be within specifically defined acceptable limits.

Examples of possible major accidents that an FNP may be required to withstand are listed in Table IV-1. Accidents may be categorized in a number of ways: by type of initiating agent (human, meteorologic, geologic, oceanographic), by system or component primarily affected (breakwater, barge, cooling water intake, reactor primary loop), by location of the initiating agent (external or internal), and by type of the accident-initiating stress (mechanical, thermal, chemical). The following discussion first treats the initiating stress, then internal accidents, and accidents during transport of radioactive materials.

Mechanical Stresses

Collisions

Ships. One possible hazard to an FNP within a breakwater is ship collision. Under normal conditions the use of sites remote from shipping lanes and in relatively shallow water will reduce the collision probability by limiting the number and the size of vessels that can reach the facility. Several accident sequences are conceivable as a result of ships striking different portions of an offshore station. Large or high-speed ships are of particular concern because the damage potential is related to the kinetic energy of the moving ship. Fire and explosion also are of concern - tankers, ammunition ships, and vessels with flammable or explosive material are additionally hazardous. In general, the breakwater must safely stop a major vessel.

As an indication of the probability of ships hitting the FNPs, collisions with offshore structures in the Gulf of Mexico were reviewed. Eight collisions reported during a 10-year period involving vessels over 1,000 gross tons are shown on Table IV-2. Twenty-two other collisions with fixed structures were also reported during this period; they are listed in Table IV-3. Of the latter collisions, 15 involved vessels less than 100 gross tons and 7 vessels were between 100 and 650 gross tons. These data indicate that the likelihood of collisions was small inspite of some 2,000 exposed structures in the Gulf of Mexico. Nonetheless, the potential for collision must be examined for each proposed FNP site.

Table IV-1

Possible Major Accidents to Floating Nuclear Powerplants

Natural phenomena, such as storms, hurricanes, tornadoes, earthquakes, tsunamis, and electrical storms, cause
  - Breakage of the morring system
  - Deterioration of breakwater effectiveness
  - Sinking of barge
  - Failure of power transmission system
  - Wreck or grounding of vessel nearby with release of hazardous cargo
  - Damage to reactor building, turbogenerators, intake and outfall structures, or other elements of the plant

A large vessel collides with breakwater

A small vessel collides with breakwater, barge, or mooring

Vessel collides with breakwater or barge and disperses hazardous cargo (combustible or toxic materials) onto or within breakwater

Plane or missile crashes into plant

An inplant accident as discussed in a later section

Vessel collides with a barge carrying spent fuel from the powerplant

Fire breaks out aboard the powerplant barge or aboard the fuel-transporting vessel

Deterioration of important elements of the plant by wave action and salt spray, e.g., undermining of breakwater or mooring system, reduction of seabed bearing strength, corrosion of barge, reduction of cable insulation or mechanical strength, corrosion or overstress of power cable connections, fouling of cooling system leading to unexpected failure

Vessel drags anchor and breaks power cables

Vessel runs aground and breaks power cables.

Table IV-2 Major Collisions of Ships and Large Offshore
Structures in the Gulf of Mexico
Fiscal Years 1963 to 1972

Vessel and structure	Type	Gross tons	Date, time, cause	Weather conditions	Estimated damage
Ganges (British)	Cargo	6,274	Nov. 9, 1963, night, personnel fault	Overcast, visibility over 2 miles, 30-knot wind, 15- to 20-foot seas	$5,000
Phillips Platform 115-3	Fixed structure				
Dauphin (O.N. 254298)	Tugboat	296	May 4, 1964, day, personnel fault	Partly cloudy, visibility over 2 miles, 20-knot wind, 5-foot seas	-
Aiple #50 (O.N.276123)	Cargo barge	1,649			-
Unknown	Fixed structure				$180,000
General Artigas (Argentine)	Cargo	1,717	Dec. 15, 1965, day, cause undetermined	Unknown	-
Shell-Phillips Federal Block 135	Fixed structure				$200,000
Unidentified vessel					
Superior 103-1	Fixed structure		Sept. 12, 1967, night	Unknown	$100,000

M/S Emma Johanna (German)	Cargo	11,612	Oct. 30, 1967, day, personnel fault	Heavy rain, poor visibility, 45-knot, SE wind, seas SE 15 to 20 feet	$12,000
Kerr-McGee oil platform OCS	Fixed structure				$1,100,000
M/S Olympic Flame	Tankship	17,791	Oct. 10, 1970, night	Clear, visibility 5 miles, 7-knot E wind, slight sea	$60,000
Placid Oil Company Platform 202-1	Fixed structure				$865,000
KIMON (Liberian)		7,299	Oct. 4, 1965, cause unknown		
Continental Oil Platform D, Block 47	Fixed structure				
ESSEX	Cargo	10,936	Aug. 27, 1969, night, personnel fault	Overcast, visibility 18 miles, 5-Knots wind gusting, moderate sea, slight swell	$10,000
Humble Oil #142-2	Fixed structure				$500,000

Source: U.S. Coast Guard, unpublished.

Table IV-3 Collisions of Ships Less Than 1,000 Gross Tons with Offshore Structures in the Gulf of Mexico Fiscal Years 1963 to 1972

Vessel type	Number	Adverse weather	Personnel fault	Equipment failure	Fault of rig	Estimated damage (in $1,000)		Persons injured
						Vessel	Rig	
Fishing vessel	10		5	1	[1]4	[2]151	24	1
Barge	2	1		1		35	68	0
Small cargo vessel	8	3	4		[3]1	[4]221	10	2
Passenger vessel	2			1	[5]1	19	0	1

[1] Three equipment failures, one insufficient/improper lighting.
[2] Includes $80,000 to one vessel that sank.
[3] Improper maintenance.
[4] Includes $130,000 to one vessel.
[5] Insufficient lighting.

The risk of a large ship breaching the breakwater depends on breakwater size. Here cost is the major limitation (see Chapter III). For a breakwater that is large enough, the primary danger from ship collision is subsequent fire and/or explosions or damage to the cooling water circulating system. Breakwater design must consider possible collisions in stormy seas. Although in severe storms, vessels would avoid coastal waters, the possibility of a vessel running out of control must be considered. Because of the potential risks, the Advisory Committee on Reactor Safeguards (ACRS) has advised that "studies should be made of the advantages and disadvantages of various additional measures to reduce ship-breakwater collision probabilities, including active warning systems and a separate ship arrester external to the breakwater."[1]

One of the breakwaters proposed by PSE&G would have two openings, each 24 feet deep and 75 feet wide. But when storms raise the sea level, large vessels could enter. Deflecting piling is being considered to prevent small ships within the breakwater from colliding with the plant. The Committee recommended further "that the possible advantages to safety of a closed breakwater (possibly employing locks) be analyzed and receive careful consideration."[2]

Aircraft. Aircraft collision is another possible hazard. Experience with onshore powerplants[3] indicates that the risk is very small except at special locations (such as a few miles from the end of an airport runway). The risk is no greater at an offshore powerplant.[4] However, because of the environment, the ACRS suggests that the acceptable probability of an aircraft crash may need to be lower for th offshore powerplant than for its counterpart ashore.[5] If helicopters ferry personnel and supplies, risk of crash must be evaluated and accommodated. Relation of the offshore site to military installations and missile sites, to be evaluated during licensing proceedings, will involve the same considerations as land-based plants.

Power Cable Damage. Reliable external power is of primary importance to reactor safety systems. For the New Jersey site, five separate transmission lines are proposed to connect the facility to shore. As at other nuclear facilities, emergency power would be supplied onsite by diesel generators.

Events that lead to loss of electric power onshore usually involve severe electrical storms, high winds, an aircraft colliding with the transmission lines, or regional grid system failures. Offshore hazards result from the possibility that a ship grounding or an anchor dragging may damage underwater transmission lines or that cable failure may result from a high-voltage leak to ground. Tranmission lines inside the basin, although flexible, may be damaged by movements of the barge or by service vessels. Table IV-4 shows the kinds of accidents that have occurred with high-voltage, high-capacity submarine cable. Burying the cables more deeply may lengthen their life if scouring and seabed changes do not expose them. The probability of cable damage may be further decreased if the cables are located away from common anchorages and where ships are less likely to run aground.

Storms, Hurricanes and Seismic Activity

The offshore environment can impose severe stresses on an FNP. Many of the natural phenomena are similar to those experienced on land. Nevertheless, by virtue of its motion and its reliance on a mooring system and a breakwater for protection, the FNP is more vulnerable. Challenges from natural phenomena are described in detail in Appendix C.

Table IV-4 Forced Outages Reported on Major High-Voltage Submarine Cables

Cable	Date in service	Date of problem	Nature of problem
Vancouver Island, 138-kV ac	1956-58	1965	Compound blocking of core gas channel
		1971	Ship's anchor
		1972	Ship's anchor
Vancouver Island, 230-kV ac	1968	1972	Ship's anchor
Long Island, 230-Kv ac	1969	1969	Ship's anchor
Sardinia, Italy 200-Kv dc		?	Trawl gear
Konti-Skan, 250-kV dc	1965	1969	Two incidents with ships' anchors
		1969	Lead sheath developed cracks

Source: Federal Power Commission, unpublished.

Exposure of the FNP to severe meteorological disturbances can lead to power outages, damage from flying debris, wave overtopping, icing, damage to the breakwater, and breaks in the mooring system. The mooring system (see Appendix A) is vital to the powerplant's withstanding high winds, heavy seas, hurricanes, tornadoes, and earthquakes. Breaks in the mooring could allow the hull to shift, severing the power lines and misaligning the catchment discharge basin. Loss of external power is within the safe shutdown design-basis criteria, but safety then depends on the emergency diesel generators.

In addition to damage to the moorings, other important effects of wind and waves are resonance, overtopping, refraction, and reflection. Because of refraction and reflection, waves around the floating nuclear powerplant can become much larger than those in the surrounding ocean. Resonance inside the breakwater may result in standing waves of substantial amplitude. The situation may be further complicated by refractive waves focusing on a section of the basin. Careful study of depth, bottom contours (including changes caused by breakwater construction), climate, etc. of each site must be made to evaluate the hazards of waves. The principles of refraction and resonance are well understood, and potentially dangerous situations can be foreseen. A completely enclosed breakwater might afford the plant better protection against waves and possible resonance within the breakwater. It may also offer protection against fire; see discussion below.

Each FNP will have some onsite capabilities for meteorological measurement and analysis and will be linked to other sources of meteorological information. Thus, it is extremely unlikely that a severe storm will strike without adequate warning to allow safe shutdown.

Although the preceding discussion emphasizes threats to the offshore plant, onshore facilities - including transmission lines - will also be threatened. If transmission facilities are damaged, the plant may have to cope with a loss of load; a DBA that any nuclear powerplant can experience without serious consequences.

Floating and land-based plants may be exposed to earthquakes causing ground shaking, landslides, liquefaction and soil loosening, faulting and ground rupture, tectonic uplifts or subsidence, and tsunamis. Seismis activity could induce cracking, settling, or other rearrangement of the breakwater. The quality of the seabed under the breakwater affects the ability of the seabed to support the breakwater and to transmit seismic motion to the breakwater. Liquefaction -- water-saturated soils' behaving like fluids when subject to seismic shocks -- may also jeopardize breakwater integrity.

In reviewing the safety of the proposed Atlantic Generating Station, the ACRS cited several items related to the breakwater and its ability to withstand wind, waves, and seismic forces simultaneously without loss of function.6/

Ground faulting or gross tectonic movement directly under the offshore facility could displace water in the basin, damage the mooring system, and damage the breakwater. Pieces of breakwater could fall into the basin; to avoid damage to the powerplant, sufficient clearance is required between breakwater and barges.

Floating nuclear powerplants could receive seismic loads through the water and from the mooring system. Horizontal forces transmitted through the water from the basin floor should be minor, since water can transmit only small shear forces. However, submerged, inclined or vertical surfaces such as the side of a breakwater can induce significant horizontal impulses in the water which, in turn, can act upon the floating plant. A relatively stiff mooring system can also impose sizeable horizontal forces on the floating plant.

The horizontal earthquake impulse that can be transmitted through the water to the barge hull becomes smaller as the breakwater slope is diminished.7/ For a floating nuclear powerplant proposed by Offshore Power Systems, it has been estimated that the horizontal acceleration imparted by water would be only 50 percent of the ground horizontal acceleration.

From the point of view of the hazard associated with tsunamis, the FNP would be better off in deeper water than the depth (45 feet) of the proposed Atlantic Generating Station site. Although tsunamis may present a hazard within the lifetime of an FNP, other phenomenon will impose limiting design criteria. Over much of the east coast, phenomena such as storm surges and hurricanes are more important than tsunamis.

Sabotage and Other Hostile Acts

FNPs will be a target for sabotage and other hostile acts just as land-based plants are. However, an offshore plant may be potentially more vulnerable because of its location. Further, depending upon its location offshore (i.e., in the territorial sea or on the high seas), actions that may legally be taken to prevent these willful acts may be constrained (see Chapter VII). The vulnerability of each site must be examined and security measures developed to protect against threats of this kind.

Other Mechanical Hazards

Each FNP has a design requirement that platform sinking not interfere with safe plant shutdown. In the proposed Atlantic Generating Station, hull compartments vital to plant safety are watertight to a height of 76 feet above the keel allowing for sinking and concurrent storm waves. The basin floor is expected to be maintained in a fairly level sandcovered condition.

The barge hull is designed to sustain two flooded compartments without sinking, which could result from corrosion, operator error in compartment isolation, or fire, explosion, turbine failure, or mooring system failure. All these possibilities are considered in the design, but the sinking criterion has nevertheless been imposed for first generation offshore plants.

The mooring system conceivably could fail simply because of deterioration. The ACRS placed particular importance on fatigue in the presence of corrosive sea water and recommended consideration of a secondary mooring system.

Thermal and Chemical Stresses

If a ship carrying hazardous materials (combustible, corrosive, explosive, or toxic) collides with the breakwater and if any appreciable part of the cargo is released, the potential exists for adverse effects on operation of the plant. Unless the probability of such accidents approaches zero, FNPs must have engineered safety features which enable them to shut down and to maintain a safe shutdown condition during the course of such accidents.

The probability of such a collision depends on the site selected. There may be sites where, for example, no shipping lanes are near. For each proposed site, unique hazards must be evaluated. Then, if the likelihood of hazards is nonnegligible, either the FNP has to be designed to cope with the hazard or a new site found.

Inplant Accidents

Because the offshore nuclear powerplant is similar in design to an onshore plant, the spectrum of possible internal accidents is about the same for both. If the fission products involved in an accident are released in a gaseous state or as fine particles so that a significant portion becomes airborne, dispersal of the radioactive material over a wide area surrounding the plant depends on prevailing meteorological conditions. The likelihood of exposing a significant number of people within a radius of several miles from an FNP is less than for most onshore plants. However, beyond the first several miles, the population density for the landward side of an FNP might exceed that of an onshore plant and the overall exposure might be higher.

Some of the airborne radioactivity over the water will settle on the water which would then disperse the activity. Water would also act as a medium for dispersing small amounts of radioactive material accidentally released in liquid form.

Many component systems of the FNP proposed by OPS[8/] are essentially the same as those used in onshore plants designed by Westinghouse. Inplant nuclear accidents will be similar provided the motion of the FNP is kept small under all environmental conditions so that the operation of equipment designed to cope with accidents is not affected. An inplant accident unique to the FNP involves penetration of the barge by missiles generated by turbine failure; which could result in partial flooding or listing of the plant. It should perhaps be noted that safe shutdown during a sinking emergency is a DBA requirement.

Consideration of the environmental risks of accidents will take into account both the probabilities of their occurrence and their consequences. For analytical purposes, possible accidents at a nuclear plant are classified and each class characterized by an occurrence rate and consequences.[9/] Severity ranges from relatively trivial events which result in essentially no risk and which might occur with moderate frequency to accidents which have serious consequences but which are unlikely. Experience does not provide a statistical basis for determining the probability of design-basis or more severe accidents.

The AEC is working on quantifying these risks. The Reactor Safety Study[10] is an effort to develop realistic data on the probabilities and sequences of accidents in water-cooled power reactors. In its safety review of a site, the AEC uses very conservative assumptions in determining the adequacy of the engineered safety features and in calculating the dose from a hypothetical accident for comparison with siting guidelines.[11]. The guidelines specify that an individual located at any point on the site boundary for 2 hours immediately following onset of the radioactive cloud resulting from an accident or at any point on the outer boundary of the low population zone[12] during the entire period of the passage of the radioactive cloud resulting from the postulated fission product release should not receive a dose to the whole body in excess of 25 rems or a dose to the thyroid in excess of 300 rems.[13] Because of the conservative assumptions, the doses calculated in the safety analysis are much greater than those used in evaluating the environmental impact of accidents. Best estimate accident doses have been calculated for several classes of FNP accidents by OPS. The results are summarized in Appendix B. The radiological consequences are comparable to doses computed for onshore plants of similar size and design.[14]

TRANSPORTATION OF RADIOACTIVE MATERIALS

About 30 metric tons* of fresh nuclear fuel, 30 metric tons of spent nuclear fuel, and radioactive solid wastes must be transported to and from an FNP each year (see Appendix A) giving rise to concern that in transporting there may be an accidental release of radioactive materials. Loaded casks are transferred to a barge and shipped to a shore facility or transfer point -- these activities present hazards different from those at a land-based plant. After the materials reach the shore transfer point, the transport mode is the same as for land-based wastes, shipment to a fuel processing plant or to a waste disposal facility by truck or rail.

The environmental impact of transporting fuel and radioactive wastes has been evaluated on the basis of accident experience for truck, rail, and barge traffic. The discussion that follows is based largely on the AEC evaluation.[15/]

Most shipments of radioactive material move on conventional equipment in routine commerce. They are therefore subject to the same transportation environment, including accidents, as other cargo. Primary reliance for safety in transport is placed on packaging the radioactive material.[16/] Coast Guard, AEC, and State standards require packaging to prevent loss or dispersal of the radioactive contents, retain shielding efficiency, assure nuclear criticality safety, and provide adequate heat dissipation under normal conditions of transport and under specified accident damage test conditions (i.e., the DBA).

Experience with land-based plants is useful in estimating the number of shipments required. As indicated in Table IV-5, the total number of barge shipments involving radioactive materials could range from 10 to 23 per year.

The risk of accidental exposure during transit is small. Based on accidents reported, the number of shipments per year, and shipping distance, the probability of an offsite transportation accident involving nuclear fuel, solid radioactive waste, or empty fuel shipping containers is about once each 50 years of reactor

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* 1 ton=0.907 metric tons

TABLE IV-5. ESTIMATED ANNUAL SHIPMENTS OF RADIOACTIVE MATERIALS FOR AN OFFSHORE NUCLEAR POWERPLANT (TWO 1,100 PRESSURIZED-WATER REACTORS)

Operation[1]	Number per Year
<u>Fresh (unirradiated fuel</u>	
Fuel fabrication plant to shore transfer point	12 trucks [2]
Shore transfer point to offshore powerplant	2 to 3 barges[3]
<u>Spent (irradiated) fuel</u>	
Offshore powerplant to shore transfer point	4 to 10 barges[3]
Shore transfer point to fuel reprocessing facility	120 trucks or 22 rail cars
<u>Solid radioactive wastes</u>	
Offshore powerplant to shore transfer point	4 to 10 barges[3]
Shore transfer point to disposal facility	92 trucks or 20 rail cars

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[1] Empty fuel casks and irradiated fuel casks require the same number of shipments as when they are full.

[2] Initial loading of one reactor requires about 18 truckloads of fuel.

[3] Number depends on capacity of barge.

Source: USAEC Directorate of Regulatory Standards, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants," WASH-1238, December 1972.

operation if all shipments are by barge and about once each 5 years of reactor operation if a combination of truck and barge shipment is involved. Over 70 percent of the accidents would be minor, producing little or no damage to a shipment. Less than 1 percent of the accidents would involve a severe impact or fire.

The probability of accidental release of radioactive material or increase in external radiation levels is small. One-third of the shipments is empty containers. In a severe accident, the carrier may absorb most of the impact and fire may not involve the radioactive material. Packages containing radioactive materials must be designed to withstand accident conditions. The contents of those that do not are limited, so only a small amount of radiation exposure would result should the package be damaged.

Fuel

The packaging and size of new fuel shipments are designed to prevent criticality* under normal and severe accident conditions. Only in an extremely severe accident involving severe damage or destruction of more than one package would conditions arise that could lead to accidental criticality. If criticality were to occur in transport, persons with 100 feet of the accident could receive a serious exposure and persons within a few feet of the accident could receive fatal or near-fatal exposures unless shielded. Beyond that distance little detectable radiation effects would be likely. Although there would be no nuclear explosion, heat generated in the chain reaction would probably separate the fuel elements so that the chain reaction would stop. The reaction would not be expected to continue for more than f ew seconds and normally would not even recur. Residual radiation levels due to induced radioactivity in the fuel elements might reach a few roentgens per hour at 3 feet. There would be very little dispersion of radioactive material. If criticality occurred under several feet of water, no radiation effects would be expected.

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*Conditions wherein the fuel geometry and surrounding environment are such that a nuclear chain reaction is initiated.

Quantities of radioactive materials accidentally released during shipment of spent fuel have been estimated when contaminated coolant is released and when gases and coolant are released. The coolant is incorporated in the shipping cask to remove decay heat generated by the spent fuel.

Leakage of contaminated coolant resulting from improper closing of a cask is possible even though the shipper is required to follow specific procedures which include tests and examination of the closed container before shipment. This kind of accident is most unlikely during the 40-year life of a plant.

Leakage at a rate of 0.001 milliliter per second or about 80 drops per hour is about the smallest amount of liquid that can be detected visually. If an undetected leak were to occur, the amount would be so small that the individual exposure would not exceed a few millirems and only a very few people would receive such exposures.

Release of gases and coolant is an extremely remote possibility. However, should the cask containment be broken and the cladding* of the fuel assemblies penetrated, some of the coolant and gases could be released. In such an accident, the amount of radioactive material that can be released is limited to what is in the coolant and in the void spaces in the fuel rods.

If releases occur they would take place in a short time and would affect a limited area. The very nature of this severe accident implies that persons would not be expected to remain in the vicinity. If the accident occurs in water, the primary hazard would be from waterborne radioactivity. Persons downwind and within 100 feet of the accident could receive doses as high as a few hundred millirem. On land, a few hundred square feet may require decontamination; on water, the contaminants would be diluted and dispersed. Chapter V illustrates the effects of such an accident.

Solid Radioactive Wastes

The containment for solid radioactive wastes is provided by the nature of the contamination -- which is bound on clothing, dispersed in concrete, or otherwise confined to some degree, and by the packaging - drums in most cases. The radioactive contamination in compacted waste usually will not be in an available form if

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*The thin walled metal tube encasing each nuclear fuel element is known as cladding.

released in an impact; that is, pieces of contaminated clothing and other materials may be spread around, but the contamination is bound on the inert materials and is unlikely to be relased unless burned or washed out by water. If released in a major waterway, dilution and dispersion of the limited amount of radioactivity would make any significant exposure highly unlikely. Contaminated concrete is not likely to be affected by fire, but some of the concrete could be shattered by a strong impact force.

On land, spread of the contamination beyond the immediate area is unlikely and, although local cleanup may be required, no significant exposure to the general public would be expected. On water, dilution and dispersion may preclude significant exposure. The probability of a barge accident is of the same order of magnitude as the probability of a rail or truck accident; however, the likelihood of cargo damage in a barge accident is less. Recovery of solid waste material spilled into the water would be complicated, but exposure to the public would be negligible.

Accident Statistics

Most accidents occur at low vehicle speed. Severity is greater at higher speeds but the frequency decreases as the severity increases. Transportation accidents generally involve some combination of impact, puncture, and fire. The probabilities of truck, rail, and barge accidents in each of five severity categories are shown in Table IV-6. As the table shows there are only small differences among the truck, train, and barge accident probabilities in terms of accidents per mile in each of the severity categories.

Fiscal year 1970 domestic waterborne traffic records show a total of 506 billion ton-miles with 548 barge accidents reported.[17/] Although data are not available on the ton-miles for barge traffic, the AEC estimates it at 380 billion.[18/] According to the Coast Guard,[19/] miscellaneous types of vessels, including cargo barges, were involved in accidents which resulted in 33 injuries and 33 fatalities during that period.

TABLE IV-6

TRANSPORTATION ACCIDENT PROBABILITIES

Severity	Vehicle speed (mph)	Fire Duration (hr)	Rail	Probability per vehicle-mile Truck	Barge[1]
Minor	0-30	<1/2	6×10^{-9}	6×10^{-9}	--
	0-30	0	4.7×10^{-7}	4×10^{-7}	1.6×10^{-6}
	30-50	0	2.6×10^{-7}	9×10^{-7}	1.4×10^{-7}
Total			7.3×10^{-7}	1.3×10^{-6}	1.7×10^{-6}
Moderate	0-30	1/2 - 1	9.3×10^{-10}	5×10^{-11}	--
	30-50	1/2	3.3×10^{-9}	1×10^{-8}	8×10^{-9}
	50-70	<1/2	9.9×10^{-10}	5×10^{-9}	2×10^{-9}
	50-70	0	7.5×10^{-8}	3×10^{-7}	3.4×10^{-8}
Total			7.9×10^{-8}	3×10^{-7}	4.4×10^{-8}
Severe	0-30	>1	7.0×10^{-11}	5×10^{-12}	--
	30-50	>1	3.9×10^{-11}	1×10^{-11}	9.3×10^{-11}
	30-50	1/2-1	5.1×10^{-10}	1×10^{-10}	1.3×10^{-9}
	50-70	1/2-1	1.5×10^{-10}	6×10^{-12}	3.3×10^{-10}
	>70	<1/2	1×10^{-11}	1×10^{-10}	--
	>70	0	8×10^{-10}	8×10^{-9}	--
Total			1.5×10^{-9}	8×10^{-9}	1.6×10^{-9}
Extra Severe	50-70	>1	1.1×10^{-11}	6×10^{-13}	2.3×10^{-11}
	>70	1/2-1	1.6×10^{-12}	2×10^{-13}	--
Total			1.3×10^{-11}	8×10^{-13}	2.3×10^{-11}
Extreme	>70	>1	1.2×10^{-13}	2×10^{-14}	--
			1.2×10^{-13}	2×10^{-14}	--

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[1] Barge accident probabilities are based on the duration of the fire and actuarial data on cargo damage. The impact velocities of all barge accidents are considered less than 10 miles per hour, but minor cargo damage is assumed equivalent to vehicle impact speeds of 0 to 30 miles per hour, moderate cargo damage 30 to 50 miles per hour, and severe cargo damage 50 to 70 miles per hour.

Source: Directorate of Regulatory Standards, U.S. Atomic Energy Commission, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants," WASH-1238, December 1972.

On the basis of information supplied by the Coast Guard, it is assumed that the cargo weight of a typical barge is about 1,200 tons. The number of barge-miles would then be about 310 million. And the accident rate would be about 1.8 accidents per million barge miles.

There are very few data available on the severity of barge accidents. Because barges travel only a few miles per hour, the velocity of impact would be small. However, severe impact forces could be encountered by packages (spent fuel casks) aboard the barges. A barge could hit a bridge pier and then be hit by other barges. A coastal or river ship could knife into a barge. In either case, fire could result. The AEC considers an extreme accident - that is, an extreme impact and a long fire - of such low probability that it is not a DBA. The AEC considers a severe fire in barge accidents quite unlikely because of the availability of water at all times. Also, because casks can be kept cool by spraying with or submergence in water, loss of mechanical cooling can be compensated for.

The likelihood of cargo damage in a barge accident is much less than in rail accidents. The AEC estimates[20/] that about 90 percent of barge accidents would result in minor or no damage to the cargo and would not involve fires. Moderate cargo damage from impact would result in 8 percent of the barge accidents and severe damage in 2 percent. Fire would be likely only in accidents involving moderate or severe cargo damage, and the AEC estimates that the likelihood of a fire in severe accidents is 10 times that in moderate accidents. The AEC also estimates that fire would occur in 0.65 percent of the moderate accidents and 6.5 percent of the severe accidents.

If a cask were accidentally dropped into water, it is unlikely to be damaged unless the water is deep. Most fuel is loaded into the casks underwater, so immersion would have no immediate effects. The water would dissipate the reaction heat, so overheating would not occur. AEC regulations[21/] require that each cask withstand an external pressure equal to water pressure at a depth of 15 meters (50 feet). Most designs will withstand external pressure at much greater depths. If a cask were to collapse due to excessive pressure in deep water, only the small amount of radioactivity in the cask coolant and gases from perforated elements in the cask cavity are likely to be released. The direct radiation would be shielded by the water. About 10 meters of water, the depth of most storage pools, is ample shielding for radiation from exposed fuel elements.

From AEC evaluation, sinking of a cask in deep water would not result in serious radiological consequences. The most likely mechanism for loss of containment from external water pressure would be through failure of the pressure relief valves, which would result in an inflow of water and subsequent release of some of the contaminated coolant and radioactive gases in the cask cavity. If all the coolant and gases were released, the total activity would be on the order of 300 curies, mostly krypton-85 gas. The vast quantities of water would significantly dilute it.

The fuel elements, which contain most of the radioactive material, are excellent containers. In an operating reactor, the fuel elements are under water at elevated temperatures and pressures on the order of 1,000 to 2,000 pounds-per-square-inch guage. Thus exposure to water pressures at depths of 600 to 1,200 meters should have no substantial effect on the fuel elements themselves.

Except under very unusual circumstances in which it could not be located or was submerged in extreme depths, the cask probably could be recovered with normal salvage equipment. If the cask and elements were not recovered, there would be a gradual release of radioactive material over several hundred years.

If dropped into shallow water, damage is unlikely. In most cases, a package, cask, or drum dropped into deep water would leak inward, through a gasket or valve, so the external and internal pressures would equalize as the package, cask, or drum sinks. Or the container might collapse, releasing small amounts of radioactive material.

SUMMARY

The safety considerations of FNP versus onshore nuclear powerplants are compared in Table IV-7. It is significant that the accident potential is often a function of design and site selection. It is also significant that the accident potential variation is a function of an offshore environmental versus an onshore environment and not one of technology.

TABLE IV-7

NUCLEAR POWERPLANT SAFETY (ONSHORE SITE VS. OFFSHORE SITE)

Type of Stress	Example of threat	Accident Likelihood		Remarks
		Onshore	Offshore	
Mechanical				
Collision Ships	Breakwater damage FNP damage	N/A	Potential concern	Function of siting and breakwater design. See also thermal chemical. May enhance sensitivity to meteorological stresses.
Aircraft	Breakwater damage FNP damage	Comparable		Function of siting and breakwater design. Helicopter accidents possible with offshore plant (low probability). See also thermal chemical.
Power cable damage	Ship grounding	N/A	Potential concerns	Function of routing, depth, and design.
	anchor dragging	N/A		
	meterological,	Comparable		
	geological	Comparable		
Meteorological Storms	Storm surge, waves winds, etc.	Inland - minimal shoreline - comparable		Function of siting and breakwater design. Storms generally more severe offshore. Consequences for FNP may possibly be more severe due to motion of barge. May compound risk of ship and helicopter collisions.
Hurricanes	Refraction, resonance, etc.	N/A	Resonance concern	
Tornadoes/ Watersport	Winds, flying debris	Comparable		
Seismic Tsunamis	Stress loading of moorings and barge Grounding of barge damage to breakwater	N/A inland shoreline -	comparable may have slight adv.	Function of siting and design. May compound risk of ship collision or meteorological damage. Settling effect of concern. Water may insulate FNP against some motion.
Tectonic motion	Damage to breakwater		may have slight adv.	
Sabotage Plant		Not clear		Function of ability to enforce security measures.
Transport		Not clear		
Thermal, chemical	Fires, corrosives explosives	Possible advantage	Shipping accidents of concern also coastal pipelines	Function of siting, design, and protective measures.
In-plant accidents	9 accident classes			Function of design and siting (relative to external threats).Motion of barge may be factor. Dilution of oceans may mitigate releases but added problems of food web effects and inability to isolate exposed organisms may be factor. Possible advantage of offshore due to more remote population distributions.
Airborne release		Not clear		
Waterborne release		Not clear		

TABLE IV-7 (CONT'D)

Type of Stress	Example of threat	Accident Likelihood Onshore	 Offshore	Remarks
Transportation	Barge and truck or train collisions	See Table IV-6		Function of scheduling and routing. Remarks similar to those for airborne releases. Possible added problems of materials recovery.

REFERENCES

1. Letter from H. G. Mangelsdorf, Chairman, Advisory Committee on Reactor Safeguards, to Hon. Dixy Lee Ray, Chairman, U.S. Atomic Energy Commission, Oct. 18, 1973.

2. _Ibid_.

3. D. G. Eisenhut, "Reactor Sitings in the Vicinity of Airfields," _Trans. Amer. Nucl. Soc. 16_, June 1973.

4. Pickard and Lowe Associates, "A Study of the Probability of an Aircraft Hitting the Atlantic Generating Station," March 26, 1973.

5. H. G. Mangelsdorf, _op.cit_.

6. H. G. Mangelsdorf, _op.cit._

7. Holmes and Narver, Dames and Moore, "California Powerplant Siting Study," May 1973.

8. "Plant Design Report," Application for License to Manufacture Eight Floating Nuclear Powerplants," submitted to the AEC by Offshore Power Systems, Jacksonville, Florida (Docket No. 50-437).

9. Proposed Annex to Appendix D of 10 CFR Part 50.

10. The scope of the study has been described in correspondence with EPA which has been placed in the AEC Public Document Room (letter, Doub to Dominick, dated June 5, 1973.

11. 10 CFR Part 100.

12. The low population zone is defined as "the area immediately surrounding the exclusion area which contains residents, the total number and density of which are such that there is a reasonable probability that appropriate protective measures could be taken in their behalf in the event of a serious accident." 10 CFR §100.3(b).

13. 10 CFR §100.11(a) (1),(2).

14. See "Final Environmental Statement, William B. McGuire Nuclear Station, Units 1 and 2," USAEC Dockets No. 50-369 and No. 50-370, October 1972.

15. Directorate of Regulatory Standards, U.S. Atomic Energy Commission, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, " WASH-1238, December 1972.

16. Coast Guard Packaging Standards.

17. U.S. Coast Guard, unpublished.

18. Information provided to CEQ.

19. U.S. Coast Guard, unpublished.

20. Information provided to CEQ.

21. 10 CFR §7.32(b)

Chapter V

Direct Environmental Effects

This chapter discusses a broad range of potential direct environmental effects which might result from siting and operating an offshore, nuclear-powered generating station consisting of two 1140 MWe units moored within a breakwater structure. Construction, operation, maintenance, and decommissioning of an FNP facility are phases of siting and operation which directly affect the environment. Each phase includes major events, such as construction of breakwaters or installation of transmission facilities, which are assessed here for their potential environmental impact. Additional detailed discussions of direct ecological effects appear in Appendix C.

Chapter VI addresses indirect, secondary effects and activities not directly impinging upon the project site such as mining or construction of breakwater materials; socioeconomic changes in local industrial, commercial, and residential communities; and adjustments in local and regional governmental institutions.

Siting

The environmental effects of a powerplant depends upon location of the plant the output and products of the plant, natural resources present in the vicinity and the susceptibility or resiliency of these resources to damage or degradation from construction and operation. Thus, site location of an individual powerplant is a key element in its possible environmental effects.

For an assessment of environmental effects, it is necessary to judge the significance of the impacts to the continuation of beneficial uses of desirable resources, as well as to the dynamic processes of natural ecological communities. For example, construction of a breakwater over a sand bottom may have the physical effect of replacing 100 acres or so of sandy surface with a hard, artificial "reef" having several times as much surface area for attachment at aquatic organisms. The attendant biological effect may be establishment of a local community of reef organisms and associated fishes. If this occurs in an area where reefs and reef communities are relatively abundant but sand bottom communities are scarce, the initial impact would probably be considered negative; if the local sand bottom is relatively sterile and there are few reefs in the area, the impact of siting and construction of the plant may be positive. Of course, the ultimate impact depends upon the effects of station operation on the artificial reef community established.

In most cases, the physical effects of powerplant operation -- those resulting from cooling water intake or the discharge of heated effluent -- may be described generically because of anticipated standardizations in plant design. However, the biological effects of intake and discharge are site specific and must be assessed plant by plant. Such effects must be related to ecosystem dynamics and beneficial uses of the resource. For example, the resulting impacts of fish impingement on powerplant intake screens depend upon the species populations affected. If these include rare or endangered species, members of depleted or stressed populations, species which are uniquely abundant locally, or species of particular economic, recreational, aesthetic, or ecosystem importance, then such impingement losses may constitute decidely negative impacts. On the other hand, if the impinged fish are abundant with reproductive and immigration potentials which can easily compensate for losses, the effects of impingement may not be significant.

Thus, in most cases, it is plant design that determines environmental effects, but site location that translates these effects into biological impacts.

FNP siting will likely be proposed for coastal areas with additional power demand and with limited potential for terrestrial sites. Several alternative sites should first be identified using existing information and scientific judgement; then studies are conducted of the physical, chemical, biological, economic, and social aspects to identify optimal site. The siting of FNP's should include special attention to potential impacts on the production of shellfish or developmental stages of marine fishes, as well as to areas important in harvest of the resources.

Each FNP requires extensive landside support facilities. During construction, shore facilities would include a concrete batch plant with bulk storage for cement and aggregates, an area for the manufacture and storage of concrete caissons and dolosse, a shipping dock, and heavy equipment to serve storage, production, and shipping areas. There would also be transfer facilities for handling quarry rock, a rock storage area, a barge loading dock, and related heavy equipment. In addition, facilities are necessary to transport personnel between the station and the mainland. A switchyard would be constructed onshore to receive and distribute power from the offshore station.

Extreme care must be exercised to protect and avoid estuarine areas in the vicinity of these landside facilities. Except for the switchyard, the site location can be to some extent discretionary, and where possible, existing docks and remote loading facilities should be utilized.

The need for these measures results from benefit/cost consideration of coastal wetlands, estuarine areas, and other natural coastal resources.

When defined in a narrow sense as semi-enclosed arms of the sea where fresh and salt water mix,[1/] estuaries of the United States are small, but they are highly productive and essential to maintenance of marine resources. In a broader context, the semi-protected waters of Long Island and the Middle Atlantic Bight fulfill biological requirements of estuarine systems by providing areas for the mixture of numerous shellfish and finfish species of the North and Middle Atlantic. It has been estimated that 68 percent of the commercially harvested fish and shellfish in the United States are dependent on estuaries.[2/] In certain areas, such as the Gulf of Mexico, up to 98 percent of these species may be estuarine-dependent.

In addition to avoiding estuaries and other coastal wetlands, clustering power stations may be desirable in some locations. Clustering reduces the need for shoreside support facilities, but obviously the marine facilities would cover a broader area, need longer breakwaters, and cause greater localized cooling water flow.

In an assessment of the options for siting individual FNP's, it is imperative that final selections optimize the multiple-use capacities of our endangered coastal resources.

Preparation of Shoreside Facilities

During construction, operation, maintenance, and decommissioning, shoreside support facilities to provide for the needs of the FNP complex would vary in character and in the land area required.

As discussed in the "Siting" section above, remote location of major support facilities should be considered. However, distance from the site may require the construction of safe harbor and dredging and maintenace of navigation channels of depths permitting free passage between the shore and the site.

Initially, when staging for breakwater construction, much traffic would pass between the harbor and construction site. After this initial activity, traffic may diminish; however, there would be a continuing need for vessels for maintenance and repair. Harbor requirements in the event of decommissioning are difficult to predict at this time.

Additional transportation facilities may include helicopter takeoff and landing areas for transfer of supplies and personnel to the FNP facility.

Although proper selection would avoid siting landside support near sensitive natural areas, it is possible that the development of such facilities may involve considerable construction and possibly filling of some shallow water areas of the estuary, including marsh or wetlands. The environmental effects of this development would result in substantial irreversible and irretrievable losses of marine and estuarine resources.

Estuaries are fringed by salt marshes providing important habitat for invertebrates, finfish, reptiles, birds, and mammals.[3/] These marshes provide breeding and nursery areas for many migratory and resident fish and wildlife species and are significant in the recycle of nutrients to the estuarine system.[4/] Annual growth and decay of marsh plants release large quantities of organic detritus, which is broken down and metabolized by bacteria and invertebrates; these organisms became prey for larger organisms, and the nutrients are thus available for the ultimate production of harvestable fish and wildlife.[5/]

The loss of estuarine wetlands through dredging and filling must be viewed as significant and should be avoided.

Construction and maintenance of navigation channels for support vessels may require dredging and spill disposal. Dredging disturbs and removes bottom sediments, modifying the ecological and physical characteristics of the area. The magnitude of these impacts depends upon the following factors: stability of the bottom, tide and current patterns, extent of dredging and amount of substrate removed, type of dredging operation (hydraulic, hopper, bucket, etc.), season, duration of dredging, type and quality of substrate, abundance and variety of organisms, and the resiliency of the ecosystem. The effects of dredging may include elimination and destruction of organisms, removal of bottom areas from production, and destruction or degradation of surrounding habitat caused by turbidity and sedimentation.

In an estuarine environment, the substrate or bottom muds support a wide variety of benthic and epibenthic organisms. Most of these species are important to man, directly as food (oysters, clams, and shrimp) or indirectly through their contribution to the food chain (bacteria, worms, and snails).

Materials removed by dredging may be disposed of by uncontained deposit in the open ocean or estuary or by containment behind dikes in shallow estuarine areas and wetlands or on associated terrestrial areas. Spoil disposal may produce increases in levels of turbidity and sedimentation, especially if uncontained. Although some recent studies of nearshore marine dredge spoil disposal have not demonstrated ecological damage, an increase in turbidity and sedimentation is believed to affect aquatic organisms both directly and indirectly.[6/] Respiration in fishes can be impaired by clogging gills or mechanical abrasion of gill filaments. Reproduction can be affected by suffocation of eggs or inhibition of spawning of demersal organisms. Sediments can suffocate nonmotile benthic organisms, reducing productivity of important shellfish. Photosynthetic activity may be reduced by the lowering of light penetration. The normal activity and feeding cycles of some organisms may be altered and the ability to escape predation may be impaired. Each effect is dependent upon the extent, intensity, and geographic site of the physical perturbation.[7/]

Construction of a transmission network between the FNP site and its shoreside facility may cause another type of direct environmental impact by altering freshwater inflow from surrounding uplands to wetlands and shallow water areas and possibly by increasing sedimentation and water temperature of the inflow.

In summary, planning and preparation of shoreside facilities must include *rigorous efforts to avoid destruction of estuarine or estuarine-dependent resources.* An obvious way of minimizing impacts is to concentrate support facilities in areas which are already developed. The incorporation of engineering practices designed to mitigate environmental damage could also minimize some of the direct environmental effects.

Preparation of the Offshore Site

As presently envisioned, an FNP would be located within 3 miles of the coast, in waters between 45 and 75 feet deep. Prior to installation of the floating facility, breakwater structures and other wave energy-dissipating devices would be emplaced. The only FNP for which a construction permit has been requested so far has a massive D-shaped breakwater as the centre of its plan. This structure is designed to have a center core of rock-filled caissons, progressively covered with quarry stone and larger rocks, and topped off with dolosse. First, caissons would be floated to the site, sunk, and filled with rock; quarry rock would then be placed on the seaward face of the caissons and topped with dolosse. Other FNP installations may employ a different breakwater configuration or perhaps even a totally different engineering approach for protection.

Prior to emplacement of materials at the site, dredging will probably be required to develop a firm foundation or base on which to construct the breakwater; clearly this is dependent upon the nature and depths of the substrate. If the breakwater is located in relatively shallow water (less than 45 feet), additional dredging may be required within the basin to float the FNP. Methods of dredging and spoil disposal and their biological effects will depend on local conditions.

Direct environmental effects from preparation of the type of offshore site presently proposed include destruction or displacement of the biological communities associated with approximately 100 acres of the unconsolidated sea floor sediments and increased turbidity and sedimentation over a much broader area. However, even where local sediments are most prone to resuspension and redistribution, careful construction practices may help minimize possible adverse biological effects.

For example, in spite of the present requirements for consideration of alternative sites, it is possible to envision installation of an FNP in an area supporting important populations of shellfish or other bottom organisms. In such a case, dredging or spoil disposal may be limited to periods of maximum currents, allowing suspended materials to be widely rather than locally dispersed. Similarly, if an FNP were sited in an area seasonally important to larvae or juvenile forms of marine organisms, appropriate studies could be conducted to determine seasonal intervals to minimize impacts of site preparation.

A relatively small volume of sedimentary overburden -- less than 500,000 cubic yards -- is expected at any single FNP site. Consequently, with careful construction measures it is expected that the direct impacts of offshore site preparation can be nominal and locally contained. Long-term, irretrievable losses are those associated with the destruction or alteration of bottom areas and biota within and under the breakwater structure. Unavoidable damages to marine resources are also possible from local increases in turbidity and sedimentation; however, such damages are expected to be transitory. No uncompensable losses are expected to result from careful preparation of a properly selected offshore site.

Installation of the Breakwater and FNP

Preliminary estimates suggest that up to 3 years may be required to complete construction of a breakwater and install an FNP. This time may vary considerably, depending on the type of site, volume of materials placed on the breakwater, weather conditions, and the availability of construction materials.

Breakwater construction would be initiated during or shortly after final preparations of the offshore site. Construction materials for the breakwater would be barged to the area and emplaced. Initially, quarry rock would be unloaded from barges into caissons emplaced on the bottom as a base or core. Later, as the structure increased in height, materials would be placed by floating cranes or similar equipment. Because this activity depends upon the use of barges and other floating equipment, work would be conducted during calm seas. Once construction is initiated, it is expected to continue until the breakwater reaches a stage at which storm conditions can be sustained with minimum damage.

The adverse environmental effects of breakwater construction are expected to be minor in comparison with those occurring during site preparation. Principal adverse effects at this stage are probably those due to sedimentation from "fines" associated with the emplacement of quarry stone; however, these materials are expected to occur in small, rapdily settling amounts.

When the breakwater is complete, populations of reef-associated organisms are expected to establish themselves in and along the breakwater. Initially, these populations would be of a "pioneer" type; with time and aging of the substrate, this biological community is expected to become more complex and more stable. Within months the breakwater may support a relatively luxuriant reef community, depending upon physical aspects of the location and the season. This community, if undisturbed, could substantially enhance local marine resources but is not expected to be significant on a regional basis.

Because of the narrow choice of methods available for constructing a breakwater in the open ocean, there appear to be few opportunities to mitigate damage resulting from placing quarry rock, large stones, and concrete dolosses at the site.

Installation of Marine Transmission Facilities

At most sites, a submarine power transmission system is necessary to convey electricity from the FNP installation to the land. A two-unit, 1140 MWe station requires approximately five separate underwater cables. Each cable would be buried in the bottom sediments a minimum of 10 feet and, as presently envisioned, would have an 80-foot right-of-way.

Cable installation would probably be accomplished by special ship-mounted equipment that dredges, lays the cable, and backfills in one continuous operation. If the right-of-way traverses rocky or solidly compacted sediments, the use of explosives may be necessary to loosen the material for burial of the cable.

Laying submarine transmission cables may cause local, short-term impacts where the right-of-way passes through productive plant and animal communities. However, if sensitive environments are avoided, biological effects of this phase of construction may be minimal. Principal effects would be destruction of benthic organisms from dredging and locally increased turbidity and sedimentation. It is conceivable that sediments containing undesirable concentrations of toxic materials will be redistributed, especially if construction occurs in an estuary or nearshore area receiving industrial or domestic wastes.

In summary, the potential environmental impacts of installing a submarine electrical transmission system may be avoided by careful selection of routes avoiding sensitive biological areas and by careful selection of time periods to avoid intervals of high biological productivity or activity.

Installation of Terrestrial Transmission Facilities

Landside power transmission facilities are needed to convey electricity generated at the FNP to major load zones or transmission networks. It is well known from environmental impact analyses of conventional powerplants that terrestrial transmission facilities must be judiciously sited and properly designed, constructed, and maintained to avoid substantial environmental impacts.

Because of comparative costs and other considerations, electricity is usually transmitted by overhead lines rather than by subterranean cable. System reliability requires clearance of large vegetation in power line rights-of-way and construction of all-weather access roads for maintenance of the lines. Access roads in low-lying coastal areas are constructed on fill; in the uplands, roads are constructed by cut and fill.

Significantly negative environmental effects may occur from filling low-lying coastal wetlands. The fill may eliminate areas of natural vegetation, including salt marsh, and modify the topography adjacent to the roadbed. Depending upon design of the road, local patterns of runoff may be changed, affecting the natural salinity regimes of adjacent coastal wetlands.

In the uplands, vegetation clearance and control in the right-of-way may be either beneficial or detrimental to wildlife, depending upon the species involved and the degree of treatment. Depending upon the topography and soils, eroded materials may be transported from the roadbed to disturb adjacent areas.

Many of the described effects can be avoided. For example, roadways through low-lying coastal areas, especially wetlands, may be constructed on piles, minimizing or avoiding most of the undesirable effects of construction. Upland areas subject to erosion or with low revegetation potential should be avoided during route selection. Some vegetation control in the rights-of-way could be accomplished by hand or mechanical means. Plant species low to the ground with relatively high wildlife habitat value may be introduced to improve wildlife carrying capacity of the area.

Operation of the FNP

It is assumed that each FNP would contain two standard 1140 MWe nuclear generating units. To dissipate waste heat, approximately 1 million gpm of cooling water with a maximum temperature increase of 16°F (9°C) during passage through the powerplant is required by each unit.

Cooling water is obtained by circulating pumps which draw water from the basin in which the FNP floats, via an intake structure located on the barge. The intake structure will contain trash racks, as well as fixed and/or traveling screens to prevent debris and large objects from entering the cooling water system.

Cooling water from two parallel FNPs may be combined and discharged shoreward of the breakwater. Time of transit for passage of water through the powerplant cooling system will be approximately 4 minutes, depending upon the length of the discharge conduit. All secondary liquid wastes (such as wash water and sewage) from the plant, as well as liquid radioactive wastes, will be treated and discharged into the heated effluent.

Operation of the FNPs may directly affect marine organisms by entrapment, impingement, entrainment, thermal and chemical additions, and the physical interactions of the discharge flow with the marine waters and substrate of the area.

Entrapment Within the Breakwater

The circulation of 2 million gallons of water per minute through an FNP will induce large volumes of water to flow into the breakwater structure. Openings in the breakwater are expected to be perpendicular to the coastline, parallel to the longshore currents. This alignment may result in differential rates of flow through the openings in the breakwater and will probably attract a variety of marine organisms to settle there.

At existing shoreside plants employing once-through cooling, entrapment may occur at any recessed opening offering refuge, such as intake canals or portions of the intake forebay. Once fish or shellfish are within these areas, the probability of "escape" is reduced simply because of size or weak swimming capabilities. Proper design of the breakwater and plant can be of great importance in reducing entrapment.

Based on shoreside experience, currents generated by the FNP will attract many fish species which are either permanent or temporary residents of areas near proposed FNP installations. Certain species of fish and shellfish utilize currents and tidal streams for transport and may be significantly affected. For example, soles (Solea solea) have been observed immobile or swimming slowly at the surface, to take advantage of maximum current velocities expected there.[8/] The apparent result of this behavior is passive transport by tidal currents in the direction of the fishes' spawning grounds. Fairbanks and co-workers[9/] reported winter flounder (Psuedopleuronectes americanus) commonly observed swimming steadily with the current, several feet off the bottom, in Cape Cod Canal. It is postulated that these fish followed currents created at a nearby powerplant because many adult flounder were observed near the forebay and were subsequently collected from intake screens.

Fishes with a positive rheotaxis may also be affected by pump-induced current patterns. Such behavior has been observed for a number of marine species, such as scup (Stenotomus chysops), butterfish (Poronotus tricanthus),[10/] chinook salmon (Oncorhyncus tshawytscha),[11/] and plaice (Pleuronectes platessa),[12/] as well as a number of fresh and brackish water species.

The susceptibility of organisms to entrapment can also be affected by other seasonal and diurnal behavioral characteristics. For example, where intake structures withdraw cooling water primarily from the center of the water column, benthic organisms lying on the bottom during some periods of the day are less susceptible to entrapment and secondary effects. Species reflecting such a daily variation in activity include the tautog (Tautoga onitus),[13/] winter flounder,[14/] cunner (Tautoglabrus adspersus),[15/] sea robin (Prionotus carolinus), puffer (Sphaeroides maculatus), and sculpin (Myoxocephalus aeneus). However, when feeding, these species may swim upward in the water column in search of food and increase their chances of entrapment.

Some fishes take advantage of the characteristic of induced water currents to aggregate food organisms. This has been observed at the Pilgrim Nuclear Plant, Plymouth, Massachusetts, where dense populations of pollock (<u>Pollachius virens</u>) inhabit areas immediately adjacent to the intake structures, apparently to feed upon food organisms carried by the induced current.[16/]

Large schools of fish have been entrapped and subsequently impinged on the water intake screens at some power stations located in the marine or estuarine environment. These occurrences may result in a reduction in power generation or plant shutdown. An early incident occurred in 1925 at the Brooklyn Edison plant on New York harbor, where the plant intake structure became clogged with spot (<u>Leiostomus xanthurus</u>). The plant was shut down for days while crews shoveled out tons of fish. In May 1973, at the Crystal River power station in Florida, a large school of Atlantic threadfin was attracted into the long intake canal. These fish became emaciated from lack of food and ultimately were impinged on the intake screens. The plant shut down for a period of 4 to 5 days.

<u>Impingement</u>

Impingement, a common problem in cooling water withdrawal systems at existing powerplants, represents a significant area of concern regarding FNPs. Direct mortality or injury to impinged organisms can generally be related to four factors: mechanical damage caused by direct contact with screens; asphyxiation or exhaustion caused when water pressure holds the organisms against the screen, particularly when screens are clogged with debris and differential pressures are maximized; mechanical damage from high pressure jets used to wash the screens; and damages associated with handling the organisms after removing them from the screens. The latter two factors may be minimized with proper plant design; the former are largely dependent on plant siting. However, it should be recognized that organisms surviving the initial shock of impingment are subsequently washed from intake screens and may be more susceptible to death, disease, and predation.

The location and design of intake structures and associated screening devices are critical in powerplant design. Typically, trash racks and adjacent fine mesh screens are located in recessed channels at the sides of the intake. Because the intake opening is smaller than the water body from which water is drawn, velocities increase as it passes into the system. Organisms drawn into the intake first encounter a trash rack composed of vertical bars approximately 3 inches between centers; following that is either a fixed or traveling screen, ususally of 3/8 inch mesh. At some facilities a fixed fine-mesh screen is followed by a screen of similar mesh which travels vertically to enhance washing of organisms and debris from the screens. Regardless of the number of screens, impingement of organisms in substantial numbers can occur if such organisms are locally abundant and unable to avoid the system.

Impingement rarely occurs at the outer trash racks because the spacing allows passage of large organisms. In addition, organisms large enough to encounter the trash racks without going through them are usually capable of swimming out of the area. However, certain large invertebrates are susceptible to impingement, and their presence in large numbers has been documented. For example, approximately 2,000 horseshoe crabs (Limulus polyphemus) were collected from the screens on a single sampling date at the Brayton Point Electric Generating Station, Somerset, Massachusetts. 17/ At the same site, as many as 380 blue crabs (Callinectes sapidus) were collected in a single sample.

Most impingement damages affect juvenile or small fish because they pass through the trash racks and may be drawn against the fine mesh screens unless they are capable of exiting the forebay. Typically, fish and other entrapped organisms may escape only by swimming against the current, retraversing the trash racks, and finally, exiting the intake system. Obviously, the greater the current velocity and the smaller the organism, the more difficult escape becomes.

As previously indicated, the quantity of fish impinged and the rapidity of occurrence are occasionally such that a plant is shut down because cooling water flow through the screens is impeded. In a few instances, impinged fish and debris have caused screens to buckle because of differential pressures. 18/

At a number of conventional generating stations, the rate of screen-induced mortality has been extremely variable. At plants along the Hudson River, Long Island Sound, and Galveston Bay, for example, heavy kills have been reported during all seasons, often at night.

The magnitude of fish impingement mortality may be a function of cooling water velocity. In addition to increasing impingement, higher velocities may cause larger fishes to become vulnerable. Observations at the Indian Point Nuclear Generating Plant on the Hudson River suggest that when approach velocities exceeded 1.0 feet per second, the number of impinged fishes greatly increases; reducing flow reduces the number of impinged fish.[19]

Because there are no offshore powerplants at present, no operational fish impingement data support estimates of possible FNP impingement losses. Even for existing estuarine powerplants, impingement records vary greatly in detail and accuracy. Table 1 summarizes some of the more serious cases of fish impingement observed at once-through powerplants in saline or brackish water. Although not representative of routine losses or of marine conditions, these examples underscore the potential seriousness of impingement.

Once impinged, organisms are held captive by the force of water flow. Where the plant is equipped with traveling screens, they are periodically rotated and strong water jets dislodge the fish and debris, which fall into a collecting trough for disposal. The interval and duration of the rotation of traveling screens are usually determined by experience in operating the plant and depend upon plant location, population levels, and seasonal and diurnal cycles controlling the vulnerability of organisms.

Certain fish species appear able to survive impingement better than others. For example, flounders habitually lie on the bottom and may survive impingement when exposure time is short and where other conditions are favorable.[20] Because dense schools of pelagic and benthic fishes normally inhabit shelf waters of the Atlantic coast, the potential for substantial impingement kills at FNPs must be carefully considered. Such impingement losses may be great enough to affect local commerical and recreational fisheries and important food chain organisms. Although FNP siting and cooling water system designs appear to present options for mitigating such effects, impingement must be a continuing concern in any FNP licensing.

As a result of increased construction of large once-through generating stations, the frequency and magnitude of impingement-related problems at shoreside powerplants

Table V-1. Impingement Data

Power Plant	Impingement Event	Period	Comments
Millstone, Niantic Bay Conn.	Massive kill of small menhaden (more than 2.0 million), screens clogged.	1971	Occurring late summer, early fall; plant shut down on 8/21/71; cause unknown persistent low kill of 10 other species.
P.H. Robinson, Galveston Bay, Tex.	7,191,785 fish impinged in one year.	1969-70	Projected from sampling of operating plant; principal species were menhaden, anchovy, croaker; highest in March.
Indian Point, No. 1 Hudson River, N.Y.	Yearly kill of 1.0 to 1.5 million fish.	1965-72	Primarily white perch with 4-10% striped bass.
	Kill of 1.3 million in 9 1/2 weeks	1969-70	10% striped bass; plant closed Feb. 8.
Indian Point, No.2	Massive kills; maximum per day 120,000.	Jan. 71	Testing cooling system of new plant (no heat); white perch & other species.
	175,000 fish killed in 5 days.	Feb. 72	Testing again (no heat) Con. Ed. fined $1.6 million by N.Y. for kills.
Indian Point, No. 1,2	Predicted total kill 6.5 million fish per year.		With both plants in full operation.
Port Jefferson, Long Island, N.Y.	2 truckloads (at least) of fish killed on screens in 3 days.	Jan. 26-28 1966	Mostly small menhaden; also white perch.
Crystal River (near) Cedar Key, Fla.	Predicted annual kill of 400,000 fish and 100,000 shellfish.	1969	Based upon operation of 3 units (2 units now destroy 1/2 this amount).
Brayton Point, Mt. Hope Bay, Mass.	350,000 fish impinged in one year; mostly menhaden.	1971-72	Heaviest from Nov.-March; flounder, silverside, & others also impinged.
Oyster Creek, Barnegat Bay, N.J.	10,000 fish, 5,000 crabs, destroyed per month in spring and summer.	1971	Estimated from 19 days of sampling; screen kill in cold season unknown.
Surry Power Station James River, Va.	6 million river herring destroyed in 2-3 months	Oct.-Dec. 1972	Estimated by AEC from screen samplings during partial power runs.

Source: John Clark and Willard Prownell, Electric Power Plants in the Coastal Zone: Environmental Issues, American Littoral Society Special Publication No. 7, October 1973, Table V-B.

have increased. Studies to develop methods to reduce this problem are underway by government, industry, and scientific institutions.[21] Such programs have thus far met with limited success; however, a number of important factors have been identified which influence impingement. Plant siting and water velocity appear to be the most critical. Decreasing the rate of flow, thereby reducing intake velocities, has been successfully used to reduce impingement;[22] however, this technique requires an increase in the differential temperature of the cooling water.

To some extent, intake design factors can reduce impingement. Construction of a curtain wall extending down into the water column in front of the intake structure may inhibit pelagic fishes' entering an intake system; construction of a sill extending from the bottom upward into the water column may discourage benthic fishes and shellfish from entrance.[23] Construction of trash racks and traveling screens to minimize recessed areas is a promising way to reduce entrapment of fishes in the vicinity. Clearly, research efforts are required to improve intake structure designs and to identify physical, chemical, and biological factors important to the impingement process.[24]

Entrainment

In current industry practice, the smallest mesh size commonly used in powerplant intake screening is 3/8". Aquatic organisms small enough to pass through 3/8" openings are potentially subject to entrainment, passage through the pumps and condensers of a powerplant circulating water system.

Entrainable organisms include phytoplankton; zooplankton; eggs and larvae of fishes and invertebrates (meroplankton); fry and juvenile fishes; and other groups such as the protozoa, bacteria, and aquatic fungi. Although the distribution of plankton in natural waters is stratified and clumped (patchy) rather than uniform or random, a general assumption may be made that in most cases, the quantity of entrained aquatic microbiota will proportionately reflect the rate of intake flow.

During condenser passage, entrained organisms may be subject to thermal shock; mechanical shocks and abraison; pressure changes; toxic chemicals, including chlorine; and additional thermal stress, turbulence, and predation in the discharge.

In general, the many previous studies of entrainment effects verify the fact that considerable damage to entrained organisms has resulted from thermal stress as well as from other types of stresses and shocks[25] (see Appendix E). In some cases, however, measurable damage has been slight.

Most frequently, the major effect reported on condenser passage of phytoplankton has been the apparent stimulation of photosynthesis during months when ambient (intake) water temperatures are low and the apparent inhibition of photosynthesis when water temperatures are high. Although most data exhibit considerable variability, this effect has been evident in a number of studies of primary productivity in condenser discharge samples that were compared with condenser intake samples.[26]

It appears that these increases and decreases in primary productivity primarily reflect sublethal, physiological effects on the phytoplankton and decreases are produced mainly by thermal, chemical, and mechanical stress or damage during condenser transit. In general, the higher the discharge temperature at a given powerplant and aquatic system, the more pronounced the observed photosynthetic inhibition.

Some powerplant entrainment studies have included observations of entrained organisms at times when the plant is producing no power and, therefore, no heat. By running the circulating water pumps without heat transfer, the effects of mechanical damage to entrained organisms may be studied in comparison with the combined thermal-mechanical effects measured during normal plant operation.

In a number of powerplant entrainment studies, mechanical damage to phytoplankton has been measured using productivity and chlorophyll assays as well as microscopic observation for broken diatom frustules or other signs of structural cell damage. However, the magnitude of these effects does not appear to be as large as that due to thermal stresses.

Severe reductions in the productivity of phytoplankton entrained during condenser chlorination also has been observed in many studies. Cell damage and loss and reduction in the chlorophyll a content of discharge samples have accompanied the reduced productivity.[27]

Zooplankton also are subject to entrainment, and both thermal and mechanical stresses have been observed by various investigators to be lethal to entrained crustacea. Lethal "thermal doses" for entrained opossum shrimp (Neomysis awatschensis) were exceeded, for example, in laboratory simulations and condenser passage studies at the Pittsburgh and Contra Costa powerplants on the Sacramento-San Joaquin estuary in California.[28] When discharge temperatures exceeded 30°C, mortality usually exceeded 65 percent. Neomysis mortality was described in these studies as being influenced more by absolute discharge temperature than by the temperature change. Presumably, this was due to the relative independence of the organism's upper lethal temperature from modification by acclimation. Studies at the Indian Point powerplant on the Hudson River have also reported increased entrainment mortality of Neomysis and other crustacea when discharge temperatures exceeded 32°C in summer.

The physiological significance of the duration of condenser transit, as well as of temperature, in the effects of entrainment of zooplankton has been emphasized by several investigators. In studies at four coastal powerplants in California, the relationship between absolute discharge temperatures and zooplankton entrainment mortalities was significant and linear. At the Potreo, Humboldt Bay, Moss Landing, and Morro Bay powerplants, average temperature rises of 9, 15, 13 and 13°C and condenser transit times of 1.4, 3.4, 11.6, and 11.9 minutes produced average zooplankton entrainment mortalities of 1.3, 5.9, 10.7, and 6.7 percent, respectively. When discharged zooplankton were held for 24 hours at discharge temperatures, further increases in mortality were observed. When similarly held at intake temperatures, neither significant recovery nor delayed mortality was noted.[29]

Some mechanical damage to entrained zooplankton also has been reported. At power stations where lethal time-temperature conditions apparently are not reached in condenser transit, average zooplankton mortalities have ranged from 6 to 12 percent.[30]

Powerplants have been described by analogy as "large, artificial predators" acting upon populations of entrainable organisms. This predation is selective. Entrainment damage which results from lethal time-temperature combinations at various powerplants obviously is more damaging to the more temperature-sensitive species of plankton. Similarly, for powerplants in which entrainment damage to zooplankton is

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primarily mechanical, the "predation" also is selective on the basis of size, being more damaging to the larger entrained organisms.

Delayed effects of entrainment have been reported for zooplankton. At the Millstone Point powerplant on Long Island Sound, zooplankton entrainment mortality of approximately 70 percent was noted. Immediate examination of samples at the condenser discharge, however, showed only a 15 percent kill. On the other hand, a significant recovery of condenser-passed zooplankton, sometimes exceeding 20 percent of those observed to be immobile immediately after discharge, has been reported to occur after 4 hours' storage at intake water temperatures.[31]

Damage to the eggs, larvae, and entrainable young of fishes in a powerplant cooling water system is also a potentially serious problem.[32] Generally, careful location and design of intakes appear to be the most effective opportunities for reducing such effects, whereas other cooling water system design options do not appear effective. In other words, this problem is more effectively avoided than corrected.

At the Millstone Point[33] and Chalk Point[34] powerplants, mortality to entrained fish larvae was reported at and above 90 percent. At the Indian Point station, approximately 46 percent of entrained white perch and striped bass larvae reportedly were killed,[35] and considerable concern has been expressed regarding the impact of this loss on the striped bass fishery.[36]

In studies at the Connecticut Yankee powerplant (Connecticut River), it was reported[37] that during the 93-second condenser passage, at discharge temperatures of 28, 33, and 35°C, only 35, 19, and 0 percent, respectively, of entrained fish larvae and fry (mostly alewives and blueback herring) survived. Almost none of these young fish was observed to survive subsequent transit down the plant's long (1.83 km) discharge canal in summer, when condenser discharge temperatures exceeded 30°C. In a later report,[38] however, 72-87 percent of the observed mortalities were attributed to mechanical damage, with thermal stress responsible for the rest.

As with zooplankton, mechanical damage to entrained young fish increases with the size of the fish.[39] On the other hand, mechanical destruction of entrained fish eggs also appears to occur. At the Vienna, Maryland, powerplant, 99.7 percent average mortality of striped bass eggs was reported,[40] and large differences were observed in the numbers of eggs entering and leaving the cooling system. The assumption might be made that some egg destruction occurred during plant passage.

The kinds of marine organisms which can become entrained in powerplant cooling water systems are vital to the energy flow, nutrient budget, and dynamic stability of the marine ecosystem, as well as to the production of various species of commercial and recreational importance. In any case in which powerplant entrainment has a potentially significant adverse effect on any of these important natural processes, remedial measures are mandatory. In every aquatic ecosystem, however, certain kinds and amounts of biotic damage can occur locally without significant ecological impact. Planktonic populations, for example, are naturally exposed to considerable grazing or predation, which may dramatically affect their abundance. These populations are also exposed to seasonal and transient changes in the physical, chemical, and biological characteristics of their environments as well as to other natural stresses and limiting influences. The life span of most plankters in natural waters is less than 1 month. Density-dependent phenomena such as the rates of reproduction and natural mortality enable populations to compensate for large losses. With regard to entrainment losses of fish eggs, larvae, and young, it is noteworthy that in some species which have pelagic eggs and larvae, natural survival rates from egg to adult are believed to be on the order of 0.001 percent.[41]

Although a number of general principles concerning entrainment effects apparently can be surmised from previous studies conducted at shoreside powerplants, it is also true that many important questions regarding investigative methods and ecological significances of entrainment damage remain largely unanswered. In the first place, known daily variations in the physiology, behavior, and distribution of entrainable organisms can profoundly affect the results of sampling as well as the results of measurements of lethal and sublethal effects of entrainment. Examples of these include variations in the heterotrophic activity of phytoplankton and the vertical distribution of zooplankton. The influences of such phenomena on the results of entrainment studies need to be better characterized. Second, microbial groups such as protozoa, natural bacteria, and nannoplankton are important in the dynamics of aquatic ecosystems and are generally characterized by high physiological responsiveness. We have little knowledge about the effects of entrainment on these organisms and need to investigate such effects further. Third, sampling mortality, as well as sampling gear efficiency and selectivity, need to be better characterized and/or reduced. In zooplankton entrainment studies, for example, mortality in intake samples is commonly subtracted from that in discharge samples; however, sampling mortality is increased among these fragile organisms, resulting in somewhat biased estimations of entrainment damage. In addition to the foregoing, studies are needed regarding the influences of sublethal entrainment stresses to entrained zooplankters on their abilities to evade sampling gear. Such stresses can appreciably reduce the ability of organisms to evade sampling gear in the condenser discharge samples, resulting in higher collections of stressed (albeit live) plankters after condenser passage. Finally, we need to understand better the delayed effects of entrainment, including moribundity, sublethal stress, and recovery; the ecological significance of the increased susceptibility of entrained organisms to predation; the influences of skewed entrainment mortality and changes in reproductive potentials on plankton community dymanics; and, in general, the limits of compensatory population response potentials and the effects of powerplant-related mortalities on marine food web relationships.

It should be obvious from the preceding examples that although a great deal of work is needed to enable better characterization and assessment of the effects of cooling water system entrainment on marine biota, most of the areas of present uncertainty reflect limitations in state-of-the-art biological methodology and knowledge. It should also be apparent that it is not necessary to answer every conceivable question before certain general conclusions, such as those reached in this section, can be reached regarding the effects of entrainment.

Discharge Effects

The discharge of heated effluents from an offshore nuclear power station may cause adverse effects on marine resources. The magnitude of these effects depends upon plant design, operation, and site location. A detailed summary of discharge effects observed at existing shoreside powerplant sites is provided in Appendix C. In addition to heat, chlorine is widely used to control fouling in the condenser system, and other chemical preservatives and boiler blowdown are released as wastes to the effluent. Chlorination is usually periodic, depending upon local seasonal growth conditions, and is more frequent in warm seasons. Chlorine is highly toxic even at low concentrations;[42/] however, mortalities at powerplants are not commonly observed partly because the benthos of the receiving waters are reduced to resistant animals that tolerate the periodic treatments and because mobile organisms tend to avoid lethal concentrations.

Even so, a number of chlorine-caused kills of fish and shellfish are known to have occurred in past years at shoreside powerplants. A few have occurred at estuarine plants, such as a large kill of menhaden at the Cape Cod Canal power station and another in which 40,000 blue crabs were killed at the Chalk Point power station in Maryland.[43/] Many other kills, particularly those limited in space or time, may have gone unrecognized or unreported. Chlorine toxicity data indicate that very small concentrations may be lethal during long exposures and that amounts exceeding 0.3 milligrams per liter may be lethal to some organisms during short exposures of 10 minutes or less.[44/]

Chlorine and its attendant problems may be avoided by using alternative anti-fouling methods. In some plants, relative success has been achieved by diverting a portion of the heated discharge into the cooling system to defoul the condenser. At the San Onofre power station in California, for example, this technique is used without causing large fish kills. At the Surry power station in Virginia, Amertap mechanical cleaning has been incorporated into the plant design and is reported to be satisfactory at that site.

In addition to chlorine, cooling water discharges may contain small amounts of toxic metals such as copper, chromium, and nickel. Quantities of these metals leached from any one power unit are normally too small to cause concern, but it is conceivable that the cumulative release from several plants may prove unacceptable.

Another problem which has become recognized in recent years is the mortality of fish due to gas embolism. When intake waters are cool, gas concentrations in the water withdrawn are at or near saturation levels. Elevating the temperature of the cooling water in the condensers causes supersaturation of these atmospheric gases (principally nitrogen). Fish exposed to water supersaturated with gases quickly reflect similar gas concentrations in their blood. When the gases in the blood reach a sufficient concentration, bubbles (or emboli) form, capillaries become first distended and then break, hemorrhage of highly vascularized tissue occurs, and frequently death follows by blood loss.

The movement of fish into a heated plume may also cause gas disease when the dissolved gas concentrations in the blood of these fish is at or near saturation. Although an embolism-related fish kill had been previously observed in fresh water,[45/] the first documented example in marine waters occurred in 1973 at the Pilgrim Nuclear Power Station, Plymouth, Massachusetts;[46/] an estimated 50,000 adult menhaden died in this incident.

The most obvious effects of powerplant discharges are seasonal increases in fish attracted to the immediate discharge area by dead or dying food organisms as well as by warm discharge waters. Although these attractions may be advantageous, especially to recreational fisheries, organisms residing within this area may be subject to lethal or sublethal elevated temperatures, cold shock, chemical effects, changes in metabolism or behavior, increased incidence of disease, and other hazards. Examples of some of the more serious discharge-related fish kills occurring at estuarine powerplants are shown in Table 2.

Fish kills caused by powerplant discharges are not generally well documented. It is probable that many kills go unrecorded because dead fishes or other organisms are not observed or are attributed to other causes. In many cases, dead fish sink quickly and disappear from sight[47/] or are eaten by seabirds or other scavengers. In some instances, kills have not been reported simply because the observer did not know the mechanism necessary to report the incident. When fishes or other organisms are killed, it is often difficult to determine the specific cause. Thus far, there has been no compilation of powerplant-related fish mortalities on a regional or national basis.

Table V-2. Discharge-Related Mortality Events at Powerplants Located on Estuarine Waters

POWER PLANT	EVENT	DATE	COMMENTS
Oyster Creek, Barnegat Bay, N.J.	100,000-200,000 menhaden killed	Jan. 28-30, 1972	Cold shock following winter plant shutdown. Fish were resident in plume. Approximately 25°F drop in temperature.Continuing winter 1973.
Northport, Long Island Sound, N.Y.	10,000 bluefish killed	Jan. 17, 1972	Cold shock caused by sudden shifting of plume (ΔT 25°F) due to winds and tide. Fish resident in plume exposed to cold. Bodies on bottom; count made by diver.
Millstone Point, Long Island Sound, N.Y.	tens of thousands of adult menhaden killed	Spring, 1972	No reason given (we suspect nitrogen gas embolism--authors).
Turkey Point, Biscayne Bay, Fla.	thousands of dead fish	June 26, 1969	High temperature shock, apparently. Plant discharge temperature 95-100°F
Lovett, Hudson River, N.Y.	1,000 fish killed	June 7, 1971	Species not given. Power plant caused. Lovett assumed responsible; closed plant to Thompkins Cove, where reported.
P.H. Robinson, Galveston Bay, Texas	significant kill of menhaden	Aug. 21, 1968	Unknown quantity. Cause given as high temperature shock.
Pilgrim, Cape Cod Bay, Mass.	from "thousands" to 75,000 or more adult menhaden		Smithsonian report, 1,000's; press, "...fight for life...school in excess of 75,000." Apparent cause nitrogen embolism.
Cape Cod Canal, Cape Cod Canal, Mass.	kill of several hundred to several thousand menhaden per treatment	Aug./Sept., 1968	Chlorine treatment (residual Cl=0.8-1.5ppm) twice daily; kills occurred at high water slack.
	repreated mortality of large schools of silversides and menhaden	late summer, 1968	Near discharge; lethal temperatures 90-94°F; predation by gulls.
Chalk Point, Patuxent River, Md.	40,000 blue crabs killed, minimum		Cause not determined; probably chlorine.

Source: John Clark and Willard Brownell, Electric Power Plants in the Coastal Zone: Environmental Issues, American Littoral Society Special Publication No. 7, October 1973, Table VI-A.

The effects of temperature on marine organisms has been extensively documented.[48] Many marine organisms exist at temperatures near their "upper incipient lethal limit"; exposure to temperatures above this limit for sufficient time results in death. However, organisms may withstand brief exposures to high temperatures, particularly if previously acclimated to elevated temperatures. Even so, these sublethal thermal shocks can affect behavior and result indirectly in mortality. Conversely, the consequences of cold shock, mortalities induced by a sudden reduction in temperature from plant shutdown, are well-known.

Up to a point, lethal temperature levels are significantly affected by the previous thermal history; fish acclimated to cold temperatures have a lower incipient lethal temperature than fish acclimated to higher temperatures.[49] Therefore, seasonal temperature regimes may have a profound influence on the temperature tolerances of fish.[50] In addition to thermal history, age, season, day length, sex, water quality, diet, and hormonal condition may directly or indirectly affect lethal temperature tolerance of fish.[51]

Fish mortalities directly related to high temperatures from offshore power stations will be an infrequent event because most species avoid lethal situations; however, certain prey species congregating in the vicinity of the plume may be driven into a lethal zone by predatory species.

Occasionally a powerplant may shut down or reduce load rapidly. At such times, fish living in the warm effluent in colder seasons may be subject to a rapid, lethal drop in temperature. Factors involved in determining the degree of severity of the shock include individual species characteristics, size, ambient temperature, the absolute temperature change, the rate of temperature change and others. For example, menhaden can tolerate a drop of 3.6 to 20.7°F, depending upon size and acclimation temperature.[52] As observed at the Oyster Creek Atomic Plant, Barnegat Bay, New Jersey, in 1972 and 1973, menhaden die when these lethal limits are exceeded.

An additional problem related to heated discharges is possible recirculation of heated effluent through the plant. Under certain wind and current conditions, heated water may flow around the breakwater rather than dissipating into surrounding waters. At that time extraordinary temperatures would be experienced in the discharge, increasing the likelihood of direct discharge damage to resident biota and entrainment mortalities. Heated waters may also enter the revetment, causing additional mortality of entrained organisms, increased incidence of impingement, and thermal stressing of biological communities established on the breakwater.

Although the heated effluent will primarily be a surface phenomenon, the plume may occasionally contact the bottom. When that occurs, the structure of benthic communities proximal to the discharge may be modified and perhaps simplified in structure. However, dissipation of discharge velocities and temperature to tolerable levels is expected within a short distance, minimizing this impact.

There is potential for increased predation in the area of discharge. At the Pilgrim Nuclear Station, for example, divers have observed striped bass and cod positioned beneath the plume. These fishes periodically prey upon menhaden congregated in the thermal effluent. At the Pittsburgh Power Station in California, striped bass collected from the area of the thermal plume had greater numbers of chinook salmon smolts in their stomachs than did those collected from nearby "reference" areas. Although this impact does not necessarily amount to an adverse effect, the possible proliferation of offshore plants could lead to the increased cropping of juvenile forms of fish species utilized by man. Additionally, if the heated effluent attracts large schools of sport or commercial fishes, these schools may not be accessible for harvest in the immediate vicinity of the FNP because of safety factors.

Maintenance of FNP Facility

One direct environmental impact of FNP station maintenance will result from the continued need for landside support facilities (vessels, docks, loading equipment, etc.) to transport materials to the site for breakwater repair.

Within the breakwater, sedimentation may necessitate periodic maintenance dredging; frequency is site-specific and dependent upon currents, substrate, water depth, and rate of deposition.

Barges housing the FNPs will require periodic repair and refurbishing. Major hull repairs may necessitate enclosing the structure behind watertight barriers for temporary drydocking. Although improbable, emergency repair may be required on the submarine transmission cables in addition to routine maintenance.

The environmental effects of maintaining landside facilities probably will not require a commitment increased over that of the construction phase. Depending upon location, it may be possible to use existing facilities; if so, the expected FNP impacts may be minimal.

Emergency repair of the breakwater facilities requires maintenance of barges loaded with dolosses and other materials at least seasonally near the site. Vessels and cranes should be readily available to expedite repair. Because integrity of the breakwater is essential in the safe operation of the FNPs, repair is essential as soon as physically possible after damage.

Periodic maintenance dredging within the breakwater may disrupt biological communities established in those substrates and on the breakwater. Depending upon frequency and duration of dredging and the season of the year, adverse effects could be locally severe and could greatly reduce enhancement resulting from the installation of the reeflike breakwater. Maintenance dredging would also necessitate disposal of dredge material; those effects may be similar to but less severe than those occurring during construction.

Presumably, design will minimize the need for substantial overhauls of the FNP hulls; however, in the event that such a need arises, considerable disruption of the local area and increased support activity may occur at shoreside facilities.

Environmental effects from maintenance of underwater transmission facilities could be minimized and acceptable if performed during seasons of least biological effect. Repairs would be accomplished on an emergency basis and adverse environmental effects would be unavoidable, short-lived and local.

Decommissioning

Decommissioning will involve disposition of the floating nuclear powerplant itself, the breakwater, and shore support facilities. The nuclear fuel would be removed prior to the decommissioning process. Experience with land-based facilities indicates that the plant can be decommissioned without incurring excessive environmental costs. Obviously nuclear fuel, wastes, and radiation-contaminated materials will be removed for disposal by proper nuclear authorities prior to decommission.

Decommissioning the breakwater by dismantling would be both expensive and likely to cause adverse environmental impacts, and abandonment could create potential hazards to navigation. The most satisfying alternative may be to find uses for the breakwater which would not require its removal. Onshore facilities, including the transmission lines, may be decomissioned with relatively limited economic and environmental costs, with the similar possibility of finding alternative uses.

Experiences with decommissioning small, land-based nuclear reactors indicate that this process can be readily accomplished with a variety of satisfactory disposal methods. Before a large FNP is decommissioned, however, further development of standards and regulatory requirements may significantly alter the present procedures.

A number of decommissioning alternatives are specifically applicable to the floating barge. These include: long-term storage without major disassembly, long-term storage with partial disassembly, and plant disposal by decontamination and subsequent sinking of the barge.

It appears feasible to disassemble and dispose of a barge-mounted reactor system using techniques developed for small land-based power reactors. Casts for dismantling and removing the reactor system from a floating hull are difficult to predict without further detailed study. If dismantling commences within a few years of active operation, the associated costs may be high; a delay of 30-50 years would permit neutron-induced radioactivity in structural components to decay considerably, drastically reducing both dismantling and disposal costs.

Conventional shipyard graving docks are too narrow to accommodate an FNP hull for scrapping, and unless special techniques are used to cut up the hull afloat, the builder's facilities may be required. Special procedures would be required to deal with residual radioactive contamination and neutron-induced radioactivity in the hull structure.

Long-term lay-up, protective custody, and storage without major disassembly may be provided in a freshwater estuary or river following fuel removal and decontamination. Hull maintenance in saline waters requires impressing a cathodic current on the metals to reduce electrolysis, regular inspection, and occasional repairs and replacement of parts. Drydocking may also be possible but at considerable cost and only if a dock of suitable size were accessible.

Recommissioning the barge with a new reactor or conversion to a fossil-fueled powerplant may be viable alternatives. However, possible residual levels of radioactivity, quality assurance for safety-related components, hull deterioration, and licensing problems require further study and engineering development.

Disposal of the FNP units or portions thereof may be accomplished at fairly low decommissioning costs by sinking at sea. Prior to sinking, fission products would be removed, leaving only lower levels of neutron-induced radioactivity in reactor plant structural components. To minimize leaching of radioactive material from the reactor vessel and other components, extensive preparation would be required, including severing pipes, welding seals, and perhaps filling some systems with a material impervious to seawater. Another safeguard would be to fill the reactor subcompartment with concrete, preventing direct access of seawater to external surfaces of the vessel, thermocouples, control rods, and so forth. Because the reactor shield building is a distinct unit, it may be practical to design the plant to allow detachment and sinking of the containment structure while the remaining platform structure is salvaged or scrapped.

At the end of the useful life of a floating nuclear powerplant, decisions regarding removal or use of the breakwater would be required following an evaluation of the economic and environmental costs of removal, perpetual care, and alternative uses, including installation of another powerplant.

If the breakwater has no further use, the structure would be removed, requiring an engineering effort of equal or greater magnitude than that involved in its emplacement. The sequence of operations would be as follows: (1) removal of armor units (dolosse) from around the caissons on the leeward breakwater as required to refloat the caissons, (2) removal of ballast and refloat of the caissons to permit removal of the FNP from within the breakwater, (3) removal of the FNP, (4) location and removal of armor units and underlayer materials, (5) removal of remaining caissons from leeward and seaward breakwaters, and (6) transportation of materials to disposal sites. These activities would be highly dependent upon calm weather and sea conditions, and heavy floating equipment would be required.

At decommissioning, a number of onshore facilities associated with the floating plant may require permanent disposal. These include facilities associated with energy transmission, communications, supply, transportation, maintenance, personnel services, and emergency and disaster services. These functions are also common to land-based nuclear plants, but the principal facilities are concentrated.

The environmental effects of decommissioning an FNP station depend upon the methods, as previously described. Because of uncertainties in definition of decommissioning procedures to be used many years hence, plans should be developed to incorporate design options allowing a high degree of flexibility for decommissioning.

Actual decommission of each facility depends upon the prospects for its use at that time. Ports, transmission systems, shops, and buildings may be appropriately used for other types of power generation or even for entirely different purposes. Facilities that become useless may be removed, particularly where salvage values, land values, or government policies favor that course. In any event, it does not now appear that removal of land-based facilities involves greater long-term environmental disturbance than initial construction.

Aesthetic restoration of areas occupied by transmission lines, railroads, piers, and other highly visible features should be undertaken to satisfy laws and regulations in force. Materials and equipment from the visible structures probably would not be valuable enough to justify their salvage. In time, the space occupied by old structures may be needed for other purposes, in which case conversion would be effected for economic reasons. Shops and wharves located in an industrialized area would probably continue to be of value.

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CHAPTER VI

INDIRECT ECONOMIC AND ENVIRONMENTAL EFFECTS

This chapter addresses the indirect economic and environmental effects associated with the deployment of FNPs. Based upon the energy scenarios presented in Chapter II and with no foregone conclusions about the preference that will be given to FNPs, three conceivable deployment levels for 1,150-megawatt offshore plants are discussed. For the period 1980 to 2000, the manufacture of FNP units, construction of breakwaters, and commercial operation of FNPS are projected to occur simultaneously along the U.S. east and Gulf coasts, albeit at different rates of intensity and at sites far apart. The categories of impact overlap for all three activities although they may vary significantly in magnitude.

Manufacturing the Powerplant

Though the physical layouts of specific production sites may vary, the proposed OPS Jacksonville facility illustrates the predominant features of the shipyard-like complex.

Production shops of the manufacturing facility[1] are designed so that raw materials enter at one end and finished products exit the other. Shop locations permit easy transportation to the assembly slip. Major production complexes include a steel fabrication shop, concrete plant, condenser shop, sheet metal shop, electrical shop, and pipe shop.

A plant will be assembled in a wet slip approximately 400 feet wide. As a new platform structure is completed and launched from the graving dock at one end of the slip, each plant in the slip will advance one position. All major assembly activities and heavy installations will be completed while the plant is in the wet slip.

Material receipt and storage areas are strategically located throughout the facility. As an assembly nears completion, the plant will move out of the slip to a mooring at the final outfit and test area, which can provide circulating water, shore steam, and electrical power during functional testing.

After final outfitting and satisfactory completion of the functional testing, the plant will be stationed at a seawall slot until it is towed to an offshore site.

Manufacture of an FNP prototype will take approximately 50 months. By the time the eighth FNP is completed, labor efficiency and refined production techniques should reduce the time to about 26 months.[2] Under steady state production conditions, the proposed Jacksonville complex should turn out four FNPs per year. The product is a complete, unfueled plant. Provided that purchasers obtain permits and licenses promptly without institutional delays, OPS projects that online commercial operations could proceed within 18 months of completion.

FNP Market Potential. Based upon the scenarios in Chapter II, an additional 450,000 to 500,000 MWe of nuclear generated electricity will be required on the east coast by the year 2000. This is an equivalent requirement of roughly 400 1,150-MWe nuclear powerplants in 20 years.

For purely illustrative purposes, assume that FNPs could capture 12 percent, 25 percent, or even 50 percent of this market. Then, 50, 100, or 200 FNPs would have to be manufactured before 2000. At the low end of the range, the OPS facility at Jacksonville -- with, perhaps, moderate expansion -- could accommodate the market assuming eight FNPs manufactured prior to 1983 and a steady state production rate of four FNPs per year for a total of 76 by 2000.[3] At the higher end of the demand curve, it appears that one or even two sister facilities would be required.

It must be noted that the market potential can be expected to change during this period. Technological advances, installation experience, and a host of other factors may significantly change the share of the market captured by the FNP. It is quite reasonable to assume, however, that other consortiums would enter the market.

If more than one manufacturing facility were required, it is reasonable to assume that regardless of ownership, additional manufacturing complexes would be very similar to one proposed for Jacksonville. If OPS also operated the additional facility (ies), the "learning curve interval" (production of the first eight FNPs over approximately 6 years at Jacksonville) could be significantly reduced for the additional facility (ies) with the benefit of personnel and technology transfers, installation experience, etc. A second facility might not be necessary until the mid-1980's. Even if OPS does not operate the second facility, the production rates may be sufficient to alleviate the need for a third facility.

The FNP Versus Competitive Concepts. The alternatives to FNPs are primarily onshore plants. The environmental effects of constructing them are tabulated in Appendix D. To compare those impacts with their FNP counterparts, one must consider manufacture of the FNP unit as well as construction of the breakwater and the required land support facility. Direct comparisons are complicated by the facts that an FNP facility will produce four 1150-MWe units per year and that FNPs may be clustered in groups of two or four within a breakwater. However, because of the four identical units, one-fourth of the plant emissions effluents, etc. can be allocated to each unit. By combining that one-quarter share and the breakwater construction impacts, one can approximate the aggregate effect for comparison with construction of a single conventional onshore nuclear powerplant of corresponding capacity. It should be noted, however, that for FNPs the effects may occur in two quite distant places.

Effects Associated with the Planning and Preconstruction Phase

Site Evaluation and Selection. For an FNP manufacturing site, there are essentially three alternatives: to purchase an active facility and upgrade it, to rebuild and refit an abandoned yard, or to build a new facility.

Based upon a comprehensive (60 sites) survey conducted in spring 1971 by a Westinghouse-Tenneco evaluation team, the first two alternatives were discounted as infeasible.[4] No yard could meet either the acreage or channel depth requirements or had a graving dock of adequate size. Older or abandoned yards were judged too costly because of the typically crowded facilities arrangement and state of deterioration. Often adjacent development had encroached upon the yard area. In almost every case new facility construction would be required in addition to bulkheading, dredging, and filling.

In the site selection analysis, the following minimum requirement criteria were established:

- Minimum 750 to 1,000 acres of level land with approximately 5,000 feet of waterfront
- Site-adjacent natural harbor for protection from the open sea
- Site access to a channel that is 600 feet wide by 40 feet deep and no overhead obstructions between the site and the sea lower than 250 feet
- Minimum 1,000-foot wide basin adjacent to the construction bulkhead and main channel
- Climate conducive to outside fabrication and construction and general good weather year-round
- Adequate transportation systems for receiving materials for facility construction and FNP manufacturing
- Progressive host community with an adequate population base to support a work force of 10,000 to 12,000
- Soil conditions capable of supporting heavy equipment and crane rails
- Proximity to the east coast candidate FNP sites
- Availability of abundant supplies of water, gas, and electric power.

It was mutually agreed that no site located north of Baltimore would even be considered on the basis of weather conditions, the highly competitive labor market in the Northeast, and hull designs required to overcome the Gulf Stream enroute to southeast and Gulf sites.

Table VI-1 shows the weights assigned to each major locational determinant by the OPS evaluation team.

<u>Preliminary Economic Activity</u>. Because the preconstruction phase may span several months -- for the Jacksonville plant, the estimated time is 18 to 21 months -- some local and regional economic multiplier effects[5] attributable in large part to the payroll disbursements to administrative and planning personnel, land acquisition payments, and local ad valorem taxes may be measured.

For example, a preliminary economic evaluation prepared by McFarland Research Associates[6] indicates that over the first 18 months, Jacksonville and Duval County should realize incremental tax revenues in excess of $250,000; the total areawide

TABLE VI-1

Relative Weight of Manufacturing Facility Site Criteria

First Order Ranking		Second Order Ranking	
FACTOR	WTG	FACTOR	WTG
Labor	.40	Work force	.25
		Variety of skills	.20
		Vocational training	.10
		Productive attitude	.20
		Union activity	.10
		Related industries	.10
		Government work force	.05
Transportation	.20	Water	.40
		Air	.15
		Rail	.10
		Highway	.15
		Product shipment	.20
Community	.15	Industrial base	.08
		Civic and cultural facilities	.06
		Recreation and leisure activities	.12
		Water and air pollution	.08
		Residential areas	.14
		Educational and training facilities	.10
		Medical services	.08
		Population trends	.06
		Population mix	.08
		Impact on community	.10
		Community attitude	.12
Physical Characteristics	.15	Location	.06
		Orientation to city	.06
		Temperature range	.10
		Moisture and severe storms	.10
		Topography	.04
		Soil conditions	.08
		Highway and rail conditions	.06
		Acreage and boundary conditions	.10
		Water front footage	.10
		Channel and tide conditions	.12
		Expansion options	.10
		Pollution and perimeter conditions	.08
Utilities	.10	Power	.30
		Gas	.30
		Water	.30
		Sanitary	.10

economic impact should be about $0.40 million.* The state will collect an estimated $0.55 million in consumer taxes of all types, and the total economic impact will be about $0.82 million. The impact will probably be greater when sites are nearer dense urban areas and when all new construction is undertaken.

Effects Associated with Construction

Environmental. Preparation of the production facility may involve either refitting a shipyard complex or new construction on undeveloped land. In the latter case, the scope of activities could well entail clearing, dredging, diking, shifting and disposal of unsuitable soils, earthwork, and draining. Depending upon the physical characteristics of the site, the level of preparation could be great. Blount Island (Jacksonville) site preparation will probably take at least 3 years.[7] The dredge and fill operations will modify over 950 of a total 1,660 acres of Blount Island, including 200 of 240 existing acres of Back River. Twelve and one-half million cubic yards of material will be dredged and some 3.8 million cubic yards deposited on Blount Island. About 24,000 linear feet of bulkheading will be installed around the entrance channel to form the construction slip and 13 structures (approximately 3 million square feet in total area) and 75 acres of parking. The construction slip will be 400 feet wide, 38 feet deep, and about 0.5 miles long. The seawall lining the channel will provide anchoring positions for the FNPs under construction.

During dredge and fill operations damage to water bottom organisms due to temporary increases in water turbidity may be reasonably minimized by utilization of a temporary bulkhead with adjustable weirs and settling basin.

A temporary increase in odors could result from the release of gases trapped in the dredged sediments. The extent of detection, concentration, and dispersion of odors and dust propagation will depend upon the intensity and direction of

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*The figures quoted are in current dollars for the 18 months beginning July 1, 1972. An economic multiplier of 1.5 is used to reflect the total impact transition from projected ad valorem and consumer-based taxes. Gross payrolls of the 1972 and 1973 projected levels of 225 and 500 administrative and planning personnel, respectively, are $10.9 million, to which a multiplier of 2.0 is applied to yield a total areawide economic impact of $21.8 million.

prevailing surface winds. Noise generated by heavy earth-moving equipment, pile-drivers, etc., can be expected during the first 2 years immediately after dredging.

Depending upon the size of the area to be developed and wildlife uses as a nursery and feeding or nesting ground, lost terrestial and biological productivity may be significant. Also, though a site may be zoned for industrial and commercial purposes, it may still be suitable for other uses, including recreation.

At almost any site, a noticeable rise in traffic and some highway congestion is likely when construction workers commute almost entirely by auto. Slow-moving trucks and construction equipment aggravate the condition.

Economic. As exemplified by the proposed Jacksonville OPS facility, fiscal pressures will be created during the second phase of construction by the growth demands placed upon local institutions. Part of this growth will create only short-term pressures. However, a significant portion will represent relocation of key personnel and a large permanent influx of households and families.

The projected buildup of administrative and professional personnel from an initial 500 to 1,200 will occur by the end of the fifth year of construction. The bulk of these employees can be expected to form the nucleus of the managerial and administrative structure of the facility.

The temporary construction force, on the other hand, is projected to peak at approximately 4,000 by the middle of the fourth year of construction and then to fall back to its first-year level of about 1,500 workers. A large portion of this force will be specialized personnel brought in from outside the region through construction contracts.

Another transitory segment of the construction force will represent local short-term dislocations and shifts within the region. Some of the non- and low-skilled construction workers may have come from among the unemployed and jobless and may well revert to that category after particular stages of the construction phase. There also may be intra- and inter-regional migration of semi-and non-skilled workers hoping to gain an edge in the competition for the relatively few jobs available to those of limited skills in the facility construction and early operations.

The permanent employment base growth will be absorbed into the local economies over a longer term. However, the short-term (possibly several years) influxes of transient workers can place a heavy burden on some services before plans for long-run expansion are implemented, and may cause acute fiscal and infrastructure (hospitals, schools, etc.) problems. In general, available capacities above current demands of the following elements will determine the ability of the local area to meet growth pressures until long-term development materializes:[9]

- Elementary and secondary schools
- Sewage and waste water treatment
- Potable water accumulation and distribution
- Sanitary and strom sewers
- Primary limited access, feeder, and local roads

For Jacksonville, according to McFarland Research Associates, a construction phase of about 5 years is indicated with some front-end overlap with preliminary physical site preparation activities and post-end overlap with plant startup and prototype program commencement. Tables VI-2, VI-3, and VI-4 illustrate the direct payroll and capital stocks purchase economic effects forecast for the 5-year construction period.[10] Table VI-2 illustrates payroll-induced effects for all phases and Tables VI-3 and VI-4 illustrate purchase-induced effects for all phases. For sites nearer urban centers with large pools of skilled union labor, the average annual rates for skilled workers would be 70 percent to 120 percent[11] higher than those shown for Jacksonville and the economic multiplier effect nearer 2.5 or 3.0.

In addition to payroll disbursements during construction, significant construction-associated purchases will entail interregional dollar and commodity flows. The primary expenditures will be heavy construction equipment and capital goods and contract construction purchases, a pattern that will hold for the induced industrial and commercial construction as well.

TABLE VI -2

Illustrative Economic Impacts of Direct Payroll Disbursements and Indirect Personal Consumption Expenditures Construction Through Production (1973 - 1984)

(in millions of 1973 dollars)

YEAR	Skilled Construction (contract labor) 1/	Manufacturing (OPS) 2/	Total Payrolls 3/		Total Impact 4/	Indirect Employment 5/
			Contract	OPS		
1973	$12.50 (1500)	-	$ 12.45 (1500)	$ 5.95 (350)	$ 36.80	525
1974	16.92 (2000)	$ 3.77 (430)	16.92 (2000)	13.43 (1130)	60.70	1285
1975	20.79 (2500)	13.01 (1485)	20.79 (2500)	23.12 (2225)	87.82	2215
1976	33.78 (4000)	21.25 (2425)	32.78 (4000)	32.35 (3250)	132.26	3100
1977	12.82 (1500)	28.83 (3290)	12.82 (1500)	40.93 (4200)	107.50	3925
1978	-	35.10 (4005)	-	48.20 (5000)	96.40	4620
1979	-	47.01 (5365)	-	61.79 (6500)	123.58	5920
1980	-	58.93 (6725)	-	75.40 (8000)	150.80	7225
1981	-	70.85 (8085)	-	88.99 (9500)	177.98	8530
1982	-	82.77 (9445)	-	102.60 (1100)	205.20	9830
1983	-	94.68 (10805)	-	116.18 (12500)	232.36	11135
1984	-	105.16 (12000)	-	128.00 (13800)	256.00	12265
TOTAL 6/	$96.76 7/	$61.36	$96.76	$736.94	$1667.40	-

SOURCES: Offshore Power Systems
McFarland Research Associates
King Helie Planning Group, Inc.

1/ The estimates of construction force size and payrolls are taken from the McFarland Report. All annual wage rates were derived from Florida state rate projectsion; construction force requirements were provided by Reynolds, Smith and Hills, Architects.

2/ These estimates were taken from the King Helie report, personnel requirements and wage rates were provided by Westinghouse-Tenneco.

3/ A 4% per annum deflator is applied to all current dollar estimates subsequent to 1973 to maintain consistency between the McFarland and King Helie figures.

4/ Both the McFarland and King-Helie reports assume indentical 2.0 economic multipliers to compute the total economic impacts attributed to direct payroll and personal consumption expenditures.

5/ These estimates are taken from the King-Helie report and represent the effects of personal consumption expenditures by the permanent OPS employment base only (contract labor excluded). The figures are derived from U.S. Bureau of Labor Statistics estimates of personal consumption patterns by major industry group and King-Helie estimates of proportionate consumption expenditures likely to be made locally.

6/ Figures may not total due to rounding.

7/ McFarland associates include approximately $7.5 million in this total more appropriately assigned to the site preparation phase.

TABLE VI-3

Ilustrative Intra-and Inter-Regional Economic Impacts of Capital Stock and Production Inventory Purchases

(in millions of 1973 dollars)

Summary of Expenditures Impact

Year	FNP Units Produced	Total Direct Expenditures [1]	Local Expenditures [1]	Total local Economic Impact [1]
1972	-	-	-	-
1973	-	$ 310.0 [2]	$ 154.00 [2]	$ 231.00 [2]
1974	-	-	-	-
1975	-	10.0 [3]	2.97 [3]	6.54 [3]
1976	-	15.0	4.89	10.77
1977	-	32.5	11.53	25.40
1978	-	47.5	18.23	40.16
1979	1 (1)	37.5	15.48	34.10
1980	1 (2)	52.5	23.17	51.04
1981	1 (3)	95.0	44.67	98.41
1982	1 (4)	120.0	59.88	131.92
1983	2 (6)	135.0	71.26	156.99
1984	4 (10)	205.0	113.97	251.08
1985	4 (14)	250.0	139.00	306.22
TOTALS	14	1310.0	659.05	1343.63

Sources: McFarland Research Associates
King Helie Planning Group, Inc.
Offshore Power Systems

[1] The figures in parentheses represent cumulative production as of January 1973.

[2] McFarland Associates reports this expenditure for construction materials as occurring in the period 1972-1974. The exact composition of these expenditures is unclear and it is presumed for simplicity, here, that the total would net out to the equivalent shown above in 1973 dollars. A total of $154 million (42 million - dredging, filling, road construction and utilities hookup; 56 million - docks, bullheads, craneways, warehouses and shops; $52 million - foundations and equipment; $4 million - support buildings and offices) are presumed to be sent intra-regionally and estimated to create 1.5 economic multiplier effect. The remaining $156 million (welding machines, cranes, material movers, etc) are presumed to be regional impacts.

[3] All expenditures subsequent to 1974 are estimated by King Helie. The local expenditures portion is adjusted by a 2.203 multiplier based upon an analysis of inter-industry linkages in the shipbuilding industry by the offices of Business Economics in the 1963 Input-Output Study of the U.S. Economy.

Table VI-4

Illustrative Interindustry Flows
4 FNP/Year Production

(in millions of 1973 dollars)

	Industry Affected[1]	Total OPS Purchased[2]		Local Purchases[3]	
SIC Code	Description	Amt.	%	Amt.	%
25	-	$ 3.7	1.5	$ 3.7	1.5
28	Chem. and Allied Prods.	1.8	0.7	-	-
32	Stone, clay, and glass	45.0	18.0	20.0	8.0
33	Primary metals	12.9	5.2	0.5	0.2
34	Fabricated metals	86.7	34.7	85.7	34.3
35	Nonelectrical mach.	31.0	12.4	15.9	6.4
36	Elec. equip. & spls.	10.4	4.2	4.6	1.8
37	Trans. equipment	8.6	3.4	8.6	3.4
Other Manufacturing		49.5	19.9	-	-
Total Purchases		249.6	100.0	139.0	55.6

[1] All expenditures subsequent to 1974 are estimated by King Helie. The local expenditures portion is adjusted by a 2.203 multiplier based upon an analysis of inter-industry linkages in the shipbuilding industry by the offices of Business Economics in the 1963 Input-Output Study of the U.S. Economy.

[2] Excludes nuclear steam supply system and turbine generators purchased from other Westinghouse operating divisons

[3] Includes some industry outputs from enterprises not currently in the Jacksonville area, but likely to be induced into the area by OPS presence These sales represent $76.3 million or 30.52% of all purchases. All other purchases in the "local" category are projected for plants currently within a 50 mile radius of Duval County.

Sources: McFarland Reserach Associates
King Helie Planning Group, Inc.
Offshore Power Systems

Public financed expenditures for transportation and distribution network extension, improvement of sewage and waste water treatment facilities, etc. will also necessitate interregional purchases, although most contract construction and materials purchases can be expected to be local or intrastate. This growth may mean large Federal and state grants, matching monies, etc.

Effects Associated with Operations

Environmental. The gaseous and particulate emissions from facility operations will not be generated from particular processes. Rather, they will be volatile emissions and fugitive particulates from materials handling, mixing, and preparation.

Table VI-5 presents estimates of emission rates, uncontrolled and controlled, for each FNP at a production rate of four units per year.[12] Based upon the controlled emission rates, the ambient air quality will depend largely on ground level concentrations of sulfur dioxide and suspended particulates in the surrounding area.

Table VI-6 shows solid waste estimates based on the four-unit-per-year production rate. Salvage operations could be significant, with raw materials expected to provide between 10 percent and 25 percent salvageable materials on an equivalent weight basis, the purchased components category to provide virtually no salvage.

The wastewater products shown in Table VI-7 may be generally classified as acid and caustic, oily, sanitary, and miscellaneous wastes.

The industrial wastewaters requiring pretreatment are of primary concern -- the acid-caustic wastes and those with excessive concentrations of oil and grease. (See Table VI-7.) All others can be safely mixed with sanitary sewage and processed by a conventional secondary municipal plant with no environmental threat beyond that normally associated with treated sanitary sewage.[13]

Hot functional testing of a completed FNP will involve operation of the unit's condenser circulating water system, thereby affecting the surrounding waters both thermally and mechanically.[14] Operation of the water pumps in the condenser circulating system can entrap fish, and damage to entrained planktonic biota must not be forgotten. The significance of entrainment depends largely upon the water volume exchange with the source relative to net flow past the testing berths.

TABLE VI-5

ESTIMATED GASEOUS EMISSION LEVELS FROM FNP PRODUCTION FACILITY OPERATIONS, FOUR FNPs PER YEAR

Function	Gas Waste Product	Control	Uncontrolled Emissions Lbs/Hour	Controlled Emissions Lbs/Hour	EPA Allowable Emissions Lbs/Hour
Pipe Shop	NAOH and H_2SO_4 vapor from cleaning tanks	Forced Air Vent (filter if required)	0.08 0.03	0.0008 0.0003	LT LT
Outfitting	Paint volatiles & fines	Forced Air Vent (filter if required)	178.0	1.78	LT
Steel Shops Shaped Plate preparation	Dust & mill scale particles	Forced Air Vent through bag houses	142.9	1.43	LT
Plasma Cutting Flame Cutting Carbon Arc	Oxides of nitrogen, smoke & dust, ozone, propane, acetylene, CO_2	Forced Air Vent	28.6	0.29	LT
Assembly Blast Assembly Paint	Dust Volatile fumes	Forced Air Vent through big houses	71.5	0.72	LT
Burning through Primer	Noxious gases, smoke and dust	Forced Air Ventilation	14.3	0.14	LT
Concrete Aggregate storage	Dust	Water Spraying			
Aggregate Rinsing & Screening	Dust	Water Spraying or Enclosure			
Aggregate Bin Charging	Dust	Water Spraying or Enclosure	1.0	0.05	LT
Cement & Fly Ash Unloading	Dust	Pneumatic Conveying with filtered vents			
Cement & Fly Ash Bin Charging	Dust	Pneumatic Conveying with filtered vents			
Concrete (Cont'd) Catching & Mixing	Dust	Bag Dusthouse, Hopper	3.5	0.18	LT
Miscellaneous Operations	Sulfur Hexaflouride, glycol, freon, compressed air, steam		--	--	--
Boiler for Steam Generation	Particulates, hydrocarbons, nitrogen oxides, sulphur dioxide	300,000 lb hr	71.3 part.	10.7	46
		150 psig	620 SO_2	--	368
		200,000 lb hr	73.6 part.	11.0	48
		1,000 psig	640 SO_2	--	--

LT - Latest Technology

Source: Offshore Power Systems, "Environmental Report Supplement to...," op. cit.

TABLE VI-6

ESTIMATED ANNUAL SOLID WASTE GENERATION BY FNP PRODUCTION FACILITY OPERATIONS, FOUR FNP's PER YEAR

Function	Solid Waste Product	Control
Air Filters	Dust Particles, Spend Abrasive, Scale and Rust	Truck Away
Pipe Shop	Cleaning Tank Sediment Pipe, 315 tons	Truck Away
Test	Spent Demineralizer Resins, 5000 cubic ft/year	Truck Away
Test and Ice Plant	Spent Demineralizer Resons, 10,000 cubic ft/year	Truck Away
Outfitting	Wire Bits and Insulation Wood and Plastic Fabric, Scrap Sheet Metal, Rust, Metal Chips	Truck Away
Steel Shops	Sheet and Shape, 3,500 tons sheet held, 350 tons	Scrap yard and recycle
Electrical Shop	Electric Cable, 50 tons Electric Conduit, 2 tons	Scrap Yard
Concrete	Settling Pond Sediment 525 tons/year	Truck Away or use as onsite fill material
	Waste Aggregate 100 tons/year	Reclaim
	Waste Lumber 100 tons/year	Truck Away
	Waste Concrete Batches 600 tons/year	Fill on Site
	Waste Reinforcing Bar & Misc. Steel, 80 tons/year	Periodic Salvage
	Dust from Dust Control Equipment, 1970 tons/year	Truck Away
Shops and Offices	Waste Paper, Cardboard, Packing Crates	Truck Away
Miscellaneous	Plywood, 150 tons Lumber, 146 tons Staging Boards, 108 tons	Truck Away

Source: Offshore Power Systems "Environmental Report Supplement to...." op.cit.

TABLE VI-7

ESTIMATED ANNUAL LIQUID WASTE GENERATION BY FNP PRODUCTION FACILITY OPERATIONS

Function	Liquid Waste Product	Concentration	Volume at Four Plant Per Year Production Gal./Yr.
Pipe Shop	NaOH	3 1/4 % by Wt.	216,000
	H_2SO_4	6-8 % by Wt.	200,000
	Rinse		1,788,000
	HNO_3	10-30 % by Wt.	200,000
Pipe and Shop Test	Na_2HOP_4)	Industrial Grade	22,500
	Na_3PO_4)		
	NaH_2PO_4)		
	Detergent Rinse		3,600,000
	Hydrazine)	Industrial Grade	7,500
	Moraphine)		
Test	Boric Acid	4 % by Wt.	20,000
	Oil, Diesel Fuel		1,000
	Oil, Turbine Lube		500
	K_2CrO_4		Trace
Outfitting	NaOH	3 1/4 % by Wt.	Trace
Ice Plant	Borate	4 % by Wt.	10,000
Component Ship	NaOH	3 1/4 % by Wt.	20,000
	Oil, Light flush		1,000
Steel Shops, Maintenance Garage Test	Oil, Motor & Lube		1,000
All Shops	Paint Waste		3,000
	Emulsifying Agents		2,000
Labs, Clinic, Food Prep., Photo Lab, NDT Lab	Laundry and Chemical		600,000
Personnel	Sanitary Sewage		165×10^6

Source: Offshore Power Systems, "Environmental Report Supplement to...", op. cit.

The noise generated at the facility will equal that of a modern shipyard. The facility will look like a modern manufacturing plant, with two gantry cranes the tallest structures in the complex. The gantry will be about 325 feet in height. (As a point of reference, common high-tension transmission towers are approximately 324 feet high.)

As with any plant of comparable size, the effects of heavy traffic will be most acute near the factory during changes in shifts.

Economic. Again Tables VI-3 and VI-4 show the projected aggregate economic impact of local payroll disbursements and capital stocks and inventory purchases for 1973 through 1985, which represents the initial pilot shakedown and manufacture learning curve period, when the prototype and seven other units are scheduled for production. Also shown is the impact of local purchases economic multiplier for a typical year, 1985, early in the projected 4-unit-per-year steady state production cycle. The economic multiplier estimates shown here may be lower (by as much as 50 percent) than for alternative sites.[15]

Facility operations at a production rate of 4 plants per year annually require:

- 576 million gallons of deep well potable water
- 9 million cubic feet of oxygen
- 36 million cubic feet of nitrogen
- 420,000 gallons of liquid propane
- 120,000 tons of steel
- 320,000 tons of concrete
- 400,000 gallons of paint
- 1,440 miles of wire and cable.

It is likely that steam, compressed air, oxygen, nitrogen, and demineralized water will be produced onsite and distributed by underground systems. The facility operating load should be about 40 MWe. The expected load during nonnuclear functional testing of a plant is 50 MWe, but the peak load could be as high as 60 MWe.

At the rate of four FNPs per year, the estimated annual consumption of fuels for the facility is 480,000 gallons of No. 6 fuel oil for heating and test steam, 300,000 gallons of gasoline and 1,600,000 gallons of diesel fuel for material handling equipment.

The presence of the FNP manufacturing plant will attract other industrial and commercial activity. The facility will provide not only direct service/supplier ties but the impetus for service quality upgrading (utility services, transportation, and distribution services, etc.). It will be the major source of "draw" or concentration (size and skill mix of area labor pool, etc.), and, because of its size, it will set areawide industry standards (productivity, wages, etc.). Further, OPS will provide preparatory, vocational, and eductional training programs to local minority and currently displaced categories of workers as well as preferentially assigned on-the-job training programs.

Constructing the Breakwater

Construction of the Onshore Support Facility

Construction and operation of this onshore facility to support construction of the breakwater are but a relatively small part of the total physical effort and resources. Because the offshore construction and onshore supply and support activities will be closely interwoven, the economic effects of the onshore facility (separate from those associated with the offshore construction) are far more difficult to isolate than are the environmental effects.

Construction of the breakwater structures is the responsibility of the FNP purchasers. The contractor selected may already be operating a concrete casting facility, but not necessarily proximate to the offshore construction site. The location of the onshore support facility will be based upon tradeoffs between facility construction and materials shipment costs. Because land transport of bulk materials is considerably more expensive than water transport, distance on land is important. Additionally, water access is required for moving caissons and dolosse to the breakwater site.

Associated with determining the long-term effects of the breakwater construction support facility is the viability of its operating after the initial breakwater units are complete. It is possible that the facility could manufacture concrete castings for breakwaters at other sites as well as components for inland construction. It would then provide employment for semi- and non-skilled personnel, thus easing local unemployment and job dislocations. Again shipping costs and risks and alternative capacity utilization economics must be weighed.

Economic. The indirect economic effects of building the facility will be transient and minimal. It will take about 1 year, and much of the activity will be site preparation. The materials and supplies can generally be purchased locally. Payroll disbursements will not significantly affect the local economy, nor are housing markets, commerical activities, etc. likely to be disturbed. Perhaps the most significant factor will be the initial capital investment. It is conceivable that some utilities will have to pay for new onshore construction support facilities.

Environmental. The construction period is only several months in duration and would not result in any significant or lasting effect on the environment beyond the changes made directly at the site of the facility. (See Chapter V.)

Operations of the Onshore Facility

Raw Materials Supply and Demand. The breakwater consists of concrete caissons filled with and surrounded by rock, stone, and sand -- 6.5 million tons of materials.[17] A breakdown is shown in Table VI-8.

Assuming 735 pounds of cement per cubic yard of concrete, a concrete density of 4,000 pounds per cubic yard,[18] and a ratio of cement to water of six to one,[19] the requirement of 705,000 tons of concrete equals approximately 130,000 tons of cement, 22,000 tons of water, and 551,000 tons of sand and gravel. The total sand and gravel requirement is then 936,000 tons (551,000 tons for cement and 385,000 tons as fill for the caisson). Some of the sand and gravel used for fill could possibly be dredged at the breakwater site.

The effects of breakwater construction on the cement, stone, and sand and gravel industries may be evaluated by comparing the raw material requirements with the yearly production figures. Because the observations resulting from this analysis were made on an industrywide basis, they must be considered indications, not definitive statements. In order to make definitive statements, a microanalysis of the industry would have to be conducted. It would indicate whether the configuration of the industry would enable existing facilities to provide the cement. Current but unused capacity would have to be analyzed to determine whether it is realistic to assume that this capacity could be utilized.

Another consideration is that the analysis is based on 1971 demands and supply, which may not be representative when the breakwater is built.

In order to assess the long-term effects of more FNPs, deployments of 50, 100, and 200 were evaluated. Schedules to achieve these goals have not been formulated beyond the eight FNPs to be produced at Jacksonville by 1984. For illustrative purposes, it is assumed that the remaining FNPs required to satisfy the deployments are produced at a constant rate between 1984 and 2000. This assumption results in a requirement of 2.6 FNPs per year for 50 FNPs by the year 2000, 5.7 for 100, and 12.0 for 200.

Four regions were selected for study of regional effects: Portsmouth, N.H.-North; Sandy Hook-Atlantic City, N.J.; Chicoteague-Cape Charles, Va.; and Cape Canaveral-Key West. In the analysis production of the offshore powerplants is assumed evenly distributed among the four. This results in an average <u>regional</u> deployment of 0.7 FNPs per year for 50 FNPs, 1.4 for 100, and 3.0 for 200. It is assumed that two FNPs are placed in each breakwater; therefore the required number of breakwater completions is one-half the number of FNPs. Each region, then, requires 0.4 breakwater completed per year (or one breakwater completion every 2 1/2 years) in the 50 FNP case, 0.7 in the 100 FNP case, 1.5 in the 200 FNP case. Raw material requirements based on these average regional construction rates are shown in Table VI-9.

The most important component of cement is limestone -- eighty-three percent of the raw materials by weight. The remainder is clay, shale, gypsum, sand, and marl. Limestone is abundant in the United States, and reserves are more than adequate to supply all foreseeable demands.[20] Any limitation would be in terms of the dollar and environmental costs of transporting the limestone to the cement plant and then to the point of use.

Another important resource used in the production of cement is energy -- 6.84 million BTUs per ton of cement.[21]

TABLE VI-8

MATERIALS REQUIRED FOR CONSTRUCTION OF A BREAKWATER

Rocks and Stones		
Ore (20-400 lb. quarry run)[1]	3,500	
Armor (800 lb. stone & 8-10 ton rock)[1]	1,850	
Caisson fill (800 lb. stone & 8-10 ton rock)[2]	111	
Total		5,461
Concrete		
Dolosse[3]	595	
Caisson[4]	110	
		705
Sand[5]	385	385
TOTAL		6,551

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[1] Environmental Report, Atlantic Generating Station, Units 1&2, Public Service Electric and Gas Co., Dec. 1973, pg. 4.1-2.

[2] Assumes 30 caissons and 3,700 tons of rock per caisson. (See Atlantic Generating Station, Preliminary Site Description, Public Service Electric and Gas Co., Newark, New Jersey, pgs. 3.1-3, 3.1-60.)

[3] 17,000 concrete dolosse each weighing from 11 to 62 tons. (See Environmental Report..., pg. 4.1-2.) For estimation purposes, an average weight of 35 tons per dolosse is assumed yielding a total weight of 593,000 tons.

[4] The concrete caisson is assumed to weigh approximately 15% of the weight of the caisson plus the fill (estimated from Atlantic Generating Station..., Fig. 3.-13). The fill per caisson weighs 20,700 tons (pg. 3.1-60); therefore the concrete weighs 3,650 tons per caisson. There will be 30 caissons.

[5] 12,820 tons per caisson (pg. 3.1-60).

TABLE VI-9

RAW MATERIALS REQUIRED ANNUALLY FOR BREAKWATER CONSTRUCTION TO THE YEAR 2000

(thousand tons)

Number of breakwaters	Number of breakwaters per year	Cement	Stone	Sand and gravel
1	1	130	5,461	385
25	.4	52	2,184	154
50	.7	91	3,823	270
100	1.5	195	8,191	577

Because stones ranging from 20 pounds to rocks of 8 and 10 tons make up 83 percent of the breakwater by weight, the economics of quarrying and transportation are important. Density, soundness, quarrying characteristics, and reactions to ocean elements are also important. The feasibility of using certain types of rock depends on its position in the breakwater. The top layers should be a sturdy rock, like granite and limestone. Sandstone, may be acceptable for the lower, more protected layers.

Due to their availability and refined quarrying techniques, rocks like granite and limestone have been used extensively in breakwaters, particularly the rock-mound variety.[22] One FNP breakwater uses 5.5 million tons of stone. That is a significant portion (29.9 percent) of the rock used for jetties, ripraps, and breakwaters in 1971 (18.4 million tons),[23] but that total is just 2.4 percent of the total national production of rocks that can be used in breakwaters, namely granite, limestone, and sandstone. The effect nationally is minimal, but established quarries, transport economics, etc. may concentrate the demand for stone for FNP breakwaters in certain localities. This impact is discussed in the regional analyses below.

Sand and gravel are used both in the making of cement and as fill for the caissons. It is convenient to use dredged sand as fill for the caissons because the sand is right there and the problem of disposal of the sand dredged at the site is alleviated. For example, the amount of dredging necessary at the proposed New Jersey PSE&G site is estimated at 1.9 million tons (950,000 cubic yards), more than adequate to satisfy the 385,000 tons required to fill the caissons.

Regional analysis: Portsmouth, N.H.-North. Table VI-10 is a summary of the supply and demand for raw materials. For the Portsmouth, N.H.-North region, the most significant effect will be on the stone industry.

In fact, there is a significant effect not only in New Hampshire, which produces no stone, but also for New England as a whole. If the Middle Atlantic states were tapped, the effect on the industry is lessened, but hauling distances would be increased. Although cement is not produced in New Hampshire, there is 526,000 tons of unused capacity in Maine and New York which could be used.[24] The sand industry does not seem to be affected significantly.

TABLE VI-10

REGIONAL PRODUCTION AND BREAKWATER CONSTRUCTION REQUIREMENTS

	Regional Annual Raw Material Requirements (thousand tons)	Breakwater Requirements as a Percentage of 1971 Raw Material Production						
		Portsmouth-North		Sandy Hook - Atlantic City Chincoteague - Cape Charles			Cape Canaveral-Key West	
		New England	New England & Middle Atlantic	New Jersey	Maryland/ Delaware	Pennsylvania/New Jersey/Delaware/ Maryland/Virginia 1/	Florida	Florida/Georgia South Carolina
Cement								
25 Breakwaters by 2000	52	2/1.0	0.4	ZP	3/2.2	4/0.4	2.3	4/0.9
50 Breakwaters by 2000	91	2/1.8	0.7	ZP	3/3.9	4/0.7	4.0	4/1.6
100 Breakwaters by 2000	195	2/3.8	1.5	ZP	3/8.3	4/1.5	8.7	4/3.3
Stone								
25 Breakwaters by 2000	2,184	60.7	2.1	96.2	22.3	2.2	5.4	2.8
50 Breakwaters by 2000	3,823	106.2	3.8	168.5	39.8	3.8	9.4	4.9
100 Breakwaters by 2000	8,191	227.5	8.2	360.5	83.3	8.2	20.1	10.9
Sand and Gravel								
25 Breakwaters by 2000	154	0.4	0.1	0.8	1.0	0.2	.7	0.4
50 Breakwaters by 2000	270	0.6	0.3	1.4	1.8	0.4	1.2	0.8
100 Breakwaters by 2000	577	1.3	0.6	3.1	3.8	0.8	2.4	1.7

ZP- Zero Production

1/ Because this region overlaps the Sandy Hook-Atlantic City and Chincoteague-Cape Charles sites, the percentage is computed based on both regions' construction requirements

2/ Includes production from New York

3/ Includes production from West Virginia

4/ Includes North Carolina and West Virginia

Source of Production Figures: Minerals Yearbook, Volume 1, Department of the Interior, 1971

Regional analysis: Sandy-Hook-Atlantic City, N.J., and Chicoteague-Cape Charles, Va. Because these two areas are in relative proximity, they were analyzed together as well as separately. What was said above for the northern region is applicable to New Jersey and Virginia. There is no cement production in New Jersey, but Maryland and Delaware together can provide the necessary cement.

The stone industry on a local basis will be strained; the 1971 production is less than the annual requirement in all the cases. To meet the need, then, stone production will have to increase or costs to transport the stone from other states will be incurred. The latter could lead to significant additional expenses and additional wear of the roads used. However, in terms of the whole region, the impact is significantly less.

Sand production does not seem a problem for this region. New Jersey and Maryland/Delaware each produce at least twenty-five times the region's requirement for the largest deployment case.

Regional analysis: Cape Canaveral-Key West. Florida seems capable of absorbing the cement, stone, and sand and gravel requirements without much expansion. Again the raw material which is subject to the most expansion is stone. It is important to note that because of Florida's size, significant transportation costs could be incurred depending upon how the materials are distributed throughout the state. A detailed county-by-county analysis would resolve this issue.

Environmental Effects of Raw Materials Production. There are potential hazards resulting from the supply of materials needed. Dust from mining raw materials and manufacturing cement is the primary environmental effect of the cement industry. The rotary kiln is the major source of dust at a cement plant, although the dryers and grinders also emit dust.

Collection of dust from the rotary kiln is made difficult by the volume of gas (280,000 cubic feet per minute); its temperature (500° to 600°), the fine particles (85 percent is smaller than 20 microns), and water vapor where the wet process is used.[25] The emission is about one-half calcium oxide with some silver dioxide and aluminum and iron oxides.

Regardless of the location or size of the plant, to achieve acceptable emission levels electrostatic precipitators or fabric collectors must be used. They can operate at about 98 percent efficiency.[26] It is important to note that particles in the sub-twenty micron range can be a health hazard.

Another source of dust is the storage silo. Because storage silos are under high pressure after they are filled, a bag-like collector is used as a receptacle for the dust-laden air.

Some of the dust can be reused in cement production. That which cannot due to its high alkali content may be treated for reuse in cement, or it may be used for agricultural limestone, fertilizer, or mineral filler. If it cannot be used, it is disposed of in abandoned quarries or storage piles. To avoid release into the atmosphere, the dust should be covered, enclosed, or sprayed with water to form a crust.

Also possible is environmental degradation from concrete forming and curing. Over time, the runoff of wet concrete from production of dolosse and caissons could disturb the ecology in the immediate area.

Environmental concerns about surface mining and quarrying -- in this case, limestone and stone -- are land reclamation, damage from blasting, aesthetics, dust, noise, and unwanted residue.

Of particular concern is the issue of reclamation. It requires a major outlay of capital beyond the capability of many quarry operators. How the land is reclaimed, for residential, commercial, industrial, or recreational purposes, is an important consideration of the long-term effects of quarrying.

One common use of abandoned quarries is for sanitary land fills. The area can then be covered with topsoil to make it acceptable for later use. An important note on use of such land is that it is subject to settling and therefore cannot be used for heavy buildings. However, it could support a one-level parking lot or low-density storage area.[28]

The quarrying of stone for the breakwater will have a greater impact than the quarrying of limestone for the cement, because each breakwater requires 5.5 million tons of stone but only 110,000 tons of limestone (130,000 tons of cement).

Except for blasting, the environmental effects of onshore sand production are similar to those described for quarrying. Of special concern again is restoration of the depleted lands. The value of the land must be evaluated on a site-by-site basis.

If the sand is produced by dredging, many organisms living on the ocean floor are destroyed. Another major effect is increased turbidity in the surrounding water. (See Chapter V for a detailed discussion of the environmental effects of dredging.)

Economic Effects of Raw Materials Production and Transportation. Production of the breakwaters will increase revenues of each of the raw materials industries. For <u>one</u> breakwater, at 1971 prices, cement at $18.72 per ton[29] is valued at $2.4 million, stone at $1.63 per ton[30] is worth $8.9 million, and sand at $1.25 per ton is worth 1.2 million. These costs do not include transportation costs.

The ultimate impact on the income of the region in which the raw material is produced is a function of income multiplier effects. The income multiplier reflects the fact that a possible increase in population will require a wide range of services -- ranging from the retail outlets for consumer goods to schools, hospitals, churches, etc. -- which will create further income for the region.

The extent of a local multiplier effect depends on existing industrial and commercial facilities. If many of the goods and services required by the new population are produced locally, the local multiplier effect will be greater than if they were produced outside the region.

At a Florida site the localized area would tend not to have most of the services. On the other hand, New Jersey would because of the high concentration of population and industry.

The economic effect of increased production will depend on how it is achieved. If the increase can be achieved by expansion and increased use of existing facilities with little added capital investment, the effect would be less than if significant amounts of capital were required for new facilities. The incremental amount of manpower and, therefore, incremental income, are less in the former case than in the latter.

An estimate of the capital needed to increase cement production can be made by comparing the investment cost of $59 per ton[32] for new plants and $43 per ton for expansion of existing plants. If the incremental production requirement of 130,000 (see Table VI-9) is produced in a new plant, the investment is approximately $7.7 million. In an expanded plant, it is $5.6 million.

The considerations influencing the effects of stone and sand production on a community are similar to those discussed for cement. However, because the primary investment is in moving equipment and not in a fixed plant, the investment is considerably less than for cement plants.

<u>Breakwater Construction Industries</u>. <u>Dredging</u>. Dredging required for construction of the breakwater will be used to level and condition the sea floor and provide a turning basin at the breakwater site, to provide sand if onshore sources are not used, to lay the cables, and, if necessary, to deepen the harbor area and channel for shipment of materials to the site.

The dredging industry is comprised of the Army Corps of Engineers and a large number of private dredging companies. The size and type of dredging jobs vary widely.

In 1972 the Corps dredged 380 million cubic yards.[34] Comparable data are not available for the private sector, but it has been established on a national level that 40 percent of dredging in the United States is by the Army Corps of Engineers.[35] In order to draw some inferences on a regional basis, it is assumed that the national ratio applies uniformly to the regions. This results in total regional dredging by private dredging concerns as shown in Table VI-11.

Table VI-11

Possible Breakwater Dredging Requirements As a Percentage of the 1972 Dredging Volume

Powerplant Site	Dredging Region	Estimated Volume Dredged by Private Firms (millions of cubic yards)	Dredging Requirements[1/] as a Percentage of the 1972 Production		
			25 Breakwaters	50 Breakwaters	100 Breakwater
Portsmouth, N.H., North	New England	0.9	57.8	101.1	216.7
Sandy Hook-Atlantic City	New York/Delaware River/Wilmington	14.9	3.5	6.1	13.1
Chincoteague-Cape Charles	Baltimore/Norfolk	19.1	2.7	4.8	10.2
Sandy Hook-Atlantic City/ Chincoteague-Cape Charles	New York/Delaware River/Wilmington/ Baltimore/Norflok	34.0	[2/]3.1	[2/]5.4	[2/]11.5
Cape Canaveral-Key West	Jacksonville	6.8	7.6	13.4	28.7

[1/] Possible total requirement per breakwater is 1.3 million cubic yards. Source: For Army Corps of Engineers data, Disposal of Dredge Spoil: Problems, Identification and Assessment and Research Program Developments, U.S. Army Waterways Experiment Station, Vicksburg, Miss.; for the national ratio of private to Corps dredging (3:2) used to generate regional numbers, Testimony prepared by the National Association of Rivers and Harbor Contractors for the Office of Management and Budget, National Resources Program, 1973.

[2/] Because the Army Corps of Engineers regions being considered overlap the two powerplant regions, both regions' requirements are considered.

How much dredging is needed at the site depends, of course, on water depth. It is expected that 950,000 cubic yards will be dredged for the PSE&G New Jersey site.[36] The amount required for deepening the shipping channel from the construction plant to the offshore site will depend on the nearshore coastal area. If it is deep enough for barges, there will not be much dredging. The amount of dredging required for laying the cable is a function of the distance along the route of the cable, the depth and minimum trench width required, and the trench contour (a function of the composition of the ocean bottom and the dredging technology employed). For the New Jersey site, this could amount to as much as 200,000 to 400,000 cubic yards.

Soil dredged can be used as fill for the caissons. Each caisson -- and there are 30[37] -- uses 12,280 tons of sand;[38] a total of 385,000 tons, or 189,000 cubic yards, is required. This volume is approximately one-fifth of the materials dredged at the site, so that very little, if any, offsite dredging or land production would be required.

Not including the possibility of deepening the barge channel and assuming that the caisson fill comes from the onsite dredging, the total dredging required could be as much as 1.3 million cubic yards. This requirement as a percentage of the dredging along the Atlantic by region for 1972 is shown in Table VI-11. It is evident that an FNP in New England would significantly affect the industry in that region.

The dredging industry in the Sandy Hook-Atlantic City and the Chincoteague-Cape Charles regions, considered both separately and jointly, would not have to expand as much. The highest production requirement of 100 breakwaters by the year 2000 results in less than a 15 percent expansion. The requirement is lessened even further by the fact that production is expected to begin about 1985. Possible expansion is greater in Jacksonville (28.7 percent of the present level) but not so large as in New England.

As stated in the discussion of the cement industry impacts, these observations are made on a statewide basis and therefore are subject to local factors and constraints. It must also be remembered that a national ratio was applied to the regions. Further, dredging requirements will vary for individual sites.

Breakwater installation. Breakwater construction involves transporting the components and emplacing them at the site.

What is needed is the onshore construction support facility (see Chapter V), 2 derrick barges, 32 transport barges, 16 tugs, and 3 personnel boats.[38] The technology to achieve all facets of the operation is available.[39] However, the large volume of materials being transported and installed could stimulate development of new equipment, such as large derrick boats used for the placement of the dolosse.

Land Use Patterns. The effect of the breakwater on land use patterns nearby will depend much on existing land use. For example, there is no industrial activity within 10 miles of the New Jersey site. In addition, a New Jersey Wetlands Order[38] protects the area against industrial development. Possible sites for the construction support facility are the industrialized shoreline of the Delaware River near Wilmington and Philadelphia or of the Hudson River in New Jersey. Because they are already industrial, the effect will tend to be relatively minor, whether a new or existing facility is used.

If the Florida breakwater construction support facility were to be located near the Jacksonville nucler powerplant construction facility, the land use effects would be similar to those resulting from the Jacksonville construction facility discussed earlier.

If existing waterways or roads are adequate for shipping raw materials to the construction site, environmental effects of the additional shipping would be significantly less than if new construction or dredging is required. With the amount of shipping now in the vicinity of the proposed New Jersey breakwater construction support facility sites, new road construction would tend to be less than in less developed areas. Local traffic congestion could result, the heavy materials could significantly degrade the roads.

For those sites that cannot accomodate the barges, dredging would be required. (The environmental effects of dredging are discussed in Chapter V.) The barge traffic would result in heat, oil, and other emissions.

Since the raw materials for the breakwater are expected to be shipped by water, additional access roads required are expected to be relatively minor. During construction of the support facility, a period of several months, the roads will be used primarily for personnel and construction equipment. During the operations phase, they will be used by personnel and for raw materials not shipped by barge.

Socioeconomic Effects. The socioeconomic effects will depend on how long the construction plant operates. If it is used for several breakwaters and perhaps other jobs, the short-term socioeconomic effects will persist.

A major economic effect of plant operations will be the demand for raw materials, discussed earlier. Most contract expenditures for barge, rail, and truck hauling services will be intraregional and sometimes sizable.

Approximately 200 construction workers would be required for 1 year to build the construction support facility off the southern New Jersey coastline, and 450 would be required for 4 or 5 years to build the breakwaters.[39] Therefore, for each subsequent breakwater constructed that uses the support facility, approximately 450 employees would be required over a 4-year period. The skills, salaries, and offshore/onshore allocation of the construction work force has not yet been clearly defined.

FNP OPERATIONS

The direct effects of FNP operations from radioactive materials, thermal pollution, etc. are discussed in Chapter V. Relatively little data can be found to evaluate the indirect effects, the economic effects of employment at the site, the induced industrial growth and associated commercial and residential location, air and water pollution due to industrial and related growth, and the effects of the land-based support facility and of fuel reprocessing.

Economic Effects of Plant Employment and Purchases

The types of effects due to the payroll disbursements and purchases on the local economy are discussed in the chapter. Employment at the FNP facility during operations is expected to be between 100 and 200. Assuming the larger number, the economic effects of payroll disbursement will total approximately $4 million per year.[40/]

Excluding the nuclear fuel,the major purchases required for operation of the FNP are diesel fuel. Revenue from the chemicals is not significant compared to the purchases for the FNP manufacturing facility. There will be some additional income to local suppliers, but in general the effects of plant purchases will be small.

The requirement for special skills for plant operations can have some effect on the local labor market, particularly if other FNP facilities are planned in the same area. In addition to the operation personnel, there will be a need for employees with special skills required for the maintenance of the hull and maintenance and repair of the breakwater. It is possible that some maintenance and repair will be contracted out. If a large number of FNP's are operating in a region, there may be some economic effects because of the jobs created.

Induced Effects on Industrial Growth

Perhaps the most significant indirect effects are the induced industrial growth due to availability of electric power and the associated commercial and residential location. Industrial location depends on several factors. Availability of electricity is an important one as shown Table VI-12, which ranks

Table VI-12

Relative Weight Indices of Industrial and Commercial Locational Determinants and Attractiveness Factors[1/]

INDUSTRIAL	Production	Storage and Distribution	Research and Development
Labor Costs and Availability			
Wage rates	5	6	4
Productivity	4	2	8
Size of available labor pool	8	4	8
Utilities Cost and Availability			
Gas	6	4	4
Electricity	6	4	4
Water	4	2	2
Waste Disposal	4	2	2
Public Service Costs	5	10	5
Quality of Public Services			
Fire and police protection	4	5	8
Other	1	-	8
Accessibility			
Proximity to major highways	15	19	3
Availability of rail services	5	4	-
Proximity to airport	1	1	2
Proximity to suppliers and services	2	-	2
Proximity to customers	2	9	2
Proximity to similar activities	4	3	2
Land Costs and Availability			
Cost of developer sites	10	11	4
Availability of large sites	4	4	1
Quality of Environment			
Residential attractiveness	2	3	8
Site attractiveness	4	4	15
Community attractiveness	4	3	8

Table VI-12 (cont'd.)

COMMERCIAL

	Local Service Market	Middle Service Market	Regional Service and Headquarters Market
<u>Regional Location</u>			
Proximity to major highways	2	3	4
Public transportation	1	2	3
Proximity to airport	1	2	3
Proximity to executive residential areas	3	3	3
Distance from CBD	2	3	3
Proximity to major concentrations	4	4	3
<u>Developer Capabilities</u>			
Prior Experience	2	3	4
Prominence	2	3	4
Network of contacts	3	4	4
Marketing skills	3	4	4
<u>Population Growth</u>			
Growth in immediate area	4	3	3
Growth in county	3	3	3
<u>Site Specific Considerations</u>			
Development density	1	2	2
Land costs	3	3	2
Other magnets	4	3	2
Topography	1	1	1
Utilities	1	2	2
Labor Availability	2	3	3
Public services	1	2	2
Prestige	2	3	3
Visibility	2	3	3
<u>Competition</u>			
Vacancy rate	3	4	4
Space under construction	3	4	4

Source: Real Estate Research Corporation, San Francisco, based on a nationwide survey conducted by the American Trucking Association and a survey of over 400 of the Nation's largest manufacturing firms conducted by <u>Fortune Magazine,</u> Society of Industrial Realtors, Industrial Real Estate (2d ed. 1971). Also considered was Forbes Marketing Research, Inc; <u>A Study of the Factors Influencing Industrial Plant Location Since 1957,</u> September 1960.

industrial location determinants and attractiveness factors for production, storage and distribution, and research and development.

The availability of power is especially important to the energy-intensive industries. They are listed in Table VI-13 for the United States and Table VI-14 for New Jersey. The historical and projected industrial growth is shown in Table VI-15 for New Jersey. A number of projections of employment by SIC code have been made for New Jersey.[41] The projections in Table VI-15 are from the 1972 OBERS projections.[42] The OBERS projections were made primarily for 173 BEA Economic Areas, from which the state projections were derived. Some caution must therefore be exercised in using the projections in Table VI-15. However, the OBERS projections are the most recent comprehensive economic projections at the state level for all states and include projections through the year 2020.

The continuing industrial growth will require additional electric power. Historically there has been a trend toward increased electricity intensiveness, as demonstrated by the increased power consumption per unit of industrial production.[43] The recent emphasis on energy conservation may change this trend. However, there is little experience regarding the effect of conservation on the energy-intensiveness of major industries, although there may be a 5 to 10 percent conservation potential in some industries.[44] PSE&G estimates the increase in electricity intensiveness at approximately 3 percent in the industrial sector.[45]

In view of the continuing increases in electricity demand, two types of effects could result from FNP operations.

- Increased employment at expanded or new industrial facilities that developed because of additional power availability. This effect is more likely to occur where the electric power costs less than other energies and the cheap electricity acts as a special inducement.

Table VI-13

Electric Energy Intensive Industries in the United States

SIC Code	Industry	Employment (thousands)	Value added (millions of dollars)	Purchased electric energy (billion kilowatt hours)	Electric energy consumed (billion kilowatt hours)
20	Food and kindred products	1,574	34,109	35.4	38.0
22	Textile mill products	907	9,995	24.9	25.4
26	Paper and allied products	632	11,682	35.0	60.4
28	Chemicals and allied products	849	29,431	99.6	119.2
29	Petroleum and coal products	141	5,616	23.7	29.1
32	Stone, clay, and glass	583	10,757	24.9	25.8
33	Primary metals	1,169	21,133	122.4	147.0
35	Nonelectrical machinery	1,743	30,680	22.3	22.7
36	Electrical equipment and supplies	1,659	27,874	23.6	23.8
37	Transportation equipment	1,621	34,845	27.5	N.A.
	Total Manufacturing	18,363	314,151	517.8	600.5

Sources: U.S. Bureau of the Census, Annual Survey of Manufacturers, 1971; U.S. Bureau of the Census, The 1972 Census of Manufacturers - Fuels and Electric Energy Consumed, 1972.

Table VI-14
Electric Energy-Intensive Industries in New Jersey, 1971

SIC Code	Industry	Employment (thousands)	Value added (millions of dollars)	Estimated Electricity 1/ Consumption (billion kilowatt hou
20	Food and kindred products	55.2	1,400.5	1.56
22	Textile mill products	25.0	402.5	1.02
26	Paper and allied products	30.6	507.7	2.62
28	Chemicals and allied products	95.2	3,487.0	14.12
29	Petroleum and coal products	7.0	294.5	1.53
32	Stone, clay, and glass	37.3	637.9	1.53
33	Primary metals	30.9	502.7	3.49
35	Nonelectrical machinery	62.8	1,169.1	0.86
36	Electrical equipment and supplies	101.7	1,563.2	1.33
37	Transportation equipment	25.1	826.8	N.A.

1/Assuming U.S. figures for electricity consumed per value added.

Source: U.S. Bureau of the Census, Annual Survey of Manufacturers, 1971.

Table VI-15
Economic Projections for New Jersey

POPULATION, EMPLOYMENT, PERSONAL INCOME, AND EARNINGS BY INDUSTRY, HISTORICAL AND PROJECTED, SELECTED YEARS, 1950 - 2020

	1950	1959	1962	1968	1969	1980	1990	2000	2010	2020
POPULATION, MIDYEAR	4,872,000	6,015,000	6,388,000	7,046,07?	7,129,000	8,115,000	9,361,000	10,651,000	12,104,000	13,656,000
PER CAPITA INCOME (1967$)	2,530	2,875	3,149	3,843	3,939	5,480	7,030	9,367	12,703	15,831
PER CAPITA INCOME RELATIVE (US=1.00)	1.23	1.22	1.22	1.16	1.15	1.15	1.14	1.13	1.12	1.11
TOTAL EMPLOYMENT	1,997,001	2,397,107				3,327,700	3,814,900	4,454,000	5,106,200	5,788,300
EMPLOYMENT/POPULATION RATIO	.41	.40				.41	.41	.42	.42	.42
				IN THOUSANDS OF 1967 $						
TOTAL PERSONAL INCOME	12,328,000	17,893,000	20,119,000	27,076,000	28,078,000	44,473,000	65,812,000	99,704,000	147,710,000	216,017,000
TOTAL EARNINGS	9,479,200	13,736,837	15,377,009	20,204,817	20,186,706	33,763,900	49,497,800	74,276,400	109,839,400	158,949,600
AGRICULTURE, FORESTRY & FISHERIES	237,959	171,740	181,999	154,631	155,889	146,800	145,100	171,700	223,100	298,700
AGRICULTURE	225,348	170,998	175,150	150,519	152,344	141,200	138,000	162,500	211,100	283,300
FORESTRY & FISHERIES	12,601	4,742	6,852	4,113	3,545	5,500	7,100	9,200	11,900	15,200
MINING	22,696	29,390	29,911	27,204	32,777	41,900	55,700	76,600	104,300	144,000
METAL	(D)	(D)	(D)	(D)	1,982	1,900	2,600	3,100	4,000	5,200
COAL	167	0	0	0	0	(S)	(S)	(S)	(S)	(S)
CRUDE PETROLEUM & NATURAL GAS	(D)	(D)	(D)	(D)	224	(S)	(S)	(S)	(S)	(S)
NONMETALLIC, EXCEPT FUELS	13,885	22,874	26,079	25,0?4	30,571	34,700	52,900	73,100	99,600	136,700
CONTRACT CONSTRUCTION	602,730	832,601	951,065	1,262,4?9	1,278,371	2,084,000	3,104,100	4,715,200	6,986,400	10,221,900
MANUFACTURING	3,877,390	5,393,296	5,986,567	7,234,441	7,040,961	10,982,000	15,197,300	21,685,600	30,513,800	43,166,300
FOOD & KINDRED PRODUCTS	292,843	462,324	475,077	539,5?0	530,499	724,100	927,200	1,188,000	1,498,200	1,903,200
TEXTILE MILL PRODUCTS	306,157	198,319	181,450	214,2?7	225,794	250,700	266,000	344,100	411,300	502,500
APPAREL & OTHER FABRIC PRODUCTS	311,891	323,320	354,971	403,7?0	408,224	556,400	690,200	888,000	1,132,300	1,494,200
LUMBER PRODUCTS & FURNITURE	72,668	87,874	93,187	110,9?6	115,921	151,700	193,800	254,300	332,800	430,700
PAPER & ALLIED PRODUCTS	130,000	196,280	227,331	275,8?6	270,895	443,100	641,500	951,100	1,391,290	2,022,700
PRINTING & PUBLISHING	127,111	218,461	236,719	316,6?3	333,878	532,100	772,800	1,147,200	1,668,900	2,417,600
CHEMICALS & ALLIED PRODUCTS	460,151	682,825	761,149	1,139,341	1,190,183	1,842,100	2,638,400	3,876,100	5,509,500	8,025,400
PETROLEUM REFINING	110,133	96,027	97,933	126,598	133,098	161,600	193,200	233,500	263,600	391,700
PRIMARY METALS	219,601	293,990	301,943	341,025	357,346	462,100	539,400	672,800	826,900	1,029,000
FABRICATED METALS & ORDNANCE	222,343	372,492	400,690	539,0?2	562,706	921,200	1,369,900	2,007,400	2,934,300	4,296,300
MACHINERY, EXCLUDING ELECTRICAL		431,889	492,909	684,441	704,762	1,018,600	1,397,100	1,976,700	2,762,200	3,861,400
ELECTRICAL MACHINERY & SUPPLIES		902,970	971,900	1,048,03?	1,092,201	1,628,100	2,314,300	3,365,400	4,792,800	6,827,400
TOTAL MACHINERY (1950 ONLY)	882,390									
MOTOR VEHICLES & EQUIPMENT	80,336	121,031	185,290	170,378	171,394	311,900	527,000	691,000	1,443,700	2,021,700
TRANS. EQUIP., EXCL. MTR. VEHS.	146,518	235,471	225,769	194,3?9	136,085	195,100	230,900	386,300	396,100	516,100
OTHER MANUFACTURING	593,780	852,899	972,904	1,164,016	1,225,196	1,792,100	2,491,900	3,372,700	5,051,900	7,137,900
TRANS., COMM. & PUBLIC UTILITIES	736,849	1,000,871	1,219,691	1,343,803	1,632,899	2,426,200	3,423,800	4,960,100	7,061,800	10,020,600
WHOLESALE & RETAIL TRADE	1,604,189	2,241,211	2,442,970	3,216,420	3,337,032	5,349,700	8,147,300	12,255,300	17,994,300	26,182,200
FINANCE, INSURANCE & REAL ESTATE	408,172	671,104	706,409	932,608	949,536	1,477,400	2,063,300	2,960,700	4,297,600	5,993,300
SERVICES	1,121,626	1,770,331	2,141,949	3,048,468	3,191,830	5,694,300	9,369,600	14,987,000	23,245,300	35,606,200
GOVERNMENT	866,274	1,533,870	1,799,844	2,790,2?1	2,861,991	5,159,900	8,011,600	12,497,700	18,619,900	27,558,100
CIVILIAN GOVERNMENT	699,798	1,275,988	1,534,575	2,361,2?2	2,451,196	4,639,900	7,338,100	11,503,000	17,330,400	26,092,000
ARMED FORCES	166,476	257,889	265,269	429,0?9	410,795	519,900	673,500	993,000	1,129,500	1,466,000

POPULATION, APRIL 1, 1970 7,168,164

Source: U.S. Department of Commerce, Social and Economic Statistics Administration, The 1972 OBERS Projections - Economic Activity in the U.S. by CEA Economic Areas, Water Resources Region and Subarea and States - Historical and Projected 1929-2020, prepared for the U.S. Water Resources Council, U.S. Gov't Printing Office, 1972.

- Reduced unemployment and maintenance of industrial production where potential power shortages exist. This will include reversal of out-migration of jobs and related labor force and population. This effect could occur where the cost of electricity is high but the area is otherwise attractive. In such situations, the lack of electricity may be limiting growth, which would become possible if power were available.

The specific effects of the FNP, of course, depend on the rate of industrial growth in the vicinity, the availability of power from other sources, the availability of land, water, labor, utilities, and services, etc. One 1150-MWe plant will generally produce 8.05 x 10^9kilowatt-hours of electricity annually (assuming a 7,000-hour baseload operation).[46]

The amount electricity consumed per industrial employee depends on the type of industry; the type of activity within the industry; labor and energy intensiveness trends; the price of electricity relative to other energies; the price of energy relative to labor and capital; projected availability of energy; technological changes in production processes; trends in product mix, markets, etc.; regulatory factors, such as environmental regulations; and energy conservation measures.

These variables make it difficult to project the incremental employment of an FNP facility. Based on 1971 data, a simple quantitative assessment of the employment impact can be made for the New Jersey site area:

- The ratio of nonmanufacturing to manufacturing employment in New Jersey is projected to be approximately 2.0 in 1980.[46] An incremental change in manufacturing employment of 100, therefore, will bring about an additional change in nonmanufacturing employment of 200 - for a total employment change of 300.
- The employment participation rate (total employment to total population) is projected at 41.1 percent in 1980.[47] Thus, there will be a change in population of approximately 730 from this employment change.

- Using an average household size of 2.96,[48] this would imply a change in households of approximately 247.
- From the average electrical consumption figures for industrial, commercial and residential customers,[49] the total electricity consumption per incremental industrial employee can be calculated at 50,721 kilowatt-hours at 1971 consumption rates. This is based upon electrical consumption of the industrial customers at 18,906 kilowatt-hours per employee, of the commercial customers at 8,831 kilowatt-hours per employee, and of the residential customers at 5,730 kilowatt-hours per customer.[50] (Therefore, since every incremental industrial employee implies 2 incremental commercial employees and 2.47 incremental households, the total electrical consumption per incremental industrial employee is 50,721 kwh (18,906 kwh x 1, plus 8,831 kwh x 2, plus 5,740 kwh x 2.47).)
- Assuming a 4.5 percent increase in consumption per household and a 3.0 percent increase in consumption per employee,[51] the corresponding figures for 1981, 1990, and 2000 are 71,125, 99,036, and 143,888 kwh, respectively. (1981 is the first year that both units 1 and 2 could be operational).
- Based upon a total electricity generating from the PSE&G Atlantic Generating Station of 16.1 x 10^9 kwh,[52] the facility can support the levels of activity shown in Table VI-16.

In general, the effects of additional FNPs may be extrapolated from the table. However, location of four FNPs in a line or clustered may attract heavy industry and related support industries. For example, a refinery and petrochemical complex may be located in the same areas as a number of FNPs. In the year 2000, there may be as many as 50, 100, or 200 FNPs along the East Coast. With linear extrapolation, they will support manufacturing employment of 2.8, 5.6, and 11.2 million and populations of 20.5, 40.9, and 81.8 million, respectively.

Table VI-16

Activities Supported by Two 1,150-MWe Powerplants
(in thousands)

Year	Manufacturing Employees	Nonmanufacturing Employees [1]	Households [2]	Population [3]
1981	226	452	557	1,650
1990	163	326	430	1,190
2000	112	224	314	818

---

[1] Assuming manufacturing employees to nonmanufacturing employees to a constant ratio of 2.0 between 1980 and 2000.

[2] Assuming household size projections of 2.96 in 1981, 2.77 in 1990, and 2.60 in 2000.

[3] Assuming a constant labor force participation rate of 41.1 percent between 1980 and 2000.

Source: Based on extrapolation of data for Middle Atlantic Region from Statistical Abstract Office - U.S. 1972.

These figures indicate the potential economic significance of the FNPs. For example, should once-in-a-century storm curtail operation of 100 FNPs on the East Coast, virtually all economic activity would shut down, seriously affecting over 40 million persons.

Environmental Effects of Induced Growth

The secondary effects of the FNP - the incremental industrial employment and associated commercial and residential growth - will lead to air and water pollution, noise, solid wastes, and strain on or growth of transportation and other community services. The community impacts may be analyzed using the methodology described by Isard and Coughlin.[53]

Environmental effects will depend on location of the incremental households, economic conditions in the area, municipal services, etc. They will depend on the industrial mix, physical characteristics of the region, concentration or dispersal of the industrial, commercial, or residential growth, and other regional characteristics. Because power can be transmitted long distances, the growth effects may not be local. However, as transmission distance increases, so do the costs of power. In general, the effects of FNPs will not be different from those created by a comparable nuclear powerplant onshore.

Effects of the FNP on Regional Development Policies

The induced industrial growth need not be in the immediate vicinity of the FNP. Indeed, the impacts of the FNP could be felt over several counties and across state boundaries, especially when the cost of power, including transmission costs, is competitive. Because the area within 10 miles of the proposed PSE&G site contains no land zoned for industrial use,[54] the industrial growth impact would occur outside the immediate vicinity of the FNP.

The possibility of locating growth over a region means that the FNP can influence regional development policy. For example, by locating a powerplant offshore, a state experiencing rapid economic growth can accommodate continued growth, and a state which is relatively less developed can attract growth from an area under substantial pressure with minimum adverse environmental impact. In general, industry tends to locate where public services are already available and therefore creates additional demand for power.

Obviously any use of the FNP in formulating policy must be coordinated with land use policy and the provision of transportation, utilities, and other services needed for planned growth with minimum degradation of the environment. An FNP could be used in conjunction with a new community in an undeveloped area.[55/] A possible example of relating the development of a new town to the FNP exists in New Jersey, where the Bass River New Town is proposed for a site less than 20 miles from the PSE&G Atlantic Generation Station.[56/]

It should be remembered that in the absence of a regional development policy, the location of the FNP may provide the impetus for growth in an area where further growth may cause significant adverse environmental effects. Potential growth effects must be carefully assessed.

Effects of Onshore Support Facility

The FNP onshore support facility is parimarily an assembly area; it includes a dock, switching station, storage enclosure, parking lot, and office. The facility will be used as a transfer point, and the traffic and number of personnel during normal plant operations will be small.[57/]

Although it is possible that the nuclear fuel for the plant operation and fuel from the FNP for reprocessing could both be handled at the land support facility will handle any nuclear fuel. The proposed PSE&G support facility will not. It is anticipated that PSE&G will use a separate onshore facility for nuclear fuel.[58/]

During the construction of the breakwater, the support facility will use about 100 acres. Only about 15 acres is needed during operations, and the remaining land may function as a buffer area. The equipment and structures at the facility will probably not be readily visible from a distance.[59/]

Effects of Fuel Reprocessing Facilities

Approximately 92,000 pounds of fuel will be used in the reactor each year. This represents about one-third of the initial fuel loading. (See Chapter V.) The spent fuel will be taken to a fuel reprocessing facility to reclaim all the unconsumed uranium, fissionable plutonium, and other usable materials created by the fission process. Although an FNP uses no more uranium than a comparable facility onshore, obviously a number of FNPs in a region will require more shipping and reprocessing. The effects of transshipment are discussed in Chapter V. The environmental effects of nuclear fuel reprocessing is described by the AEC in Environmental Survey of the Nuclear Fuel Cycle.[60/]

Current plans indicate the reprocessing facilities located on relatively large, remote sites. The capacity of each facility is equivalent to the annual requirements of approximately 26 model PWRs.[61/] The effect of a single FNP facility on fuel reprocessing is relatively minor. However, if many FNPs are located in a region and thus require a new fuel reprocessing facility, all the environmental effects of the facility should be assessed.

Other Indirect Effects

The pressures toward induced growth and the aesthetic aspects of the FNP are likely to have some political reverberations. Those interested in protecting the natural beauty of the coastline will oppose the FNP. There will be pressures on local government to rezone for growth. Local citizen groups may protest the pressures and attempt to maintain the existing quality of life. Therefore, where strict land use controls are absent, there will be significant political pressures on the local government.

Because FNP facilities can be located far from major load centers, transmission lines will be longer, and there may be some problems in obtaining adequate transmission rights-of-way.

The FNP could affect recreation in the nearby shore areas. If the thermal discharge raises the water temperatures at nearby beaches, swimming in the area may benefit. On the other hand, some seasonal residents and weekend visitors may avoid the beaches in the vicinity of the FNP because of feared radiation hazards. Recreational boating may be restricted in the vicinity.

Chapter VIII discusses existing and potential uses of the coastal regions and the outer continental shelf.

Comparison with Onshore Nuclear Powerplants

The operation of an offshore nuclear powerplant is similar to that of a comparable onshore nuclear plant. The environmental effects of nuclear powerplants were reported in a previous CEQ report, Energy and the Environment - Electric Power.[62] Following is a brief comparison of the indirect effects of operations both offshore and onshore:

- Induced industrial growth -- The effects on industrial growth are caused primarily by the need for more electric power and its availability. Assuming similar output, their effects will be comparable.
- Environmental effects of induced growth -- These environmental effects depend upon a number of factors, including demographic and economic characteristics and local municipal services, not upon location offshore or onshore of the power source.
- Effects of Fuel Reprocessing -- The amount of fuel used is comparable for either location. The indirect effects of fuel reprocessing will therefore by very similar. There will be some differences in shipment of the fuel and the associated effects. Because of the flexibility of locating and clustering FNPs, a fuel reprocessing facility may have to be located nearby. But so it would if several onshore plants were clustered.
- Land support facility -- The offshore plant requires a land support facility that the onshore plant does not. However, the indirect effects of the facility are not significant.
- Other effects -- The economic effects of payroll disbursement and purchases during the operation of the plant will be comparable. The offshore plant does have some effect on recreation, land use, transportation, etc. which are different from those resulting from onshore nuclear plants.

FOOTNOTES

1. For a detailed step-by-step discussion of the complete production cycle, see Section 3.2 of "Environmental Report Supplement to Manufacturing License Application," submitted to U.S. Atomic Energy Commission by Offshore Power Systems, Inc., May, 1973.

2. "Environmental Report Supplement..." *op.cit.* Sections 1.3 and 1.4.

3. See Page 1-9, "Environmental Report Supplement...," *op.cit.*, for a discussion of the FNP market as perceived by OPS.

4. Unpublished siting study conducted by OPS and forwarded to the Army Corps of Engineers.

5. Commonly used in the literature to denote the aggregate "purchase/repurchase" stimulus effects created in certain economic sectors due to investments, expenditures, and similar activities in other sectors. The precise values and meanings of various multipliers may differ as a result of the region of application or the type of model employed. Thus, careful consideration must be given to the context in which multipliers are used. See *Methods of Regional Analysis*, Walter Isard, MIT Press; Cambridge, Mass., 1960. See particularly Chapter VI, "Regional Cycle and Multiplier Analysis."

6. "The Economic Impact on Duval County and the State of Florida of a Proposed Place on Blount Island to Produce PMNP (Platform Mounted Nuclear Power)" prepared for the Jacksonville Port Authority by McFarland Research Associates, Jacksonville, Florida, May 1972.

7. See Section 1.0 entitled "Blount Island Development Project Description Final Environmental Impact Statement Evaluation; "Jacksonville District Army Corps of Engineers, Jacksonville, Florida, August 3, 1973.

8. See "Differential Responses in the Decision to Migrate," Charles E. Trott, Regional Economic Division, Bureau of Economic Analysis, U.S. Department of Commerce, November 1971.

9. See "Municipal Costs and Revenues Resulting from Community Growth," Walter Isard and Robert Coughlin, Urban and Regional Studies Group, MIT, Cambridge, Mass., for detailed estimates of incremental municipal costs and revenues which result from community growth for both residential and industrial-residential communities. Empirical data from specific case studies are presented.

10. McFarland Research Associates, "The Economic Impact on Duval...," *op.cit.*

11. U.S. Department of Commerce Social and Economic Statistics Administration, *The 1972 OBERS Projections-Economic Activity in the United States by BEA Economic Area, Water Resources Region and Subareas and States-Historical and Projected 1929-2020*, prepared for the U.S. Water Resource Council, U.S G.P.O., Washington, D.C., 1972.

12. See Chapters 3 and 4 of "Environmental Report Supplement to...," *op.cit.*

13. See Section 3.3.3., "Environmental Report Supplement to...," *op.cit.*, for a detailed discussion of the liquid wastes from plant operations and treatment alternatives.

14. See Section 4.1.3., "Environmental Report Supplement...," *op.cit.*, describes the calculation of thermal discharge impact upon ambient water conditions based upon water volume of the testing berths, pump operating capacities, cooling effects of tidal exchange, etc.

15. The 1972 OBERS Projections...,U.S. Department of Commerce, op.cit.

16. Based upon OPS projections in "Environmental Report Supplement..." op.cit., Section 4.0

17. Environmental Report, Atlantic Generating Station, Units 1&2, Public Service Electric and Gas Co., December 1973, pg. 4.1-2.

18. Air Pollution, Vol. III - Sources of Air Pollution and Their Control, Edited by Arthur C. Stern, Academic Press, 1968, Table 8-10.

19. Building Science Series 36, National Bureau of Standards, 1971.

20. First Annual Report of the Secretary of Interior Under the Mining and Minerals Policy Act of 1970, by the Bureau of Mines, March 1972, Appendix I, pg. 42.

21. Minerals Yearbook Volume I, 1971, Bureau of Mines, U.S. Department of the Interior, pages 278,279.

22. Design and Construction of Ports and Marine Structures; Alonzo DeF. Quinn, McGraw-Hill Book Company, 1972, pg. 174.

23. Minerals Yearbook...., op.cit.

24. Minerals Yearbook...., op.cit., pg. 277.

25. Control Techniques for Particulate Air Pollutants, HEW, Public Health Service, Washington, D.C., 1969.

26. HEW, Public Health Service, op.cit., pg. 134; Air Pollution Engineering Manuel, HEW, Public Health Service, Cincinnati, Ohio, 1967, pg. 4-111.

27. "Quarry Thrives in Urban Area," Rock Products, Vol. 75, No. 2, February, 1972, pg. 58-60.

28. Since functions such as these do not exert great weight on the land surface, they are potential uses for reclaimed landfills.

29. Bureau of Mines, U.S. Department of the Interior, op.cit., pg. 275.

30. Ibid., pg. 1110.

31. Ibid., pg. 1051.

32. Ibid., pg. 260.

33. Ibid., pg. 261. The OKC Corp. planned expansion in New Orleans is used in determining investment requirements for expansion.

34. Disposal of Dredge Spoil: Problems, Identification, and Assessment, and Research Program Development, U.S. Army Waterways Experiment Station, Vicksburg, Miss., 1973.

35. Testimony prepared by the National Association of River and Harbors Contractors for the Office of Management and Budget, National Resources Program, 1973.

36. Public Service Electric and Gas Co., *Environmental Report...,op.cit.*, pg. 4.1-2.

37. *Atlantic Generation Station, Preliminary Site Description*; Public Service Electric and Gas, Newark, New Jersey.

38. *Ibid*., pg. 3.1-60.

39. Public Service and Gas Co., *Environmental Report...op.cit*.

40. Offshore Power Systems, *Environmental Report Supplement to Manufacturing License Applications*, submitted to AEC, May 1973.

41. See, for example, National Planning Association, *State Economic and Demographic Projections to 1975 and 1980*, Regional Economic Projection Series, Report No. 70-R01, April 1970.

42. U.S. Department of Commerce, Social and Economic Statistics Administration, *The 1972 OBERS Projections...*, *op.cit*.

43. *Economic Report of the President*, U.S. Government Printing Office, Washington, D.C 1971.

44. See, for example, Noland, Michael C., "Development of Industrial Energy Management Policies" in *Proceedings of the Engineering Foundation Conference on Energy Conservation through Effective Energy Utilization*, Henniker, N.H., 1973. But no comprehensive data on the entire industrial sector are available.

45. Public Service Electric and Gas Co., *Environmental Report*, *Atlantic Generating Station*, Units 1 and 2, Dec. 1973.

46. The OPS *Environmental Report Supplement* ... *op. cit*., uses 7000 hours as a typical figure.

47. National Planning Association, *op. cit*.

48. Extrapolated from data in *Statistical Abstract of the U.S. - 1972*, for Atlantic Region.

49. Edison Electric Institute, *Statistical Yearbook for the Electrical Utility Industry* for 1971.

50. Based on data from Edison Electric Institute, *Statistical Yearbook ...*, *op. cit*., and State of New Jersey, Department of Labor and Industry, *1971 Covered Employment Trends in New Jersey*, December 1972.

51. From PSE&G *Environmental Report ...*, *op. cit*.

52. Offshore Power Systems, *Environmental Report Supplement to ...*, *op. cit*.

53. Isard and Coughlin, *Municipal Costs ...*, *op. cit*.

54. Public Service Electric and Gas, *Atlantic Generating Station*, *op. cit*.

55. The New Communities Act (Title VII of the Housing and Urban Development Act of 1970) allows for Federal financial guarantees to new community development. One type of new community is the freestanding growth center. For further information, see Draft Regulations, Urban Growth and New Community Act of 1970, P.L. 91-609, U.S. Congress and *New Communities: Systems for Planning and Evaluation*, Report submitted by Decision Sciences Corporation to U.S. Department of Housing and Urban Development, 1970.

56. *Bass River New Town - Preliminary Studies*, submitted by Vincent G. Kling and Partners to the U.S. Department of Housing and Urban Development.

57. Offshore Power Systems, *Environmental Report Supplement to ...*, op cit.

58. Public Service Electric and Gas Company, *Atlantic Generating Station*, op. cit. It is anticipated that PSE&G will use a separate onshore facility for transshipment of nuclear fuel.

59. Offshore Power Systems, *Environmental Report Supplement to ...* , *op. cit*.

60. U.S. Atomic Energy Commission, *Environmental Survey of the Nuclear Fuel Cycle*, November, 1972.

61. *Ibid*.

62. Council on Environmental Quality, *Energy and the Environment: Electric Power*. August 1973.

CHAPTER VII

CONFLICTS WITH OTHER USES OF THE COASTAL REGIONS AND OUTER CONTINENTAL SHELF

The previous chapters discuss the regions that are more likely candidates for initial siting of FNPs and the challenges that the environment and the FNP present each other. This chapter looks at their interactions as they apply to other uses -- existing or in the future -- of the coastal regions (CR) and the outer continental shelf (OCS).

The CR and the OCS comprise a vast natural resource whose value is currently unknown but is certainly appreciated (e.g., considerable legislative concern) and is presumably underutilized. As a public and possibly international resource, they have many uses, some are compatible but others are incompatible or at least in direct competition, for example, harvesting benthic species and disposing of certain process effluents. Decisions on use of the CR or the OCS, then must be made in light of the interactions of all current and anticipated uses.

This chapter categorizes uses as related to energy resources, outdoor recreation, and commercial development. The categories were selected because of their relevance to major issues and because they illustrate the myriad uses and issues that must be considered when deploying FNPs. The regulation and resolution of conflicting uses are addressed in Chapter VIII.

USES RELATED TO ENERGY RESOURCES

Chapter II presents some U.S. energy supply and demand projections which illustrate the shortcomings of domestic energy resources and the changes in energy consumption profiles in response to these shortcomings. The energy supply scenarios and projected petroleum shortfalls which give rise to increased reliance on the consumption of electricity (which lead to the focus on nuclear power and the concept of FNPs) also lead one to other new uses of the CR and OCS related to energy resources.

The inadequacy of currently developed domestic energy resources has placed increasing dependence on foreign sources, increased fuel prices rapidly, raised serious questions about international balances of payments, focused attention on alternative energy sources and recovery or conversion technologies, and may seriously constrain U.S. and world economic growth. Because of the need to develop new energy sources, both the CR and OCS will be more involved than before in energy-related activities -- not only in extraction of oil and gas located there but also in transportation, storage, and processing of offshore and imported oil and gas.

Without exception the major conflict between FNPs and these other uses is the possibility of an accident that would endanger the safe operation of the FNPs. The safety of the FNP is based upon adequate design against potential accidents internal to itself, engineered safety features against reasonable and unavoidable external threats, and site selection to minimize external threats. As discussed in Chapter IV, the major external threats presented by these uses are collision of a vessel with the breakwater or FNP, exposure of the FNP to corrosive materials, or exposure of the FNP to fires and/or explosions.

Another possible interaction between FNPs and other uses associated with energy-related resources should be mentioned. Extraction, transportation, storage, and processing of oil and gas are energy consumptive. Depending on supply and demand, cost, etc. of alternative energy sources, the FNP's electric energy may invite these operations to locate nearby. For example, refineries and petrochemical plants are intensive consumers of electrical energy, and the electricity provided by the FNP may prove attractive to them (see Chapter VI).

Thus, on the one hand, the external threats presented by possible accidents resulting from other uses indicate that these uses should be excluded from the proximity of the FNP; yet the electricity generated by the FNP may attract these uses. This is obviously an oversimplification, but similar issues underlie decisions to deploy FNPs.

Extraction of Oil and Gas

One of several alternatives that could partially alleviate the energy supply/demand imbalance is developing OCS oil and gas resources. In consultation with the U.S. Geological Survey and other Federal agencies, CEQ identified several hypothetical oil and gas accumulations on the Atlantic OCS.[1/] They are areas where available geological data indicate favorable potential for oil and gas accumulation (see Figure VII-1). Precise identification of oil and gas

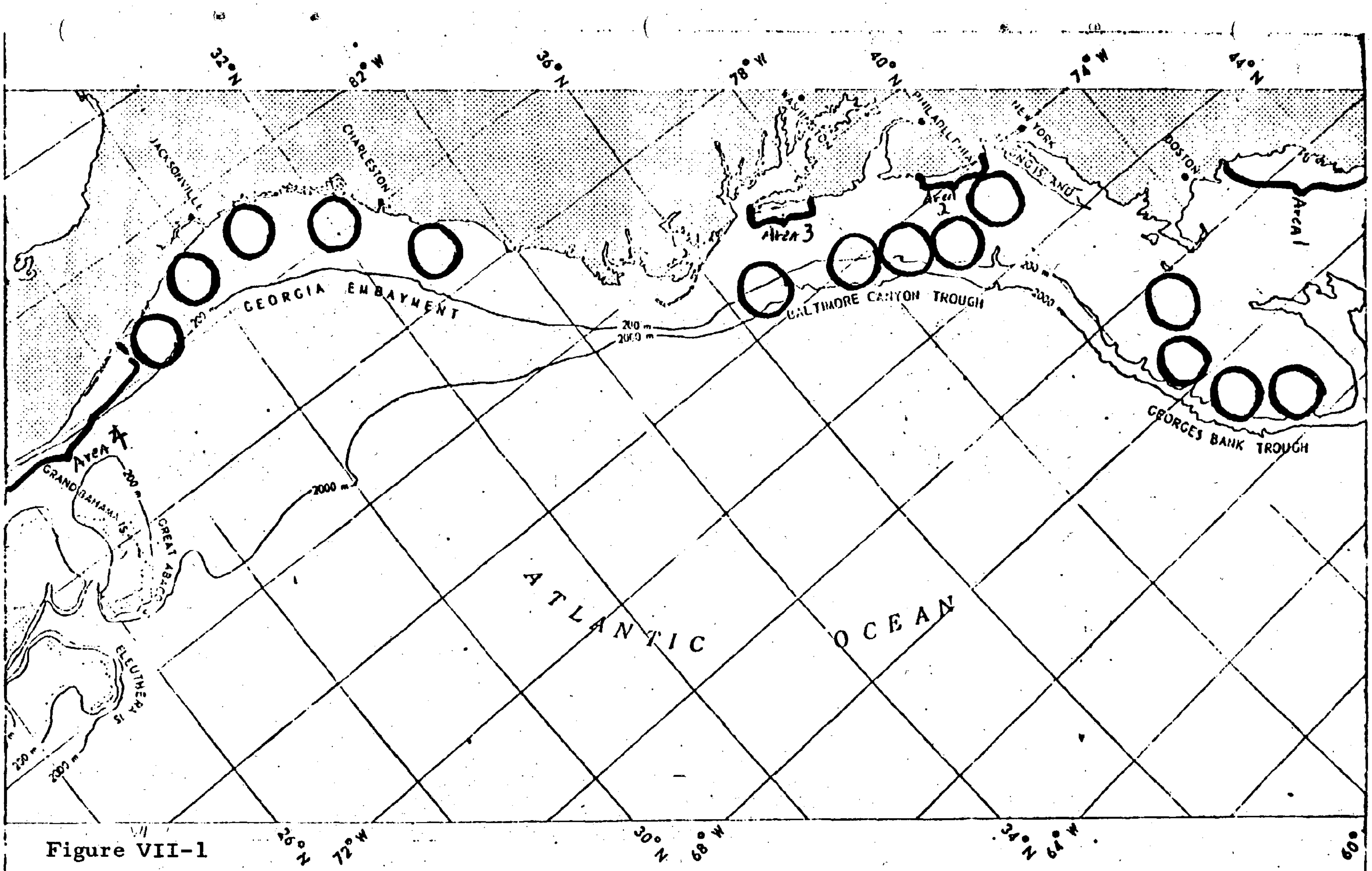

Figure VII-1

U.S. ATLANTIC OCS

HYPOTHETICAL LOCATIONS OF POSSIBLE OIL AND GAS ACCUMULATIONS

accumulations depends upon the results of future geological reconnaissance and exploration. Here, these hypothetical locations are used to illustrate possible interactions between FNPs and development of OCS oil and gas resources. The four east coast areas that have been identified as candidates for early deployment of FNPs are also indicated on Figure VII-1.

Although the exact locations of oil and gas resources are not currently known, the geologic structures off the central and northern Atlantic coasts suggest that drilling will be in water at least 150-200 feet deep. Because the reasonable water depth for initial deployment of the FNPs ranges from 45 to 75 feet (see Appendix A) and because the continental shelf slopes gradually in these regions (see Appendix C), it may be seen from Figure VII-1 that FNPs deployed in areas 1, 2, or 3 would not be directly challenged by drilling or extraction activities on the central or northern Atlantic OCS -- a conclusion based upon the assumption that massive accidental oil spills will not reach the FNP areas.[2/]

Area 4, however, is much nearer the possible oil and gas resources than the other three areas. But because of depth and distance and because of the uncertainties in the projected FNP deployment areas and the oil and gas resource locations, even in area 4 the conflict between drilling and extraction activities and the FNPs is not considered significant. However, for all decisions involving specific FNP deployment and OCS oil and gas development, the potential conflict must be assessed.

Drilling and extraction present another possible conflict. Vessel traffic to provide supplies, personnel, etc. must be considered in the same light as other shipping activity. As mentioned in Chapter IV, FNP siting must be such that the possibility of ships colliding with the breakwater is at an acceptable level. Although the added traffic resulting from these oil and gas development activities should not present a significant conflict with deployment of FNPs, it too must be considered when specific siting decisions are made. A more significant conflict between FNP deployment and OCS oil and gas transport requirements arises in moving the resources to shore.

Transportation of Oil and Gas

One way to balance U.S. energy supply and demand is to increase the volume from outside the continental United States. Whether it comes from the outer continental shelf or is imported from foreign countries, it passes through our coastal waters by pipeline or tanker. This passage may conflict with the deployment of FNPs. Again the extent of this conflict depends upon the possibility of an accidental oil or gas spill, which in turn is a function of the type, design, etc. of the transport media, proximity to the FNPs, meteorological and oceanographic conditions, and so forth.

OCS Development. Currently, the movement of oil or gas by submerged pipeline is not an issue with the four candidate FNP areas. However, the development of OCS oil and gas or construction of an offshore port could present a conflict. The proximity of some of the hypothetical OCS development sites to the candidate FNP areas may create a pipeline or tanker routing conflict. The CEQ study selected -- for analytical purposes only -- four potential onshore development areas to serve Atlantic OCS operations: Bristol County, Mass.; Cumberland/Cape May Counties, N.J.: Charleston, S.C.: and Jacksonville, Fla.[3] If the OCS oil and gas went ashore in these areas, the potential conflict between their transport and an FNP seems more likely in areas 2 and 3. However, until the location of OCS oil and gas is known and more thought is given to transportation, onshore processing, and the deployment of FNPs, etc., there may be conflicts in other areas, or there may be no conflicts at all.[4]

The mode of transport is most likely an economic decision based upon resource location and destination, size of field, and other factors. The oil or gas from several locations within a field would first be gathered and then transported via a pipeline corridor or tanker. If tankers are used, they are likely to have a draft of less than 45 feet (based on the economics of storage and transport). These two observations are particularly relevant to possible conflicts with FNPs.

The pipeline corridor would conflict less than individual pipelines with FNPs. Further, the probability of a ship damaging the pipeline and releasing its contents can be minimized by careful selection of pipeline corridors. But if there is a siting conflict, it will be more severe because of the larger volume and rate of flow of the oil or gas through the corridor.

If small (<45-foot draft) tankers are used, they may operate in the same depths at which the FNPs will be deployed (45-75 feet). Moreover, with small tankers more trips (or more tankers) will be necessary. These two factors enhance the likelihood of an accidental oil or gas spill. On the other hand, with their smaller loads, these tankers may spill less per accident.

Deepwater Ports. CEQ identified three Atlantic coast deepwater port locations for analytical purposes: Boston, Mass.; Cape Henlopen, Del.; and Morehead City, N.C.[5] If any were in fact a superport location, there is little anticipated conflict between them and the candidate FNP areas. But possible conflicts cannot be summarily dismissed.

Deepwater ports would be situated in water depths exceeding 90-100 feet in order to accommodate the very large ships. Further, consideration of potential oil spills suggest that deepwater ports will be sited farther offshore than the initial deployment of FNPs. The deepwater ports would seem to present little challenge to the FNP directly or by collision with the breakwater of vessels carrying hazardous cargo destined for the deepwater ports. The major challenge of deepwater ports is, as for OCS development, transporting the oil and gas to shore.

Should deepwater port and OCS development take place at the same time, it is unclear whether the FNP would be more seriously challenged. There may be a need for greater "transportation" corridors in the OCS and CR with deepwater ports and OCS development. Whether or not this seriously threatens FNP deployment clearly depends on the extent to which they vie for the same areas. Perhaps all the pipelines can utilize the same transportation corridors. Moreover, harbor access time, unloading delays, etc. may attract OCS tankers to offload at the deepwater ports. In this event OCS tanker traffic in the vicinity of FNPs could be decreased. These are issues that can better be resolved in individual siting decisions.

Storage of Oil and Gas

How much the storage of oil and gas threatens the safe operation of FNPs is a function of distance from the storage area to the FNP, the likelihood of a storage accident, and the mechanisms (air movements, currents, etc.) by which spilled resources could reach the FNP. These factors can perhaps best be considered as follows.

It is unlikely that existing facilities would be expanded if doing so would significantly increase the risk to public health and safety or to the environment. Thus, if an FNP location were compatible with an existing storage facility, it would probably be compatible with an expanded facility. With the concern for land use and the ecology of the coastal zone, wetlands, etc. in the FNP candidate areas, it is unlikely that new facilities would be permitted if the risk to the environment were unacceptable.[6/] Oil spilled from an onshore facility may generally be directed onshore. In general, one might accept the storage facility in a coastal region if the mode of transportation to the storage facility presented an acceptable challenge. Although these issues are here treated cursorily, for each siting decision they must be considered in sufficient detail to ensure that the impacts are anticipated and are acceptable.

A secondary effect of storage must be considered a source of possible conflict with FNPs. FNP siting decisions take into account the populations that might be exposed in the event of accidental release of radioactive materials.[7/] New or expanded storage facilities could induce industrial (and commerical and residential) growth in an area, and the changed population distributions could result in unacceptable exposure[8/] in the event of an accident at an FNP that had been located nearby prior to the growth. As mentioned earlier, the availability of the FNP-produced electric energy may even contribute to this growth.

Processing Oil and Gas

For OCS development, deepwater ports, and storage, accidental spills are the major potential conflict with FNP deployment. This is again important in processing oil and gas, but of growing concern are the possible changes in population distribution resulting from use of the CR for processing oil and gas. These new population distributions could render the possible cumulative exposure of the regional population in the event of an accidental radioactive release to a level unacceptable to the AEC. Clearly the concern is with expansion or with new facilities in the area, not the substitution of incoming resources for resources already processed there, for if an FNP location were acceptable for the resources being processed, it is likely to be acceptable for new resource processing. A substitution is not likely to incur significant population redistributions.

Further, any induced growth may enhance competition of other uses for the OCS or CR. In particular, pressure for recreational and commercial development may increase.

USES RELATED TO OUTDOOR RECREATION

People are turning to the outdoors for recreation, relaxation, and rewarding use of their leisure time in increasing numbers each year. In its recent publication, Outdoor Recreation Trends,[9/] the Bureau of Outdoor Recreation indicates that by the year 2000, participation in the 16 major forms of summer outdoor recreation activities will quadruple over what it was in 1960. This figure converts to 16.8 billion recreation activity occasions in the United States by the turn of the century.

Aside from its aesthetic values, water is essential to outdoor recreation. Of the 16 major summer outdoor recreation activities identified by the Bureau, 4 are wholly dependent on water: swimming, fishing, boating, and water skiing. Six others are frequently associated directly or indirectly with water: walking for pleasure, driving for pleasure, picnicking, nature walks, camping, and hiking. Large numbers of people are involved in these activities. For example, in 1965, 48 percent of our population 12 years of age or older went swimming, 30 percent fished, 30 percent enjoyed boating (including canoeing and sailing), and 6 percent participated in water skiing.

The consensus is that pressures for water-associated recreation activities can only grow. Current projections indicate that by the turn of the century, swimming activities will increase 207 percent, boating about 215 percent, water skiing almost 365 percent, and fishing nearly 80 percent.[10/] Each of the six activities mentioned earlier which are frequently associated with water will increase by at least 125 percent. All of this adds up to even more severe pressures for water-based and water-associated recreation activities in the future.

From a national standpoint, public (owned by Federal, state, and local governments) recreation areas and facilities are a relatively small proportion of the total land bordering the coasts, Great Lakes, and rivers on which there is navigation. The balance is privately owned. Some is developed for public recreation use. Most of it may not be developed specifically for recreation, but it has recreation potential.

Table VII-1 shows how much of the U.S. shoreline was in outdoor recreation in 1973. Literally, the entire three coasts of the United States, all the Great Lakes shoreline, and a sizable percentage of our river and tributary stream banks are actual or potential recreational areas of great value -- a value that will undoubtedly increase in the years ahead.

Recreational Activities in the FNP Candidate Areas[11/]

Portsmouth, N.H., to Canada. The major recreational resources are listed in Table VII-2. In the south the ever increasing demands for more public beaches are expected to cause development of publicly owned shorefront through beach widening and raising. Residential development will continue to expand throughout the entire southern region. More attractive motel complexes will be built to satisfy an increasing tourist and summer population. In the northern section the state and towns will continue to develop parks and scenic viewing points. The many natural embayments will be provided with facilities for growing recreational boating use.

Sandy Hook, N.J., to Cape May, N.J. The major recreational resources are listed in Table VII-3. In the southern reach the shoreline is mostly long, sandy barrier islands separated from the mainland by tidal marshes, bays, creeks, and lagoons. Most of the habitable land has been developed, primarily for recreation. The shoreline of Reach 11 is 240 miles long, about 35 miles in

Shoreline Ownership and Use
(in miles)

	OWNERSHIP				OUTDOOR USE			
					Recreation			
Region	Federal Government	State & Local Government	Private	Uncertain	Public	Private	Nonrec. Development	Un-developed
North Atlantic	580	840	7,200	0	1,020	2,600	2,430	2,570
South Atlantic Gulf	1,870	1,960	8,250	2,540	690	1,500	2,440	9,990
Lower Mississippi	240	330	1,370	0	20	30	50	1,840
Texas Gulf	390	50	2,060	0	400	160	110	1,830
Great Lakes	130	520	3,030	0	370	1,220	250	1,840
Calif.	380	350	1,080	0	440	190	230	950
North Pacific	240	270	2,310	20	350	120	190	2,180
Alaska	41,350	5,500	450	0	10	0	330	46,960
Hawaii	110	260	560	0	90	0	200	640
Total	45,290	10,080	26,310	2,560	3,390	5,820	6,230	68,800

Source: National Shoreline Study, Report of the Chief of Engineers, Department of the Army, Washington, D.C., 1973, pg. 46, Vol. 1.

Table VII-2

Recreational Resources from Portsmouth, N.H., to Canada

Section	Description	Shore ownership (miles)	Shore use (miles)
N.H. state line to Kennebec River, Me.	Two state parks Crescent State Beach and Popham State Park); other publicly owned beaches are Oganquit Wells, Kennebunkport, and Old Orchard. Beaches are heavily used throughout the entire reach of shore.	10 Federal 50 Other public 540 Private 600 Total	8 Public rec. 522 Private rec. 10 Nonrec. 60 Undeveloped 600 Total
Kennebec River, Me., to Canada.	Essentially no public beaches. The coast is nationally known for scenic qualities. Acadia National Park is Federal Property.	10 Federal 10 Other public 1,880 Private 1,900 Total	5 Public rec. 445 Private rec. 1,200 undeveloped 250 Nonrec. 1,900 Total

Source: National Shoreline Study, Regional Inventory Report
US Army Engineer Division, Corps of Engineers

Table VII-1

Recreational Resources from Cape May, N.J., to Sandy Hook, N.J.

Section	Reach	Annual Attendance	Shore ownership (miles)	Shore use (miles)
Cape May to Manasquan	10	52,500,000	8 Federal 66 Public 23 Private 97 Total	88 Public rec. 0 Private rec. 0 Nonrec. 9 Undeveloped 97 Total
Bays and Lagoons Cape May to Manasquan	11	Not available	30 Federal 27 Public 183 Private 240 Total	119 Public rec. 23 Private rec. 1 Nonrec. 97 Undeveloped 240 Total
Manasquan to Sandy Hook	12	6,940,000	6 Federal 11 Public 10 Private 27 Total	14 Public rec. 10 Private rec. 0 Nonrec. 3 Undeveloped 27 Total
Raritan Bay and Sandy Hook	13	Not available	0 Federal 7 Public 13 Private 20 Total	8 Public rec. 2 Private rec. 9 Nonrec. 1 Undeveloped 20 Total

Source: National Shoreline Study, Regional Inventory Report
US Army Engineer Division, Corps of Engineers.

sandy beaches. Most of the development is related to recreational boating. Reach 12 is highly developed for both recreation and residences, which are generally high cost ocean front. The northern reach is primarily residential and recreational, with important recreational boating. Here is a section of the newly created Gateway National Recreational Area.

Chincoteague, Va., to Cape Charles, Va. The major recreational resources are listed in Table VII-4. This region is characterized by a number of barrier and interior islands. The barrier islands alone account for 126 miles of shoreline between Cape Charles and the Maryland/Virginia border. Of this, the sandy windward shores measure 62 miles and the marshy leeward shores measure 64 miles. The area is very important in the lives of migratory waterfowl and sea birds because of the numerous islands and interwoven marshes and the local climate.

Cape Kennedy, Fla., and South. The major recreational resources are listed in Table VII-5. This region is characterized by heavy recreational and recreational-based residential and commercial development. As the winter playground of a large U.S. population and as a retirement area, it is heavily developed in recreational economies.

Possible Interactions of FNPs and Recreational Uses

Recreation in the coastal regions is obviously closely tied to their natural resources. Fishing, hunting, clamming, and scuba diving, for example, are all directly related to the biological populations of a given region. Thus, the effects of FNPs and associated activities on the environment directly affect the recreational uses of that environment. But effects on recreation are not all direct, for people often base their decisions on factors other than facts. If an individual believes that an FNP contaminates the surrounding biota, he will modify his use of the area, even though no contamination has resulted. It is the users' concept that is important -- not just the real interactions.

Given an accidental release of contaminants, it would be difficult to isolate the exposed organisms because many ocean biota are very mobile and are often migratory. This mobility added to the caution of individuals may result in avoidance of large segments of the water volume and biological inventory if an accident is suspected. Any attempt to analyze the effects of an FNP on recreation, then, becomes quite difficult.

Table VII-4

Recreational Resources from Chincoteague, Va., to Cape Charles, Va.*

Section	Description	Shore ownership (miles)	Shore use (miles)
Chincoteague to Cape Charles	113 miles of Atlantic coast with Assateague National Seashore at the northern end.	30 Federal 32 Public 302 Private 364 Total	2 Public rec. 20 Private rec. 30 Nonrec. 312 Undeveloped 364 Total

* Including the Chesapeake Bay shoreline of Virginia

Source: National Shoreline Study, Regional Inventory Report
US Army Engineer Division, Corps of Engineers

Table VII-5
Recreational Resources for Cape Kennedy, Florida and South*
(In miles)

County	Description		Shore Ownership			Shore Use			
	Shore Length	Beach	Federal	Non-Federal Public	Private	Public Recreation	Private Recreation	Nonrecreation	Undeveloped
Brevard									
Ocean	72.0	72.0	36.2	1.9	33.9	35.8	------	36.2	------
Bays and estuaries	243.0	------	80.0	2.0	161.0	------	------	221.0	22.0
Subtotal	315.0	72.0	116.2	3.9	194.9	35.8	------	256.2	22.0
Indian River									
Ocean	22.0	22.0	------	2.3	19.7	0.5	21.5	------	------
Bays and estuaries	71.0	------	------	------	71.0	------	------	6.0	65.0
Subtotal	93.0	22.0	------	2.3	90.7	0.5	21.5	6.0	65.0
St. Lucie									
Ocean	22.0	22.0	------	1.2	20.8	20.0	2.0	------	------
Bays and estuaries	89.0	------	1.0	6.0	82.0	4.0	2.0	14.0	69.0
Subtotal	110.0	22.0	1.0	7.2	102.8	24.0	4.0	14.0	69.0
Martin									
Ocean	21.0	21.0	------	0.8	20.2	0.8	20.2	------	------
Bays and estuaries	81.0	------	------	------	81.0	------	------	25.0	56.0
	102.0	21.0	------	0.8	101.2	0.8	20.2	25.0	56.0
Palm Beach									
Ocean	44.9	44.9	------	3.6	41.3	3.6	41.3	------	------
Bays and estuaries	127.0	------	------	------	127.0	------	------	81.0	46.0
Subtotal	171.9	44.9	------	3.6	168.3	3.6	41.3	81.0	46.0
Broward									
Ocean	24.0	24.0	0.2	8.2	15.6	8.2	15.3	0.2	0.3
Bays and estuaries	69.0	------	------	1.0	68.0	1.0	------	63.0	5.0
Subtotal	93.0	24.0	0.2	9.2	83.6	9.2	15.3	63.2	5.3
Dade									
Ocean	34.8	34.8	0.1	7.6	27.1	7.6	11.1	0.1	16.0
Bays and estuaries	104.2	2.2	0.1	14.5	89.6	14.5	1.0	36.0	52.7
Subtotal	139.0	37.0	0.2	22.1	116.7	22.1	12.1	36.1	68.7
Total									
Ocean	240.7	240.7	36.5	25.6	178.6	76.5	111.4	36.5	16.3
Bays and estuaries	784.2	2.2	81.1	23.5	679.6	19.5	3.0	446.0	315.7
GRAND TOTAL	1,024.9	242.9	117.6	49.1	858.2	96.0	114.4	482.5	320.0

Source: National Shoreline Study, Regional Inventory Report
US Army Engineer Division, Corps of Engineers

*[illegible]

Based on Chapter V discussions, some possible interactions of the FNP and recreation are:

- The thermal effluents during normal operations provide a volume of water at higher temperature than the surrounding ocean. This could attract all forms of marine life, even sharks and other predators, thus precluding other water activities.
- The breakwater, acting as an artificial reef, will concentrate the local biomass, thus enhancing fishing opportunities.
- Possible accidental or chronic kills of marine organisms could provide "spectacular" evidence of adverse environmental effects which, if they occurred during the peak recreational season, may seriously affect the local economy.
- Some seasonal residents and weekend visitors may prefer to avoid the FNP area due to suspected radiation hazards. This effect is likely to be more pronounced in the early stages of operation when the populace is not fully knowledgeable about potential radiation exposure. It may be severe in shore communities that depend on summer visitors.
- But others may visit the shore communities in the vicinity of the FNP because the FNP is there. Some communities may benefit from special tourist trade based on sightseeing trips around the FNP.
- Recreational boating may be curtailed in the vicinity of the FNP.

Within a 10 mile radius of the proposed PSE&G FNP facility, there are 58 marinas and approximately 6,283 boats.[12/] More than 13,500 boats are berthed within 30 miles.[13/] Although the currently planned exclusion zone of the plant is only 0.4 miles, recreational boating may be further constrained to assure the safety of the FNP and the boats. This could have a significant effect if recreation boating were excluded from the area around the breakwater -- where the biota is concentrated. Similarly, recreational flying may not be permitted within some distance of the FNP.

As recreational development will vary throughout the four areas candidate for FNP deployment, so too will the possible effects of the FNP on recreational activity. Though the actual effects are not known, it is clear they can be significant. Appendix F illustrates the possible impact of FNPs on the recreational economy of one FNP candidate area in Atlantic and Cape May counties in New Jersey, a major summer resort area. It is clear for that area that even a small change (positive or negative) in the recreational economy will result in a larger change for the economy of the region. This arises from the rather large income multiplier ($\sim$3.0) for the region. Thus for every dollar change in basic earnings (e.g., recreational income), there will be a $2.06 charge in supporting income flows. Further, the range of income multipliers for the other three FNP candidate areas ranges from 2.16 for the sparsely developed region from Chincotegue to Cape Charles, Va., to 3.05 for Portsmouth, N.H. north.

USES RELATED TO COMMERCIAL DEVELOPMENT

Of major concern are commercial development to support oil and gas processing, commercial development to support recreation coastal transportation, offshore mining, and commercial fishing.

Coastal Transportation

As in any industrialized nation, transportation systems in the United States are an important component of the economy. As shown in Table VII-5, the total transportation industry contribution to the GNP decreased from 5.9 percent to 4.0 percent in the last quarter century, and water transportation rose by only 5 percent, from $2.0 to $2.1 billion (in constant 1958 dollars). Yet it is clear that in spite of these relatively small contributions to the GNP, a significant decrease in transportation industry activities would have a serious effect on the national economy. Moreover, it is vital to the U.S. commitment "to a continued expansion of world trade,"[14] that coastal transportation commerce not be unduly restricted by future action.

That the FNP may possibly conflict with coastal transportation must be considered in terms of safety. Key to interference is the cargo that is shipped.

Table VII-6

Transportation Industry - Economic Data Estimates

Year	GNP in (billions) current dollars	GNP in (billions) 1958 dollars	Total Transportation: Percentage GNP current dollars	Total Transportation: Percentage GNP 1958 dollars	Total Transportation: Expenditures in (billions) current dollars	Total Transportation: Expenditures in (billions) 1958 dollars	Water Transportation[1/]: Percentage GNP current dollars	Water Transportation[1/]: Percentage GNP 1958 dollars	Water Transportation[1/]: Expenditures in (billions) current dollars	Water Transportation[1/]: Expenditures in (billions) 1958 dollars
1947	231.3	309.9	5.9	6.8	13.6	21.1	0.5	0.6	1.1	2.00
1960	503.7	487.7	4.5	4.6	22.5	22.5	0.4	0.4	1.8	1.7
1972	1155.2	790.7	4.0	4.6	45.8	36.1	0.25	0.27	2.8	2.1

1/ Including allied services: maintenance, stevedoring, etc.

Source: Data prepared by the Bureau of Economic Analysis, U.S. Department of Commerce from unpublished materials available in the Regional Economic Information System.

Hazardous Materials. For this discussion, hazardous materials is generally defined as materials that would significantly threaten an FNP by fire, explosion, toxicity to personnel, or corrosion if deposited in the vicinity. Natural gas, crude oil, many petroleum products, concentrated acids, munitions, and numerous chemicals would fall in this category.[15/] As discussed earlier in the chapter regarding transportation of oil and gas, hazardous materials must be kept sufficiently remote from FNPs so that any threat is at an acceptable level. Further, the FNP must be so located that it does not interfere with the transport of hazardous materials, quite separate of their threat to FNP operations.

Nonhazardous Materials. For coastal transportation of nonhazardous cargo, the major concerns are loss of life and property resulting from vessels' colliding with the breakwater and the breakwater's inability to protect the FNPs after the collision. Because the breakwater is designed to protect the FNP from ship collisions, a collision is likely to damage the vessel seriously and could significantly lessen the breakwater's capability to protect the FNP against further ship collisions or weather. (Particularly if a large vessel running out of control in very heavy seas were involved in a high speed collision with the breakwater.) Additionally, even vessels carrying non-hazardous cargo carry fuel which could be released as a result of a collision and present a threat to the FNPs.

Vessel Traffic. An important consideration in decisions on FNP deployment is the number of ships to be expected in the area.

Table VII-7 lists the coastal tanker traffic for the candidate FNP areas for 1970. The densities apply to coastal tank ships that pass the locations en route to onloading or offloading ports. It should be noted that there could be a range of distances offshore that the tankers use when passing these locations. Off the east coast of Florida, however, because of the strong northerly current not far offshore (see Appendix C), northbound ships tend to move in this current and southbound ships to stay out of it (shoreward of it). Representative of the coastal traffic in this east coast of Florida is the illustration of ratio of passage presented in Figure VII-2.

Table VII-7 1970 U.S. Coastwise Tank Ship Traffic Density

	Location	Tanker Density [1]
1	East Coast of Florida	45 Tankships/Day
2	Chincoteaque to Cape Charles	30 Tankships/Day
3	Atlantic City, N.J. to Sand Hook, N.J.	32 Tankships/Day
4	Portsmouth, N.H. and North	4 Tankships/Day

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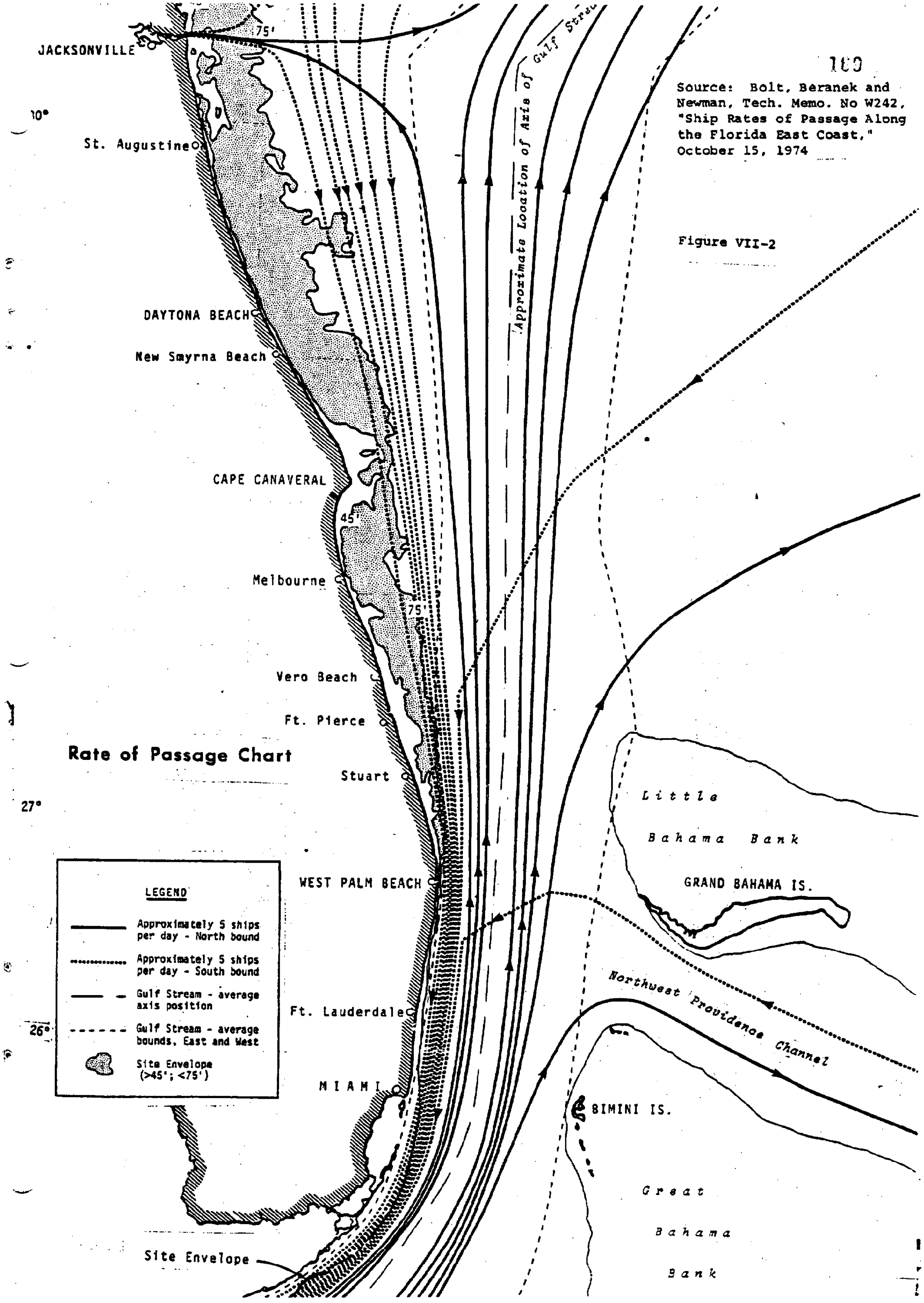
[1] Traffic density includes traffic in both directions--for one way traffic halve the density figures.

Source: All information extracted and extrapolated from Analysis of the Coastal Tank Vessel and Barge Traffic -- Design and Development of System Alternatives to Identify and Locate Ballast Tank Vessels and Barges Report DOT-CG-23560-A prepared for Commandant (GWEP) April 1973.

Source: Bolt, Beranek and Newman, Tech. Memo. No W242, "Ship Rates of Passage Along the Florida East Coast," October 15, 1974

Figure VII-2



Rate of Passage Chart

Offshore Mining

Sand and gravel have been taken from the continental shelf for a number of years, and mining manganese nodules and crusts is about to begin. The effects of this ocean mining on nuclear powerplant decisions will differ with the location of the mineral deposits.

Sand and Gravel. Sand and gravel deposits of commercial thickness (some are 200 feet thick) and quality are common along the Atlantic Shelf. Although in this country the deposits are large, the sand and gravel industry is having difficulty finding new deposits near markets that permit high production rates at reasonable prices. For this reason as well as growing public concern over the environmental aspects of sandpits, the industry is interested in continental shelf deposits.[16]

Mining continental shelf sand and gravel may conflict with FNP location. In the discussion here it is assumed that mining technology will be similar to what the industry is employing in the United Kingdom, as described below.

> Some dredges recover material from a single point while at anchor. This results in the creation of a pit 10 or more feet deep initially, and finally, a pockmarked deposit. Other dredges recover material while drifting at anchor with the changing tidal current. This results in the creation of a crescent-shaped trench about two to three feet deep. Eventually the deposit becomes laced with these trenches. Other dredges recover material while drifting unanchored. This results in numerous shallow trenches, each about one foot in depth.
>
> Most UK dredging operations are governed by the tides, operating on a 24-hour cycle whereby the dredges take advantage of high tides for leaving and returning to normally shallow-water cargo discharge points in estuaries or rivers. Generally, a dredge leaves port at the start of ebb tide, steams to its lease area, fills its hopper in a matter of one to three hours, returns on the flood tide, discharges in one or two hours, and again leaves for sea. If the draft of the dredge is not a critical factor, and the lease area not too far away -- 80 miles is not uncommon -- the cycle may then occupy less than 24 hours. The majority of deposits worked in the UK are relatively short (1 to 20 miles), comparatively close to market, generally in 60 to 100 feet of water, and from 3 to 30 feet thick.

> Sand and gravel is economically mined from the sea floor in several ways: clam-shell barge; bucket-ladder dredge; suction dredge; and, steam shovel barge. The clam-shell technique is gradually phasing out as uneconomic, except in certain deep water glacial lakes such as are found in Switzerland.
>
> Except for a few old barge-mounted clam-shells, the UK marine mining fleet is made up of suction hopper dredges. Cargo capacities of the dredges range from about 500 to about 10,000 tons. The trend is toward larger and larger dredges to reduce the cost per unit of material dredged. Recovery of sand and gravel is done by use of high-capacity pumps which suck up the materials from the sea floor (up to about 100 feet beneath the ocean surface) through a large pipe. The slurry, about 10 percent solids, is fed to the hopper where most of the solids remain. The excess water weirs overboard, along with the fine particles trapped in suspension.[17]

Possible conflicts between FNP development and offshore sand and gravel mining are evident from both operations at the mining sites and transport of the materials to port, depending on the proximity of these activities to the FNPs.

Operations concerns are possible interference with submerged cables and with FNP operations and, to a lesser extent, possible contamination of the sand and gravel deposits caused by FNP operations or accidents. Materials in suspension from dredge mining could accelerate erosion of the secondary cooling system, resulting in abnormal chemical releases (see Chapter V); accelerate maintenance dredging of the materials deposited in the FNP basin to assure safe operation of the FNP; compound environmental effects resulting from the once-through cooling system (see Chapter V) as the suspended materials interact with the mechanical and thermal loads on the environment; etc. Radioactive contamination of the sand and gravel could render them unacceptable (see Chapter IV for discussion of design to minimize this possibility).

Any transportation problems are the same as for other nonhazardous materials. Should the phosphorite deposits in these regions be developed, the effects would be similar to those of sand and gravel mining.

Manganese Nodules and Crusts. Existence of manganese nodule deposits on the Atlantic continental margin have been known for many years. Although nodules occur in some freshwater lakes and in some shelf areas, the highest quality are in the deep ocean (5,000 to 6,000 meters) over areas measured in millions of square miles.

Knowledge of the nodules may be traced back to 1875, when they were found at many stations of the Challenger expedition. The current economic attraction is their relatively high concentration of copper, nickel, manganese, and cobalt.

The following describes how the manganese may be mined:

> Three main types of mining systems are proposed: hydraulic, air lift and continuous line bucket (CLB). In the first two types, vertical transport is accomplished by hydraulic or air-lift pumping and the nodules and sediments as well as bottom water are forced to the surface through a pipe lowered from the mining ship to the sea floor. The nodules are then separated from the entrained sediment and bottom water, which can be discharged either at the surface or at some intermediary level in the water column (such as a platform rigidly suspended beneath the mining ship).
>
> The CLB dredge system consists of a continuous line which travels from the bow of the ship down to the bottom -- along the bottom -- and then up to the stern of the ship and back down again. Large, open mesh buckets are attached to this line at regular intervals. As the rope is circulated, the buckets descend, scrape the ocean bottom and then ascend to the ship where they are unloaded and lowered again. This system is designed to bring only nodules to the surface, but in practice some benthos and sediment will also be transported and washed out throughout the water column.
>
> In all systems, probably 3 to 4 tons of sedimentary material will be stirred up and resuspended by the collection devices -- mostly in the lower water column -- for every ton of nodules recovered.[18/]

Because the most attractive nodule deposits are distant from the FNP candidate areas, there will probably be no interaction between FNP operations and the mining. Any possible conflict arises from the transport of these nonhazardous materials to shore.

Commercial Fishing

Perhaps one of the oldest users of all coastal regions and the shelf is the commercial fishing industry. An indication of the size of this industry is total catch. All countries took 500,000 metric tons of finfish from the Atlantic from Cape Hatteras to the Bay of Fundy in 1960 and over 1,500,000 metric tons in 1972.[19/] In addition, 217 million fish were landed by sports fishermen in the Atlantic Ocean (35.3 million in the North Atlantic, 69.5 million in the Middle Atlantic, and 112.2 million in the South Atlantic).[20/]

Conflicts between FNP and fishing obviously depend on how far apart they are. The FNPs such as proposed by OPS are likely to be in depths of 45 to 75 feet and within 12 miles of shore. Most sport fishing is within a few miles of shore.

Further, nearly one-half the value of the U.S. commercial fish catch off the Atlantic, Gulf, and Pacific coasts was within 12 miles of shore in 1972. Tables VII-8 and VII-9 present some details on Atlantic and sport fishing.

Fishing activities remote from the FNP present a possible conflict only on their way through the FNP area. Comments on transportation are apropos here. On the other hand, the FNP may conflict with both commercial and sport fishing because many species could be exposed to the environmental challenges discussed in Chapter V. Further, their mobility and the ocean transport mechanisms are such that in case of significant contamination, the fishing activities over a much larger area than that of the FNP could be affected.

If FNPs are located in areas that do not support fishing activities, their structures and effluents may tend to concentrate the local biomass, thus stimulating local fishing activities and increasing traffic in the vicinity. The concerns, there, are those for nonhazardous cargo transport.

The numerous species which are currently not commercially significant but whose abundance and characteristics are such that they represent potential commercial value, must also be considered in FNP decisions.

Summary

The extent and severity of potential conflicts between FNPs and several other uses of the coastal area and shelf vary considerably. It is reasonable to assume that careful consideration of and accommodation to possible interactions would permit several uses simultaneously without interference. Further, if the competition among uses is low intensity (either because development of the use is low intensity or the high-intensity development is spaced geographically), then mutual development of several uses appears compatible. Yet the areas that are attractive for some uses also have high potential for other uses -- for example, the New Jersey coastal region and outer continental shelf have been identified for a nuclear powerplant, for oil and gas, for a deepwater port, all this where recreation, transportation, and commercial fishing are heavy. If some or all of these uses are developed to a large extent, competition and potential hazards could be unacceptable.

Table VII-8. Value of Commercial Species Caught 0-12 Miles from Shore Atlantic (millions of dollars)

pecies Group 1/	New England	Middle Atlantic	SE Atlantic	Total
	Region			
hrimp (pandalid)	2.8			2.8
od	2.6			2.6
ea Herring	2.2			2.2
ea Scallop	2.0			2.0
obster	24.4	1.2		25.6
inter flounder	3.5	0.1		3.6
hiting	1.1	0.3		1.4
ummer flounder	0.1	1.3		1.4
ard clams	1.8	16.1	0.3	18.2
triped bass	0.2	1.9	0.4	2.5
tlantic menhaden	0.4	11.2	1.5	13.1
urf clam		2.8		2.8
ea trout		1.0	0.4	1.4
lounder			1.5	1.5
hrimp (penaeid)			18.3	18.3
UBTOTAL	41.1	35.9	22.4	99.4
thers	5.1	5.5	9.0	19.5
OTAL	46.2	41.4	31.4	119.0

1/ Species groups with landed values greater than $1 million are listed separately. Species restricted to estuaries and bays are not included.

ource: Unpublished statistics assembled by the National Marine Fisheries Service

Table VII-9. Saltwater Angler Catch -- 1970 Atlantic (millions of fish)

Species Group 1/	New England	Middle Atlantic	SE Atlantic	Total
	Region			
Winter flounder	21.6	7.5		29.1
Atlantic mackerel	33.6	18.4		52.0
Weakfish	0.7	9.4		10.1
Summer flounder	8.5	4.2	3.7	16.4
Puffers	11.0	27.6	9.1	47.7
Striped bass	43.3	9.8	0.1	14.2
Bluefish	10.7	12.3	12.9	35.9
Sea basses	0.3	3.8	7.2	11.3
Kingfishers	2.7	1.9	15.0	19.6
Porgies	2.9	1.2	16.2	20.3
Perches		15.1	0.4	15.5
Spot		33.0	12.1	45.1
Croakers		4.6	8.5	13.1
Catfish		2.4	11.2	13.6
Grunts			21.8	21.8
Yellowtail snapper			10.8	10.8
SUBTOTAL	96.3	151.2	129.0	376.5
Others	20.7	17.0	55.2	92.9
TOTAL	117.0	168.2	184.2	469.4

Species groups with catches of over 1 million fish are listed separately.

Source: Statistics collected by the U.S. Bureau of Census for the National Marine Fisheries Service.

Further it appears that in these cases involving intense conflicts among alternate uses, the severity of the conflict between the high intensity use and lower intensity uses may not depend upon which use is developed at high intensity and which use is developed at low intensity. For example, the severity of conflicts between heavy deployment of FNPs in a region and low intensity OCS oil and gas development in the region may not differ significantly from the conflicts between heavy OCS oil and gas development in a region and low level deployment of FNPs in that region.

The extent to which this competition occurs will depend in large part upon the laws that have been and will be passed and the institutions that are established to regulate the offshore activities. Chapter VIII discusses these legal and institutional issues.

FOOTNOTES

1. Council on Environmental Quality, *OCS Oil and Gas -- An Environmental Assessment*.
2. This assumption is based on studies detailed in the OCS report. It should perhaps be reiterated that the FNP has special safety features should such an event occur (see Chapter IV).
3. The selection of potential onshore areas was for analytical purposes only; it does not represent judgment on where oil and gas should come ashore.
4. Transhipment of oil and gas between onshore destinations may well involve OCS and CR routes.
5. These locations were selected for analytical purposes only. See Potential Onshore Effects of Deep Water Oil Terminal - Related Industrial Development, CEQ 1973.
6. See, for example, the New Jersey Wetlands Act.
7. See Appendix A.
8. This does not imply that an individual would receive a hazardous exposure but that certain siting guidelines would no longer be adhered to.
9. Bureau of Outdoor Recreation, unpublished data.
10. Taken from the *National Shoreline Study*, *Regional Inventory Report*, U.S. Army Engineer Division, Corps of Engineers.
11. Public Service Electric & Gas Company, *Atlantic Generating Station*, 1973.
12. Bromley, G.W. and Company, *Boating Almanac*, Vol. 3, New York, 1972.
13. *Economic Report of the President* (Washington, D.C., 1974).
14. For a discussion of these materials see "*Maritime Administration Bulk Chemical Carrier Construction Program*, "Draft Environmental Impact Statement, EIS 740366, Dept. of Commerce, March 1974.
15. *Report to the Congress on Ocean Dumping and Other Man-Induced Changes to Ocean Ecosystems*. Prepared by the Office of Coastal Environment, NOAA, February 15, 1974.
16. *Ibid*.
17. *Ibid*.
18. *Ibid*.
19. U.S. Bureau of Census for the National Marine Fisheries Service.
20. National Marine Fisheries Service, unpublished.

CHAPTER VIII

LEGAL AND INSTITUTIONAL CONSIDERATIONS

This study considers some of the environmental challenges and potential conflicts of the FNP with other uses of the coastal region and the outer continental shelf. The United States will want to consider these effects to ensure that the design and placement of offshore nuclear powerplants, as well as their operation -- indeed, the initial decision to build them at all -- are consonant with national and international interests.

Provisions of international law on the construction and regulation of activities associated with offshore nuclear powerplants must be considered. Further, any deployment of FNPs which would constitute a claim of sovereignty over areas of the high seas would violate Article 2 of the Convention of the High Seas and could jeopardize other U.S. interests in freedom of the high seas.

Federal regulation is essential to compliance with the applicable provisions of international law and to the interests of individual states. An effective and efficient overall regulatory process can be carried out with a minimum of duplicative effort by the Government agencies concerned while assuring public health and safety and incorporating environmental values.

States too will need legislation to ensure consideration of their environmental, economic, and social interests. Further, Federal and state regulations must ensure that all interested parties, including the general public, are an effective part of the decisionmaking process.

This chapter treats the major legal and institutional considerations of offshore nuclear powerplants on all three levels. From the discussion several general observations and conclusions arise:

1. Under international law, the United States may deploy FNPs in its territorial sea, or on the high seas. As with all activities on the high seas, however, the FNP must be constructed and operated with reasonable regard for other uses and must not involve an assertion of sovereignty.
2. The Federal process for licensing floating nuclear powerplants

in coastal waters involves several agencies, each with separate responsibilities. Streamlining the licensing process to eliminate unnecessary duplicative efforts appears to be a definite possibility.

3. Federal and state regulatory procedures provide opportunity for interested parties to participate in consideration of environmental, economic, and social questions. Any change in regulatory procedures should preserve this opportunity.

INTERNATIONAL LAW ASPECTS OF OFFSHORE NUCLEAR POWERPLANTS

A major legal issue is whether international law permits construction and regulation of offshore nuclear powerplants in the ocean. International law defines ocean areas beyond the 3-mile territorial sea as high seas.[1]

The Territorial Sea

Articles 1 and 2 of the Convention on the Territorial Sea and Contiguous Zone state that a coastal nation has sovereignty over the waters, seabed, and subsoil of the territorial sea. Thus, in its territorial sea the United States can regulate activities connected with the construction and generation of FNPs (including such activites by foreign nationals) and navigation in the vicinity of these facilities with due consideration of the right of innocent passage.[2]

The High Seas

Construction

What international law permits on the high seas may be determined in part from the 1958 Convention on the High Seas. Article 2 provides:

> The high seas being open to all nations, no State may validly purport to subject any part of them to its sovereignty. Freedom of the high seas is exercised under the conditions laid down by these articles and by the other rules of international law. It comprises, *inter alia*, both for coastal and non-coastal States:
> 1. Freedom of navigation;
> 2. Freedom of fishing;
> 3. Freedom to lay submarine cables and pipelines;
> 4. Freedom to fly over the high seas.
>
> These freedoms and others which are recognized by the general principles of international law, shall be exercised by all States with reasonable regard to the interests of other States, in their exercise of the freedom of the high seas.

Construction and operation of offshore nuclear powerplants is not an enumerated high seas freedom. However, it is clear that the article is not all inclusive. And although it is quite unlikely that offshore nuclear powerplants were contemplated when the Convention was negotiated in 1958, the United States has taken the position that the phrase "and others which are recognized by the general principles of international law" should be interpreted with flexibility so as to accommodate reasonable new ocean uses as they arise -- deepwater ports, for one. The United States could likewise justify offshore nuclear powerplants as a reasonable use of the high seas. Clearly, the freedom to undertake new high seas uses would have to be exercised with reasonable regard for other high seas uses and users. For example, it would be necessary to ensure that the powerplant does not unduly interfere with navigation, scientific research, construction of submarine pipelines, and fishing.

It should be noted that although a deepwater port may be viewed as an enhancement to navigation, offshore nuclear powerplants are not directly related to navigation, ports of refuge, or navigational aids. In these respects, the reasonable use argument for offshore powerplants is not so strong as for deepwater port facilities.

Two other existing theories about offshore facilities have been considered in connection with deepwater port development -- jurisdiction over continental shelf resources and the "roadstead" theory. The United States has interpreted the Convention on the Continental Shelf as restricting the exclusive jurisdiction of coastal nations to the exploration and exploitation of resources and other express grants of jurisdiction in the convention -- neither of which is appropriate to FNPs. The roadstead theory restricts use to the loading, unloading, and anchoring of ships. Further, it permits facilities to be treated as an enclave of the territorial sea. As a matter of policy, the United States is reluctant to take action that extends sovereignty into the high seas in this manner. Under the reasonable use concept, the United States can and must assure that deployment of FNPs in no way constitutes a claim of sovereignty over an area of the high seas.

Legislation might be necessary to ensure that a complete regime of civil and criminal law will govern generating stations located beyond the territorial waters. The Constitution and all federal law should be made applicable. And certain federal laws, such as the Longshoremen's and Harbor Workers' Compensation Act, should be made specifically applicable. Relevant and non-conflicting state law should be assimilated to apply to an offshore facility. Provision should be made to control matters generally regulated at the city and county level.

Regulation of Activities of Foreign Entities

There are two questions concerning activities of foreign vessels and nationals on the high seas: whether the United States can regulate activities of foreign nationals within the offshore nuclear powerplant facility and whether the United States can regulate the navigation of foreign vessels in the vicinity of the facility.

Because the powerplant[3] would not be used as a port facility, foreign nationals in the facility would probably be employed there or otherwise engaged in commercial relationships with the United States. In this event, presence in the plant could clearly be conditioned on the acceptance of U.S. criminal and civil jurisdiction for activities undertaken thereon.

The question of controlling navigation by foreign flag vessels in the vicinity of the facility is more difficult. While, under international law, the United States may define reasonable warning areas, promulgate navigational safety warnings, and indicate them on widely publicized charts these precautions would not be binding on foreign vessels. In addition, physical markers such as buoys, lights, and other effective means of warning may be deployed where practicable. These kinds of steps can be taken to warn foreign flag vessels. Should they go unheeded, compliance could be requested, with the potential denial of use of U.S. ports and bunkering facilities as an indirect sanction. Compliance would not be mandatory and could not otherwise be enforced.

In extraordinary cases of imminent physical danger, U.S. authorities could legally intervene on the high seas to prevent harm to the powerplant or persons within it. The need for immediate measures would be particularly strong where nuclear contamination is possible and reasonable preventive measures would be acceptable under customary norms of international law in certain limited circumstances. This would not, however, be a general regulatory right and could be exercised only in an actual case of danger.

Although powerplants may be considered a reasonable use of the high seas, the United States is seeking agreement in the Law of the Sea Conference to strengthen and formalize the right of coastal nations to construct such facilities off their coasts. The United States has proposed recognition of an exclusive right to authorize and regulate installations relating to a nation's economic interests in its coastal seabed economic area[4/] subject to certain international standards.

FEDERAL REGULATION

Assuming that FNPs comply with international law, the United States is obligated to assure that they do not unreasonably interfere with other uses and users o with the marine environment. In light of the potenital environmental effects discussed in Chapters V and VI, the assurance is best provided through licensing.

The Atomic Energy Commission has major responsibility for licensing a nuclear powerplant. When the powerplant is offshore, other Federal agencies (particularly the U.S. Coast Guard) too have licensing and regulatory responsibilities. With the exception of the Coast Guard, this additional responsibility relates primarily to siting and preserving environmental quality.

Agency Responsibilities

The AEC has major responsibility for FNPs. Under the Atomic Energy Act of 1954,[5/] as amended, the AEC is vested with licensing and regulatory authority over, among other things, the manufacture, construction, and operation by any "person" of a "utilization facility", such as a nuclear powerplant, within the territorial sea. Because of the broad definition of these terms, AEC authority is complete. The act provides for the AEC to issue permits for construction of nuclear powerplants and requires the AEC to issue licenses before powerplants can begin operations. The AEC may not issue a license to any person if doing so would be inimical to the common defense and security or to the health and safety of the public. The AEC has authority to promulgate regulations governing the design, location, and operation of nuclear powerplants in order to protect health and to minimize danger to life or property; it also has general authority to promulgate regulations to effectuate the purposes and provisions of the act. Accordingly, the AEC has promulgated regulations[6] specifically applicable to manufacture of nuclear powerplants at an industrial site for eventual location and operation at utility sites, including ocean sites.

The act confines matters to be considered by AEC in issuing permits and licenses essentially to radiological effects and the common defense and security.[7] The states are generally without authority to license or regulate nuclear powerplants from the standpoint of radiological effects or common defense and security.[8]

The National Environmental Policy Act of 1969[9] enlarged AEC authority to require full consideration of the environment and possible alternatives before issuing permits and licenses. In Calvert Cliffs',[10] NEPA was construed as requiring AEC to analyze the costs and benefits of licensing actions, to include the analysis in both draft and final environmental impact statements, and to consider cost-benefits in the same fashion as radiological issues in the licensing hearing process.

In sum, within the territorial sea AEC authority over nuclear powerplants vis-a-vis the states is comprehensive and exclusive -- comprehensive in that it covers all persons and activities and exclusive in that the Atomic Energy Act preempts the states in radiological, common defense, and security matters.[11]

In the contiguous zone and the high seas the statutory and regulatory framework applicable to manufacture, construction, and operation of a nuclear powerplant is generally the same as in the territorial sea.[12] However, AEC authority would apply only to U.S. citizens, not to foreign governments or foreign nationals.

Regardless of where the FNP is located in the ocean, the Coast Guard has responsibility under Title 46 of the U.S. Code: (1) to review and approve the contract plans for a barge-mounted plant, (2) inspect the plant during manufacturing, (3) issue a certificate of tow before it can be moved from the manufacturing facility, (4) issue a certificate of inspection before the FNP begins operations offshore.

The Coast Guard has general authority within and adjacent to navigable waters of the United States to regulate vessels and waterfront operations (onshore support facilities and construction related to the FNP), including the unlawful discharge of oil, hazardous substances, and vessel sewage into the water. This regulation extends to the transportation of dangerous cargo. Finally, where a breakwater is in the U.S. territorial sea or other navigable waters, the Coast Guard has regulatory authority over safety equipment and marking (e.g. lights and signals) on structures.

The Corps of Engineers also has regulatory authority over offshore nuclear powerplants. Specifically, a Corps permit must be obtained to construct a breakwater, locate underwater transmission cables, or place any structure in the navigable waters of the United States (including the territorial seas) pursuant to the Rivers and Harbors Act of 1899.[13/] On the Outer Continental Shelf the Corps of Engineers has authority over structures erected for the purposes of exploration and exploitation of natural resources pursuant to the Outer Continental Shelf Lands Act of 1954;[14/] its authority is not clear in other cases. Permits are also required for any activities (e.g., dredging) affecting the course, condition, or capacity of navigable waters of the United States. In addition, a Corps permit is required for the disposal of dredged or fill material in navigable waters (including the territorial seas) pursuant to the Federal Water Pollution Control Act[15/] and for the transportation of dredged material for the purpose of disposing of it in the ocean (including the territorial seas) pursuant to the Marine Protection, Research, and Sanctuaries Act of 1972.[16/]

The Coastal Zone Management Act of 1972[17/] authorizes the Secretary of Commerce to assist the states in developing land and water use programs for the coastal zone. The coastal zone is defined as the coastal waters and adjacent shorelines, including transitional and intertidal areas, salt marshes, wetlands, and beaches. Once the Secretary of Commerce approves a state program, no Federal license or permit may be granted for any activity which affects the state coastal zone without state concurrence or unless the Secretary of Commerce finds that the activity is consistent with the objectives of the act or is otherwise necessary in the interest of national security.

In addition, under the Marine Protection, Research, and Sanctuaries Act of 1972,[18] the Secretary of Commerce may designate as marine sanctuaries areas of the ocean as far seaward as the outer edge of the continental shelf, coastal waters where the tide ebbs and flows, and the Great Lakes and their connecting waters for the purpose of preserving or restoring them for their conservation, recreational, ecological, or aesthetic values. The Secretary may issue regulations to control activities in the sanctuaries by persons subject to U.S. jurisdiction. No permit or license for an activity -- including FNPs -- within a sanctuary is valid unless the Secretary certifies that the activity is consistent with the Act.

The Federal Water Pollution Control Act[19] authorizes the Environmental Protection Agency to regulate discharge of pollutants into U.S. waters, including the territorial seas, and into the waters of the contiguous zone and beyond from a point source other than a vessel or other floating craft. In general, no person subject to the jurisdiction of the United States may discharge a pollutant into these waters without first obtaining a permit from either EPA or in the case of territorial seas, the state. Before issuing a license or permit for an activity that may result in the discharge of a pollutant, Federal agencies are required to obtain certification from the state or EPA that the discharge will comply with the Federal Water Pollution Control Act. As it appears in the act, "pollutant" does not include radioactive materials regulated by AEC under the Atomic Energy Act.

The Marine Protection, Research, and Sanctuaries Act vests EPA with permit authority over transportation of material from the United States for the purpose of dumping it into ocean waters (defined as the territorial sea or the contiguous zone if the territorial sea may be affected). Overlap with other statutes is avoided by the provision that "dumping" does not include effluent from any outfall structure as regulated by the Federal Water Pollution Control Act, the Atomic Energy Act of 1954, or section 13 of the Rivers and Harbors Act of 1889. Nor does dumping include construction of any fixed structure or artificial island or intentional placement of any device in ocean waters for purposes other than disposal when such matters are regulated by other Federal law. The act also prohibits absolutely discharges of high-level radioactive waste.

Under the Outer Continental Shelf Lands Act,[20] the Department of the Interior issues mineral leases on the outer continental shelf and permits for any actions which might affect lands and mineral leases which it administers. It has no general licensing authority over offshore nuclear powerplants as such.

Under the Federal Aviation Act of 1958[21] and the Department of Transportation Act of 1966,[22] the FAA is required to review and endorse plans relative to potential obstructions affecting navigable air space. Because a nuclear powerplant limits aircraft traffic in its vicinity, the FAA is party to the permit proceedings. Any plan to operate helicopters on either the breakwater or the floating plant itself is also subject to FAA endorsement.

Licensing Procedures

AEC regulations prohibits onsite manufacture of a nuclear powerplant, including excavation or other substantial action that would adversely affect the natural environment, prior to receipt of a construction permit. Detailed requirements have been set forth regarding permit or license applications' compliance with both NEPA and the Atomic Energy Act.[23] A license is also required prior to operation.

Public hearings prior to issuance of the manufacturing license and construction permit are mandatory, and they may also be held prior to issuance of an operating license. Although the construction permit proceedings focus on the site, the applicant is required to evaluate in general terms the effects of the reactors. In addition, there is a NEPA environmental evaluation in connection with the construction permit and operating license. The regulations seek to avoid needless duplication by providing that matters resolved along the 3-step process are not reconsidered later. However, the Commission can reopen matters previously resolved if significant new information would substantially affect conclusions reached earlier or for other good cause. Final decisions by the AEC are subject to judicial review in the Federal Courts of Appeals.

The Corps evaluates permit applications submitted under these authorities to determine whether issuance would be in the public interest. It considers many factors -- conservation, economics, aesthetics, fish and wildlife values, navigation, water quality, and human needs and welfare -- by soliciting information, data, and comments from interested Federal, state, and local agencies and from private institutions. Corps personnel also make an environmental assessment of each proposed activity, sometimes finding it necessary to prepare the impact statement required by the National Environmental Policy Act when a proposed activity will significantly impact the quality of the human environment. In addition, if the proposed activity involves the discharge of dredged or fill material into navigable waters or the transportation of dredged material for disposal in the ocean, the Corps applies EPA guidelines and criteria and offers an opportunity for a public hearing during the permit review.

Decision by the Corps on whether to issue a permit, then, directly affects the proposed location of an offshore nuclear powerplant. Moreover, all District Engineers supervise all authorized activities to ensure that they are conducted and executed in conformance with the approved plans and other conditions of the permit.

A coastal state with an approved management program will exercise a kind of permit authority over location of an FNP offshore, with a right of review vested in the Secretary of Commerce. Under the Coastal Zone Management Act, an applicant for a Federal license or permit to conduct an activity affecting land or water uses in the coastal zone must certify that the activity complies with the program. He must also send the certification and backup information and data to the state. The states have been directed to set procedures for public notice of all the certifications and, to the extent that it deems appropriate, procedures for public hearings. The state then notifies the Federal licensing or permitting agency of its concurrence or objection to the applicant's certification.

The Coast Guard has no public hearing requirement for any of its certification actions. "Required" plans for the FNP are submitted, reviewed, and, when acceptable, approved. The construction of the plant and the installation of its components are monitored and inspected during both manufacture and final onsite preparation for operation. "Certificates of inspection will be issued when the inspection indicates that construction and installation is satisfactory."

The Department of the Interior has the responsibility of reviewing permit proceedings at all stages of the offshore plant life cycle. DOI authority derives from the Fish and Wildlife Coordination Act of 1958,[24] the National Historic Preservation Act of 1966,[25] the Outdoor Recreation Development Act of 1963,[26] and the Antiquities Act.[27]

In accordance with the Marine Protection, Research, and Sanctuaries Act, EPA must provide notice of an opportunity for public hearings prior to issuing any dumping permit. EPA's permit criteria include consideration of need for the proposed action; effects on fisheries--plankton, fish, shellfish, wildlife, shorelines, and beaches; effects on other uses of oceans; and land-based alternatives. A permit is issued only when EPA determines that the dumping "will not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities."[28] In addition, the Federal Water Pollution Control Act directs EPA to develop "ocean discharge criteria," and no discharge permit may be issued except in conformance with these criteria.[29] The act calls for an opportunity for a public hearing prior to issuing any discharge permit.

<u>Interagency Coordination</u>

In recognition of the number of government agencies involved in licensing offshore nuclear powerplants, an Interagency Regulatory Steering Committee was formed in mid-1973 to <u>facilitate</u> licensing procedures. The committee is chaired by the AEC and is composed of senior representatives from: the U.S. Coast Guard, National Oceanic and Atmospheric Administration, Corps of Engineers, Department of the Interior, Federal Aviation Administration, Environmental Protection Agency, Federal Power Commission, Atomic Energy Commission, and as observer, the Council on Environmental Quality and the Federal Energy Administration.

Before the establishment of the Steering Committee, the Coast Guard and the AEC had begun to coordinate their activities relating to floating nuclear plants. Their effort resulted in a "Memorandum of Understanding on the Regulation of Floating Nuclear Power Plants."[30] The Memorandum assigns primary safety and environmental protection responsibilities for review, inspection, and enforcement. The Atomic Energy Commission assumes principal responsibility for radiological health and safety, including nuclear powerplant safety, and for environmental protection. The Coast Guard is responsible for all maritime safety considerations, barge design and operation, special aspects of maritime environmental protection, and participation in the preparation of the environmental statement. Each agency will enforce its own license and certification conditions as well as its own regulations.

The Steering Committee has coordinated other similar memoranda of understanding; one between the AEC and the Corps of Engineers which is in effect, and one between the AEC and EPA which is being finalized. The initial report of the Committee on the Federal Regulatory Process for FNPs has been recently released. A summary network of the Federal Regulatory Process for licensing of FNPs has been reproduced as Figure VIII-1.

Financial Responsibility

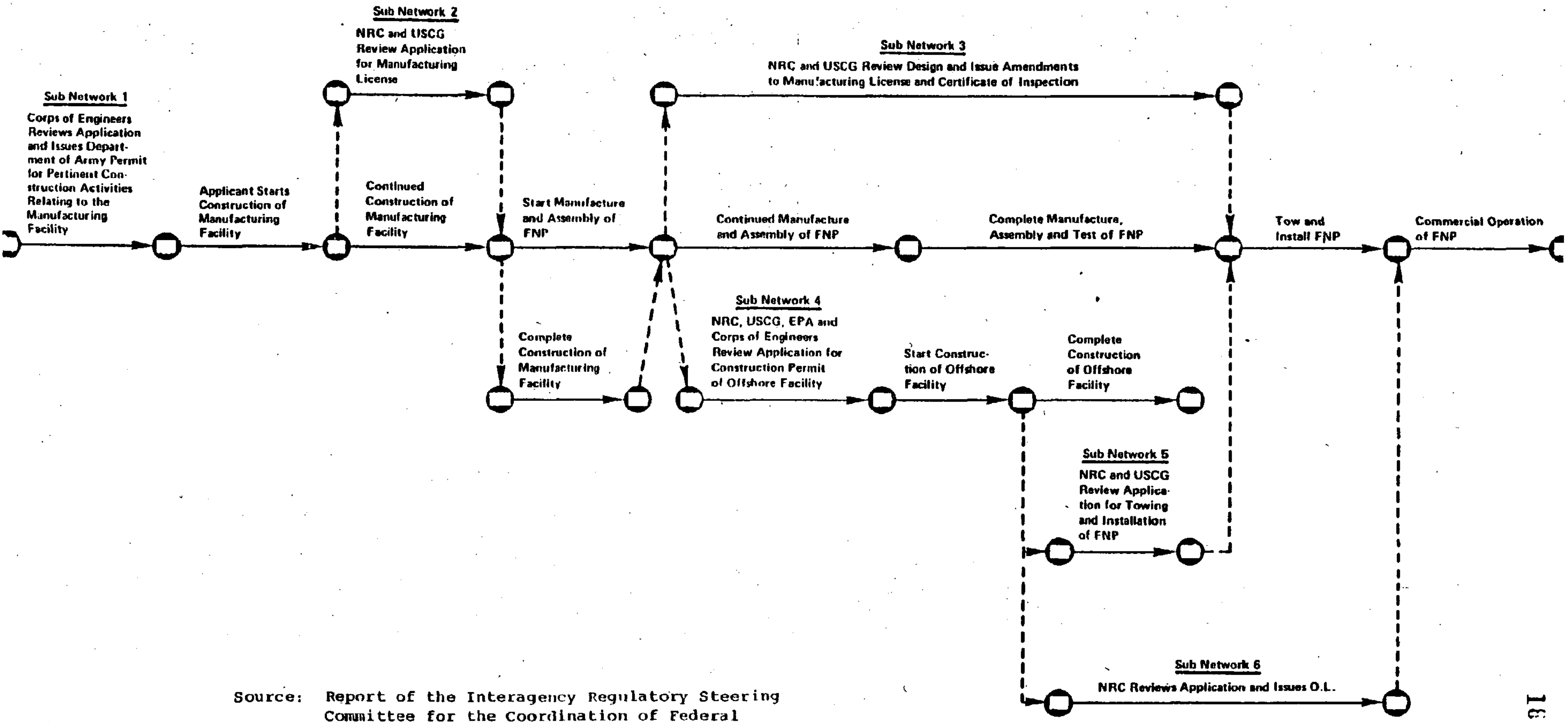
The Atomic Energy Act requires licensees to maintain financial protection to cover public liability claims for nuclear incidents in an amount equal to the maximum amount of liability insurance available from private sources (currently $110 million).[31/] In addition, the licensee must execute and maintain an indemnity agreement whereby the AEC indeminifies the licensee and other persons from nuclear liability. The net effect is that public liability claims for nuclear incidents are first covered by the licensee's insurance; the indemnity agreement covers any excess liability up to $506 million for all persons indemnified for a single incident.

The act also provides for waivers of defenses generally corresponding to the imposition of strict liability for certain types of nuclear incidents ("extraordinary nuclear occurrences").[32/] Although issues relating to whether the occurrence led to the damage could be litigated, insofar as "proximate cause" is an element in establishing the claim, the requirement that the plaintiff establish that the damages were foreseeable will be waived. The waivers of defenses extend to any issue or defense based upon any statute of limitations if suit is instituted within 3 years after the claimant first knew, or reasonably could have known, of the damage of injury, provided suit is brought within 10 years of the incident.

The financial protection, indemnity, and waivers of defenses provisions of the act would operate to the benefit of all claimants, including foreign citizens. In the event of an "extraordinary nuclear occurrence" in U.S. territorial waters, foreign citizens suffering personal or property damage would be entitled to recover

FIGURE VIII-1

SUMMARY LEVEL NETWORK OF THE FEDERAL REGULATORY PROCESS FOR LICENSING OF FLOATING NUCLEAR PLANTS (FNP'S)



Source: Report of the Interagency Regulatory Steering Committee for the Coordination of Federal Regulatory Activities Relative to the Licensing of Floating Nuclear Power Plants. July 1975 under the licensee's financial protection (generally an insurance policy) and the indemnity agreement with the AEC, and the licensee would not be able to raise as a defense such matters as a lack of negligence on its part. The purpose of the agreement and waiver of defenses is to ensure available funds to compensate for losses in the event of a nuclear incident. Financial responsibility for nuclear incidents occurring beyond the territorial limits of the United States is not covered by the act.

STATE PARTICIPATION

The states and their political subdivisions can significantly shape FNP deployment and the construction and use of related nearshore and onshore facilities through pollution control programs, land use planning and regulation, and transmission line regulation. Several states have recently enacted legislation providing for state review of development in "environmentally critical areas" and of the siting of key facilities, including powerplants and refineries.[33]

State authority over FNP-related activities may well be strengthened under existing and proposed Federal legislation. In addition to the Coastal Zone Management Act of 1972, broader land use legislation that would foster state planning and regulation capabilities is being considered by the Congress.

State reaction to potential FNP deployment is varied, even though only five states are involved in the four areas identified as FNP candidates.

At the end of 1973, the New Jersey Department of Environmental Protection suggested that offshore nuclear powerplants not be ruled out because of their potential in minimizing the environmental impact of power generation. However, outright support was reserved until further information on their environmental impacts is available. Through the Wetlands Act of 1970,[34] the subsequent wetlands order of the Department of Environmental Protection,[35] and the Coastal Area Facility Review Act of 1973,[36] New Jersey has created the mechanism for state control over the location of FNPs. Although there is some concern about the effects of FNPs, the legislature did not act on a sanctuary bill which could have prohibited offshore nuclear facilities.

The executive branch of the Florida government has expressed support of the floating nuclear powerplant concept. In approving the Jacksonville Port Authority's application for a dredge and fill permit for construction of an offshore nuclear powerplant manufacturing facility, the state controller said: "[T]he floating plants are the only answer to providing power for our cities and at considerably less ecological loss than following the conventional pattern for such power plants, which is plaguing most of the urban areas of our nation."[37/] The legislative branch, on the other hand, is somewhat neutral. It recently enacted the Florida Electrical Power Plants Siting Act of 1973 [38/] to assure that there is a reasonable balance between the need for a facility and the environmental impact resulting from its construction and operation.

The location of offshore nuclear powerplants has not become a public issue in Maine. However, the experience with the only nuclear powerplant[39/] in the state has been somewhat negative because of its poor siting. Maine's Site Location Act,[40/] Shoreland Zoning Act,[41/] Wetlands Act,[42/] and the Oil Discharge Prevention and Pollution Control Act[43/] provide regulatory authority.

The array of Federal and state power and concerns indicates a potential for conflict when Federal and state objectives on FNPs diverge. Mechanisms must be developed to identify and resolve any conflict expeditiously and fairly. The need for coordination is not less when Federal and state objectives converge. The state regulatory authorities are significant means of protecting and promoting important state interests.

Because there is no FNP experience upon which to draw, it is essential to establish expertise at all levels of government. Affected states can strengthen their coastal zone management programs by developing technical expertise on all phases of FNP deployment and its onshore and offshore impacts. The coastal zone management agencies should attempt to ensure that state interests and regulations are fully coordinated with Federal FNP technical and management activities, and Federal agencies should make every effort to coordinate and cooperate with the state agencies on an ongoing basis at all stages of management.

Simply establishing state technical expertise and calling for Federal cooperation will not necessarily yield coordination, however. Mechanisms for effecting interaction must be built into the decision-making process itself. NEPA, for instance, could be an important focus of Federal-state coordination concerning the FNP if state coastal zone management agencies and Federal agencies jointly design and prepare initial environmental analyses in addition to the states' commenting on draft environmental impact statements.

The Coastal Zone Management Act provides a framework for cooperation in FNP planning, particularly with respect to siting the switching yards, transmission lines, and support facilities within the coastal zone. State coastal zone management plans should cover transmission lines, switching facilities, and all FNP-related development in the coastal zone. Although under the statute the plans are required to provide "adequate consideration of the national interest involved in the siting of facilities necessary to meet requirements which are other than local in nature,"[44] they should consider the full range of state interests as well. State coastal zone management agencies and concerned Federal agencies should jointly develop these portions of the plans.

The legal and institutional issues are complicated by the fact that many impacts of the FNP on environmental, economic, and social interests are simply not known. It is essential that all levels of government cooperate to identify the specific areas and then set about to fill the voids. The legal and institutional questions -- international, national, state, and local -- involved in making decisions about where and how the offshore nuclear powerplant shall be sited cannot long remain unanswered.

FOOTNOTES

1/ Pursuant to Article 24 of the Convenion on the Territorial Sea and the Contiguous Zone, the United States recognizes a nine-mile contiguous zone immediately adjacent to its three-mile territorial sea for customs, fiscal, immigration or sanitary purposes, and under international law the United States also recognizes an exclusive fisheries contiguous zone in the same area.

2/ Under Article 14 of the Convention on the Territorial Sea and the Contiguous Zone, all nations enjoy a right of innocent passage through any territorial sea. No coastal nations must hamper innocent passage and are required to publicize any known danger to navigation in their territorial seas.

3/ In order for the conclusions made in this paragraph to be true, the FNP being discussed must itself be subject to U.S. jurisdiction. This could be accomplished through the nationality of the owners or operators, its shoreside connections, or its voluntary submission to this jurisdiction.

4/ (Definition of CSEA)

5/ 42 USC §2011-2282.

6/ Appendix M to 10 CFR Part 50.

7/ New Hampshire v. AEC, 406 F2d 1970 (1st Cir. 1969), *cert. denied*, 395 U.S. 962 (1969). Under *Act 105*, the AEC must also consider issuing construction permits and certain operating licenses whether the activities under the license would "create or maintain a situation inconsistent with the antitrust laws." 42 USC §2135

8/ *Northern States Power v. Minnesota*, 447 F.2d 1143 (8th Cir. 1971), *affirmed*, 405 U.S. 1035 (1972).

9/ 42 USC §4321 *et seq.*

10/ Calvert Cliffs v. AEC, 449 F.2d 1109 (D.C. Cir. 1971).

11/ There is no preemption with respect to matters not covered by the Act but covered by NEPA.

12/ For example, the AEC licensed the nuclear ship SAVANNAH with the license restrictions and specifications fully applicable to operations in the contiguous zone and on the high seas.

13/ 33 USC 403

14/ 43 USC §1333(f)

15/ 33 USC §1344

16/ 33 USC §1413

17/ 16 USC §1451-1464

18/ 16 USC §1431-1434; 33 USC §1401-1444

19/ 33 USC §1251-1376

20/ 43 USC 1331 *et seq*.

21/ 49 USC §1501. *See* 14 CFR Part 77

22/ See 49 USC §1655(g)(6)(c)

23/ 10 CFR §51

24/ 16 USC §661 et seq.

25/ 16 USC §470 et seq.

26/ 16 USC §460 et seq.

27/ 16 USC §461 et seq.

28/ 33 USC §1412

29/ 33 USC §1343

30/ 39 F.R. 2124, January 17, 1974.

31/ See 10 CFR Part 140

32/ 42 USC §2210(n)

33/ Of the states most likely to be affected by early FNP deployment, only Florida has enacted comprehensive statewide land use legislation. Some -- including New Jersey and Maine -- have passed laws regulating development in coastal areas. Others (New Hampshire, Connecticut, New York, and Maryland) regulate powerplants and transmission lines under state siting acts.

34/ State of New Jersey, The Wetlands Act of 1970, State Assembly 13:9A-1 et seq.

35/ State of New Jersey, Department of Environmental Protection, Wetlands Order, April 13, 1972.

36/ State of New Jersey, Coastal Area Facility Review Act, P.L. 1973, Chapter 185, June 20, 1973.

Chapter IX. Recommendations for Research

One of the difficulties of this generic study is that many critical questions are site-specific, and only after a site has been chosen can the questions be addressed meaningfully. Because of this, it is difficult to assess the relative importance of the recommendations. Some will be important at one site, not so important at another. Issues not considered important in general could be critical in specific cases. All recommendations should be considered within the broad framework posed by site-specific restrictions.

Although the study is one primarily of issues associated with offshore nuclear powerplants, it is clear that there are deficiencies in knowledge and data of much broader application. Further, some coastal areas have been investigated more extensively than others. Decisions bearing upon use of any marine resources suffer from these deficiencies.

Another difficulty is that much of the discussion included here is technology-specific. Although there appear to be other feasible technologies besides the FNP-fixed breakwater configuration, available information is insufficient to make meaningful comparisons.

That items are not ranked according to priority or sequence does not mean that the offshore nuclear powerplant must wait for all the answers. Nor does omission of an issue mean that implementation should proceed without considering it.

Multiple Deployment

Although it is possible to estimate the environmental, economic, and safety consequences of one facility, only the most rudimentary guesses can be made about a cluster or string of several facilities. The initial intent of this study was to address multiple deployment, but the requisite information simply does not exist. Those research efforts which will provide information necessary for multiple deployment decisions should be given high priority.

- -- What are the regional electricity demands and onshore powerplant siting constraints? What pressures does this imply for multiple offshore sites in each region.
- -- What are the economics of multiple deployment? Do economic factors make the clustering of stations likely within offshore regions? Are there economic factors affecting the pattern of clustering?
- -- What are the environmental effects of the more likely siting patterns?
- -- What are the effects on marine organisms of multiple FNPs closely spaced? What are the limiting separation distances between FNPs from the standpoint of impact on marine biota?
- -- What are the safety, reliability, and national security implications of single versus multiple deployment?
- -- How would multiple deployment conflict with other uses of the offshore area?

These are just a few of the questions that come to mind. Basically, the issue is this: a single nuclear powerplant off New Jersey may be acceptable, but what about 25 or 50 similar plants along the New Jersey coast? Is this not an issue that should be addressed now? If the first plant can be constructed and operated profitably, others will follow.

These general comments suggest the utility of a strong regulatory program. Its strength should not be confused with its complexity or comprehensiveness. Strength should be measured by the program's effectiveness in inducing both government and industry to focus on important issues and to ensure that critical questions are answered.

Safety

Safety is paramount. This study concentrates on the safety challenges and accident consequences peculiar to offshore sites although discussion of FNPs of course includes nuclear powerplant safety in general. A major handicap in analyzing safety is the lack of accident probability information -- onshore or offshore, generic or site specific. The Atomic Energy Commission hopes soon to have comprehensive probability estimates (see Chapter IV). Although generalizations presently difficult or even impossible, important problems related to offshore plant safety can be identified.

There are several basic safety challenges peculiar to FNPs which deserve more thorough examination:

- Barge-mounted plants are subject to wave and tidal motion which, although limited by the breakwater and the mooring system, could affect the performance and reliability of important plant elements. Because of these differences from onshore power stations, adequate testing and requisite design modifications are necessary. In addition, the long-term performance and reliability of important plant components should be investigated under conditions that simulate the most severe conditions anticipated for an FNP. The development of 'motion-tolerating' designs for some components may be necessary.
- Further, the FNP is located in a corrosive environment, requiring added insurance that restraining devices can tolerate the corrosion attack and still perform under severe meterological and seismic stresses.
- Nuclear plants several miles offshore will face severe storms and waves which the breakwater and barge can be designed to withstand. The probability of a storm more severe than the design basis storm, though very low, is still finite. The potential effects on the FNP and means of minimizing them should be determined.
- Unlike onshore plants, FNPs must be protected from collision with massive vessels. Again, the breakwater can be designed (possibly at prohibitive costs) to withstand the impact from a large ship moving at maximum speed. Questions arise, however, regarding vessels containing dangerous cargo, LNG, for example. Such a possibility can be minimized by siting an FNP for from shipping lanes, but a risk remains. Extensive data and data analysis concerning shipping lane traffic by type of cargo and vessel must be made available. In addition, the effectiveness of alternative breakwater designs and of ship-arresting devices external to the breakwater should be fully evaluated.
- The interaction of breakwater and seabed is crucial to breakwater stability. Questions must be examined regarding the engineering properties and stability of offshore seabed formations under breakwater loading over long periods and under heavy seas and seismic events. Can desirable

seabed characteristics be identified to aid in site selection? What extent of seabed deformation or modification will be acceptable?

-- The most important safety questions arise from the worst possible cases. A supertanker colliding with an FNP in a severe storm storm, for example. Whether such occurrences can be tolerated is an important question. Further research is necessary to assess these compound cases.

-- Although water transportation of nuclear fuel and waste is not unusual, FNP locations add new dimensions: more severe and prolonged weather and sea conditions, deeper water, and most important, for some materials there may be no alternative to water transportation. Special attention should be given to transportation accident prevention.

-- Sabotage and other hostile acts must be considered. The FNP could be a potential target for acts of political terrorism. It is potentially more vulnerable than an onshore plant. Proposed security systems must be fully developed. In addition, procedures must be worked out to neutralize hostile landings on the FNP if the proposed security systems are breached.

-- Security and national defense problems may be compounded by multiple deployment. Would clusters be undesirable militarily, and how vulnerable are they?

-- Much attention has been given to defining and describing the classes of powerplant accidents. Although it is recognized that the most severe accidents are in a sense undefinable, ongoing efforts to describe accidents in the ocean environment should be increased.

-- Limiting the dispersion of waterborne radioactivity released within the basin during an accident should be investigated. In the event of a radiological release to the basin water, it may be possible to close permanent openings in the breakwater. On the other hand, it could be preferable to dilute the release by allowing free passage into the surrounding ocean waters.

-- More needs to be known about the migration patterns and radioactive accumulation of marine organisms. Fish retaining radioactive materials (whether acquired directly or through the food chain) must be diverted from human consumption. In such a case, it would be critical to know typical movements of different fish species and how long they would remain a threat if consumed.

-- In case of a transportation accident, containers can minimized damage. Current cask designs are tested to withstand pressures in 50 feet of water, But depths may well exceed 50 feet thus cask designs must be shown adequate. Methods of revocery from deep water should be investigated and contingency plans proposed.

-- Different decommissioning methods may envolve the release of radioactive materials. Decommissioning alternatives must be carefully analyzed to minimize the threat of radioactive releases.

-- Apart from possible radioactive discharges is the possibility of accidental chemical discharges. How they would affect the offshore biota and whether and how exposed species potentially threaten man should be delineated.

-- Separate of possible radioactive or chemical discharges is the possibility of plant shutdown in the face of some accidents. In the case of multiple deployment this raises significant questions about electrical grid reliability. Since these questions could be key to multiple deployment decisions, they must be addressed.

Construction, Operation and Decommissioning

Much work is needed to explain more fully the environmental effects of constructing, operating, and decommissioning the facilities necessary to implement the offshore nuclear powerplant concept. For simplicity the facilities are discussed separately.

Onshore Support Facilities

-- The acute toxicity of heavy metals and other substances introduced to the marine environment in significant quantities has long been documented. Subtle effects from contaminated sediments, (e.g., gene mutation rate changes, effects on fecundity) are less well-known. Because construction may involve dredging and resuspension of contaminated sediments, thereby creating opportunities for biological magnification through the food web, the subtle, long-range effects of such activities are of interest.

Transmission Cables

— High-voltage underwater transmission is one of the least certain technologies involved in terms of reliability and of environmental impact. What would be the effects of electrical or magnetic fields or the leakage of toxic insulating fluids? How are the cables to be maintained and repaired?

Breakwater

— The construction of the breakwater requires the production and placement of very large amounts of materials. What are the effects of the site preparation? Are some seasons and techniques less damaging than others?

— Because the breakwaters are expected to be permanent, it is important to estimate their long-term effects on ocean currents and on the shoreline.

— Once the offshore breakwater is completed, the structure may extend from the bottom to more than 50 feet above the plane of mean low water. As such, the seasonal thermocline will be penetrated. Since organisms are directly affected by the thermocline to the extent that many are distributed of necessity above, within, or below the zone of discontinuity, the breakwater structure may interfere with the thermocline's stability if currents are deflected or upwelling occurs. The distribution of marine organisms and related food webs may, as a result, be interrupted. Additional research should determine the effect of the breakwater on the stability of the seasonal thermocline and its subsequent effect, if any, on marine organisms in adjacent waters.

-- Artificial reefs and offshore platforms attract fish, leading to the belief that local fish productivity increases as a result of their presence. If reefs and platforms concentrate organisms already in the vicinity, increased productivity is doubtful; rather, the species will have changed habitat. Research must be conducted to determine the species changes that would result from the breakwaters and the sensitivity of these changes to breakwater components and design.

-- The breakwater will alter or entirely eliminate one-quarter mile of shelf substrate benthic habitat. Should additional breakwater facilities be constructed adjacent to or in a series paralleling the coast, the loss may be correspondingly greater. Research is necessary to determine the significance of one-quarter square mile to resident and migratory species utilizing the continental shelf and the effect that the breakwater will have on an otherwise homogeneous habitat.

-- If the breakwater is located in an area reflecting a dynamic, shifting substrate, erosion may be enhanced, with subsequent benthic instability increased along its periphery. Productivity in dynamic, shifting sand areas is less than in more stable ones. How the breakwater will affect bottom currents and erosion and hence habitat stability in adjacent waters may be important.

-- The activities associated with dismantling the breakwater upon decommissioning the FNP could have severe effects on the environment. Research should be conducted to determine these effects on the marine ecosystem that has stabilized around an artificial reef.

-- Similarly, what are the effects of breakwater repairs, and what is the best way to effect repairs? How can breakwater damage be repaired during less-than-favorable weather, when wind and wave conditions limit normally anticipated repair operations?

-- Breakwaters require massive quantities of granite. Although it is very common, granite with the right qualities and in sufficient quantities is much less abundant. Effort will have to be made to determine probable locations of granite, whether alternative materials could be used may warrant study.

<u>Floating Nuclear Plant</u>

-- Much more needs to be know about ocean currents and circulation along the continental shelf. Rather than inferring circulation patterns from drift bottles, currents should be measured directly, and measurements should be made to determine tidal and wind influences, seasonal vertical temperature and salinity fluctuation, and net flushing rates. Remote offshore sensing devices should be utilized to record these data. The resulting information should permit the development of mathematical models to predict dispersion of thermal, radioactive, and other pollutants.

-- Much more needs to be known about the behavior of air masses over water, in particular, the characteristics of dispersion, and the mechanics of atmospheric plumes and instantaneous gaseous discharges from an offshore source -- including the influences of low-level temperature inversion conditions and land-sea breeze circulations. What is the nature of long-term transport phenomena, diffusion, and mass transfer among the water, the sediments, and the atmosphere?

-- More needs to be known of the potential danger to various organisms at acute and chronic exposure levels of thermal, chemical and heavy metal effluents. Are discharges of toxic effluents as important to the ecosystem as for land-based plants?

-- The individual and combined effects of action, turbulence, gas supersaturation, and pressure changes should be determined. What are the alternative discharge modes during operation of offshore powerplants, and what are the corresponding relative impacts? What is the water quality "envelope" required? Baseline data are necessary on ambient levels in the marine environment of those metals and isotopes normally associated with nuclear powerplant discharges.

-- The basin within the breakwater presents special analytical problems. What information is needed for analyzing wave resonance in the basin, sediment transport, and hydrological interactions?

One final caveat, even after satisfying the technical data requirements to permit adequate consideration of pertinent issues, the acceptability of FNP deployment will depend upon public appreication of the issues and the merits of the deployment. Thus, future efforts in response to the research needs indicated in this chapter must provide answers to the satisfaction of the public in general -- not just the technician. Further, the concerns of the public may introduce important issues for future research not identified in this chapter.

APPENDIX A

CONSTRUCTION, OPERATION, AND DECOMMISSIONING OF AN FNP

At this time, the floating nuclear powerplant protected by a massive caisson and rubble breakwater is the only one of the various technological alternatives subjected to detailed analysis.' Offshore Power Systems (OPS) has applied to the AEC for a license to manufacture barge-mounted nuclear powerplants. The information contained in the application is the basis for most of the following discussion. Public Service Electric and Gas (PSE&G) has proposed placement of two OPS FNPs inside a massive caisson and rubble breakwater (Figure A-1).

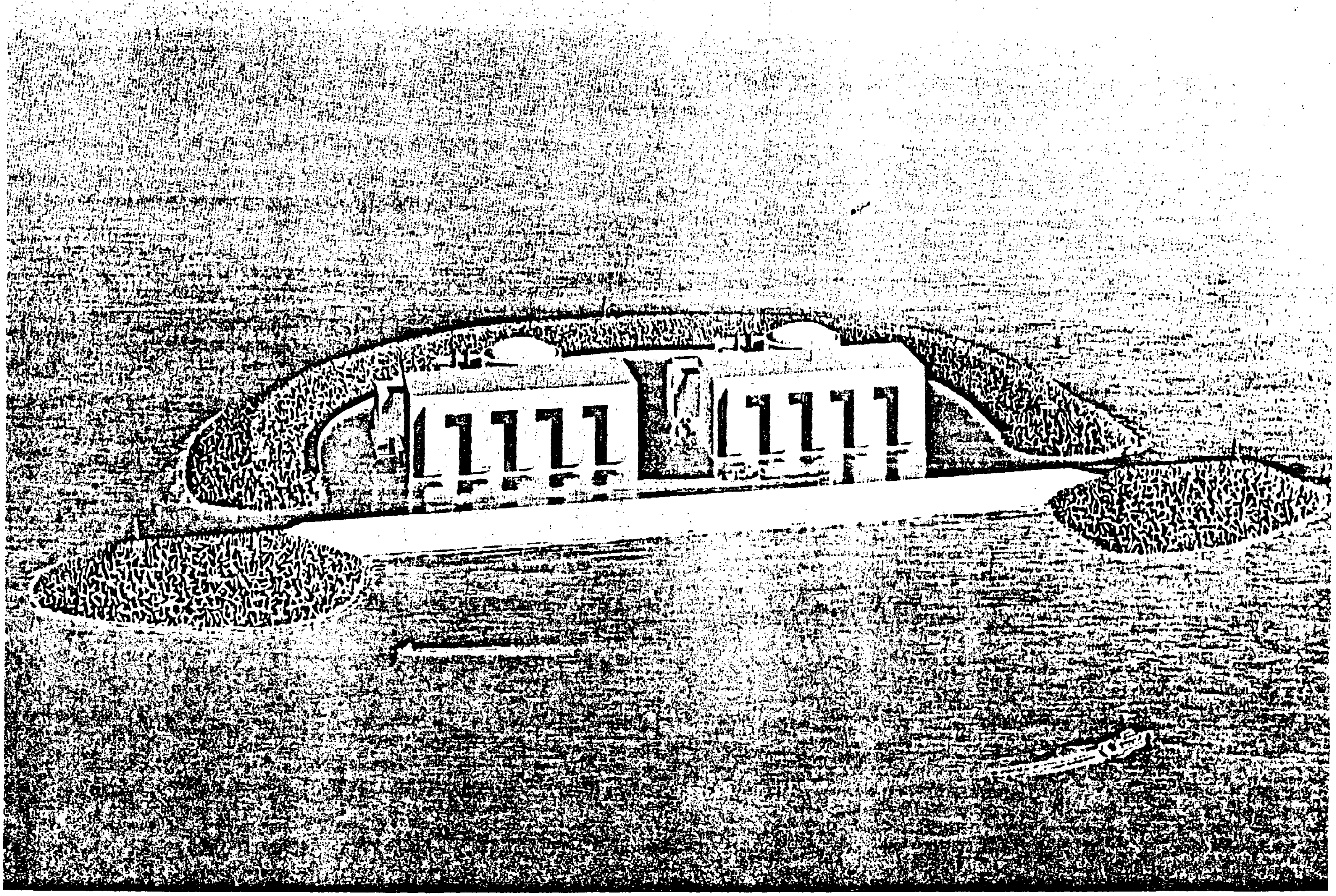
Description of a Floating Nuclear Generating Station

The FNP is a complete electric generating station of standardized design constructed on a floating platform in a shipyard-like facility. Plant components and systems are nearly identical to those of recently licensed land-based pressurized water reactor (PWR) nuclear powerplants. The supporting platform is a specially designed barge.

After the FNP has been tested but not fueled, it is towed to an offshore site where it is moored within a protective breakwater (see Figure A-2). Underwater cables transmit power from a substation on the platform to an onshore switchyard for distribution to coastal load centers. The general characteristics of the FNP are listed in Table A-1.

The Floating Nuclear Powerplant

Near the center of the platform is the plant. Its most distinguishing features are the containment structure and refueling building. The PWR nuclear steam supply system is a standard Westinghouse 4-loop, 3,425 MW thermal unit with ice condenser containment. Condenser cooling water is drawn from within the breakwater enclosure by means of six circulating water pumps at a combined rate of approximately 1 million gpm; it is discharged outside the breakwater.



PUBLIC SERVICE ELECTRIC AND GAS COMPANY
ATLANTIC GENERATING STATION

ARTIST'S CONCEPTION OF PROPOSED PLANT

Figure A-1

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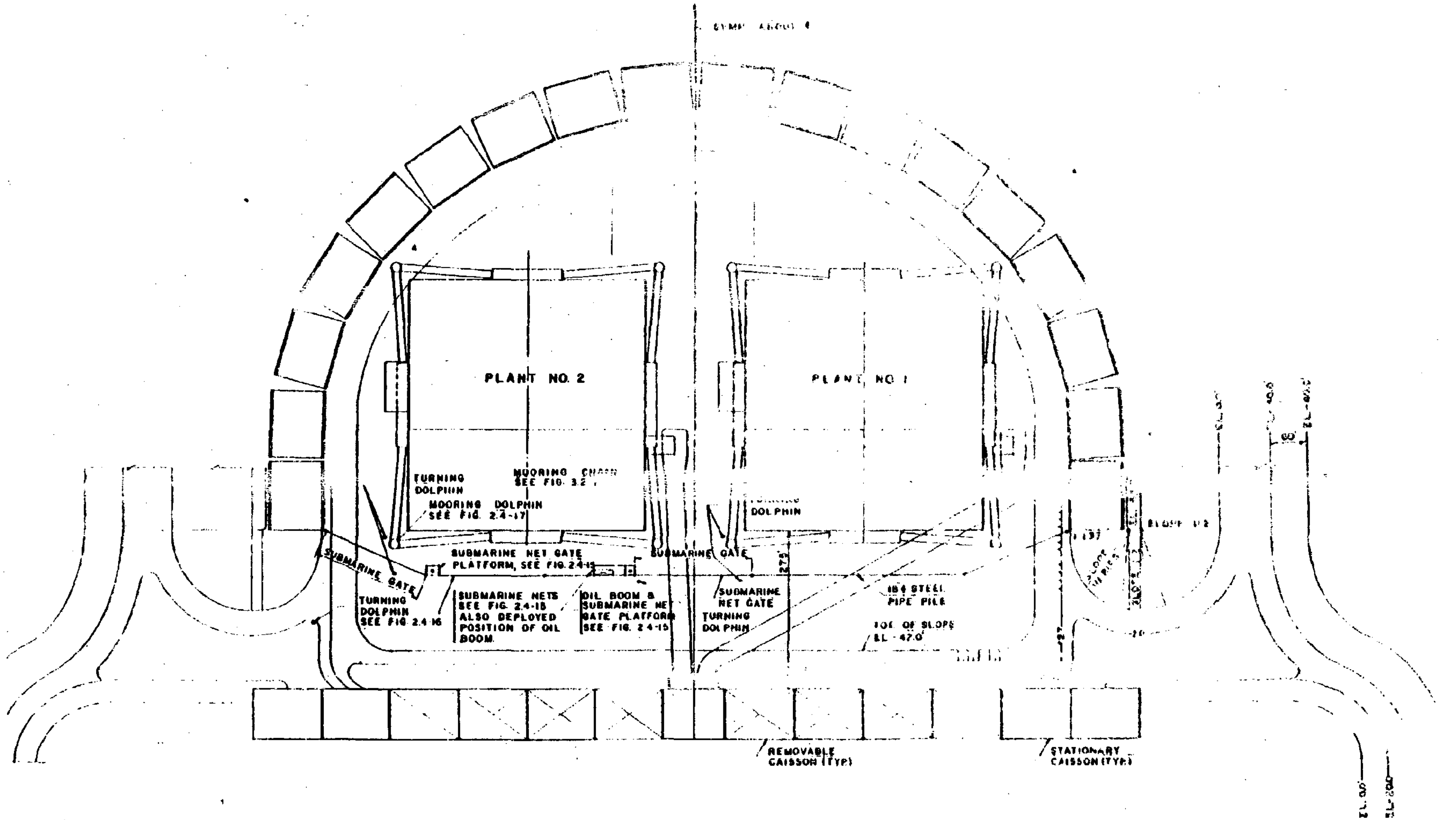

SYMM ABOUT ℄
PLANT NO. 2
PLANT NO. 1
TURNING DOLPHIN
MOORING CHAIN SEE FIG. 3.2
MOORING DOLPHIN SEE FIG. 2.4-17
DOLPHIN
SUBMARINE GATE
SUBMARINE NET GATE PLATFORM, SEE FIG. 2.4-15
SUBMARINE GATE
TURNING DOLPHIN SEE FIG. 2.4-16
SUBMARINE NETS SEE FIG. 2.4-15 ALSO DEPLOYED POSITION OF OIL BOOM.
OIL BOOM & SUBMARINE NET GATE PLATFORM SEE FIG. 2.4-15
SUBMARINE NET GATE
TURNING DOLPHIN
18 ϕ STEEL PIPE PILE
TOE OF SLOPE EL -47.0'
SLOPE 1:2
SLOPE 1:2
60'
EL -40.0
EL -28.0
EL -30.0
EL -28.0
REMOVABLE CAISSON (TYP)
STATIONARY CAISSON (TYP)

Figure A-2

TABLE A-1 <u>FNP General Characteristics</u>

Displacement	160,000 tons
Platform	378 feet x 400 feet x 44 feet
Overall Height	209 feet - 174 feet above water line
Draft (Salt Water)	35 feet
Net Electrical Output	1,150 MW
Transmission Voltage	345 kV

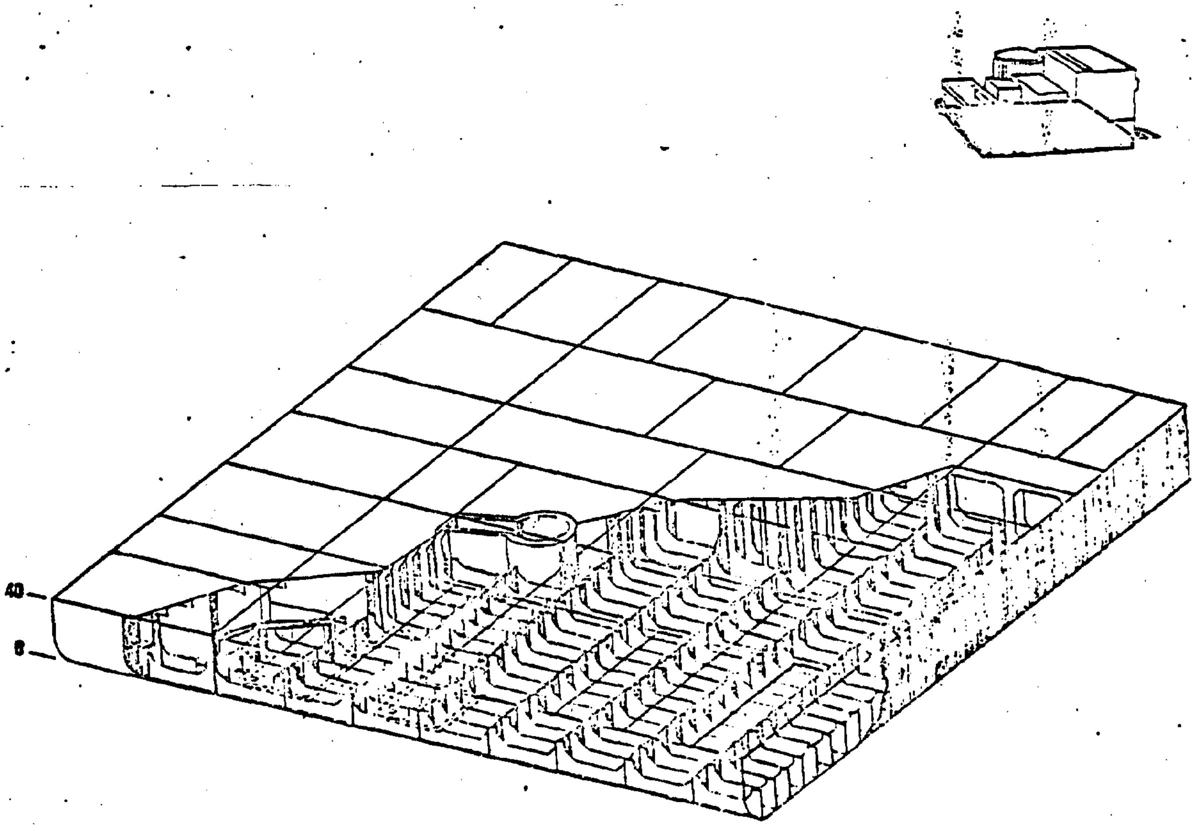


Figure A-3. PLATFORM STRUCTURE AND COMPARTMENTATION

The turbine-generator and its auxiliaries are located in the turbine building. The power generation plant contains a standard Westinghouse six-flow-tandem-compound 1,800 RPM turbine with 44-inch last row blades and a 1,400 MVA, 4-pole generator with a hydrogen-cooled rotor and a water-cooled stator. Efficiency of the power generator cycle is optimized by six stages of feedwater heating, two stages of steam reheating, and use of extraction steam to drive the feedwater pump turbine.

Output from the generator is fed into a pair of step-up transformers and then through a gas-insulated substation to potheads on the edge of the platform. Four separate onboard emergency power supplies are provided. The instrumentation and control systems are consistent with modern powerplant practice and include a centralized control room and local control stations. These systems enable plant operating personnel to monitor and operate the plant safely and effectively.

The administration and service facilities provide working and living space for operating, administrative, and maintenance personnel and supplies for normal and emergency conditions. There are sleeping quarters, a cafeteria, administrative offices, supply rooms, and recreation rooms.

The platform (Figure A-3) is a 44-foot deep grillage arrangement of shear webs (longitudinal and transverse bulkheads and side shell) separating the bottom shell and the strength deck. The strength deck and bottom shell are strengthened by longitudinal stiffeners and transverse girders. The platform's all-welded, carbon steel plate-stiffener framing is designed to meet requirements of the American Bureau of Shipping (ABS) Rules for Building and Classing Steel Vessels and Barges. To give planes of stiffness, bulkheads are framed horizontally with vertical bulkhead webs in line with the deck and bottom shell girders. The bulkheads divide the platform into watertight compartments sized to fulfill the Coast Guard criteria for a two-compartment standard of subdivision.

Structures on the platform are arranged to maintain trim. The largest single mass, the containment building and its associated structure and equipment, is slightly off center. Other major masses located around the containment building are the turbine generator, switchyard, and their foundations and equipment, the spent fuel pit and its shielding, the shielded auxiliary components in the processing and waste treatment systems, and the shielded engineered safeguard equipment.

For the major structures on top of the platform, structural steel connected by welding and similar in design to a conventional plant is generally used. Bolted joints are used in special circumstances, and concrete is used in such areas as the containment, fuel pit, auxiliary nuclear systems, and safeguards area. A steel wave shield around the plant's periphery extends from the 40- to 70-foot level and serves as a weathertight barrier, protecting the plant from waves during towing.

Several service systems are independent of the nuclear and generating plants. The platform has a general fire alarm system, and chemical foam, water spray, or carbon dioxide protection is provided on a selective basis for fire-hazardous areas. Plant list and trim are controlled by a trim system that transfers water among trim tanks to compensate for changes in weight distribution. Provisions are made for potable water supplies, collecting and treating crew-generated waste, and removal of excess water from bilges of watertight compartments and exposed weather surfaces.

Various other systems provide for control of solid, liquid, and gaseous radioactive wastes, mechanical handling equipment, and process systems for refueling operations, rejection of waste heat to the ocean, and engineered safeguards to protect the plant during accidents or other nonroutine incidents.

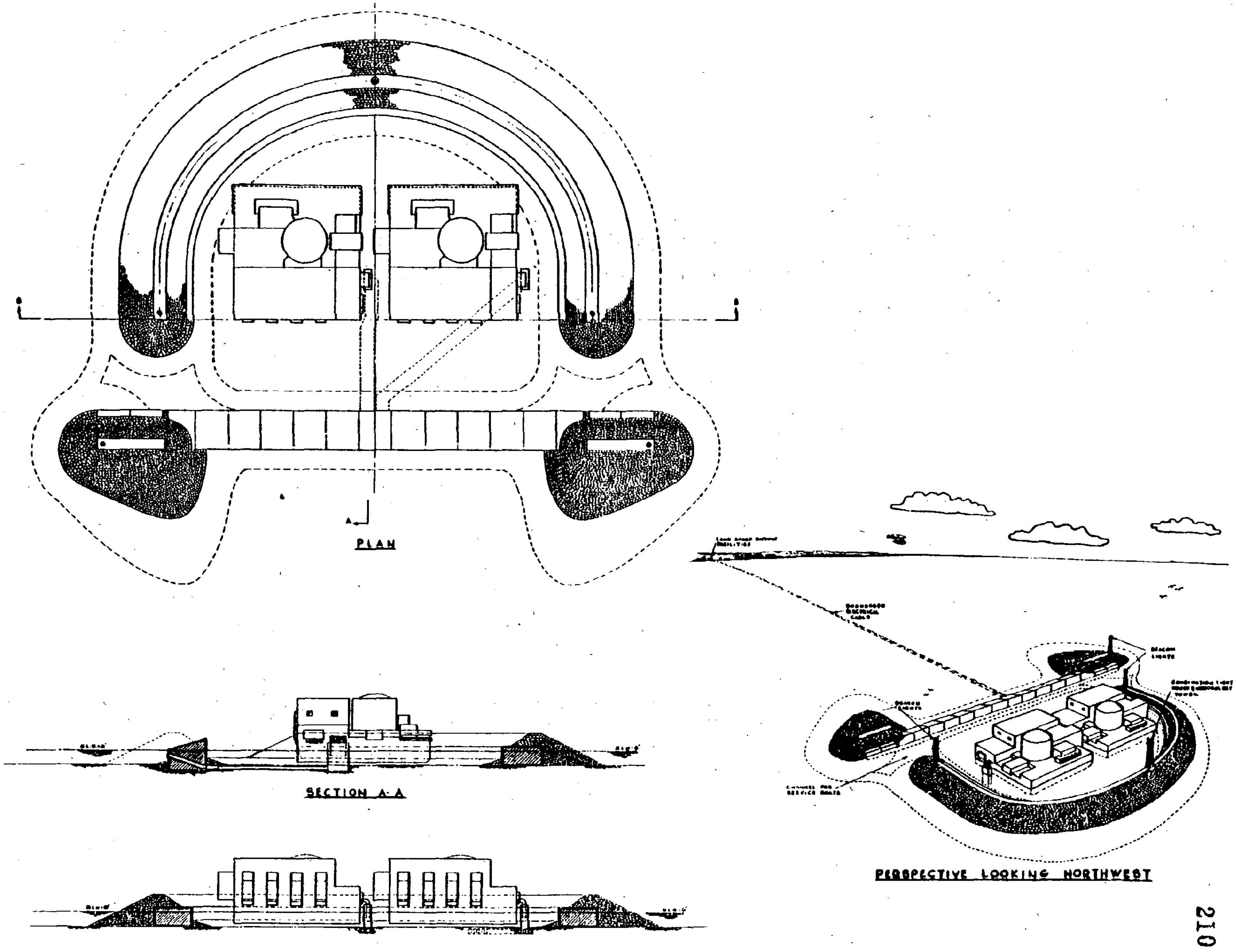
For a plant in place, the morring system, circulating cooling water discharge, and electrical power connections can accommodate movement of the platform due to tides, winds, design basis seismic occurrences, and other environmental challenges.

The Breakwater

The D-shaped breakwater forms a protective basin for two plants (see Figure A-4).[1/] For its initial application at the Atlantic Generating Station and presumably at similar sites, the breakwater covers about 100 acres. The curved portion of the breakwater faces the open ocean and is about 3,000 feet long, 300 feet thick at the base, 30 feet thick at the top and extends 64 feet above mean low water. It is not a homogeneous structure. After the foundation is prepared, concrete caissons are sunk in position and then filled with sand and rocks. Sand and quarry run rock are then placed to form a mound which becomes the core of the breakwater. The mound is covered with a layer of 800-pound rock topped with a layer of 8- to 10-ton jetty stone and then with layers of precast armor units, known as dolosse, for wave protection (Figure A-5). The breakwater contains about 6.5 million tons of sand, gravel, rock, and concrete. The straight section of the breakwater is 2,140 feet long and is constructed partially of removable caissons to permit entry or exit of the FNP (see Figure A-6). The massive ends are of rock and dolosse. The approximately 200-foot apertures between the curved and straight portions allow access to service vessels and provide circulation between basin and ocean water. Breakwaters for FNPs will be the largest manmade structures ever placed in the ocean.

Transmission Lines

A major part of the connection between the powerplant and a shore-based switching station is a proposed submarine cable. It would, of course, transmit



PLAN

SECTION A-A

SECTION B-B

PERSPECTIVE LOOKING NORTHWEST

PUBLIC SERVICE ELECTRIC AND GAS COMPANY ATLANTIC GENERATING STATION	ARRANGEMENT AND PERSPECTIVE OF PLANT Figure A

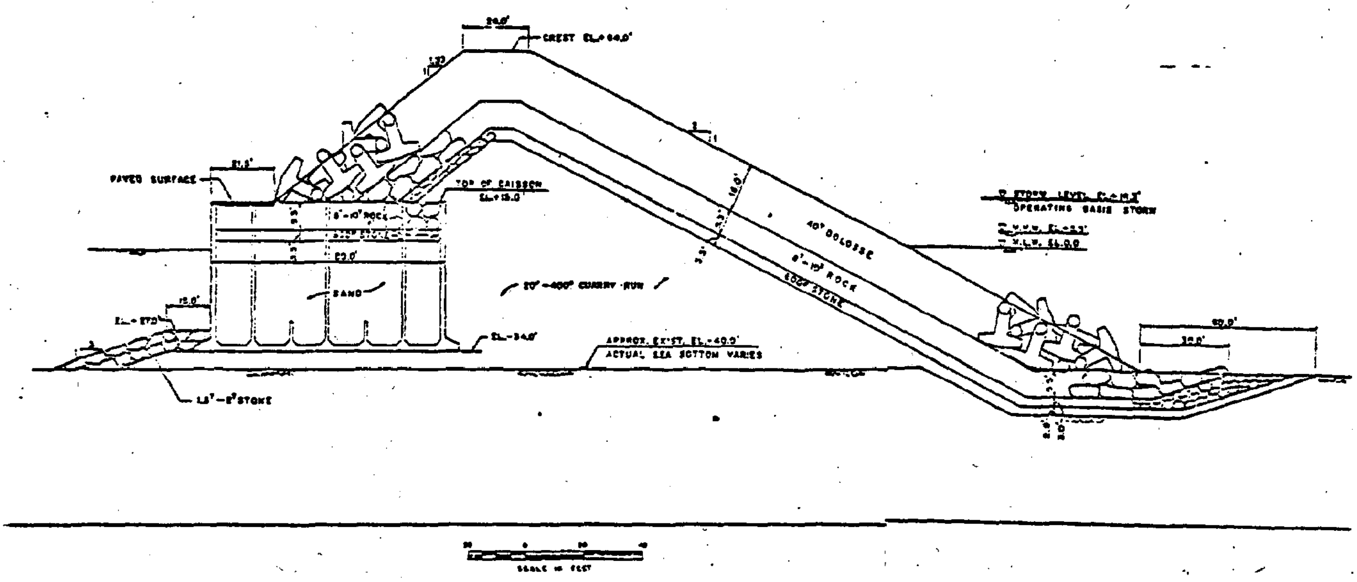


Figure A-5. Main Breakwater, typical cross section

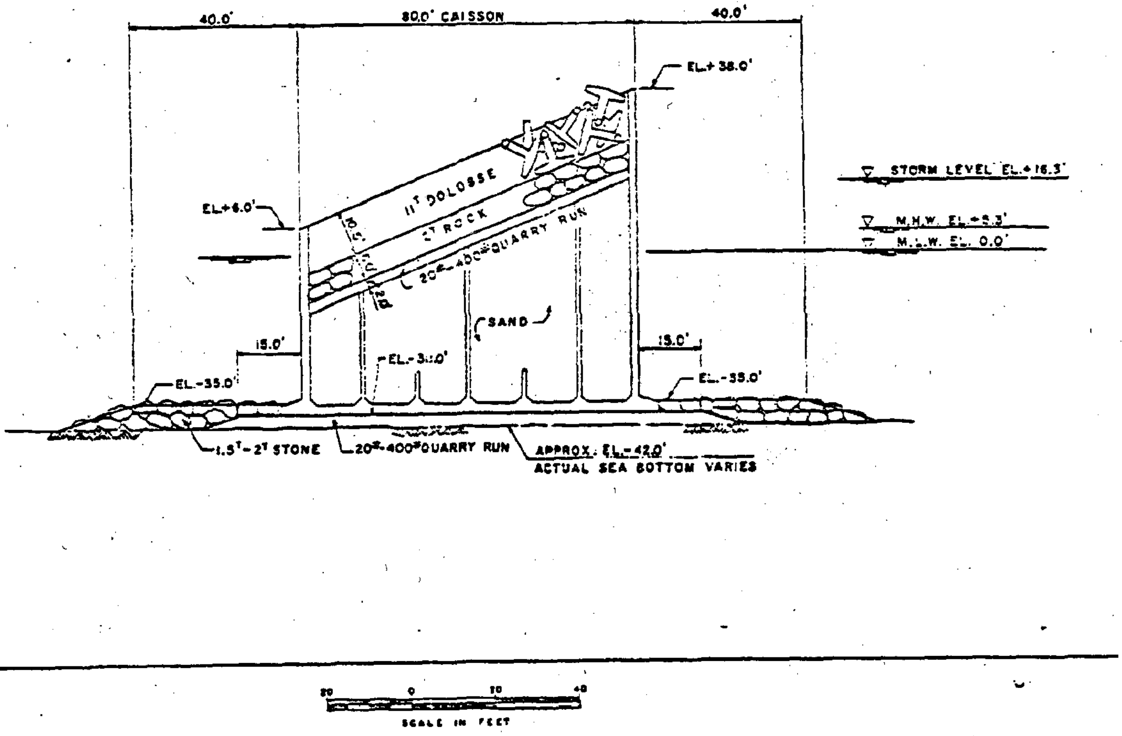


Figure A-6. Closure Breakwater Caisson, typical cross section electric power from the generating plant to the electric grid and provide an independent power source to supply the protective and safety systems in the nuclear plant.

Options for the cable system include impregnated-paper-insulated cables, solid dielectric cables, compressed-gas-insulated cables, and pipe cables. A review of submarine cable technology [2/] suggests that further work is required to develop submarine cable systems for offshore plants. Cable manufacturers say that there are no fundamental barriers to developing the required technology.

One alternative for power transmission is overhead lines supported from transmission towers or a causeway. Overhead lines appear technically feasible in warm climates, even though buildup of excessive salt deposits may be a problem, but in cold regions, spray freezing on the insulators is a problem. Overhead lines and causeways are likely to be unacceptable both aesthetically and because they obstruct marine traffic. A further drawback is the danger of ships' colliding with the towers.

Whatever system is used, a minimum of two independent three-phase circuits is needed for a single-unit installation. Multiple-unit stations will require more circuits. For example, the two-unit station proposed by PSE&G will use five circuits -- two for each offshore plant and a spare.

Installation procedures for the submarine transmission system will depend on the type of cable, but all must be buried in a trench on the ocean floor in order to protect the cables from physical damage, primarily ship anchors. Anchors can penetrate 8 feet in sand. Thus, depending on local marine traffic and on the extent of bottom sand movement due to waves and currents, cables will be buried at least 10 and possibly more than 15 feet deep.

Shore Facility

A nearby onshore construction facility may include a concrete batch plant with bulk storage areas for cement and aggregates, a paved area for production of concrete caissons and concrete armor for the breakwater, a shipping dock, and cranes serving the storage, production, and shipping areas. If rock is transported from the quarry by truck or rail, the onshore support facility must also include a rock storage area, a barge loading dock, and cranes. It no existing facilities are acceptable then a new facility is required which would occupy about 100 acres, a major commitment of land, albeit for a short time, separate from the powerplant site. Additional dredging for a 20- to 30-foot harbor and shipping dock may also be required. When construction is finished (or if existing facilities were used), the shore facility would require only about 15 acres, just enough for moving supplies and personnel to the FNP and for connecting the power transmission cables. Maintenance facilities will be a continuing need.

Site Characteristics and Design Criteria

The General Case

Several factors should be considered in offshore reactor siting:

- Other activities in the area -- recreation, conservation, industry, commerce, etc.
- Hazards to the reactor plant, i.e., airports and seismic faults in the vicinity.
- Proximity to existing power transmission corridors onshore and to electrical load centers.
- The ecological effects of plant construction and operation on the local marine community.

Water Depth and Wave Height. Acceptable water depth is determined by the draft of the FNP and the space required to assure that the barge will clear the bottom under all sea and wind conditions. Dredging for an access channel and to deepen the protective basin may be feasible in shallow water. The FNP proposed by OPS [3/] has a draft of 35 feet and requires a minimum water depth of 47 feet in the basin.

The maximum water depth practical for FNPs protected by rock breakwaters will probably be determined by economics rather than by engineering. In coastal waters, wave height is directly related to water depth; the result is that as depth increases, so must breakwater freeboard in order to supply proper protection. Thus, breakwater height and subsequently its cost increase drastically with water depth. Although technical feasibility is the overriding issue in breakwater construction, as a practical matter, the maximum depth in which an FNP is located may be limited to the extent that breakwater height and cost do not force overall costs above those of an alternative electrical power source. A maximum water depth of 75 feet has been suggested for the offshore stations proposed by OPS. Another recent study of offshore siting suggests a depth limit of about 70 feet for a 2,000-MWe station; the corresponding depth for a 4,000-MWe is 100 feet.

Meteorological Consideration. Two changes in water level characteristic of large storms may challenge the FNP. The first is a storm surge which is a positive or negative change (it may be substantial) in the mean water level caused by the normal effects of tides and the effects of pressure differentials associated with the storm's passage. The second is resonance which is the superposition of wave effects within the breakwater resulting from refraction, overtopping, on reflection of waves outside the breakwater. These are discussed in Chapters IV and V.

High winds that accompany storms, hurricanes, and tornadoes exert sizable forces on FNPs and their moorings. Engineering solutions appear available, and wind forces should not be a major issue in site selection. The PSE&G FNP is designed to withstand a tornado or waterspout with a maximum wind speed of up to 360 mph and the probable maximum hurricane with a 10-minute sustained wind speed of 200 mph below 64 feet.

The atmospheric diffusion at an offshore site must provide adequate dispersion for gaseous releases under accident and under normal operating conditions. Table A-2 shows the minimal acceptable diffusion characteristics proposed by OPS.

Population Separation Distance. Factors to be considered in site selection relating to both the proposed design and to peculiarities of the site include population density and uses of the environs, including the exclusion area, low population zone, and population center distance. The exclusion area is defined as that area around the reactor over which the reactor licensee has authority to determine all activities, including exclusion and removal of personnel and property. Activities unrelated to the reactor may be permitted in an exclusion area provided that effective control over the area can be exercised by the licensee in the event of an emergency.

The low population zone is defined as the area adjacent to the exclusion area in which the number and density of residents permits protective measures to be taken on their behalf in the event of serious accident. The population center distance refers to the distance from the reactor to the nearest boundary of a densely populated center containing more than about 25,000 residents.

TABLE A-2

ENVELOPE OF ADVERSE ATMOSPHERIC DIFFUSION CONDITIONS FOR OFFSHORE SITES

Accident Conditions

Time Following Accident	Atmospheric Conditions Equivalent to:
0-8 hours	Pasquill Type G, windspeed 1/2 meter/sec., uniform wind speed
8-24 hours	Pasquill Type G, windspeed 1-1/2 meter/sec., variable direction within a 10° sector
1-4 days	a) 50% Pasquill Type D, windspeed 1-1/2 meter/sec. b) 50% Pasquill Type G, windspeed 1-1/2 meter/sec.
4-30 days	a) 33-1/3 Pasquill Type D, windspeed 5 meters/sec. b) 66-2/3 Pasquill Type F, windspeed 2 meters/sec. c) Wind frequency in 22-1/2° Sector 90%.

Average Conditions Over 1 Year (Normal Operation)

a) 33-1/3 Pasquill Type C, windspeed 3 meters/sec.
b) 33-1/3 Pasquill Type D, windspeed 5 meters/sec.
c) 33-1/3 Pasquill Type G, windspeed 2 meters/sec.
d) Wind frequency in 22-1/2° sector, 30%.

Generally, nuclear powerplant sites which have an exclusion area radius of about 0.4 miles and a low population zone radius of 2 miles provide reasonable assurance that the exposure guidelines can be met even under extremely poor meteorological conditions. As more information of over-ocean meteorology becomes available, these distances may require modification. Further, the distances consider biological transport mechanisms only if they are currently identified and defined. The guidelines also require that the closest boundary of the nearest population center of more than about 25,000 persons be not less than one and one-third times the distance to the outer boundary of the low population zone. Where large cities or high population densities are involved, more distance may be necessary because of total integrated population dose considerations.

An exclusion area and a low population zone are as much a safety requirement for an offshore plant as they are for a land-based one. However, implementation of this requirement for an FNP may differ considerably because a land-based plant either owns or otherwise controls its exclusion area and the offshore one cannot. The breakwater could conceivably bound the exclusion area, but a larger plant would require restrictive zoning of the open sea, an action requiring careful interpretation of laws of the sea. They are discussed in Chapter VIII.

Aesthetics. Intrusion on the landscape of large containment structures, rectilinear sheet-metal buildings, cyclone fences, brick stacks, and other appurtenances of power stations may be objectionable, especially in a naturally scenic area. Offshore stations are visible from a longer distance by more people than onshore plants. Distance is important to aesthetics. A two-unit station located 10 miles offshore would be almost unnoticeable; at 3 miles it would be noticeable but probably unobtrusive once it becomes a permanent fixture of the seascape. (Just as ships have become acceptable because they are a common visual occurrence offshore).

Geology and Seismology. Requirements for nuclear power reactors siting specify that the geologic, seismic, and engineering characteristics of a site be investigated in sufficient detail to permit adequate engineering solutions to geologic features and seismic events affecting the proposed site. Here the integrity of the breakwater and the mooring system are essential to keeping the FNP motion within safe bounds.

Geologic and seismic investigations are complicated by the site's being underwater. Geologic and seismic events could include tectonic uplift or subsidence; surface faulting, possibly accompanied by permanent ground displacement; ground motion; submarine landslides; soil liquefaction; and tsunamis. Tectonic movement, surface faulting, and permanent ground displacement may result in dislocation and shifting of the ocean floor that in turn can lead both to tilting, misalignment, and failure of a breakwater founded on the bottom as well as grounding of the FNP. Obviously, locations with potential for these phenomena will be avoided.

For land-based reactors earthquake-induced ground motion is not an insurmountable problem, and it probably will not be for offshore plants. The OPS plant is designed to withstand 0.3g horizontal ground acceleration and 0.2g vertical ground acceleration.

A key factor governing response of offshore structures to earthquake motion is the character of the ocean floor material. The extensive damage from major earthquakes frequently is associated with unconsolidated water-saturated rock and soil; the problem is sediment liquefaction -- the tendency of saturated sediments to lose their shear strength or to liquefy when subjected to vibrations of the sort that must be considered in a seismic event. The rearrangement of the saturated sediment toward a more compact state while there is no escape path for the excess water can result in liquefaction. Earthquake liquefaction occurs principally in surface and near-surface sediment. Some types of relatively loose, unconsolidated sand or silt on the ocean bottom, often of recent deposition, could fail in this way. If liquefaction were to occur, the sand-water mixture would act as a fluid with density close to that of sand and would tend to cause aboveground structures to sink or tilt.

Site investigations may be necessary to determine the long-term effects of ocean waves of low frequency and large amplitude on the stability of the soil adjacent to the breakwater.

Seismic activity can create tsunamic conditions at locations remote from the source of disturbance. Tsunamis are discussed in Chapter IV and Appendix C.

The Specific Case: The Proposed Atlantic Generating Station

For PSE&G's proposed floating nuclear powerplant off New Jersey (the Atlantic Generating Station), Offshore Power Systems has prepared design criteria correlated to the specific site. Although the data have not yet been verified by the Atomic Energy Commission, the table is reproduced in Table A-3.

Activities of Plant Construction and Operation

The Atlantic Ocean, Gulf of Mexico, Pacific Ocean, and Great Lakes are all unique in terms of water quality, hydrology, climate, geology, and biology. The effects of construction and operation of FNPs, then, will be generally similar but will be site specific. Chapters V and VI discuss the effects in some detail.

Construction

Preparation of the site and construction of a breakwater for an FNP may take 4 years. It is expected to occur in the following sequences:

TABLE A-3

SITE ENVELOPE COMPARISON
PLANT WIND AND WAVE LOADS

Design	Site Envelope Value	Atlantic Generating Station Site Value
Maximum Wave Conditions Within Basin:	Must not cause greater than 3° pitch and roll of plant. Preliminary Limits: Less 20 feet in height.	Calculated to be below allowable limits - to be confirmed by model tests.
Operating Basis Wind:	180 miles per hour	156 miles per hour sustained - 1 minute.
Design Basis Wind:	(Maximum Tornado) Tangential Velocity = 300 mph Translational Velocity = 60 mph Pressure Drop = 3 psi	(Maximum Tornado) Tangential Velocity = 300 mph Translational Velocity = 60 mph Pressure Drop = 3 psi

SITE ENVELOPE COMPARISON
SITE HAZARDS

Design Criteria	Site Envelope Value	Atlantic Generating Station Site Value
Ship collision:	The breakwater must prevent colliding ships or displaced portions of breakwater from contacting plant.	Analysis shows that contact will be prevented. This will be confirmed by model testing with a scale model of a 326,000 DWT, 1,135-foot vessel of 46-foot draft.
Hazardous Cargoes:	Probability of collision and explosion of munitions ship must be less than 10^{-6}/year.	Probability of collision and explosion of munitions ship is approximately 7×10^{-10}/year and during peak traffic (wartime) years is approximately 1.5×10^{-9}/year.
	Probability of collision and fire from LNG tanker must be less than 10^{-6}/year.	Probability of collision and fire from LNG tanker is approximately 2.2×10^{-9}/year.

SITE ENVELOPE COMPARISON
SITE HAZARDS (Cont'd)

Design Criteria	Site Envelope Value	Atlantic Generating Station Site Value
Hazardous Cargoes (Cont'd)	Probability of collision and rupture of an anhydrous ammonia tanker must be less than 10^{-6}/year. OR Provide emergency ventilation or breathing apparatus.	Probability of collision and rupture by an anhydrous ammonia tanker is under study. If necessary, emergency breathing apparatus can be supplied.
	Fuel spills other than LNG must be prevented from coming nearer than 100 feet to plant.	Oil boom within breakwater prevents fuel spill from coming nearer than 100 feet to plant.
Aircraft Collision:	Probability of fixed-wing aircraft/plant collision must be less than 10^{-6}/year.	Probability of fixed-wing aircraft/plant collision is approximately 3×10^{-7}/year.

SITE ENVELOPE COMPARISON
SITE WATER DEPTH

Design Criteria	Site Envelope Value	Atlantic Generating Station Site Value
Minimum Water Depth:	48 feet (approximately 35-foot draft plus 13-foot plant motion during tornado).	50 feet - Dredged depth of 50 feet at mean low water. (Normal tide rise = 5.3 feet maximum storm surge plus tide during PMH is conservatively taken as plus 25 feet.)
Maximum Water Depth:	76 feet (during the postulated sinking occurs simulatneously with the operating basis storm OR with design basis tsunami.)	66.3 feet plus wave height within basin - (dredged depth of 50 feet at mean low water plus operating basis storm surge and tide of 16.3 feet. Wave height within basin of less than 9.7 feet during operating basis storm to be confirmed by model testing.)

SITE ENVELOPE COMPARISON
GEOLOGY AND SEISMOLOGY

Design Criteria	Site Envelope Value	Atlantic Generating Station Site Value
Breakwater Support:	Seabed must support breakwater under static and dynamic conditions.	After initial deformation, the seabed will adequately support the breakwater (approximately 10,000 lbs/ft^2.
Sunken Plant Support:	Seabed must support a static load of 1,600 lbs/ft^2.	After initial deformation, the seabed will support the plant with a factor of safety in excess of 5.
Seismic Response of Seabed:	Characteristics must not exceed defined response spectra with maximum acceleration values of 0.30g horizontal and 0.20g vertical.	Characteristics are within defined spectra. Maximum accelerations are 0.20g horizontal and 0.13g vertical.

METEOROLOGY

Design Criteria	Site Envelope Value	Atlantic Generating Station Site Value
Minimum Acceptable Atmospheric Diffusion Conditions:	Minimum acceptable conditions are shown in Table A-2.	Predicted x/q values are better than reference plant by a factor of 2. These conditions will be verified by meteorological test program.
Rainfall:	Plant is designed for a maximum of 7"/hour.	Recorded monthly precipitation (measured at Atlantic City) has never exceeded 5"/month.
Air Temperature:	Plant is designed for a minimum of (-) 5°F near sea surface.	Minimum air temperature (measured at Atlantic City) from 1951 to 1960 was 5°F. Site conditions near sea surface will be warmer - to be verified by meteorological test program.
Water Temperature:	Plant is designed for a minimum of 30°F and a maximum of 85°F.	Water temperatures obtained to date from test program are 37.2°F minimum (January 1973) and 75.7°F maximum (August 1972).

SITE ENVELOPE COMPARISON
MOORING SYSTEM

Design Criteria	Site Envelope Value	Atlantic Generating Station Site Value
Pitch and Roll:	Pitch and roll accelerations must not exceed those due to a motion having an amplitude of 3° and a period of 13 seconds.	Accelerations will be determined by wave conditions within basin. Mooring system design will not amplify these accelerations.
Heave:	Vertical accelerations must not exceed 0.03g.	Accelerations will be determined by wave conditions within basin. Mooring systems will not amplify these accelerations.
Plant/ Breakwater Contact:	The mooring system must prevent plant/breakwater contact.	The mooring system will prevent plant/breakwater contact. (Plant/seabed contact is prevented by minimum water depth).
Alignment of Connections:	Mooring system must sufficiently limit plant motion to maintain the integrity of the transmission lines and circulating water discharge structures.	Mooring system restrains horizontal motion of these points to 8.2 feet maximum, which is sufficient. (This motion occurs only under simultaneous worst motions; simultaneous worst motion is very unlikely).

- If no facility within a reasonable distance has the required capabilities, then an assembly-marshaling yard must be constructed. About 100 acres of land must be acquired, the dolosse and caisson manufacturing facility prepared, a barge docking facility built, and access and transportation facilities for people and materials established.
- Preparation of the FNP site will take several months of dredging and leveling. Construction of the breakwater will then begin; it will involve activity both on- and offshore and will probably extend over 2 or 3 years, depending on weather.
- Installation of underground transmission lines will require trenching between the site and the shore. Either an aerial or underground transmission line from the onshore facility to a substation will be constructed.

Plant Operation and Maintenance

Condenser Cooling System. The basic components of an FNP water cooling system as exampled by the proposed Atlantic Generating Station off New Jersey [4] are illustrated in Figure A-7. All the routine discharges from an FNP are contained in either the condenser cooling water or the plant building ventilation systems. No liquid wastes are expected to be discharged routinely into the protective lagoon directly.

The condenser cooling water is pumped at a rate of about 1 million gpm and a velocity of 1 ft./sec. through intake screens inside the lagoon into a high-flow, low-temperature-rise (16° F temperature increase) condenser system. It is discharged into a low-head catchment basin from which it flows to a submerged discharge structure outside the breakwater into the ocean. Discharge velocity is slightly less than 8 ft./sec.; it

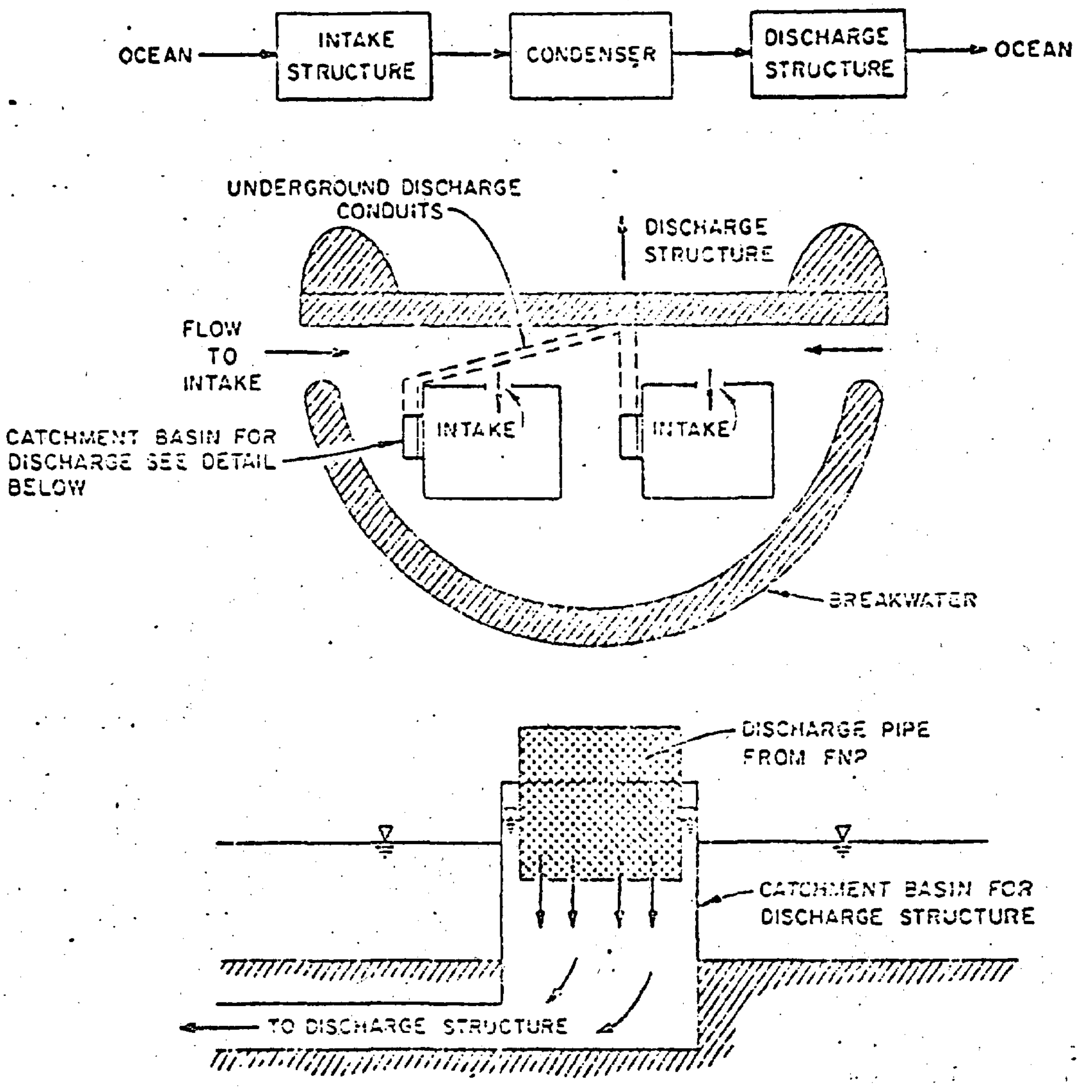


Figure A-7. Cooling water system for an offshore floating nuclear plant.

will vary with the discharge system used. Time of transit from point of intake to point of discharge is approximately 4 min. All secondary liquid waste, laundry and sanitary, as well as the liquid radioactive waste, is treated and then discharged into the catchment basin.

Waste heat discharged to the ocean per FNP will amount to about 7.5 x 10^9 BTU/hr, with the thermal plume occupying several hundred acres due to the high flow rate. Dilution and other cooling mechanisms will reduce the 16°F increase.

Hydraulic model studies have been conducted for the Atlantic Generating Station to evaluate alternate cooling water discharge arrangements.[5/] They have shown that for a two-unit FNP, either a surface or bottom point discharge can achieve a reduction in temperature elevation from 16°F to 2.5°F at the boundary of the near field. A temperature reduction of 16°F to 1°F could be achieved by a multiport diffuser,[6/] but it would increase costs and increase residence time for entrained organisms up to 300% at high temperature.

A variety of processes in the coastal zone -- tidal effects and macroscale circulation, for example -- combine to produce a hydrographic situation with no dominant current pattern. Thus, analysis of the far field effects may be very difficult for offshore plants.

The openings in the breakwater proposed by PSE&G lie normal to the coastline and thus are generally parallel to the coastal currents (see Figure A-7). Two patterns of current flow lead to two different impingement possibilities. The first we may envisage is a strong coastal current of more than 1 fps. Under this condition, water flow will be approximately 2 fps into one breakwater opening and roughly zero through the other. When there is no coastal current, flow into the breakwater will average roughly 0.75 fps, with a maximum of 1.3 fps into each opening. Water flow at the intake of the barge will be roughly 1 fps under all conditions.

The challenges presented by the condenser cooling system to the environment are discussed in Chapter V.

Radiological Considerations. Operation of the FNP station during the 30- to 40-year period for which it is licensed should differ only slightly from land-based plants with respect to nuclear operation. Periodically, fresh reactor fuel will have to be provided, and spent fuel will be removed. After the initial core loading, approximately one-third of the core, about 65 fuel assemblies, will be replaced annually. The total weight of fresh fuel shipped annually will be about 92,000 pounds.

Spent fuel will have operated on the average at the equivalent of 24,000 full power hours. Prior to shipment, the spent fuel assemblies will be cooled in the spent fuel pool for about 4 months after removal from the reactor. The potential for the accidental release of radioactivity during refueling, fuel shipment, and operations is discussed in Chapter IV.

Waste handling and treatment systems for current FNP concepts represent current LWR concepts with ice containment adjusted to apply to an offshore plant.

Before any treated liquid wastes are released, samples will be analyzed for type and amount of radioactivity. The wastes will then be recycled, released under controlled conditions into the circulating water, or further processed. Estimated liquid releases are given in Table A-4. More complete descriptions may be obtained from the environmental impact statement (EIS) of similar plants.

TABLE A-4

Estimated Annual Release of Radionuclides in Liquid Effluent

Nuclide	Release per Unit (Ci/year) [1]	Nuclide	Release per Unit (Ci/year)
Na-24	3.0(-5)	Te-129m	2.9(-4)
P-32	1.0(-5)	Te-129	1.9(-4)
P-33	5.0(-5)	Te-131m	1.8(-4)
Cr-51	2.0(-4)	Te-131	3.0(-5)
Mn-54	4.0(-5)	Te-132	3.5(-3)
Mn-56	4.8(-4)	I-130	2.6(-4)
Fe-55	1.9(-4)	I-131	2.0(-1)
Fe-59	1.1(-4)	I-132	5.9(-3)
Co-58	1.8(-3)	I-133	8.0(-2)
Co-60	2.3(-4)	I-134	1.3(-4)
Ni-63	2.0(-5)	I-135	1.1(-2)
Br-82	7.0(-5)	Cs-134m	6.4(-4)
Br-83	6.0(-5)	Cs-134	1.7(-1)
Rb-86	5.0(-4)	Cs-135m	3.0(-5)
Rb-88	9.4(-3)	Cs-136	7.0(-2)
Rb-89	4.8(-4)	Cs-137	1.2(-1)
Sr-89	8.0(-5)	Cs-138	6.4(-3)
Rb-90	2.0(-5)	Cs-139	2.2(-4)
Sr-91	2.0(-5)	Ba-137m	9.9(-3)
Y-91m	8.0(-5)	Ba-139	4.0(-5)
Y-91	3.0(-4)	Ba-140	8.0(-5)
Y-92	1.0(-5)	La-140	7.0(-5)
Nb-92	4.0(-5)	Ce-141	1.0(-5)
Zr-95	1.0(-5)	Pr-143	1.0(-5)
Nb-95	1.0(-5)	W-187	1.7(-4)
Mo-99	3.9(-3)	Np-239	7.0(-5)
Tc-99m	3.6(-3)	Total, excluding tritium	0.70
Sn-117m	1.0(-5)		
Sn-123	2.1(-3)	Tritium	350
Te-127m	6.0(-5)		
Te-127	8.0(-5)		

[1] The number in parentheses is a power of ten, i.e., 3.0(-5) - 3.0 x 10^{-5}.

In addition to the sources listed, less than 0.2 Ci per unit may be released annually in untreated effluent from the turbine building condensate leaks. The liquid radioactive waste system is capable of processing liquid effluents to satisfy requirements.

Radioactive materials released to the atmosphere as gaseous effluents will include fission-product noble gases (krypton and xenon), halogens (mostly iodines), tritium contained in water vapor, and particulate material, including both fission products and activated corrosion products. Long-lived gaseous radioactive waste will come primarily from the degassing of the primary collant during letdown of the cooling water into the holding tanks. Additional sources of gaseous waste include ventilation air released from the auxiliary building and the turbine building, off-gasses from the steam generator blowdown tanks, off-gas from the condenser steam air ejectors, and purging of the reactor containment building. Selective controlled emission ensures that gaseous wastes will be released only during favorable meteorological conditions. Estimated releases are listed in Table A-5.

One other possible radiation challenge will occur if neutrons coming from the bottom of the reactor reach the water under the barge in sufficient numbers so that induced radioactivity in the water and in aquatic species living in that volume of water becomes important.

Worker exposure will about equal that at a shore-based plant although workers will spend approximately twice as much time onsite. Living quarters will be more isolated from direct sources of radiation than working areas. If gaseous releases are controlled to take advantage of local atmospheric conditions, the individual doses to workers as a result of living onsite should be even less than those acquired on duty.

TABLE A-5

Estimated Annual Releases of Radioactive Gasses 1/

	Releases per unit (ci/year)							
				Gas Processing System		Steam Generator Leak		
Isotope	Turbine Building	Auxiliary Building	Containment Purge	Degassification	Leakage	Blowdown Tank	Air Ejector	Total
Kr-83m		1.2						2.4
Kr-85m		6.7			3		6.7	16
Kr-85		6.7	13	906	212		6.7	1,144
Kr-87		3.6					3.6	7
Kr-88		12			3		12	27
Kr-89		0.3					0.3	0.6
Xe-131m		6.2	2.3	1	1		6.2	16
Xe-133m		13	0.9		11		13	37
Xe-133		1,020	17		1,440		1,032	3,495
Xe-135m		0.8					0.8	1.6
Xe-135		20			26		20	66
Xe-137		0.6					0.6	1.2
Xe-138		2.7					2.7	5.4
I-131	0.04	0.064	0.0010			0.001	0.18	0.28
I-133	0.019	0.0840				0.0006	0.083	0.19

1/ May be controlled by permanent storage or held for release under favorable conditions.

Chemical and Biocide Systems. Operation of an offshore nuclear powerplant will result in the release of various chemicals, including biocides, to the environment. In general, their release will be of the same type and magnitude as would be expected from a shore-based plant.

The major use of inplant chemicals is control of corrosion, deposition, and fouling. Chemicals contained in the closed nuclear system are essentially conserved. Any leakage or discharge is carefully managed and subject to processing for reuse or offsite disposal.*

Chemicals used in power generation are hydrazine, morpholine, and phosphates. These materials are used in relatively small amounts and are discharged in the steam generator blowdown. Approximately 640 pounds of 35% hydrazine solution, 500 pounds of morpholine solution, and 3,300 pounds of disodium and trisodium phosphate will be discharged each year during normal plant operations. When diluted with sea water in the cooling water discharge, the hydrazine and morpholine are too dilute to be detectable, and the phosphate concentration is about 2×10^{-3} ppm.

The cooling water system consists of a noncirculating, enclosed service water system and the continuously flowing once-through cooling waters which make up the very large volume of water discharged while the plant is operating. The enclosed service water will be heavily dosed with an extremely toxic anti-corrosion chromatic solution. Loss of this water is protected to ensure that leakage will produce a chromatic concentration at the circulating water system outlet of less than 1×10^{-4} ppm. Most circulating water is continuously treated with sodium hypochlorite to control fouling by keeping the chlorine residual concentration at less than 0.5 ppm. The average concentration at the discharge is expected to be 0.1 ppm or less.

Any other chemicals used are relatively insignificant and will result in undetectable discharges. In all cases, intensional discharge of chemicals, including biocides, will be at concentrations within water quality standards.

Sanitary and Other Waste Systems. The sanitary system is self-contained. Water for all domestic used in provided by the makeup water system. Waste water is treated prior to discharge; solid wastes are handled in accordance with prevailing standards.

Decommissioning An Offshore Nuclear Powerplant

Forty years is the maximum period for which AEC issues a license to operate a nuclear powerplant on- or offshore. At the end of that time the operator must renew his license or apply for termination of the license and for authority to dismantle the facility and dispose of its components. 7/ Termination of operation and plant dismantling are generally called "decommissioning."

Land-Based Nuclear Powerplants

Decommissioning Experience. As of June 30, 1973, 33 central-station nuclear powerplants were in operation, 57 were being built, and 7 had been shut down or dismantled. All are or were land-based. Six of the decommissioned plants were thermal reactors (chain reaction based on thermal neutrons) of the same nuclear type as proposed for use offshore. Table A-6 lists the characteristics of the six reactors and summarizes the decommissioning actions that have been taken.

Methods of decommissioning varied according to conditions and objectives; they include combinations of dismantling and burial in place (Hallam), conversion to a fossil-fueled powerplant (Pathfinder), complete removal from the site and burial in a licensed area(Elk River), and entombment in place with protective abandonment (Carolinas Virginia, BONUS). This experience indicates a number of practical ways to decommission relatively small land-based nuclear powerplants. Extrapolation to the large FNPs must be considered somewhat speculative and engineering development may be required.

TABLE A-6

Nuclear Powerplants Decommissioned

Facility	Reactor Type	MWe net	MW	Description of Action
Hallam Nuclear Power Facility (HNPF), Hallam, Neb.	Sodium-cooled, graphite-moderated	75	240	Startup in 1962, shutdown in 1964. Dismantled, buried in place at cost of $3,176,671.
Carolinas Virginia Tube Reactor, Parr, S.C.	Heavy-water-cooled and -moderated	17	65	Startup in 1963, shutdown in 1967. Entombed in place. Building locked.
Boiling Nuclear Superheater Power Station (BONUS), Punta Higuera, P.R.	Boiling-water, integral nuclear superheat	16.5	50	Startup in 1964, shutdown in 1968. Entombed in place. Building is nuclear museum.
Pathfinder Atomic Plant, Siox Falls, S.D.	Boiling-water, nuclear superheat	58.5	190	Startup in 1964; shutdown in 1967. Entombed in place. Building to be used for other purposes. Plant converted to fossil fuel, 1969.
Elk River Reactor, Elk River, Minn.	Boiling-water	22	58.2	Startup in 1962, shutdown in 1968. All above-grade material removed; all below-grade material contaminated with detectable reactor-originated radioactivity removed at cost of about $5,600,000.
Piqua Nuclear Power Facility, Piqua, Ohio	Organic-cooled and -moderated	11.4	45.5	Startup in 1963, shutdown in 1966. Entombed in place, shielding added. Building used as warehouse. Cost $1,045,690

Sources: "Four Decommissioning Case Histories," Nuclear News, June 1970, pp.39-58: A. Giambusso (Foreword); B. Ureda and W.F. Heine (Hallam); W. Willoughby II and H.T. Babb (CVTR); Modesto Iriarte, Jr. and J. Hernandex-Fragoso (BONUS); and N.M. Bjeldanes (Pathfinder); "Environmental Statement: Elk River Reactor Dismantling, Elk River, Minnesota," USAEC Report WASH-1516, May 1972; "Retirement of the Piqua Nuclear Power Facility," C.W. Wheelock, Atomics International Report AI-AEC-12832, April 1, 1970.

Decommissioning Methods. Before a nuclear powerplant is decommissioned, the operator removes as much of the radioactive material from the site as can be done in standard or routine operations. All nuclear fuel is removed from the site and transported to a nuclear fuel reprocessing facility. Equipment that has been in contact with radioactive liquids or gases is cleaned and decontaminated. This process may require disassembly of some components such as valves and segments of pipe that resist decontamination by flushing. Disassembly and cleaning in a large system may be both lengthy and costly.

All solid and liquid radioactive wastes, including contaminated primary reactor coolant, are processed, [3/] transferred to suitable transport casks, and shipped to licensed repository for disposal or burial. Waste processing, limited disassembly, and cleaning have been performed during the life of the plant.

At the conclusion of these activities, most of the radioactivity remaining in the plant will be in those materials which have been exposed to the reactor's neutron flux, i.e., in the internal structures and walls of the pressure vessel, in the biological shield, and in the vessels, piping, and equipment located within the biological shield. The removal or sequestering of these materials as well as the disassembly of hard-to-clean components and systems involves unique and costly activities.

There are three basic decommissioning methods: complete removal of the entire nuclear powerplant from the site; entombment of the pressure vessel, its internals, and the biological shield and removal of the remainder of the plant from the site; and mothballing the plant. Complete removal permits the site to be turned over to other uses. Entombment permits other use of the site except for that occupied by the entombment structure. Mothballing can consist of sealing the containment structure and its contents while either removing the remainder of the plant or leaving it in place and providing security and surveillance measures that will limit access to those authorized to maintain the mothballing. Although many variations are possible, most decommissioning actions have been variants of the entombment method; only one complete removal operation was accomplished.

Radioactivity Involved in Decommissioning

Fission products and the neutron-activated materials are the two basic sources of radioactivity in a nuclear powerplant. For the most part the fission products are removed with the spent nuclear fuel; some remain in the primary coolant circuit and in plant systems for processing radioactive wastes. Careful cleaning (decontamination) removes most of the latter, so that when decommissioning begins, most of the remaining fission products are in the form of residues on the walls of vessels and pipes and in hard-to-clean spaces in valves, pumps, and other equipment.

The neutron-activated materials constitute the significant radiological hazard after the initial plant cleanup is completed. They are contained within the biological shield, that is, wherever there are neutrons when the reactor is operating. Because the neutron flux decreases outside the nuclear fuel volume, the greatest specific activity (curies per kilogram) is in the materials inside the pressure vessel (core support structure, control rod guides, diffuser plates, baffles, thermal shield, etc.). Similarly, the first few inches from the inner surface of the pressure vessel have most of the induced radioactivity, as do the inner portions of the biological shield.

After the reactor has been shut down for several months, three activities dominate: Fe-55 (2.7 year half-life), Co-66 (5.27-year half-life), and Ni-63 (92 year half-life). Both the iron and nickel radioisotopes emit relatively less-penetrating radiations (low-energy beta particles and soft x-rays) than the radioactive cobalt, which emits 1.33 and 1.17 MeV gamma rays. Because all the radioisotopes are hazardous when in airborne material or when in materials that may come into contact with the skin or be ingested, protective measures must be taken to prevent ingestion or inhalation by persons working with or dismantling contaminated equipment.

Unlike the iron and nickel radioisotopes, the radiocobalt is also hazardous at a distance and shielding is needed for protection against the gamma rays. Because of its 5.27-year half-life, the activity of the Co-60 and the associated gamma emission decreases to 10% of its initial intensity in 17.5 years and to 1% in 35 years. In practical terms, this means that a nuclear powerplant could be decommissioned by entombment and then after a few decades, when the radiation hazard is substantially reduced, the entombed material could be completely removed.

Experience with decommissioning does not provide quantitative data on the radioactivity levels that would be present in a floating nuclear powerplant at the time of decommissioning. The radioactivity would be greater than in the Elk River reactor by virtue of the larger masses of the equipment within the biological shield and the longer operating time. However, the spectrum of radioactive species would be essentially the same as experienced in decommissioning other water-cooled power reactors.

Configuration of the core and the surrounding structures has a strong influence on the level to which these materials are activated. Regardless of plant size, vessel activation is implicitly limited by design constraints imposed to assure structural integrity to the end of the plant design life.

Floating Nuclear Powerplants

Before and during the initial phases of decommissioning, all radioactively contaminated equipment in nuclear powerplants would be cleaned and decontaminated and all the fuel and liquid, and solid radioactive wastes removed. For the FNP, wastes would be shipped to licensed onshore fuel reprocessing and radioactive waste disposal facilities. Except for the removal of the tritium that has been retained in the plant, these operations are like those that will be conducted during the offshore plant's 40-year life.

Decommissioning an offshore plant can also range from mothballing onsite to complete removal from the site. For discussion, the options between these two extremes are three: permanent layup (at the offshore site or elsewhere), dismantling (at the offshore site or elsewhere) and onshore disposal, and decontamination (at the site) and sinking at sea. Table A-7 lists probable actions that might be taken in decommissioning by each of these three methods. In the following sections each of the methods is discussed in turn.

Permanent Layup. Long-term storage of the floating nuclear powerplant may be an option available to the plant operator. Regardless of whether storage is within the breakwater or at some estuarine or riverine location, the operator has to assure that radioactive materials (primarily those within the pressure vessel) are not allowed to leak out of the plant. This requires certain actions briefly cited in Table A-7.

If storage is within the breakwater, the continuous exposure of the plant to the marine environment and the wind and wave stresses require that

TABLE A-7

Probable Actions in Decommissioning a Floating Nuclear Powerplant

Component	Permanent Layup 1/	Dismantling and Onshore Disposal 2/	Decontamination and Sinking 3/
Barge	Seaworthiness must be maintained.	Seaworthiness must be maintained until plant is at dismantling site.	Seaworthiness must be maintained until plant if at sea dumping site.
Biological Shield	Sealed to prevent access and loss of radioactive materials and to reduce deterioration of contents.	Sealed during transit from offshore site to dismantling site.	Surfaces coated where necessary to prevent loss of radioactive material.
Equipment within Biological Shield	Pressure vessel sealed with inert gas or other means to prevent corrosion; all other equipment treated to prevent corrosion and deterioration.	Sealed during transit from offshore site to dismantling site.	Pressure vessel probably filled with concrete and sealed to prevent exposure to seawater at depth; all other equipment treated to reduce corrosion rate and deterioration.
Remaining Equipment and Buildings on Barge	Each building sealed with provisions for maintenance access; equipment treated to reduce corrosion and deterioration	Some equipment may be salvaged or scrapped at offshore site; remainder of plant tied down for transit to dismantling site.	All salvageable material removed while plant is in breakwater; non-salvageable material likely to float made sinkable.

1/ If lay-up is at offshore site, the entrance to breakwater would probably be closed. Additional structures might be installed on barge to protect plant from sea and storm action.

2/ Breakwater has to be partly dismantled to permit barge egress.

3/ Adequate protection against loss of radioactive materials after dumping may require extensive modification of biological shield and will have to be balanced agains the almost negligible hazard of radioactivity released by rusting of reinforcing steel in the shield.

the plant be battened down much more securely than if storage is inland. Moreover, it may be difficult to maintain the integrity of the plant hull in seawater over long periods of time. With a decommissioned nuclear powerplant remaining at the offshore site, the breakwater would have to continue to protect the barge and its components. Protection would require continued maintenance of the breakwater structure, operation of navigational aids, and surveillance to protect against unauthorized entry. If the plant has been well secured against leakage of radioactivity, some deterioration of the breakwater may be acceptable.

Depending on the condition of the hull, long-term layup and storage could be provided in a freshwater estuary or river where protective custody could be maintained. For storage within the breakwater, the hull must remain afloat; however, it is not exposed to the stresses of open sea. If the operator is required to maintain the hull in a seaworthy condition during plant operations, this method of decommissioning should be feasible. Transporting the FNP to the storage site would be possible after measures are taken to protect the plant in transit. For the most part, they would be the same as those taken when the FNP is moved from the manufacturer's plant to the offshore site. At the storage site, maintenance (if necessary) of the hull would require continued use of impressed cathodic current, regular inspection, and occasional repairs and replacement of parts. If a suitable dock were accessible, drydocking is also possible, but at considerable cost.

Both methods of permanent layup require changes in the breakwater. Storage within the breakwater might require closing the breakwater, and storage at another site would require partial dismantling of the breakwater to permit removal of the FNP.

<u>Dismantling and Onshore Disposal</u>. Dismantling in the breakwater is technically feasible but is likely to be more costly than onshore. If the seaworthiness of the hull is doubtful, partial or complete dismantling at the

offshore site could be necessary. 9/ However, it is more likely that the plant will be towed to a shore-based facility, where decommissioning will be similar to decommissioning a land-based powerplant.

Entombing the pressure vessel and internals in place is not practical; however, with adequate crane capacity at an onshore facility and with a nearby licensed burial ground, it may be practical to seal the vessel and move it a short distance from a docking area to the burial site. Or the onshore dismantling could be limited to removal of all nonradioactive components and all low-level radioactive materials, the pressure vessel and its internals would be kept on the barge and the barge would be moved to a long-term storage area. Once numerous FNPs are operational, it is possible that a dry dock capable of accomodating the dismantling of the large hulls will become a needed extension of the offshore nuclear power industry. Scrapping the hull may require development of special procedures for handling residual radioactive contamination and neutron-induced radioactivity in the hull structure under the reactor compartment. The facilities may or may not be located at the manufacturing site.

Decontamination and Sinking. After salvaging any equipment or materials of value, the FNP may be disposed of at sea. Because it is too high -- about 250 feet from the bottom of the hull to the top of the containment building -- sinking inside the breakwater, where water depth is less than 75 feet, is not possible. In order to avoid creating a navigational or fisheries hazard, it would have to be sunk beyond the continental shelf, i.e., at depths greater than 200 meters, or possibly at an EPA-designated dumping site.

Before disposal at sea, all radioactive materials would have to be removed and all remaining equipment carefully decontaminated to remove any residual fission products. Moreover, because of the neutron-induced radioactivity and fission-produced residues within the biological shield, it would be necessary to sever pipes, to weld seals, and perhaps to fill some systems with materials impervious to seawater in order to assure retention of the radioactivity. These procedures would prevent the leaching of radioactive materials and contamination of the sea. Because the dominant radioactivity (Co-60) has a half-life of 5.27 years, the protection does not have to be effective for an indefinite period.

There are variants of the decontamination and sinking method. It may be practical to detach the containment structure, sink it, and then salvage or scrap the remainder of the plant at a drydock. This method will amount to dismantling with disposal of the neutron-induced radioactivity at sea rather than at a licensed onshore burial site. Assuming that these operations meet the requirements of the 1972 Marine Protection, Research and Sanctuaries Act[10] and the Federal Water Pollution Control Act Amendments of 1972 [11] so that a dumping permit may be obtained, the floating nuclear powerplant is ready for disposal at sea. Although it is technically possible to sink the plant without radioactive or other hazard, decontamination and sinking at sea appear the least attractive method of decommissioning. No economic advantages are apparent.

A concern quite different from any of the above regards the International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. If the United States signs the convention, it will be necessary to consider whether disposal of a decontaminated nuclear powerplant at sea is advisable from the standpoint of relations with other signatories.

The Breakwater

If the plant is to be removed, the straight section of the breakwater will be disassembled. First the armor units (dolosse) will be removed from around the caissons on the leeward breakwater as required to refloat the caissons; then the ballast is removed from the caissons to refloat them; and the FNP is moved out through the opening. After decommissioning, the breakwater can either be restored or completely removed.

A decision regarding removal of the breakwater will follow an evaluation of the costs and environmental impacts of three basic options: perpetual care, complete removal, and conversion to other use.

Perpetual Care. An abandoned breakwater may be a continuing hazard to shipping. At the very least, navigational aids would be required on and around the structure, regardless of whether the FNP has been removed or is mothballed within the breakwater.

Other Use. The breakwater could continue to be used for a thermal electric powerplant site -- e.g., an improved nuclear unit, or it could be used for other purposes, with or without modification. In its original configuration, the breakwater could serve as a harbor for small vessels, lightering operations, or to contain a floating industrial plant such as a fish cannery, fish protein processing plant, or other aesthetically undesirable plant. These alternatives require minimal modification of the breakwater.

Continued use of the breakwater in conjunction with a floating industrial plant would involve intensive investment of capital. Some modifications of the breakwater -- adding slips and wharves for service operations and waste disposal facilities -- may be required. It is unlikely that the moorings for the nuclear plant can also serve the industrial plant, so new mooring will have to be provided. If the industrial activity could be designed to avoid major alterations of the breakwater, part of the original investment may be recovered by the sale or lease of rights to the basin. Electric power requirements could be met by using the buried transmission cables, thus eliminating the need for decommissioning the transmission lines or their landward connections.

A more versatile alternative would be to convert the breakwater into an artificial island. In the years immediately following decommissioning, the area enclosed by the breakwater could be used as a solid waste or dredge spoil disposal area; when filled it becomes an island. The area available at 64 feet above mean low water would be at least 30 acres. Potential uses include a resort with hotel, an industrial area with bulk transshipment facilities for coal and iron ore, and oil storage area associated with a monobuoy in deeper water.

If the breakwater is converted to an artificial island, the gaps between the leeward and seaward breakwaters would have to be closed prior to filling. It would be necessary to remove the armor units around caissons on the leeward breakwater, float the caissons, etc., and remove the FNP. A navigation warning system and maintainence of the breakwater (the artificial island perimeter) would also be necessary.

Removal. Removal of the breakwater would require an engineering effort equal to or greater than that involved in its emplacement. After the FNP is removed, the armor units and underlayer materials would be removed, the remaining caissons from leeward and seaward breakwaters would then be removed, and the materials would be taken to the disposal site.

As during the breakwater emplacement, the heavy floating equipment required will be severely restricted by adverse weather and seas. Equipment for removing the heavy dolosse would be required first. Due to interlocking of the dolosse, this lifting equipment may need to be capacities of 100 tons. Divers may be required to attach the lifting hooks to the underwater dolosse and the lifting slings to the largest rock. The smaller rock and sand can be removed from the breakwater and from the caissons using standard buckets and dredges. The loose breakwater materials and dolosse can be barged to a disposal area. Caissons can be floated to the disposal area using seagoing tugs and then sunk. The time required for breakwater removal will probably be equal to the original emplacement time, depending on site location, weather, and seas.

Shore Facilities

What is done is decommissioning each individual facility depends on prospects for future use. Ports, transmission systems, shops, and buildings may be used by the utility for other power generation operations or for other purposes. Facilities that become useless may be removed, particularly if salvage values, land values, or government policies favor that course.

Aesthetic restoration of areas once occupied by transmission lines, railways, piers, and other highly visible features is not likely to be undertaken except to satisfy laws and regulations then in force. Materials and equipment that could be salvaged from the visible structures generally would not be valuable enough to justify demolition and removal. In time, the space occupied by old structures may be needed for other purposes, in which case the conversion would be effected for economic reasons. Shops and warves located in an industrialized area would probably continue to be of value for industrial use. Isolated ports and transmission lines would be less likely to be in sufficient demand to justify restoration.

References

1. Offshore Power Systems, Environmental Report Supplement to Manufacturing Licenses Application, Part II, June 1973, p. 2-6.
2. "A Survey of Major and Unique Technical Features of the Floating Barge-Mounted Nuclear Power Plant Concept", report draft, U.S. Atomic Energy Commission, July 1973, Appendix B.
3. "Plant Design Report," Offshore Power Systems, May 1973.
4. Public Service Electric and Gas Company, "Atlantic Generating Station, Units 1 and 2, Preliminary Site Description Report," December 1972.
5. D.R.F. Harleman, E.E. Adams, and G. Doester, Interim Report: Experimental Investigation of a Near Surface Outfall for the Atlantic Generating Station of Public Service Electric and Gas Company, Newark, New Jersey, report to PSE&G, May 1973.
6. G. Jerka and D.R.F. Harleman, "The Mechanics of Submerged Multiport Diffusers for Buoyant Discharges in Shallow Water," Technical Report No. 169, R.M. Parsens Laboratory for Water Resources and Hydrodynamics, Massachusetts Institute of Technology, March 1973.
7. 10 CFR § 50.82.
8. Decontaminated fluids will be discharged to the extent permissible under AEC regulations.
9. In certain situations, it may be desirable to reduce the floating plant's displacement (which is about 31 feet) by removing some heavy components while the plant is within the breakwater. This would reduce the constraints on transporting the plant to an on-shore decommissioning facility.
10. P.L. 92-532.
11. P.L. 92-500.

APPENDIX B

INPLANT NUCLEAR ACCIDENTS: SELECTED CALCULATIONS

Consideration of risks associated with postulated accidents must take into account both the probabilities of occurrence and consequences. For analytical purposes, the accidents possible at a nuclear plant have been classified by the AEC; each class is characterized by an occurrence rate and consequences. The severity of accidents ranges from trivial to very serious. Some examples are shown in Table B-1.

Classes 1 and 2 represent occurrences which are anticipated during nuclear plant operations, and their consequences, which are very small, are considered within the framework of routine effluents from the plant. Classes 3 through 5 could occur sometime during the 40-year plant life. Classes 6 and 7 are of similar or lower probability than Classes 3 through 5 but are still possible. The probability of Class 8 accidents is very small. Class 9 involves successive failures more severe than those required to be considered in the design bases of protection systems and engineered safety features. Although their consequences could be severe, the AEC judges the probability of occurrence to be very small because of multiple physical barriers; quality assurance for design, manufacture, and operation; continued surveillance and testing; and conservative design. Best estimate accident doses (a dose is "the quantity of radiation absorbed, per unit of mass, by the body or any portion of the body"[1/]) have been calculated for several classes of accidents (see Table B-2) for FNPs by OPS. Accident doses for FNPs will be independently calculated by the AEC during the safety and environmental review of the OPS proposal.

TABLE B-1

EXAMPLES OF NUCLEAR POWERPLANT ACCIDENTS

Class	Description	Examples
1	Trivial incidents	Releases of radioactive materials within requirements for routine operations
2	Small release outside containment	Releases through steamline relief valves and small spills and leaks of radioactive materials outside containment
3	Radwaste system failure	Equipment leakage or malfunctions; release of waste gas and liquid storage tank contents
4	Fission products to primary system (BWR)	Fuel cladding defects; off-design transients that induce fuel failures above those expected
5	Fission products to primary and secondary systems (PWR)	Fuel cladding defects and steam generator leak; off-design transients that induce fuel failure above those expected and steam generator leak; steam generator tube rupture
6	Refueling accidents	Fuel bundle rod; heavy object drop onto fuel in core (inside containment)
7	Spent fuel handling accidents	Fuel assembly drop in fuel storage pool; heavy object drop onto fuel rack; fuel cask drop (outside containment)
8	Accident initiation events considered in design basis evaluation in the safety analysis report	Loss-of-collant accidents; break in instrument line from primary system that penetrates the containment; rod ejection accident (PWR); rod drop accident (BWR); steamline breaks
9	Hypothetical sequence of failures more severe than Class 8	Loss-of-coolant accident accompanied by multiple failures of the emergency core cooling systems

Table B-2

ACCIDENT EVALUATED BY OPS

Class	Description
3.1	Equipment leakage or malfunction
3.2	Release of waste gas storage tank contents
3.3	Release of liquid waste storage tank contents
5.2	Off-design 24-hour transient, release from turbine hall
5.3	Steam generator tube rupture
6.1	Fuel bundle drop
6.2	Heavy object drop onto fuel in Core
7.2	Heavy object drop onto fuel rack
7.3	Fuel cask drop
8.1	Loss-of-coolant accident small pipe break
8.1	Loss-of-coolant accident large Pipe Break
8.2(a)	Rod ejection accident
8.3(a)	Large steam line Break

Source: Offshore Power Systems "Environmental Report, Supplement to Manufacturing Application, Part II," June 1973.

The amount absorbed by individuals exposed to nuclear radiations is measured in rems. A rem is defined as "a measure of the dose of any ionizing radiation to body tissue in terms of its estimated biological effect relative to a dose of one roentgen of X-rays."[2/] A dose of 1 rem is considered equivalent to a dose or 1 roentgen of X- or gamma radiation. Radiation absorbed by a group of persons is the product of the number of persons in the group times the average dose absorbed (in rems) by each member of the group.

For each accident class, radiological consequences were calculated in terms of the dose as a function of distance from the plant. Results of some of these calculations are given in Figures B-1 through B-4. The assumptions underlying the dose values and the atmospheric diffusion factors used in the calculations are given in the OPS report. The doses computed by OPS for each postulated event are summarized in Table B-3.

Population doses within a 50-mile radius were estimated by OPS for four representative sites and are summarized in Table B-4. The sites are: --off the New Jersey coast; Onslow Bay near Wilmington, N.C.; off the Florida coast near Fort Pierce; and the Gulf of Mexico near Corpus Christi.

REFERENCES

[1/] 10 CFR §20.4(a)

[2/] Ibid.

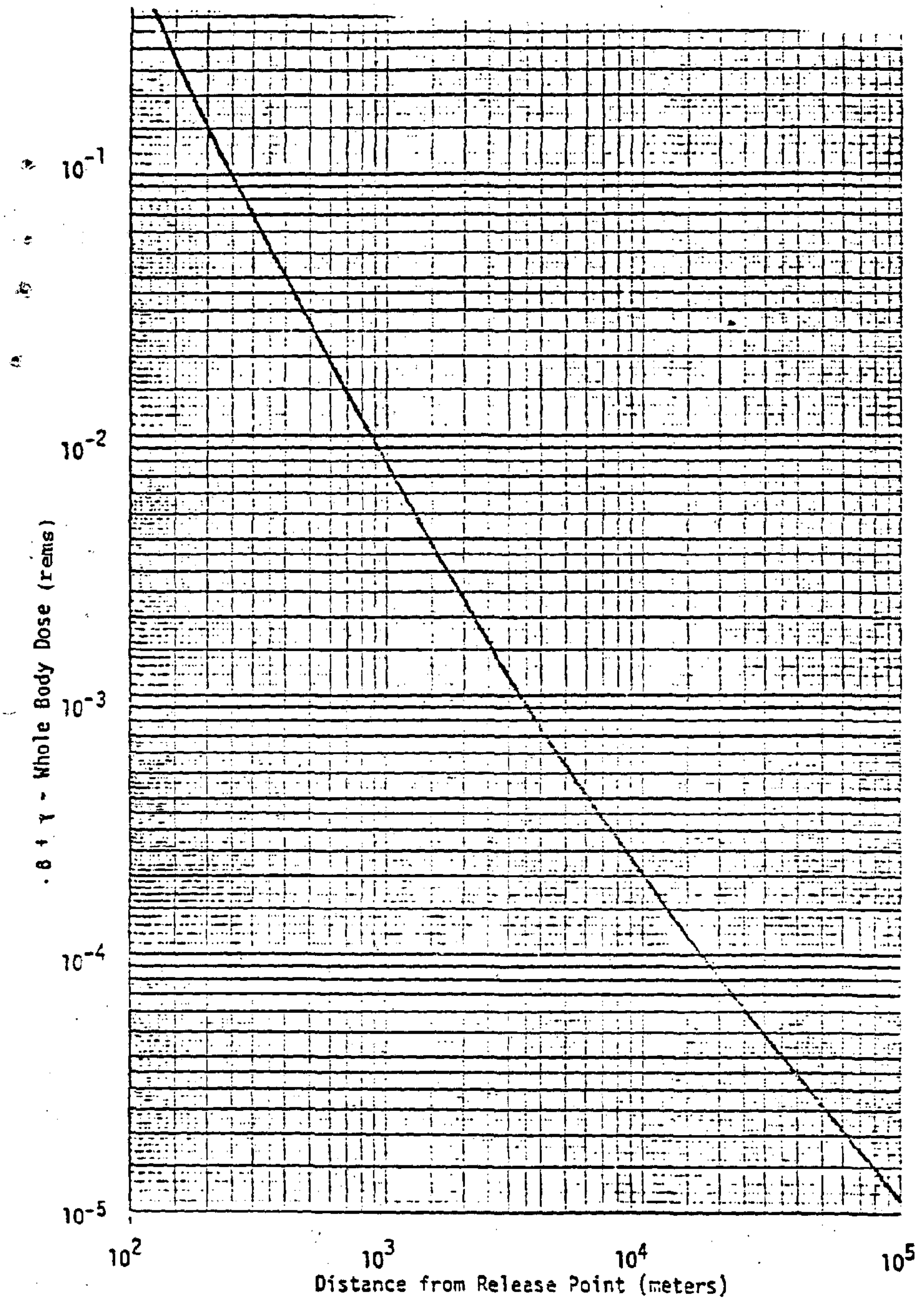
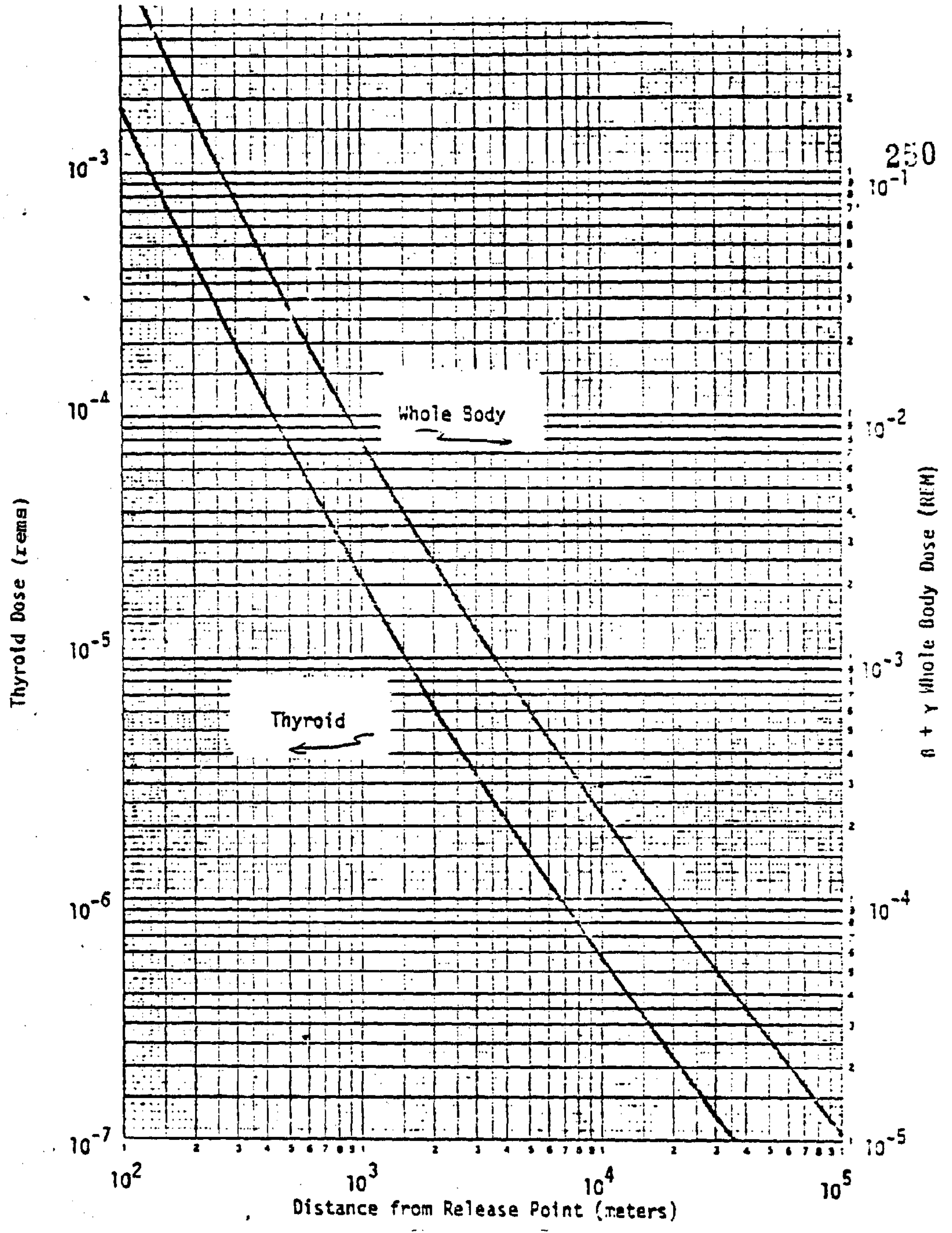


FIGURE B-1 Whole Body Dose versus Distance--Class 3.2, Release of Waste Gas Storage Tank Contents



FIGURF B-2 Thyroid Dose versus Distance --Class 3.3 Release of Liquid Waste Storage Tank Contents

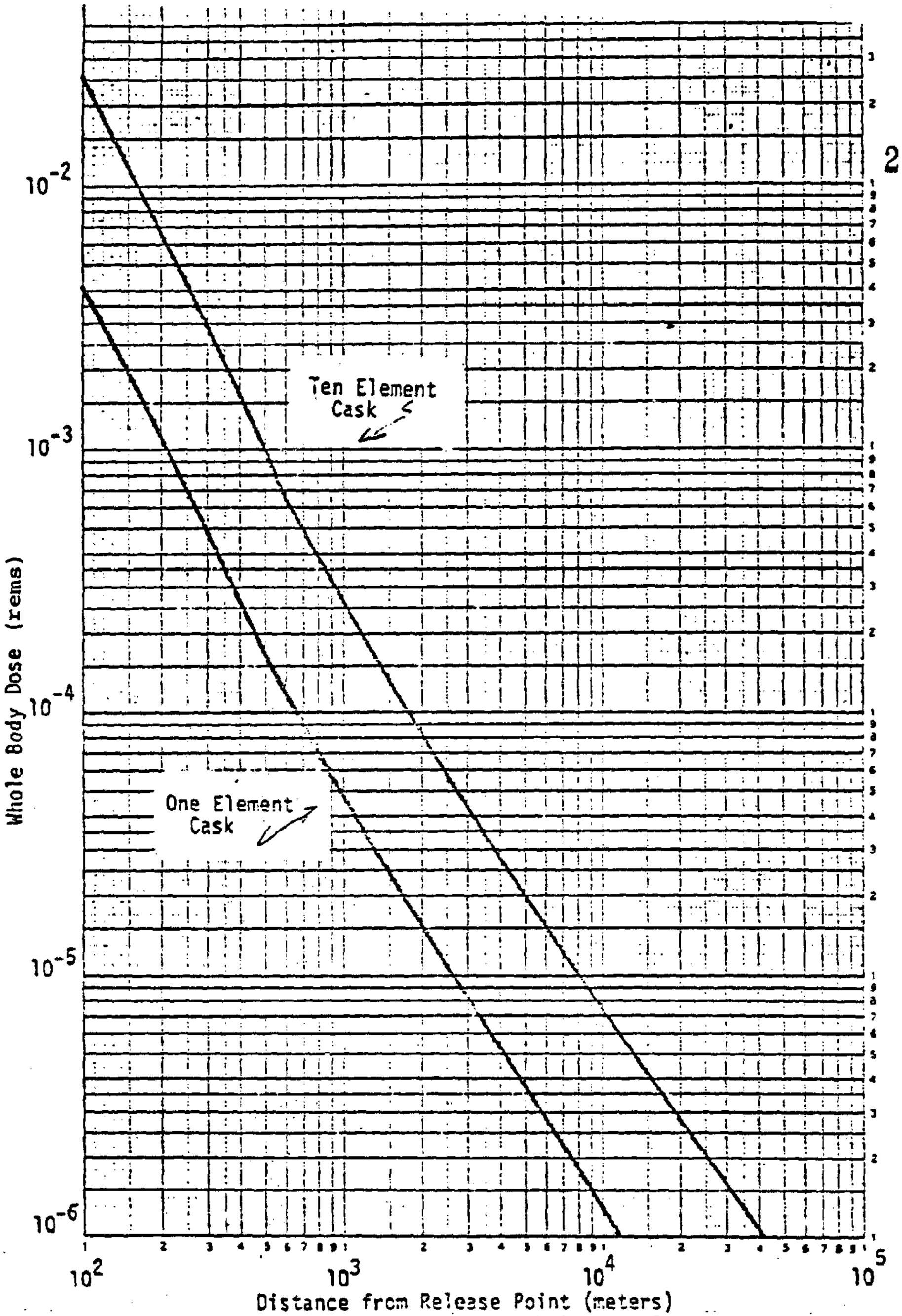


FIGURE B-3 Whole Body Dose versus Distance--Class 7.3, Fuel Cask Drop

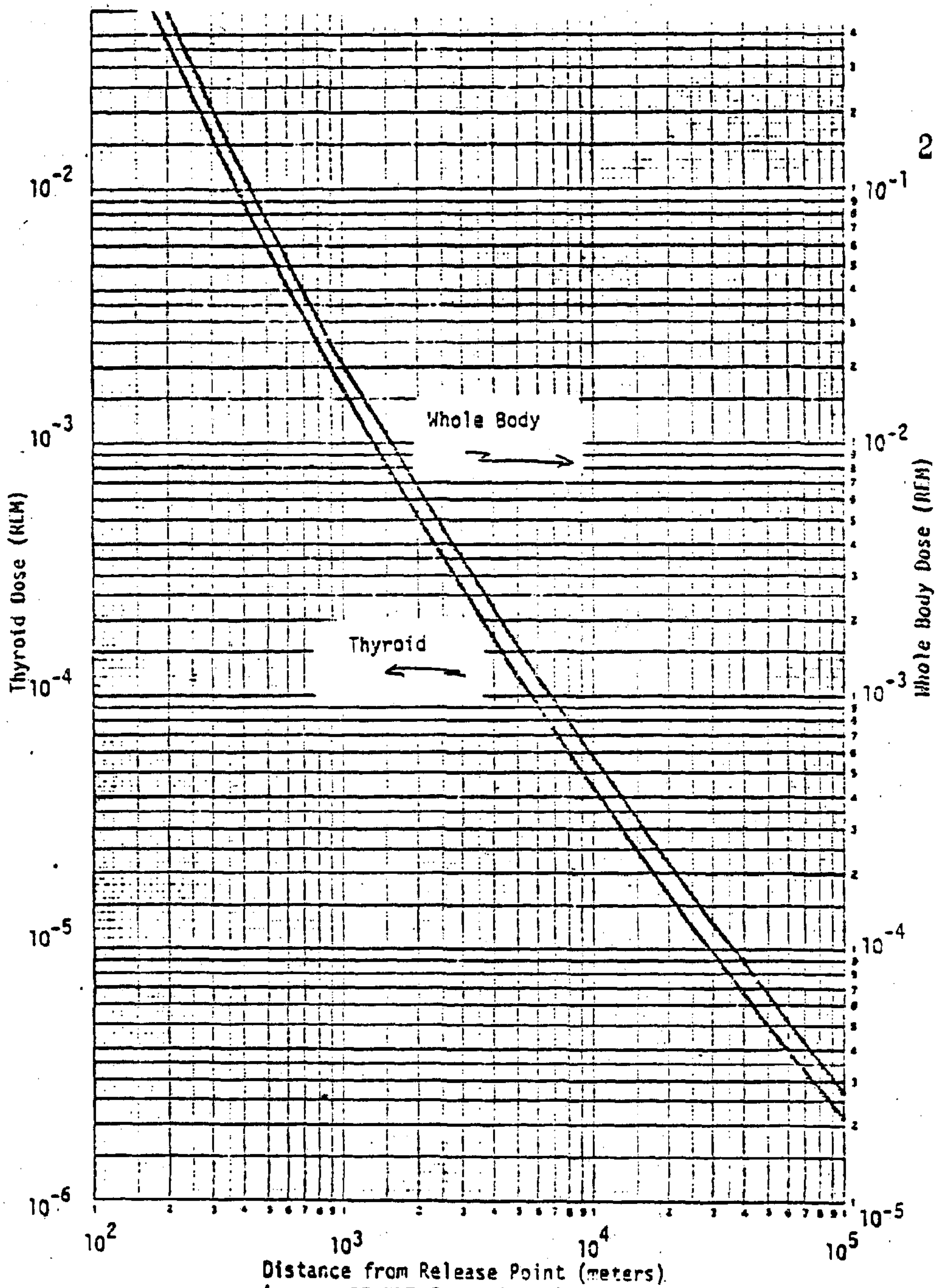


FIGURE B-4 Thyroid Dose versus Distance--Class 8.1,
Loss-of-Coolant Accident,
Large Pipe Break

TABLE B-3 RADIOLOGICAL CONSEQUENCES OF POSTULATED ACCIDENTS AT A DISTANCE OF 50 MILES

Class	Event	Fraction of Limit[1]	
		Whole Body	Thyroid
3.1	Equipment leakage or malfunction	0.040	0.00002
3.2	Release of waste gas storage tank contents	0.084	-
3.3	Release of liquid waste storage tank contents	0.084	0.0020
5.2	Off-design transients	0.0018	0.021
5.3	Steam generator tube rupture	0.016	0.0004
6.1	Fuel bundle drop	0.0014	0.0002
6.2	Heavy object drop onto fuel in core	0.027	0.0036
7.1	Fuel assembly drop in fuel storage tank	0.0014	0.0002
7.2	Heavy object drop onto fuel rack	0.0012	0.0004
7.3	Fuel cask drop (1 element cask)	0.0005	0.00001
7.3	Fuel cask drop (10 element cask)	0.032	0.00007
8.1		0.00058	0.00000
8.1		0.23	0.018
8.2(a)	Rod ejection	0.023	0.0018
8.3(a)	Steam line break (large break)	-	0.00040

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[1] The limit for both whole body and thyroid dose is 0.5 rem. 10 C.F.R. §20

Source: Offshore Power Systems "Environmental Report, Supplement to Manufacturing Application, Part II," June 1973

TABLE B-4

AVERAGE DOSES FROM OFFSHORE PLANTS TO A 1980 POPULATION (IN MAN-REMS) WITHIN A 50-MILE RADIUS

		New Jersey		North Carolina		Florida		Texas	
Class	Event	Thyroid	Whole Body	Thyroid	Whole Body	Thyroid	Whole Body	Thyroid	Whole Body
3.1	Equipment leakage or malfunction	1.8(-6)*	3.0(-3)	3.3(-7)	5.4(-4)	1.0(-6)	1.7(-3)	8.9(-7)	1.5(-3)
3.2	Release of waste gas storage tank contents	---	6.1(-3)	---	1.1(-3)	---	3.4(-3)	---	3.0(-3)
3.3	Release of liquid Waste Storage Tank Contents	7.2(-6)	3.2(-3)	1.3(-6)	5.8(-4)	4.0(-6)	1.8(-3)	3.6(-6)	1.6(-3)
5.2	Off Design Transients	1.1(-3)	5.1(-5)	1.9(-4)	9.3(-6)	5.8(-4)	2.8(-5)	5.2(-4)	2.5(-5)
5.3	Steam Generator Tube Rupture	1.4(-5)	6.1(-4)	2.5(-6)	1.1(-4)	7.6(-6)	3.4(-4)	6.8(-6)	3.0(-4)
6.1	Fuel Bundle Drop	7.0(-4)	5.4(-5)	1.3(-4)	9.8(-6)	3.9(-4)	3.0(-5)	3.5(-4)	2.7(-5)
6.2	Heavy Object Drop Onto Fuel In Core	1.2(-2)	1.1(-3)	2.2(-3)	1.9(-4)	6.7(-3)	5.9(-4)	6.0(-3)	5.3(-4)
7.1	Fuel Assembly Drop In Fuel Storage Tank	7.0(-4)	5.4(-5)	1.3(-4)	9.8(-6)	3.9(-4)	3.0(-5)	3.5(-4)	2.6(-5)
7.2	Heavy Object Drop Onto Fuel Rack	1.3(-3)	4.6(-5)	2.4(-4)	8.4(-6)	7.2(-4)	2.6(-5)	6.5(-4)	2.3(-5)
7.3	Fuel Cask Drop (one element)	4.1(-7)	1.9(-5)	7.4(-8)	3.5(-6)	2.3(-7)	1.07(-5)	2.0(-7)	9.5(-6)
7.3	Fuel Cask Drop (ten element)	2.1(-6)	1.9(-4)	3.7(-7)	3.5(-5)	1.1(-6)	1.1(-4)	1.0(-6)	9.5(-5)
8.1	LOCA (small pipe break)	1.5(-7)	1.9(-5)	2.7(-8)	3.5(-6)	8.3(-8)	1.1(-5)	7.4(-8)	9.6(-6)
8.1	LOCA (large pipe break)	9.1(-4)	8.2(-3)	1.7(-4)	1.5(-3)	5.1(-4)	4.5(-3)	4.5(-4)	4.0(-3)
8.2 (a)	Rod Ejection	9.1(-5)	8.2(-4)	1.7(-5)	1.5(-4)	5.1(-5)	4.5(-4)	4.5(-5)	4.0(-4)
8.3 (a)	Steam Line Break (large break)	1.6(-5)	---	2.8(-6)	---	8.6(-6)	---	7.7(-6)	---
Natural Background	Man-rem/year	9.46(+4)		1.40(+4)		2.02(+5)		1.99(+4)	

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* Note: Read 1.8(-6) as 1.8 x 10^{-6}

APPENDIX C: ENVIRONMENTAL AND LIVING RESOURCES DESCRIPTIONS

Part 1: Regional Environmental Considerations

INTRODUCTION

The following sections describe the general environmental conditions and living resources of four regions: the Atlantic, Gulf of Mexico, and Pacific coastal areas and continental shelves, and the Great Lakes. The ocean areas considered extend approximately 60 miles seaward.

The major disciplines covered and their order of discussion are: marine geology and topography, physical and chemical oceanography, climate and weather, earthquakes and seismic sea waves (tsunamis), and living resources. Gaps in the data and information resources currently available for these regions are also identified. Because the various environmental elements and the marine ecosystems on which they impact are interactive, major interfaces and interrelationships are cited whenever possible, and significant threshold values identified.

THE ATLANTIC COAST

GEOLOGY AND TOPOGRAPHY

1. Beaches and Shoreline. The only significant rocky shores on the Atlantic Coast are found in areas from Maine to Connecticut. Between these rocky areas are several long sandy beaches and numerous small ones used by the public for recreational activities. The remainder of the coastline, from New York to Florida, generally consists of long straight beaches.1/

Typical beach profiles on the Atlantic coast are shown in fig. 1 (vertical exaggeration 2.5x) on which the generally gentle slopes of the inner continental slopes can be seen. Nearly all profiles are sand both above and below the mid-tidal line (designated as 0 in fig. 1) except where cobbles, beachrock, or coral bottom (noted in fig. 1) are present locally. The coarse sediments are the result of relatively active currents. The average width of the beaches is about 70 meters.2/

2. The Continental Shelf. The topography of the Atlantic Shelf is generally gentle in slope. The locations of the various named segments of the Atlantic Shelf are shown

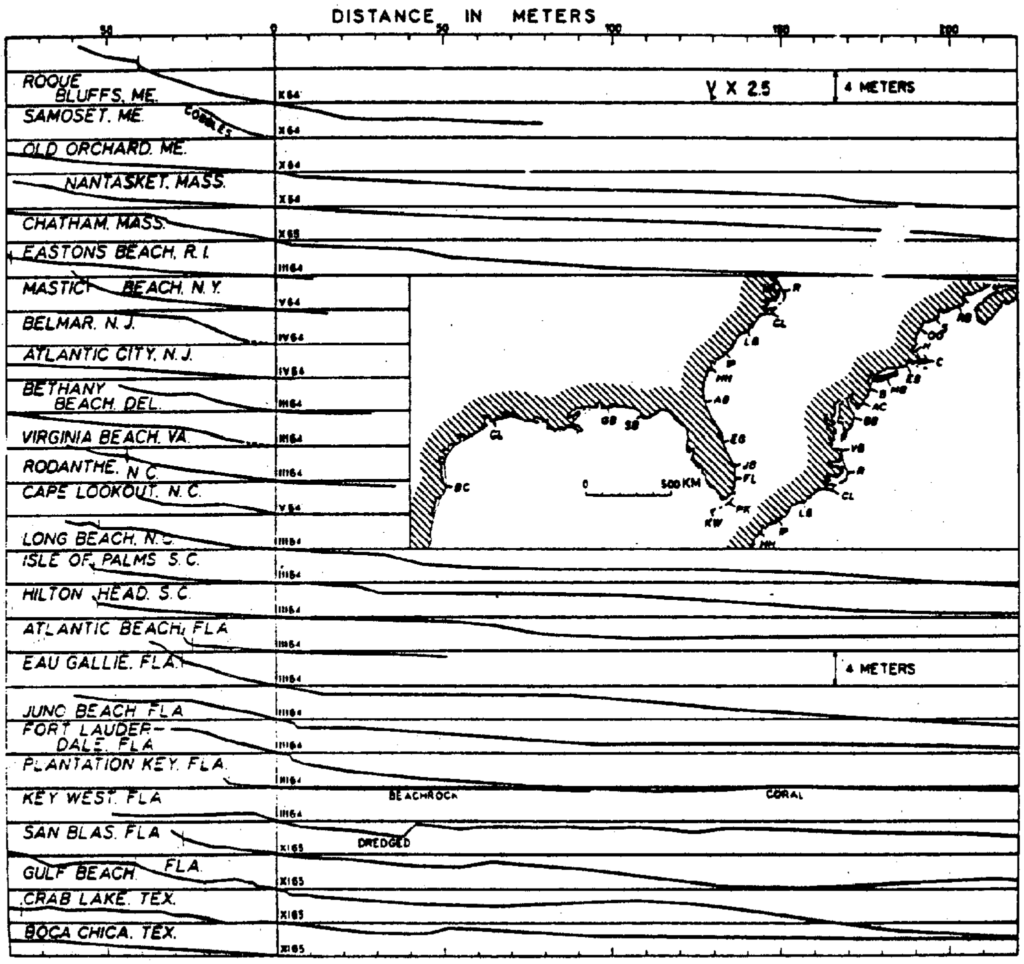


Figure 1.--Typical beach profiles of Atlantic and Gulf coasts. Vertical scale 4 m between each horizontal line. Vertical exaggeration 2.5 x. The vertical line (0 m) represents the midtide line.

Source: Emery, K.O., and E. Uchupi, 1972: Western North Atlantic Ocean, American Association of Petroleum Geologists, Memoir 17.

in fig. 2. The chief factors in the development of the individual shelf segments are:

Gulf of Maine, Bay of Fundy, and Northeast Channel--glacial erosion and marine deposition.

Georges Bank--glacial erosion, glacial meltwater, and marine deposition.

Hatteras - Cape Cod Shelf--glacial erosion, glacial meltwater, and marine deposition.

Florida - Hatteras Shelf--Marine deposition.[3]

The Atlantic shelf may be divided into three zones. In the northern zone from Nova Scotia to Nantucket Island it has broad basins separated by flat-topped banks, undulating swells, and irregularly crested hills. Some of the basins reach depths greater than 200 meters. The irregular topography of the Gulf of Maine consists of numerous banks, basins, and valleys, with mixtures of course and fine-grained sand typical of glacial deposits.[4]

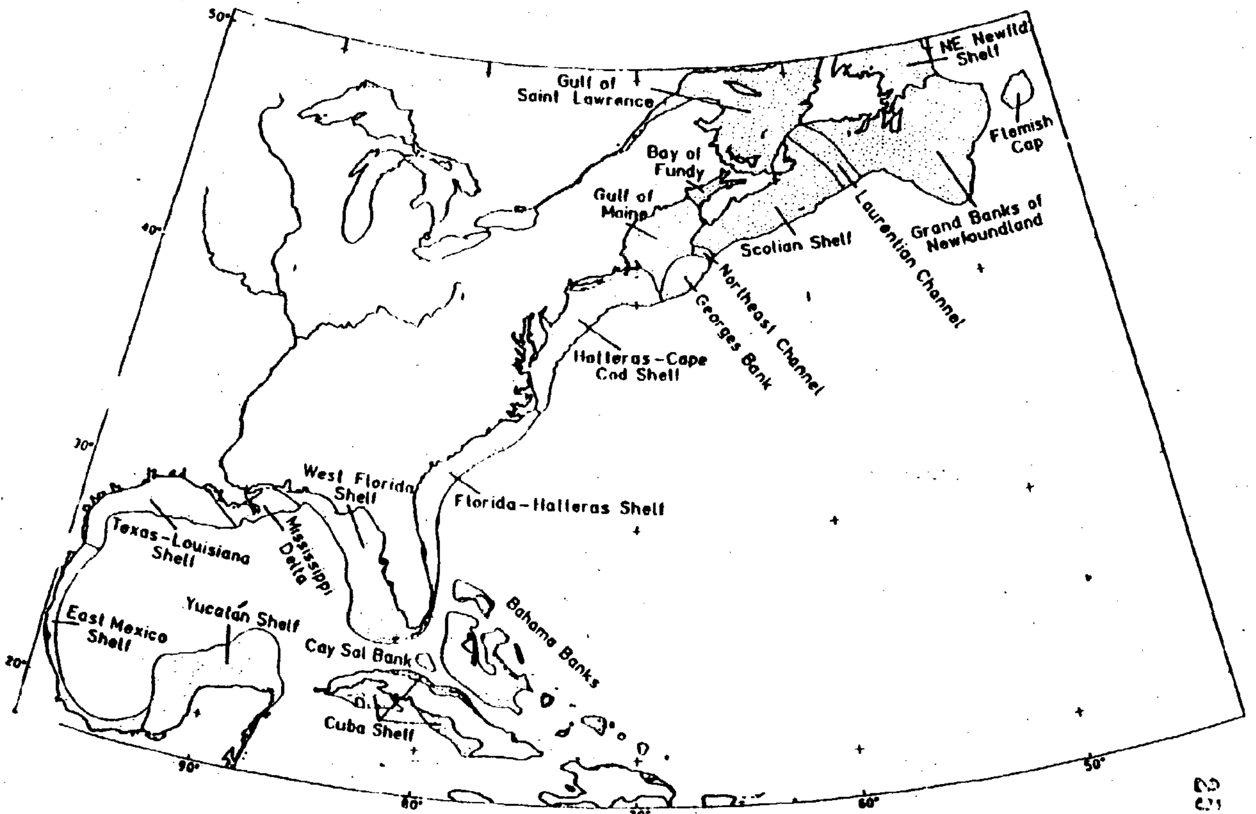
From Nantucket Island to Cape Lookout, North Carolina, the shelf is smoother, but its surface is disrupted by sand swells, channels, coral mounds and terraces. The change from the glaciated regions to the north is most abrupt in the Long Island region, where the shelf becomes relatively smooth.

From Cape Lookout to the Florida Keys shelf topography is more complicated. The slope seaward is relatively smooth, but has gradients as much as five times steeper than farther north. The area is complex, consisting of a shelf, marginal plateau (the Blake Plateau), a trough (the Straits of Florida) and the Bahama Banks. On the east coast of South Florida the shelf is very narrow because of the strong Gulf Stream currents, and in some regions of the Blake Plateau bottom sediment is removed by scouring action.[5]

The sedimentary beds overlying the Continental Shelf are generally flat to gently inclined. The depth to bedrock is 4 to 10 kilometers.

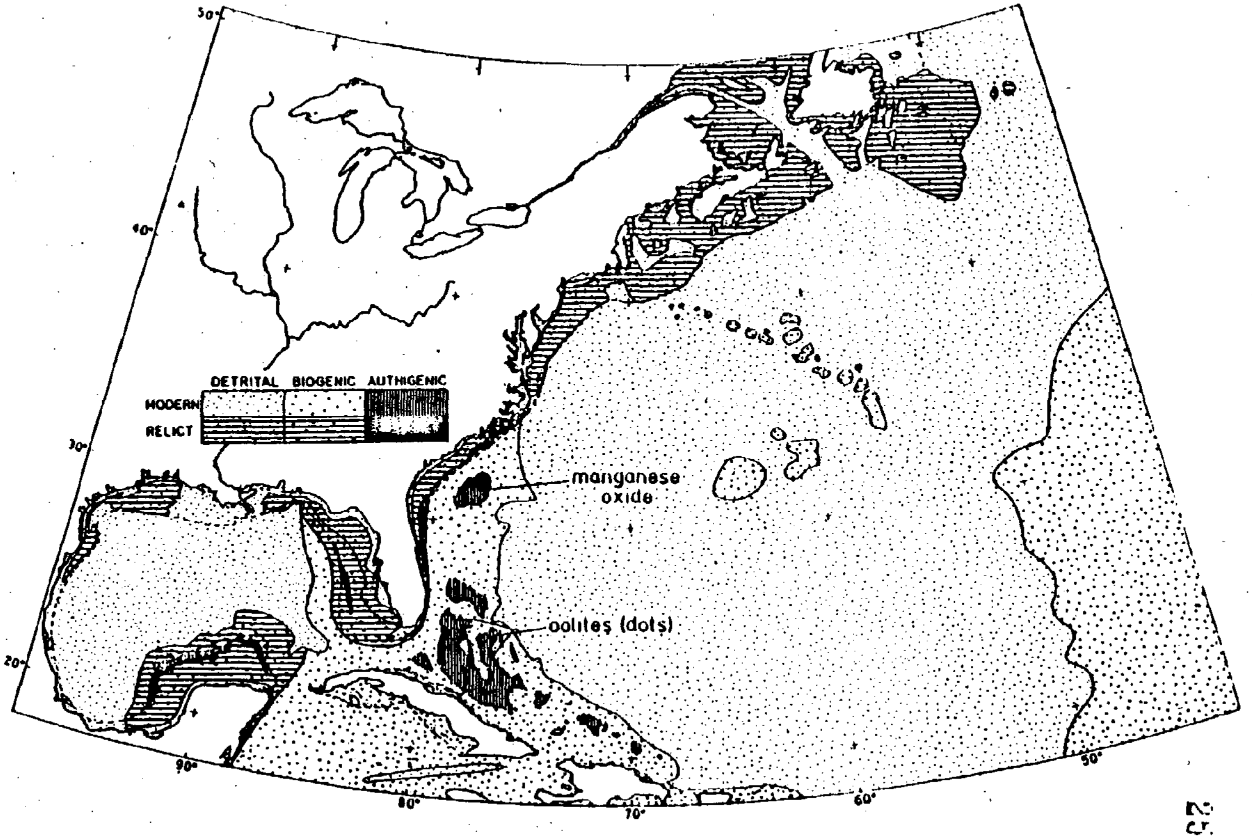
3. Shelf Sediments. The principal types of shelf sediments are: (1) detrital (supplied by streams, shores, and glaciers); (2) biogenic (skeletal material of calcareous or other composition and nonskeletal organic matter); (3) authigenic (deposited chemically from the water; (4) residual (weathered from underlying rocks); and (5) rafted (mainly by ice). Figures 3 and 4 show the distribution, origin, and the age of the sediments found on the shelf.

Figure 2.--The Continental Shelf off the Atlantic and Gulf coasts of North America.



Source: Emery, K.O., and E. Uchupi, 1972: Western North Atlantic Ocean, American Association of Petroleum Geologists, Memoir 17.

Figure 3.--Modern and relict sediments of detrital, biogenic, and authigenic origins.



Source: Emery, K.O. and E. Uchupi, 1972: Western North Atlantic Ocean, American Association of Petroleum Geologists, Memoir 17.

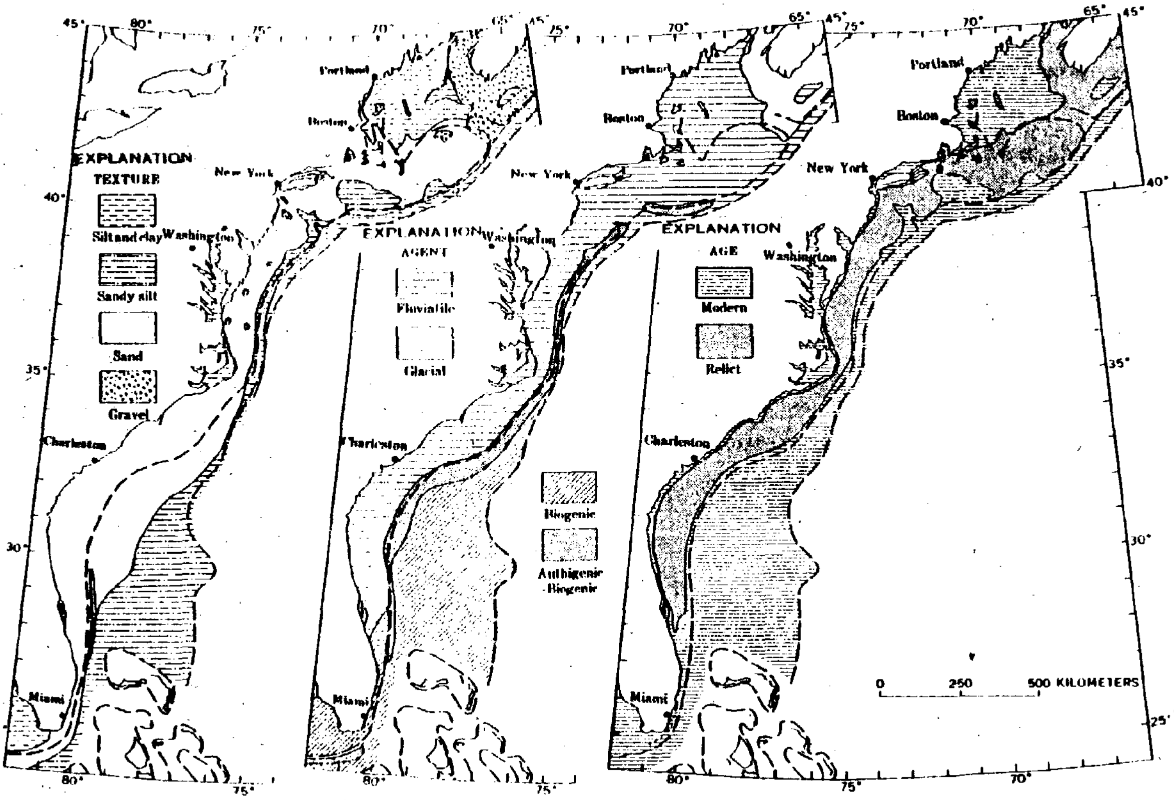


Figure 4.--Texture, mode of deposition, and age of surface sediments.

Source: Emery, K.O., 1966: Atlantic Continental Shelf and Slope of the United States. Geologic Background. U.S. Geological Survey. Professional Paper No. 529-A.

Sand is very common along the Atlantic shelf and rarely more than 10 meters thick, although there are "lenses" some several hundred meters thick. Local gravel deposits may be as much as 60 meters thick. The surface sediments tend to be underlain by a clayey substrate.

4. Sediment Movement. Sediment movement studies are sporadic on the U.S. Atlantic shelf. Representative of general conditions which may be extrapolated for this greater area are studies reported by Moody and Duane and others.6/ These studies show that sand ridges off Bethany Beach, Delaware, moved in a general southeast direction a maximum distance of 250 meters in 42 years, while the shoreline had migrated from 25 to 65 meters landward. Ridges may shift during large storms. In general, however, movement of bottom sediments are not well known.

Data obtained with current meters located 3 meters above the seabed in 50 to 80 meters of water indicate that sediment transport occurs only during storms. Bedload sediment transport is negligible compared to suspended load transport.7/ Calculations suggest that a severe storm occurring every few years might have more geological significance than a number of less severe storms.8/

5. Engineering Properties. The bottom strength on the Atlantic shelf is undoubtedly quite good because of the ubiquity of sands. However, fluvial channels can introduce unpredictable lateral and vertical sedimentological variations. Such features when recognized should be studied as regards to potential site locations. From Maine to Long Island engineering conditions necessary to satisfy foundation criteria are best found where relatively unweathered overburden is close to sea floor exposures and where the glacial overburden consists of horizontally stratified sand and gravel with an absence of thick accumulations of silt and clay and buried channels.

Buried channels from Long Island to Florida are filled with diversified sediments, their nature depending upon source and may offer a variety of engineering problems in designing foundation structures.

Much of the area from Cape Kennedy to Miami is underlain by reef-like coquina masses.9/ These masses may outcrop on the sea floor or are covered by varied thicknesses of sands. These varied subbottom conditions accordingly will produce dissimilar engineering foundation conditions.10/

OCEANOGRAPHY

1. Tides. Tides along the Atlantic coast are semidiurnal, with two nearly equal

highs and lows occurring each lunar day (approx. 24.84 solar hours). There are latitudinal variations in the mean ranges (the difference in height between mean high water and mean low water) along the coast, with alternating highs and lows. Low ranges are found at Key West, Fla. (1.3 ft.), Cape Henry, Va. (2.8 ft.), and Woods Hole, Mass. (1.8 ft.). Spring tides [11] for these areas are approximately 0.5 ft. higher than the mean range. Alternating high ranges are found at the Savannah River entrance, Ga. (6.9 ft.), Sandy Hook, N.J. (4.6 ft.), and the extreme highs in the Gulf of Maine (9.0 ft. at Boston Lightship to 18.2 ft. at Eastport, Me.). Spring tides for these locations are approximately 1.5 ft. higher than the mean range.

Very little information is available to establish tidal datum planes in the offshore region. Tidal measurements, of very short duration, are available for Savannah Light (9 miles offshore) and Texas Tower 2 (11 miles offshore on Georges Bank) for comparison with land-positioned measurements. The Texas Tower location has a mean tidal range of 4.2 feet, which is 2.5 to 3.0 feet lower than tidal ranges recorded on Cape Cod. The Savannah Light location exhibits a mean tidal ranges of 6.4 feet, which is only slightly lower ($\geq$ 0.5 feet) than adjacent coastal locations.[12]

Tidal currents in coastal waters can be identified as either reversing or rotary. Reversing tidal currents are the classic ebb and flood currents found in estuarine embayments and coastal inlets. Along the east coast, reversing currents reflect the semidiurnal tides, setting in one direction for a period of about 6 hours, after which they cease to flow momentarily (slack water) and then set in the opposite direction during the following 6 hours. Velocities are quite variable from location to location, and reflect the controlling influences produced by both the varying tidal ranges and the restrictive or non-restrictive nature of the surrounding natural barriers. The direction of flow is restricted to the channel created by the barrier, and current speeds in confined inlets exposed to the open ocean can exceed 3 knots on either the flood or ebb.

In the offshore region the tide-induced current, not being confined to a restricted channel, changes its direction continually and never comes to slack water. During a tidal cycle (about 12-1/2 hours) the current will have set in all directions of the compass. This type of tidal current is called "rotary." Current speeds are generally weak, but speeds of 1-1/2 to 3 knots have been recorded at offshore positions along the entire east coast.

2. Circulation. The northerly flowing Gulf Stream is one of the most significant features directly influencing shelf waters from southern Florida to Cape Hatteras and, more indirectly, the shelf waters north of Cape Hatteras. On a regional basis, the surface circulation over the shelf is markedly influenced by (a) river runoff creating horizontal salinity gradients, (b) seasonal horizontal temperature gradients, (c) frictional drag of the wind, and (d) the effect of the Coriolis force.[13/] Figure 5 illustrates the general surface circulation along the east coast.

(a) Gulf of Maine - Georges Bank.

(i) Surface Circulation (see fig. 5). The main feature of the circulation in the Gulf of Maine is an apparently permanent cyclonic (counter-clockwise) eddy that encompasses most of the Gulf. Input into this eddy system comes from the east across the Scotian Shelf and Brown's Bank. The westerly flow branches northward entering the east side of the Bay of Fundy. The second arm continues westward, recombining with the discharge from the Bay and turning southward to parallel the coast.

The Gulf of Maine Eddy enlarges rapidly during the spring and, by the end of May, encompasses the whole Gulf. Around the Cape Cod area, the water moves southward during fall and winter as a broad drift current. In spring and summer an anticyclonic (clockwise) eddy (Georges Bank Gyre) develops on Georges Bank, leaving only a narrow stream close to Cape Cod flowing southward.[14/]

(ii) Subsurface Circulation. In the Gulf of Maine-Georges Bank area, there is a cross-current transfer of coastal and oceanic water (movement of fresh water offshore along the surface and salt water inshore along the bottom). Superimposed on this more or less steady exchange are short-term variations caused by wind and large, frictionally driven eddies.

Based on seabed drifters released along the inshore waters of the Western Gulf of Maine, the salient bottom water movements are (1) shoreward, as well as into bays and estuaries, and (2) coastwise for varying distances. The movements along the coast are usually from east to west, except in the west, where drifters move offshore and southward.[15/]

(b) Middle Atlantic Bight (Cape Cod to Cape Hatteras).

(i) Surface Circulation (see fig. 5). The general circulation in this area apparently results from the entrainment of shelf and slope water by the Gulf Stream over southern portions, and the subsequent replenishment of the entrained waters over the remainder of the area. As a result, the normal surface circulation over the inshore

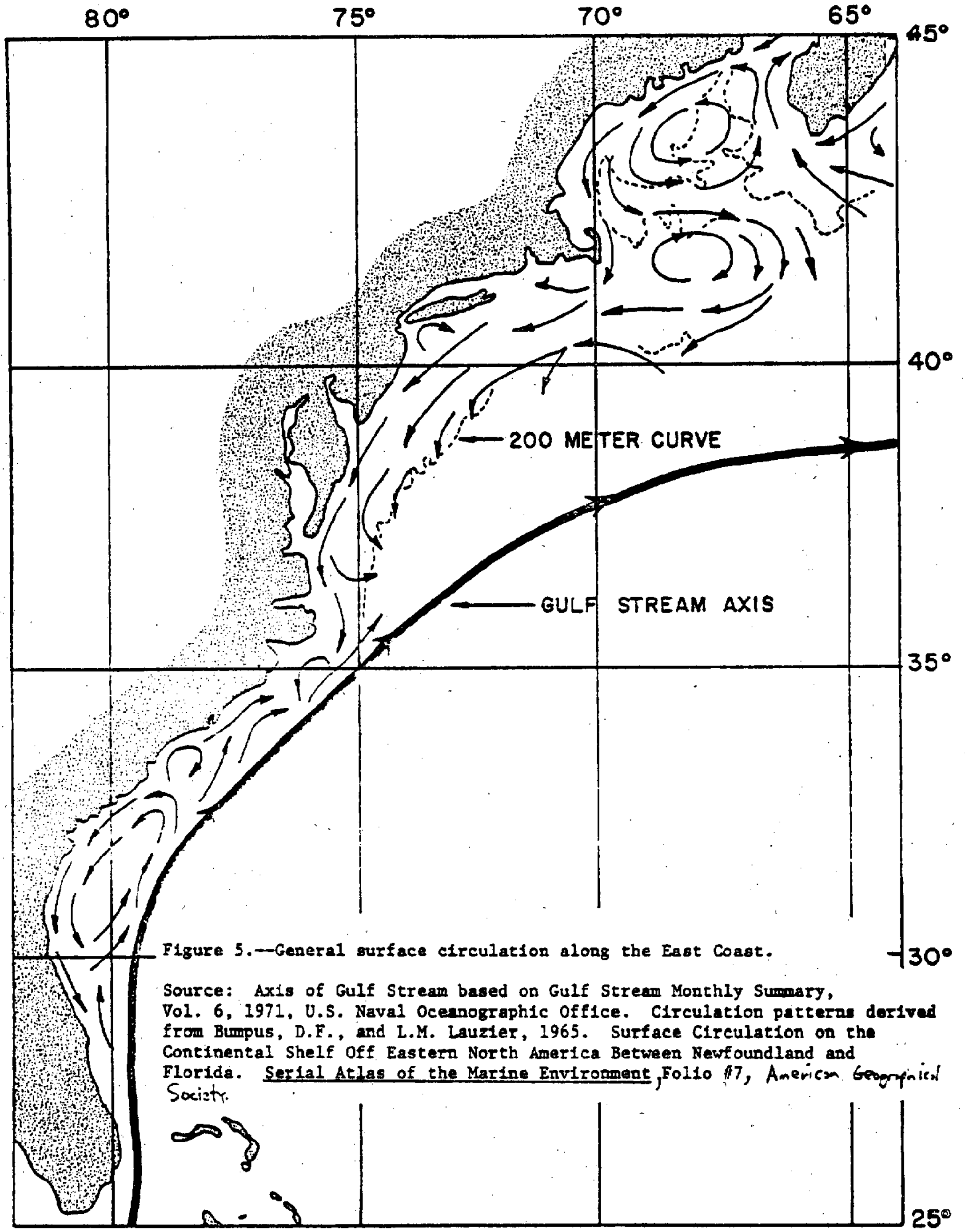


Figure 5.—General surface circulation along the East Coast.

Source: Axis of Gulf Stream based on Gulf Stream Monthly Summary, Vol. 6, 1971, U.S. Naval Oceanographic Office. Circulation patterns derived from Bumpus, D.F., and L.M. Lauzier, 1965. Surface Circulation on the Continental Shelf Off Eastern North America Between Newfoundland and Florida. Serial Atlas of the Marine Environment, Folio #7, American Geographical Society.

half of the Middle Atlantic Bight is toward the south and southwest. On the outer part of the shelf, the drift is offshore.

An indraft from western Georges Bank and from southwest of Nantucket Shoals develops during the spring and persists through June or July. During the summer, the southwesterly drift towards Cape Hatteras narrows and there is often a reversal of the southerly inshore drift off the Middle Atlantic states. In the winter, the offshore component of drift broadens and increases to become the prevailing circulation tendency.

The southerly and southwesterly longshore flow can be altered locally to a considerable degree by winds and abnormal river discharge (particularly south of Long Island and around the mouth of Chesapeake Bay). Likewise, turbulent eddies can develop around the offing of bays and in the lee of islands and points of land.16/

(ii) Subsurface Circulation. Based on seabed drifter recoveries between Nantucket Shoals and Delaware Bay, there is evidence to indicate an offshore bottom drift east of the 55-65 meter depth contours. Shoreward of this interval, the trend of bottom drift is onshore, to the west or south. The rate of bottom drift varies from <0.19 km/day to 1.3 km/day.17/ In the area adjacent to Chesapeake Bay, there is a pronounced drift toward the shore and to the southwest throughout all seasons (fig. 6), and seabed drifters have a tendency to travel toward and even to enter Chesapeake Bay. Seabed drifters released to the east and northeast of Cape Hatteras are seldom recovered, suggesting an offshore drift of bottom waters.

(c) Southeast Atlantic States (Cape Hatteras to Florida).

(i) Surface Circulation (see fig. 5). Because of its proximity to shore, the Gulf Stream has its most profound effects on the coastal circulation along the Southeast Atlantic States. From Miami to Cape Kennedy, northward flowing Gulf Stream water comes almost to the beaches. From Cape Kennedy to Cape Hatteras, the coastal circulation is mainly in the form of numerous eddies, frictionally generated from the Gulf Stream. A general northward drift is typical over the outer shelf, with southerly countercurrents along the shore. There is a general offshore drift during winter. A cyclonic eddy seems typical of the area between Cape Romain and Jacksonville, Fla., for all seasons except spring, but the strength, breadth, and configuration of this feature is probably quite variable. Topographic effects of the three, cusp-shaped embayments between Cape Romain and Cape Hatteras apparently tend to setup wave forms in the generally northerly to northeasterly flow in that region, with eddies developing in the bays at times.18/

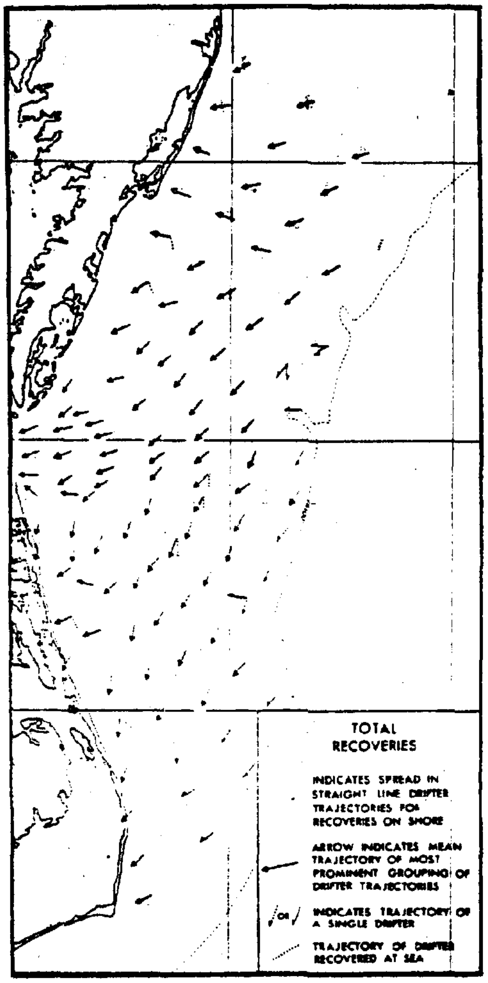


Figure 6.--Direction of bottom drift derived from seabed drifter recoveries.

Source: Harrison, W., J.J. Norcross, N.A. Pore, and E.M. Stanley, 1967: Circulation of shelf Waters off the Chesapeake Bight--Surface and Bottom Drift of Continental Shelf Waters Between Cape Henlopen, Delaware, and Cape Hatteras, North Carolina June 1963-December 1964. ESSA Professional Paper No. 3.

(ii) Subsurface Circulation. Subsurface flow is highly variable, dependent principally on meanders and perturbations along the inner edge of the Gulf Stream, with some influence from the local winds. Generally, the subsurface currents follow the surface flow, but apparently can change direction more abruptly than at the surface. This is particularly likely in the subsurface waters south of Cape Kennedy and over the outer shelf north of the Cape.[19]

3. Water Mass Characteristics.

(a) Gulf of Maine.

(i) Water Temperature. The lowest water temperatures for this coastal sector can be expected during the latter part of February and early March. The coastal belt will exhibit temperatures below 2°C at the surface all around the Gulf by the end of winter, with its central and offshore components having slightly warmer surface waters (see fig. 7).

Vertically, water temperatures are very nearly uniform by the end of winter, down to depths of 100 meters, rising slowly with increasing depth below this level. Waters entrapped in the many embayments along the coast will freeze, as well as show negative temperatures (°C) with depth.

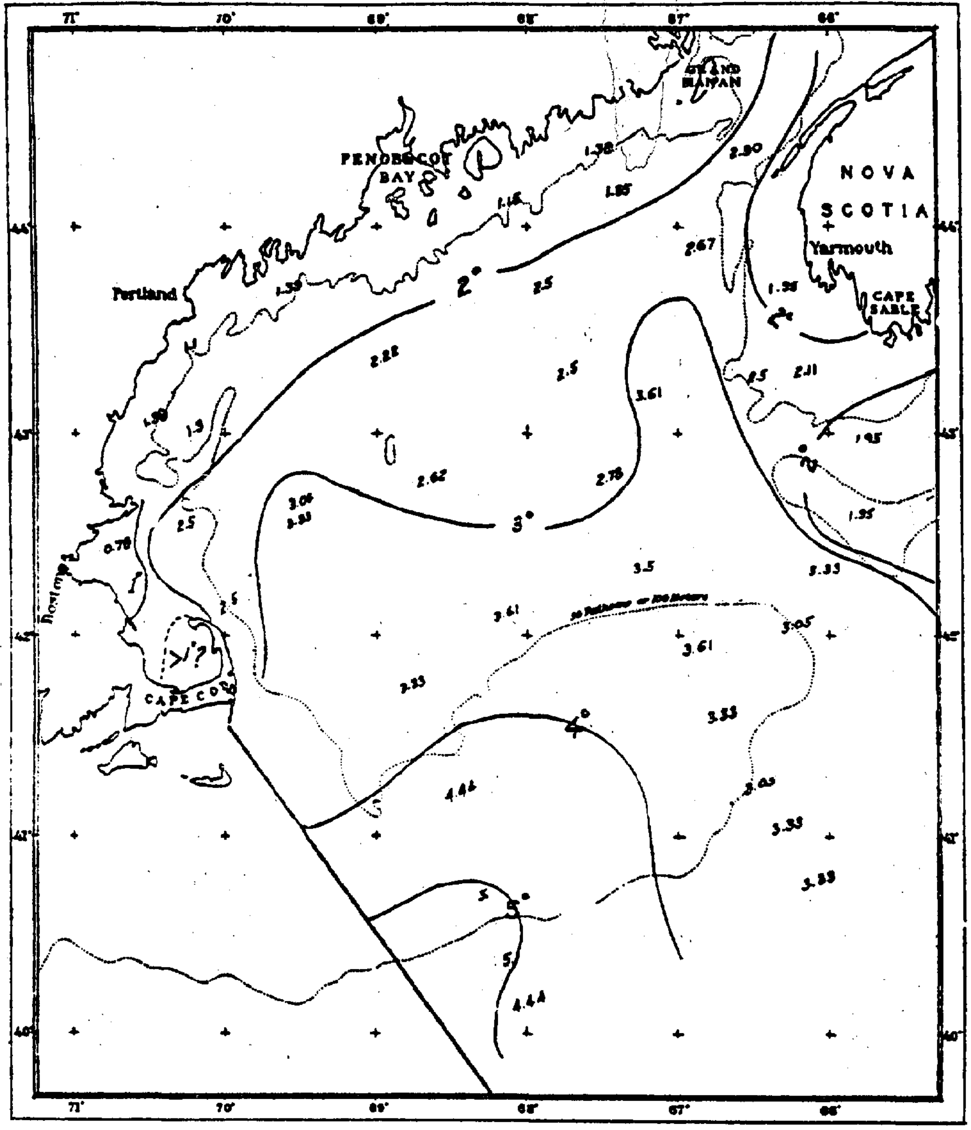
Spring warming is caused by solar input at the surface and by drafts of comparatively warm slope water entering through the trough of the Eastern Channel. Surface temperatures in June along the Massachusetts coast are >15°C, as compared to 7° and 8°C off Penobscot Bay, and >6°C on the Scotian shelf.

By midsummer the surface water has achieved its maximum temperatures (fig. 8). Temperatures are still highest along the Massachusetts and southern Maine coasts (16-18°C), with some of the lowest coastal temperatures recorded along the eastern Maine coast. During this season the vertical temperature gradient is very sharp down to 40 meters, with a slight fall in temperature with increasing depth beyond this level. Depending on locality, a slight warming or cooling trend may take place in the Gulf below 100 meters. With the onset of autumn cooling, the Gulf returns to a more homogenous vertical temperature distribution.[20]

Water temperatures from the surface to a depth of 10 meters for the Gulf of Maine as a whole exhibit seasonal ranges of $\leq$ 22°C to $\geq$ 8°C for the summer season (July-Sept.) and $\leq$ 6°C to -0.5°C for the winter season (Jan.-Mar.).

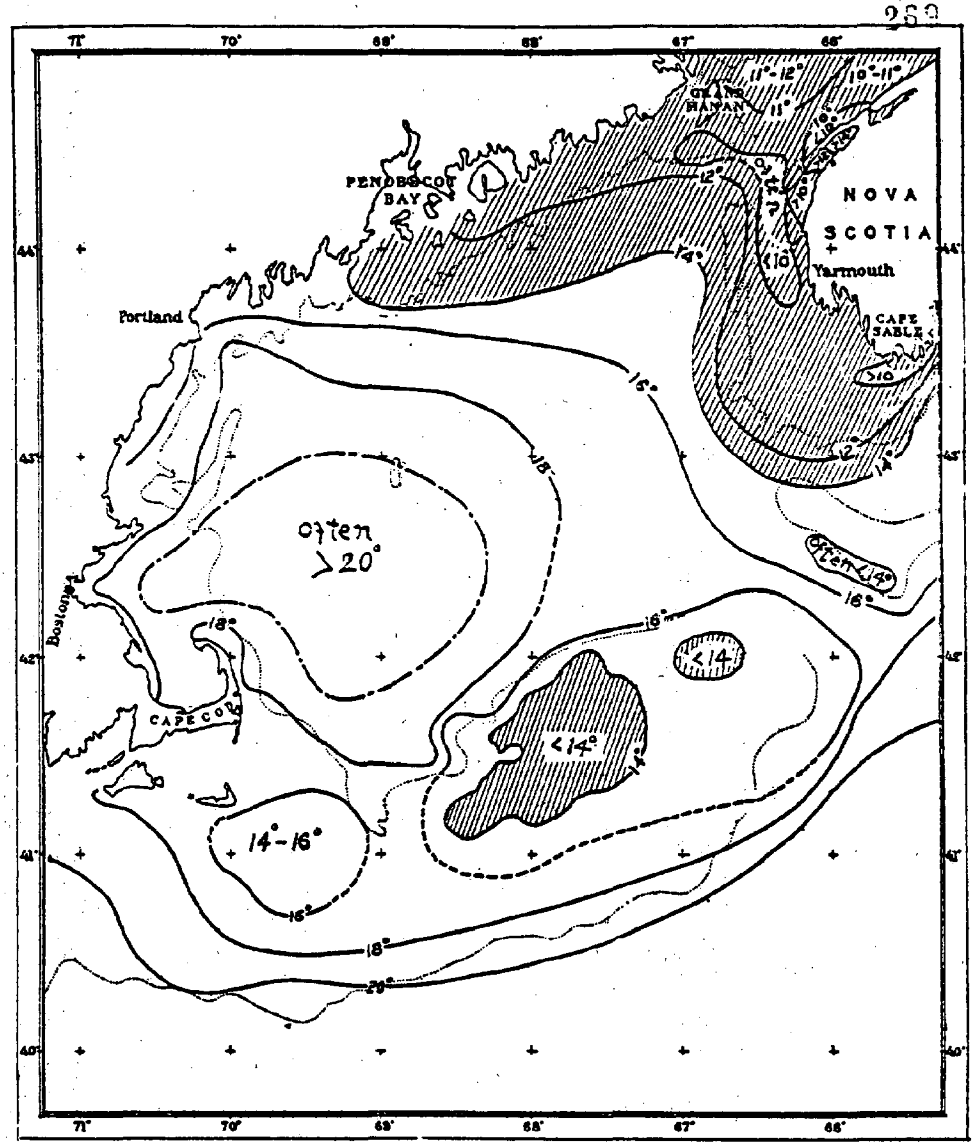
(ii) Salinity. The Gulf of Maine is characterized by low salinities averaging about 32 to 32.5 °/oo (parts per thousand) at the surface and 32.8 to 33 °/oo

Figure 7.—Surface temperatures, February–March.



Source: Bigelow, H.B., 1924: Physical Oceanography of the Gulf of Maine, Bulletin of the Bureau of Fisheries 40(2).

Figure 8.—Normal surface temperatures of mid-August.



Source: Bigelow, H.B., 1924: Physical Oceanography of the Gulf of Maine, Bulletin of the Bureau of Fisheries 40(2).

at 100 meters. The large influx of fresh water to this semi-enclosed area during the spring runoff greatly influences the salinity along the western coast for a good portion of the year.

At the end of February and in early March, the salinity of most parts of the Gulf is at its maximum for the year, except near the mouths of large rivers. The regional vertical distribution of salinity for this same period is much the same down to a depth of 40-50 meters as it is at the surface (see fig. 9); beyond this level, salinity increases with increasing depth.

The spring river runoff decreases the salinity of near-coastal waters of Maine and Massachusetts. The general distribution of salinity at this time of year indicates that the discharge from the rivers that drain into the Bay of Fundy and along the Maine coast turns westward, paralleling the shore, and does not spread southward over the Gulf. Because of this fresh water incursion, coastal areas show very sharp vertical salinity gradients, with salinity increasing with depth.21/

In summer and fall, river discharges west of Penobscot Bay intensify the salinity gradients both horizontally and vertically in the near coastal region.22/

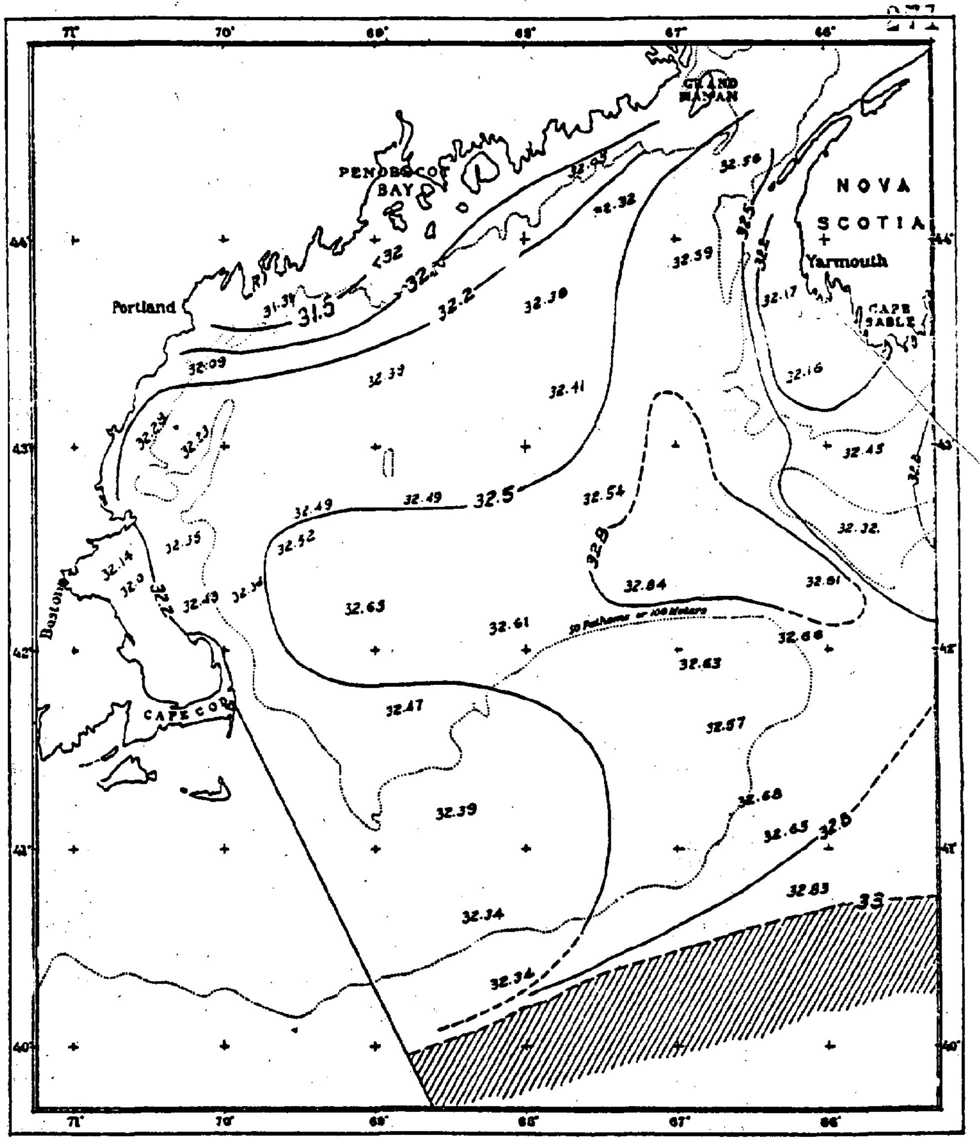
(iii) Oxygen. Oxygen values for the Gulf of Maine as a whole show high concentrations with depth during the winter (Jan.-Mar.) and spring (Apr.-June) seasons, with mean surface values of 7.43 and 7.85 milliliters per liter (ml/l) respectively. Mean surface values for the summer (July-Sept.) and winter (Oct.-Dec.) seasons are somewhat lower at 6.17 and 6.50 ml/l, respectively. The range of values is greatest during the spring, and the highest surface oxygen concentration also appears at this period, with surface values between 6.22 and 9.96 ml/l.

Oxygen values decrease slowly with depth, and relatively high values are found at depths of 125 meters. The annual mean range at 125 meters is 5.56-6.28 ml/l.

(b) Middle Atlantic Bight (Cape Cod to Cape Hatteras).

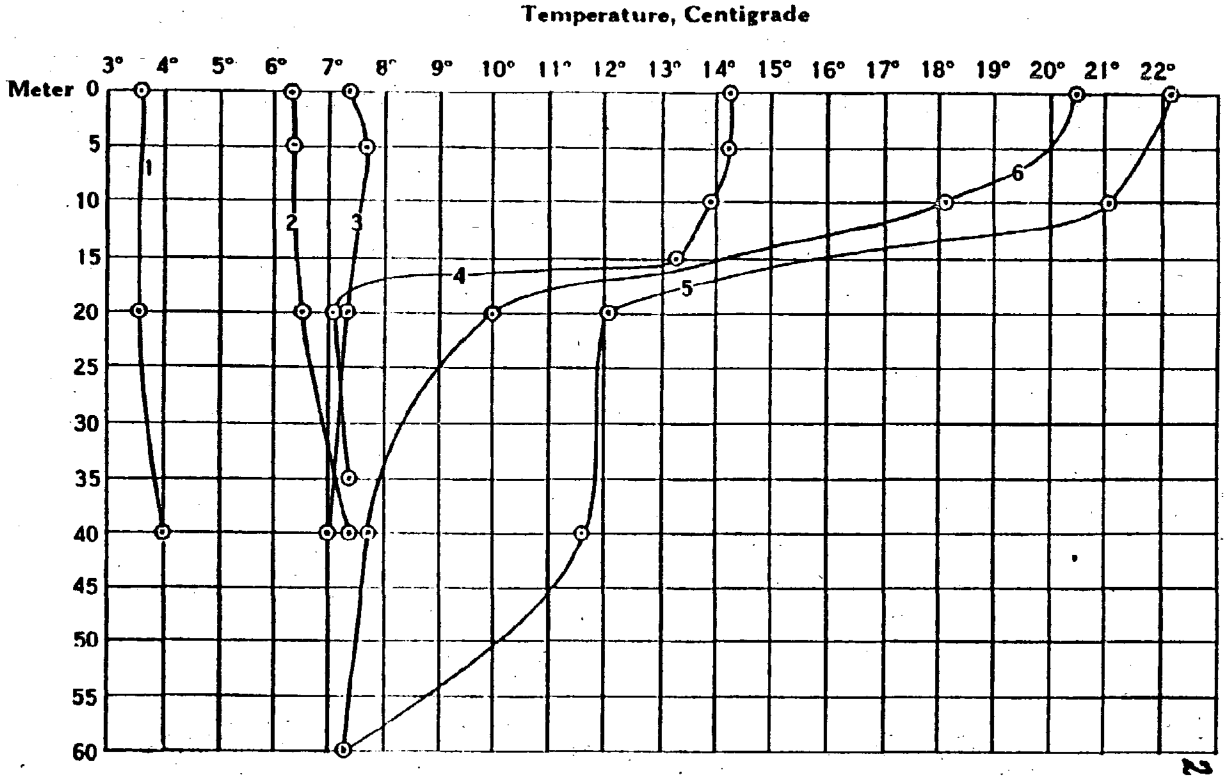
(i) Temperature. Changes in water temperature are most rapid during the spring and fall. Warming becomes apparent near the coast in early spring and by the end of April vertical thermal stratification may have developed.23/ The fully developed summer thermal structure exhibits a deeply depressed thermocline (a layer of abrupt temperature change) with the mixed layer extending 12 to 18 meters below the surface.24/ Fig. 10 illustrates the development of the thermal stratification. Because of strong tidal mixing, this summer stratification does not develop just south of Cape Cod. 25/

Figure 9.--Surface salinity, February-March.



Source: Bigelow, H.B., 1924: Physical Oceanography of the Gulf of Maine, <u>Bulletin of the Bureau of Fisheries</u> 40(2).

Figure 10.--Vertical temperature distribution of Station New York II for successive dates during 1930: 1, February 8; 2, April 10; 3, April 28; 4, June 8; 5, July 12; also 6, Station New York I, July 12.



Source: Bigelow, H.B., 1933: Studies of the waters on the Continental Shelf, Cape Cod to Chesapeake Bay I. The cycle of temperature. Papers in Physical Oceanography and Meteorology 2(4).

The pronounced thermal stratification of shelf waters is usually wiped out with the onset of cooling in September, and the water temperature profile returns to a nearly isothermal (no change in temperature with depth) situation. As cooling continues throughout the fall and winter months the water column remains thermally homogenous.[26/]

Surface water temperatures are at a minimum late in February or early March, with the lowest values near land and the highest along the edge of the shelf. During these months, inshore waters exhibit temperatures of 2-5°C, with temperatures increasing toward the south. Surface temperatures normally reach their annual maximum in early August with temperatures of 27°C off Cape Hatteras.[27/] Table 1 illustrates the seasonal temperature trends with depth for a band through the area between 38-40 degrees north latitude.

(ii) Salinity. Shelf water salinities off the Mid-Atlantic Bight increase consistently with depth and distance from shore. Isohalines (contours of constant salinities) tend to parallel the coast, but the pattern is often very irregular. This is particularly true for the mouths of large estuaries such as Chesapeake and Delaware Bays during periods of high fresh water runoff.[28/]

The chief factors tending to alter the basic salinity patterns over the shelf are: (1) freshening by river water entering near the surface inshore, causing horizontal stratification of salinity and (2) indrafts of saltier slope water over the bottom from offshore during the fall, which result in vertical mixing.[29/] Fig. 11 illustrates the horizontal stratification resulting from fresh-water input into the system, while fig. 12 illustrates the vertical stratification during periods of low fresh-water input.

Nearshore waters typically exhibit salinities less than 32 °/oo; values over the mid-zone of the shelf range from 32-35 °/oo; and values of 34-35 °/oo occur near the shelf edge. There is little difference in salinity lengthwise over the shelf from Cape Cod to Cape Hatteras, regardless of depth or season. Just south of Hatteras a wedge of pure ocean water (35.5 °/oo) presses in across the shelf (here only 27 miles wide), causing an abrupt transition southward to much higher salinity values.[30/]

(iii) Oxygen. Surface oxygen values tend to increase from Cape Hatteras (seasonal mean range 4.95-5.91 ml/l) northward, with the highest values found off Cape Cod (seasonal mean range 5.60-7.54 ml/l). The spring season (April-June) has the highest values along the entire coast, with maximum values of 9.55 ml/l occurring at the surface south of Cape Cod. Based on an in-depth survey in the fall of 1969, oxygen distribution along this section of coast decreases from the edge of the Continental Shelf toward the

Table 1.--Seasonal water temperatures vs. depth, 38-40°N, 72-75°W.

MONTHS	1 - 3 NUMBER MONTHS PRESENT 2, 3					MONTHS 4 - 6 NUMBER MONTHS PRESENT 4, 5, 6				
DEPTH	MAX	AVG	MIN	OBS	SDEV	MAX	AVG	MIN	OBS	SDEV
0	9.90	6.19	2.88	12	2.13	20.48	9.28	4.73	133	5.09
10	9.96	6.26	2.88	12	2.15	19.65	8.77	4.66	133	4.79
20	10.18	6.28	2.89	12	2.15	17.55	7.25	4.32	129	3.30
30	10.70	6.42	2.90	12	2.29	16.38	6.28	3.88	125	2.53
50	11.41	7.76	3.60	10	2.10	14.57	5.42	3.74	112	2.19
75	11.93	10.12	8.07	6	1.30	13.05	6.48	3.93	80	2.42
100	12.15	11.30	9.47	5	1.05	12.73	10.02	5.84	25	1.92
125	12.01	11.35	10.39	4	0.69	12.67	10.75	8.22	18	1.25
150	12.17	11.26	10.60	4	0.67	12.28	10.60	8.20	16	1.01
200	10.79	9.79	8.87	4	0.79	12.25	9.96	8.86	15	0.85
250	9.50	8.99	8.48	2	0.72	10.42	8.69	7.70	14	0.74
300	8.29	7.86	7.44	2	0.60	8.87	7.44	6.46	10	0.74

MONTHS	7 - 9 NUMBER MONTHS PRESENT 7, 8, 9					MONTHS 10 - 12 NUMBER MONTHS PRESENT 10, 11, 12				
DEPTH	MAX	AVG	MIN	OBS	SDEV	MAX	AVG	MIN	OBS	SDEV
0	25.88	22.27	14.65	90	2.21	20.86	13.11	6.72	66	3.17
10	25.88	21.29	12.52	89	2.66	20.84	13.25	6.82	65	3.10
20	25.22	16.78	5.10	86	5.08	20.84	13.52	7.53	61	2.94
30	22.83	13.24	4.78	76	4.96	20.92	13.50	8.72	54	2.73
50	19.86	10.21	5.25	57	3.80	18.21	12.66	8.71	39	2.34
75	15.55	11.84	5.83	38	2.25	16.36	12.94	9.85	26	1.74
100	14.65	12.08	9.52	36	1.24	15.50	13.38	10.42	18	1.32
125	13.73	11.89	9.31	32	0.99	14.82	13.02	11.77	17	0.94
150	13.11	11.40	9.10	30	1.00	14.12	12.53	11.00	15	0.98
200	12.21	10.36	8.00	24	1.12	12.42	11.18	9.50	14	1.07
250	10.74	8.99	7.05	25	1.10	11.10	9.84	8.40	14	1.02
300	9.45	7.83	6.17	24	1.09	9.74	8.48	7.22	14	0.91

Source: Churgin, J., and S.J. Halminski, 1974: Temperature, Salinity, Oxygen, and Phosphate in Waters Off United States, Key to Oceanographic Records Documentation No. 2, Vol. I, Western North Atlantic, Environmental Data Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C. In press.

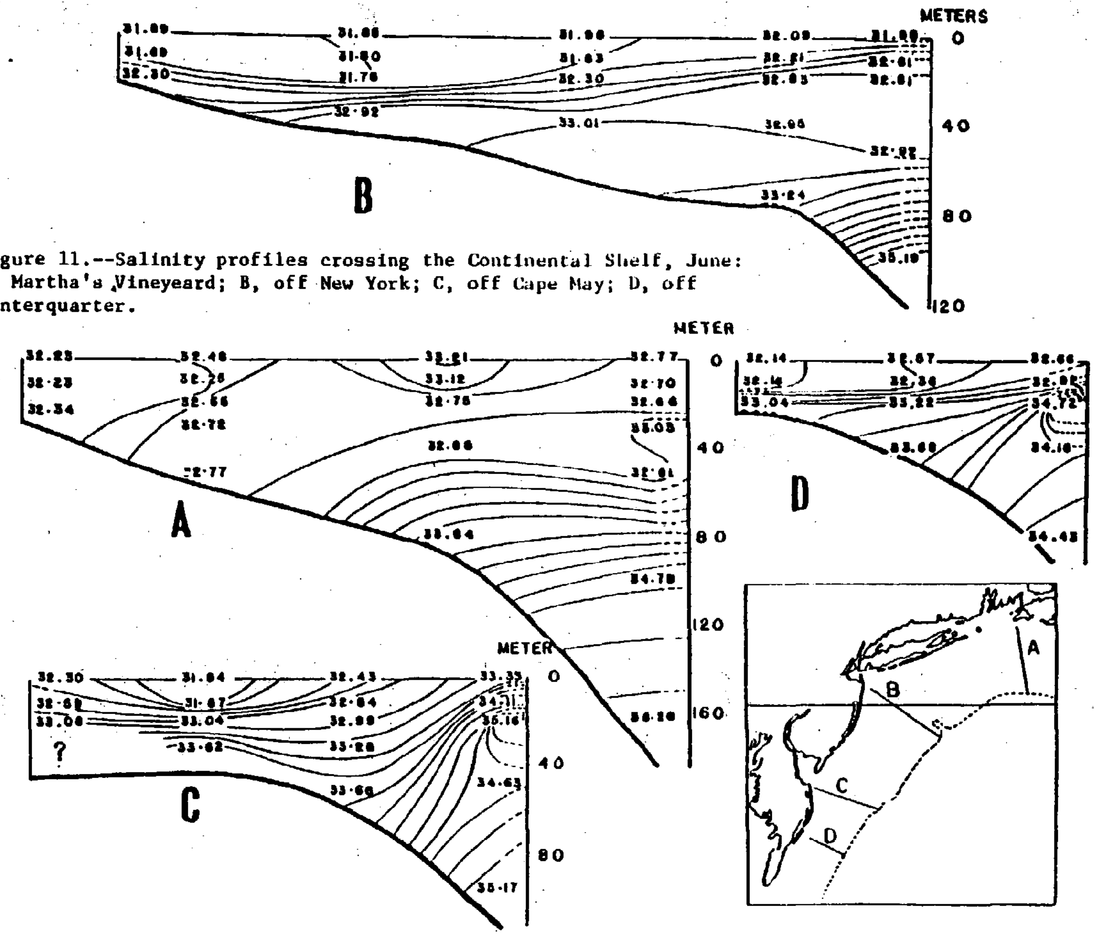
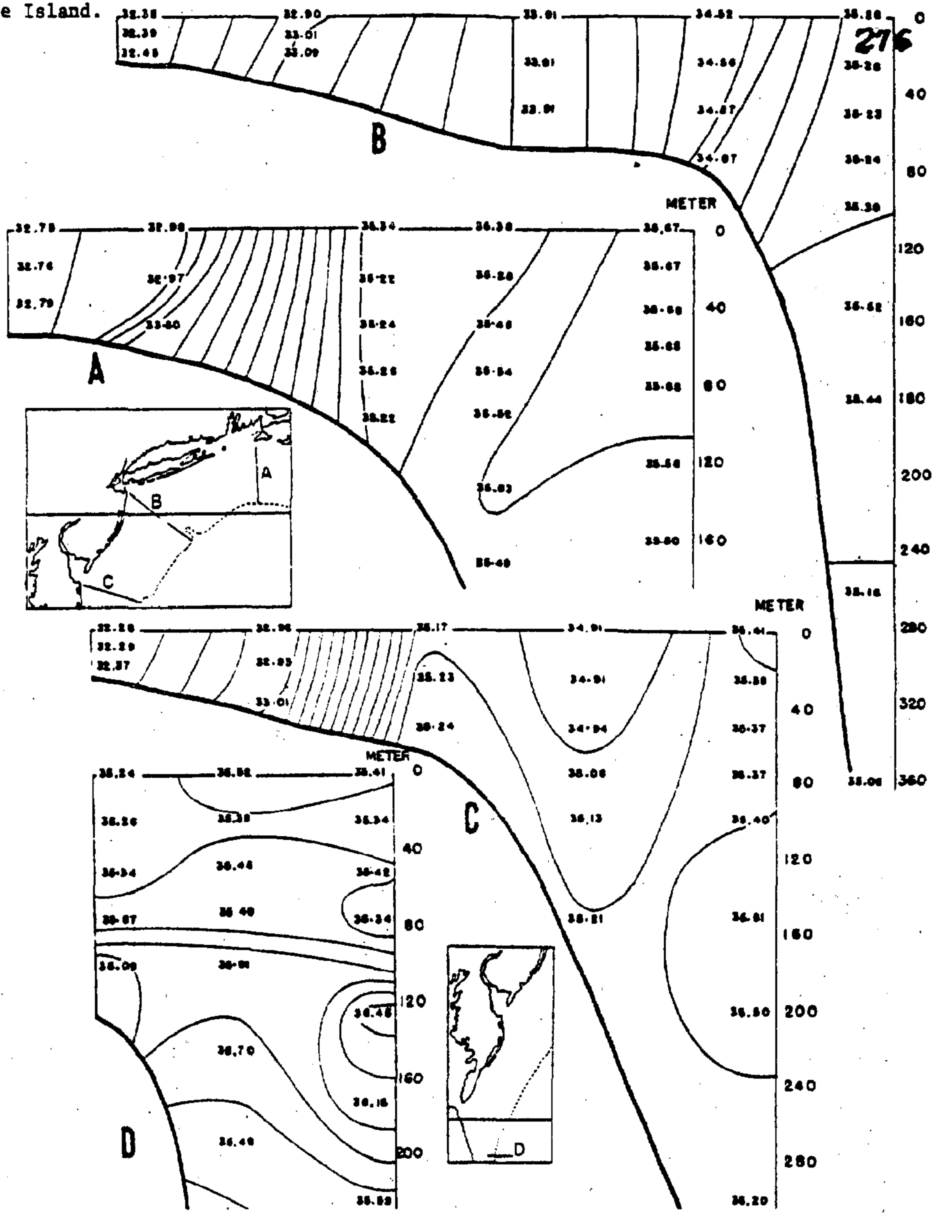


Figure 11.--Salinity profiles crossing the Continental Shelf, June: A, Martha's Vineyeard; B, off New York; C, off Cape May; D, off Winterquarter.

Source: Bigelow, H.B., and M. Sears, 1935: Studies of the Waters on the Continental Shelf, Cape Cod to Chesapeake Bay, II Salinity, Papers in Physical Oceanography and Meteorology 4(1).

Figure 12.—Salinity profiles crossing the Continental Shelf, December: A, off Martha's Vineyard; B, off New York; C, off Cape May; D, off Bodie Island.



Source: Bigelow, H.B., and M. Sears, 1935: Studies of the Waters on the Continental Shelf, Cape Cod to Chesapeake Bay, II Salinity, <u>Papers in Physical Oceanography and Meteorology</u> 4(1).

shoreline. Particularly low values, 3.2 and 0.7 ml/l, respectively, are found off the entrances to New York Harbor and Delaware Bay.[31/]

Generally oxygen decreases with depth during all seasons; however, southward from Sandy Hook mean oxygen values increase with depth during the summer season.

(c) Southeastern Atlantic States (Cape Hatteras to Florida).

(i) Temperature. This section of the Atlantic coast comes under the direct influence of the Gulf Stream, resulting in both high salinities (>36 °/oo) very close inshore and wide ranges in temperature over short distances. The wide thermal ranges are also evident at depth.

During the winter season (January-March), the waters of the coastal Carolinas exhibit a temperature increase with depth. Mean temperature values show an increase of 3°C from the surface to 75 meters. Surface temperatures range between 8 and 23°C. Off the Florida coast temperatures decrease with depth and surface temperatures range between 18 and 27°C.

During the summer season (July-Sept.), surface temperatures exhibit a much narrower range along the entire coast with temperatures from the surface to 10 meters ranging from 25°C to 29.5°C off the Carolinas and 27°C to 31°C off Florida. However, the thermal range increases with depth, and along the Florida coast at 75 meters the horizontal temperature distribution is between 12 and 28°C.

(ii) Salinity. Salinity tends to increase with depth. Mean salinity values of 36 °/oo or greater are found along this section of the coast for all seasons and depths, except near the Cape Hatteras area, where low salinity values are found during all seasons at depths of 50 meters. In the spring, surface fresh-water runoff is quite evident in the upper 10 meters off the Carolina sounds, where surface salinities range between 30 °/oo and 36 °/oo.[32/] Also during the spring season (April-June), salinities approaching 37 °/oo can be found to depths of 125 meters along the Florida coast.

(iii) Oxygen. Mean oxygen values of 4.5 ml/l are found at the surface and decrease only slightly with depth (mean value of 4.0 ml/l) during all seasons along the Florida coast. This same general trend extends northward to the Cape Hatteras area, where mean surface values reach 5.5 ml/l.

CLIMATOLOGY

1. General. The general surface wind pattern along the Atlantic coast is con-

trolled largely by the position and intensity of the Bermuda-Azores high-pressure system. The characteristics and location of this extensive High vary considerably during the year. In the winter, it usually is centered far to the southeast.

The major low-pressure storm systems, which develop over the interior, the Gulf of Mexico, and off the southeastern coast, may sweep through the North Atlantic States. These extratropical cyclones usually travel between north and east-northeast; many are intense and severe, and are accompanied by strong, gusty winds and rain or snow.

Highs from the interior usually follow the passage of these Lows, producing a pattern of rapidly changing air masses and variable winter weather conditions. There are marked temperature fluctuations and an alternation of brief stormy periods, clear crisp days, and relatively mild weather.

In the spring, the Bermuda-Azores High, although still centered far to the southeast, begins to affect the southeastern States. The Middle Atlantic and New England coasts are usually outside the high-pressure circulation, however, and are still subject to the passage of extratropical cyclones, frontal activity, and changing air masses. Warm spells, sometimes with abundant rain, alternate with cool, dry weather.

In the summer, the Bermuda-Azores High reaches its most northerly and westerly position, embracing the entire eastern seaboard within its circulation. The strength of this circulation is moderate but persistent, sufficiently so to hold back the eastward movement of the continental low-pressure system. As a consequence, the daily weather along the coast may not change much for several weeks at a time; it is controlled by the southerly and southwesterly winds bringing moist, warm air from the Gulf. This weather is characterized by frequent instability showers and thunderstorms, warm temperatures, high humidity, and relatively low wind speeds. However, the summer months also include the beginning of the hurricane season.

In the autumn, the Bermuda-Azores High again shifts southward and eastward, leaving the Atlantic coast in a weak continental high-pressure area. This gradually gives way to the winter weather pattern, bringing increased frontal activity and more frequent passage of cyclones and anticyclones.

2. Extratropical Cyclones. Extratropical or "winter" storms are generated from disturbances along the boundary between cold polar and warm tropical air masses. These disturbances may develop into intense low-pressure systems affecting tens of thousands of square miles. While they are called winter storms, they may develop at any time. The most severe ones occur from November through April.

Winter storms often form along the Atlantic polar front near the coast of Virginia and the Carolinas and in the general area east of the southern Appalachians. These are the notorious Cape Hatteras storms -- nor'easters -- which can develop to great intensity as they move up the coast, then drift seaward toward Iceland. Intense winter storms are frequently accompanied by cold waves, ice or glaze, heavy snow, blizzards, or a combination of these; often the precipitation type changes several times as the storm passes. Such storms may produce hurricane-force winds, storm surges, and high waves in coastal waters. These are discussed below. Although the annual number of extratropical storms far exceeds the number of hurricanes, only a relative few cause severe damage.

3. Tropical Cyclones.[33/] "Tropical cyclone" is a general term for storms that form in the tropics. The weakest stage is the tropical disturbance, where rotary circulation is slight or absent at the surface. Next in intensity is the tropical depression, where a surface circulation is evident, but winds are less than 34 kt. In the tropical storm stage, maximum winds range from 34 to 63 kt. At hurricane intensity, winds reach 64 kt or higher. When a tropical cyclone moves toward higher latitudes, it slowly takes on the characteristics of an extratropical storm and finally, if it survives, becomes extratropical. Most Atlantic hurricanes occur from June through November, a period usually considered the hurricane season. An average of 9.6 tropical cyclones form each season, of which about 5.6 reach hurricane intensity ($\geq$ 64 kt). Less than 3 percent have occurred out of season (table 2).

Starting with a few storms in June and July, there is a sharp increase in frequency in early August. This culminates in a peak in mid-September, followed by a decline in early October, a small increase to a secondary peak in mid-October, and finally a sharp decrease to a low level of activity in late October and November. About 79 percent of all hurricanes from 1886 through 1972 occurred during the three months from August through October.

On the average, 3.7 tropical cyclones, of which 1.8 are hurricanes, reach the U.S. coast each year (table 3). One to two of these tropical cyclones can be expected to affect the east coast. The average life of a hurricane is about 9 days. August storms normally last the longest, with an average span of 12 days. July and November storms last about 8 days.

The most dangerous single element of the hurricane is the accompanying high tides as the storm moves across a coastal area. It is here, by far, that most of the death

Frequency of Tropical Cyclones (including Hurricanes) by Months and Years

		May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1931			1	1	2	3	1	1		9
1932		1			3	3	3	1		11
1933		1	1	3	7	5	3	1		21
1934		1	1	1	2	2	3	1		11
1935					3	1	2			6
1936			3	2	6	4	1			16
1937				1	2	6				9
1938					3	1	3	1		8
1939			1		1	1	2			5
1940		1			3	2	2			8
1941						4	2			6
1942					3	3	3	1		10
1943				1	2	4	3			10
1944				3	2	4	2			11
1945			1	1	4	3	2			11
1946			1	1	1	1	2			6
1947				1	2	3	3			9
1948		1		1	2	3	1	1		9
1949					3	7	2	1		13
1950					4	3	6			13
1951		1			3	4	2			10
1952	(Feb.) 1				2	2	2			7
1953		1			3	4	4	1	1	14
1954			1	1	2	4	1	1	1	11
1955				1	4	5	2			12
1956			1	1	1	4	1			8
1957			2		1	4	1			8
1958			1		4	4	1			10
1959		1	2	2	1	3	2			11
1960			1	2	1	3				7
1961				1		6	2	2		11
1962					2	2	1			5
1963				1	1	5	2			9
1964			1	1	4	4	1	1		12
1965			1		2	2	1			6
1966			1	4	1	4		1		11
1967					1	4	3			8
1968			3		1	2	1			7
1969				1	6	2	3	1		13
1970		1		2	1	3				7
1971				1	3	6	1	1		12
1972			1		2	1				4
1973	Feb.			1	2	2	2			7
Totals	1	9	24	35	103	143	79	16	2	412

Frequency of Tropical Cyclones Reaching Hurricane Intensity by Months and Years

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1931					2				2
1932				3	1	1	1		6
1933		1	1	3	3	1			9
1934		1	1	1	1	1	1		6
1935				2	1	2			5
1936		1	1	3	2				7
1937					3				3
1938				2	1				3
1939				1		2			3
1940				3	1				4
1941					3	1			4
1942				3			1		4
1943			1	1	2	1			5
1944			2	1	3	1			7
1945		1		1	1	2			5
1946			1		1	1			3
1947				2	1	2			5
1948				1	3	1	1		6
1949				2	4	1			7
1950				4	3	4			11
1951	1			2	3	2			8
1952				2	2	2			6
1953				2	3	1			6
1954		1		2	3	1		1	8
1955				3	5	1			9
1956			1	1	1	1			4
1957		1			2				3
1958				3	3	1			7
1959		1	2		3	1			7
1960			1	1	2				4
1961			1		5	1	1		8
1962				1	1	1			3
1963			1	1	4	1			7
1964				2	3	1			6
1965				2	1	1			4
1966		1	3	1	1		1		7
1967				1	3	2			6
1968		2		1		1			4
1969				5	2	2	1		10
1970	1		1		1				3
1971				1	4				5
1972		1		1	1				3
1973			1	1	1	1			4
	2	11	18	66	90	42	7	1	237

Table 2.—North Atlantic tropical cyclone frequency for past years.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

Table 3.--North Atlantic tropical cyclone statistics for past years.

TOTAL NUMBER OF TROPICAL CYCLONES, LOSS OF LIFE AND DAMAGE								
	Total Number Tropical Cyclones*		Total Number Hurricanes		Loss of Life		Damage by Categories**	
Year	All Areas	Reaching U.S. Coast	All Areas	Reaching U.S. Coast	Total All Areas	United States	Total All Areas	United States
1931	9	2	2	0		0		#
1932	11	5	6	2		0		#
1933	21	7	9	5		63		7
1934	11	5	6	3		17		6
1935	6	2	5	2		414		7
	58	21	28	12				
1936	16	7	7	3		9		6
1937	9	4	3	0		0		4
1938	8	4	3	2		600		8
1939	5	3	3	1		3		3
1940	8	3	4	2		51		6
	46	21	20	8				
1941	6	4	4	2		10		7
1942	10	3	4	2	17	8	7	7
1943	10	4	5	1	19	16	7	7
1944	11	4	7	3	1,076	64	8	8
1945	11	5	5	3	29	7	8	8
	48	20	25	11				
1946	6	4	3	1	5	0	7	7
1947	9	7	5	3	72	53	8	8
1948	9	4	6	3	24	3	7	7
1949	13	3	7	2	4	4	8	8
1950	13	4	11	3	27	19	7	7
	50	22	32	12				
1951	10	1	8	0	244	0	7	6
1952	7	2	6	1	16	3	6	6
1953	14	6	6	2	3	2	7	7
1954	11	4	8	3	720+	193	9	9
1955	12	5	9	3	1,518+	218	9	9
	54	18	37	9				
1956	8	2	4	1	76	21	8	7
1957	8	5	3	1	475	395	8	8
1958	10	1	7	0	49	2	7	7
1959	11	7	7	3	57	24	7	7
1960	7	5	4	2	185	65	8	8
	44	20	25	7				
1961	11	3	8	1	345	46	8	8
1962	5	1	3	0	4	4	6	6
1963	9	1	7	1	7,218+	11	9	7
1964	12	6	6	4	266	49	9	9
1965	6	2	4	1	76	75	9	9
	43	13	28	7				
1966	11	2	7	2	1,040	54	8	7
1967	8	2	6	1	68	18	8	8
1968	7	3	4	1	11	9	7	7
1969	13	3	10	2	364	256	9	9
1970	7	4	3	1	74	11	9	8
	46	14	30	7				
1971	12	5	5	3	44	8	8	8
1972	4	3	3	1	128	121	9	9
1973	7	1	4	0	16	5	7	7
Total	412	158	237	77				
Mean	9.6	3.7	5.6	1.8				

**The Environmental Data Service has for some time recognized that, without detailed expert appraisal of damage, all figures published are merely approximations. Since errors in dollar estimates vary in proportion of the total damage, storms are placed in categories varying from 1 to 9 as follows:

1 Less than $50	4 $5,000 to $50,000	7 $5,000,000 to $50,000,000
2 $50 to $500	5 $50,000 to $500,000	8 $50,000,000 to $500,000,000
3 $500 to $5,000	6 $500,000 to $5,000,000	9 $500,000,000 to $5,000,000,000

*Including hurricanes

\# Not reported in literature, believed minor.

+Additional deaths for which figures are not available.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

and destruction occurs. Every hurricane crossing a coast produces a rise in normal sea level, called a "storm surge," (and, incorrectly, a "tidal wave"). Storm surges ranging up to 18 feet or more above mean sea level have been reliably reported in connection with hurricanes (in the Florida Keys, during the Labor Day hurricane of 1935). Records of such surges are rather incomplete, and higher ones may have occurred.

The highest, and consequently most dangerous, portion of the storm surge usually develops near the storm center, extending 20 to 50 miles in the direction of the onshore hurricane winds. On the other side of the storm center, the offshore winds may, but do not necessarily, result in tides well below normal. This means that for Atlantic hurricanes, the dangerous storm tide is usually at and to the right of the center, if the storm is moving from sea to land, and at and to the left, if it moves from land to sea (looking in the direction the storm is moving).[34]

The 100-year return for tropical cyclone surges along coastal areas could be anywhere from 10 to 20 feet; this large range occurs because of the variability of storms versus location, as well as the variability of ocean bathymetry. This means that at a particular coastal location, and in a year's time, there is a one percent chance that a storm surge of 10 to 20 feet will occur. The 500-year return period can be anywhere from 15 to 30 feet.

There are many instances of tornado occurrences associated with hurricanes. Most of these have been observed in Florida, Cuba, and the Bahamas, or along the Gulf and South Atlantic coasts of the United States. Over water, a tornado is called a waterspout. Latest information from the National Severe Storms Laboratory of NOAA indicates that some waterspouts may be as severe as tornadoes are over land.

Some of the highest ocean waves are generated by the winds of the tropical cyclone. In the Atlantic, it has been found that in an average hurricane waves of 35 to 40 feet are developed, and that great hurricane waves may send up peaks to 50 to 55 feet.

Hurricanes have brought extreme winds to the U.S. Atlantic coast from Florida to Maine. In the Florida Keys, winds have been estimated at up to 175 kt, and 100-kt-plus winds have occurred in New England.

Some of the world's heaviest rainfalls occur in association with hurricanes. The rainfall is always heavy, probably 3 to 6 inches on the average, frequently much more. It is quite likely that the exact rainfall in these storms is never known, since after the wind reaches 45 kt or more, it is possible that not more than 50 percent is actually caught by the rain gauge.[35] Extreme rainfall amounts up to 30 inches have been recorded in a 24-hour period during a tropical cyclone. The remnants of Camille dumped 27 inches near Massies Mill, Va. in less than 12 hours. Large amounts often occur in slow-moving storms.

June storms develop in the northwestern Caribbean or the Gulf of Mexico, and the Texas coastline is the most vulnerable section of the United States at this time of the year. A few recurve toward Florida, but these are usually quite weak.

July tropical cyclones are slightly larger than those in June. They tend to have a rather strong westerly component and are about as likely to reach the coast line of one State in the hurricane belt as another.

The main hurricane season begins in August, with a marked increase in number and intensity. During August and early September, some storms reach hurricane intensity within 10° to 15° longitude of the Cape Verdes Islands, and if they remain on a fairly straight westerly course and move steadily along at around 15 mph, they will approach the United States coast line as very large and severe hurricanes. However, the great majority of August and early September hurricanes develop west of longitudes 45° and 50°. The trade winds are normally strongest in August, and August hurricanes usually have strong westerly components and have the highest average hourly movement (in the tropics) of any month. If they recurve up the Atlantic, they usually follow a comparatively smooth parabolic path.

The climax of the hurricane season is reached during the first half of September. During the first half of the month, most of the storms come from the Antilles, or to the eastward; but during the last half of the month, many also develop in the western Caribbean, and storms gradually begin to follow more northerly tracks as the polar westerlies move southward. There is a rather marked decrease in storm frequency during the latter half of the month.

In early October, hurricanes develop in the northwestern Caribbean, often within 150 miles of Swan Island. All have strong northerly components and recurve fairly quickly. Rarely do hurricanes move as far west as Texas after September 15. The frequency and average intensity decline rapidly after mid-October. Florida, Cuba, and Jamaica are frequent targets for October storms.

4. <u>Winds</u>. From October to March, the prevailing wind direction over the ocean north of 30°N is between west and north. From March until the summer regime is established, the winds are variable, but from June to September, they generally are between west and south. The windiest period is from December to March, while the weakest winds occur

from May to August. Off and along the Florida coast south of latitude 30°, easterly winds are prominent throughout the year.

North of Florida, wind speeds average 14 to 20 kt from December through March, and about 8 to 12 kt from May through August. The summertime prevailing southwesterlies are more persistent than the wintertime northwesterlies, because of the lack of extratropical cyclone activity during the warmer months. At times, however, the quiet periods of summer are disturbed by tropical cyclones and severe thunderstorms.

During winter, gales (wind 34 kt or higher) are encountered about 3 to 8 percent of the time north of 30°N. They are most likely to arrive with westerly or northwesterly winds. The area from Cape Hatteras to Cape Henry, exposed to the ocean, is subject to severe northeasterly winter storms. Gales are rare in summer, but may be encountered in tropical cyclones or thunderstorms.

In general, the wind regime at coastal stations is similar to that of the ocean areas, with west to north winds predominating in the winter, and south to west winds in the summer. The average force of the winds reported at coastal stations, however, is less, because wind speeds over the open sea are nearly always higher than over land, and topography may cause local changes within the general regime. At coastal stations, the hot summer afternoons often are relieved by a refreshing sea breeze blowing onshore from the cooler waters adjacent to the coast.

Wind speeds along the Florida coast are generally moderately light, averaging 8 to 12 knots through the year. Monthly averages vary in summer from 6 to 10 knots, and 8 to 15 knots in winter. Wide departures from these averages should be expected in all seasons. In the immediate coastal area, the windward side of promontories may be buffeted by gales and heavy seas, while the lee side is relatively protected. Averages do not show these variations.

5. High Waves.[36] High waves along the North Atlantic coast can be generated by extratropical or tropical cyclones. Since extratropical are more frequent than tropical storms, the chance of high waves is greatest from about September through June. The highest waves recorded have occurred south of Cape Hatteras, where 60- to 70-ft waves have been reported. Waves of 30 to 40 feet have been recorded off New Jersey, with 26- to 32-ft waves off New York and New England.

The highest frequencies of waves $\geq$12 feet occur in January and February, and range from about 8 to 12 percent north of Florida. Highest frequencies of waves $\geq$20 feet, north of Florida, also occur most often in January and February, and range from 1 to 2 percent.

In seas off Florida, waves are $\geq$12 feet about 4 percent of the time in September, October, and November, and $\geq$20 feet about .7 percent in September. This reflects the influence of tropical cyclones; maximum seas have been recorded at 33 to 40 feet in these waters.

6. Visibility. Poor visibility may be produced by fog, haze, rain, and snow. Advection sea fog is the most common cause along the East Coast, particularly north of Cape Hatteras. Although it occurs most frequently in late spring and early summer, when the winds are from the south or southwest and the warm, humid air is cooled to its dewpoint by the still-cold Labrador Current, it may occur in any season. Along the New England coast, these fogs have been known to persist for three weeks almost without interruption. Areas along the coast, at the heads of bays, and near rivers are often comparatively clear, while elsewhere the fog is very thick. Over the interior waters, the fog usually clears during the middle of the day.

Radiation fog is also frequent along the coast, forming shortly after sunset. These fogs generally do not extend any great distance seaward, but may seriously restrict harbor activities. Sea fogs sometimes drift onshore on hot summer days, persisting for many hours in a shallow layer along the coast. Over the land, dispersal usually begins at the surface, giving the effect of lifting. Over the water, fog generally persists at the surface and restricts visibility until the last vestige of the formation disappears.

Steam fog (sea smoke), sometimes encountered in winter, forms in very cold weather when the air temperature is much lower than that of the water.

The frequency of fog occurrence is in opposite phase over land and ocean; most land fog occurs in winter, most sea fog in summer. As a result, statistics for fog occurrence or poor visibility at inland or sheltered harbors are no guide to conditions offshore.

Fog is more likely to form with light to moderate winds. The most frequent wind speeds accompanying sea fog are less than 10 knots. Fog rarely forms and persists with winds of gale force.

In general, fog frequency increases with increasing latitude. The offshore fog season runs from late winter and spring to summer. Visibilities from North Carolina to Delaware drop below 2 mi 4 to 5 percent of the time from February through May. This frequency increases 6 to 7 percent off Delaware and New Jersey from April through June. In the waters around New York, visibilities drop below 2 mi 8 to 12 percent of the time from April through July. Fog is a real threat off the New England shores from April through

September. Visibilities drop below 2 mi 8 to 23 percent of the time. Fog is of little consequence in offshore waters south of North Carolina.

7. Air Temperatures. Average winter air temperatures along the east coast range from about freezing off Maine to 52°F off Cape Hatteras to 72°F in the Florida Keys. Along the New England coast, where average winter temperatures range from 32° to 37°F, temperatures drop below freezing about 40 to 45 percent of the time. This frequency falls to 35 to 40 percent off southern New England and New York, where average temperatures range from 35° to 40°F. Winter temperatures fall below freezing about 7 to 14 percent of the time off New Jersey and Delaware, and 4 to 7 percent of the time off the Outer Banks of North Carolina. Average temperatures increase to near 60°F south of Cape Hatteras. Freezing temperatures are uncommon from the waters off Georgia to the Florida Keys, where average temperatures increase from 65° to 72°F.

By April, temperatures are on the rise. Average temperatures range from 40°F off Maine to 60°F off Cape Hatteras to 76°F in the Florida Keys. In New England waters, average temperatures are up to 55°F by June and reach a peak of about 62°F during July and August. Temperatures above 85°F are rare. Off New York and New Jersey, average temperatures increase from around 50°F in April to 65°F in June, and reach a peak of 72° to 75°F during July and August, when temperatures get above 85°F about 4 to 5 percent of the time. Off Virginia and Maryland, temperatures are slightly warmer, and midsummer averages run about 79°F, with temperatures over 85°F occurring about 5 percent of the time. Off the Outer Banks and South Carolina, spring temperatures in the mid- to upper-sixties give way to midsummer temperatures in the low eighties. Temperatures get above 85°F about 10 to 15 percent of the time. This increases to 25 to 30 percent of the time off the Georgia-Florida coast, where midsummer temperatures average 83° to 84°F.

By September, temperatures slowly begin to fall. The October range of averages runs from about 54°F off Maine to 68°F off Cape Hatteras to 78°F in the Florida Keys. Temperatures do not drop below freezing consistently along any portion of the coast until December.

8. Precipitation. In general, precipitation frequencies in coastal waters decrease from north to south. The biggest decrease occurs in winter between New England and the coastal waters to the south. Winter precipitation frequencies range from 20 to 25 percent off New England north of Cape Cod and 8 to 10 percent south to Cape Hatteras.[37]

Late fall through spring is the rainy season north of Cape Hatteras, while to the south, where frequencies are less than 5 percent year 'round, summer and early fall have more rain. North of Cape Hatteras, snow can be expected from November through March, with maximum frequencies in January and February. Off New England, snow is reported 5 to 10 percent of the time in January and February.

From May through September, showers and thunderstorms provide much of the rainfall. Precipitation frequencies range from about 2 to 8 percent along the entire coast, and it still rains more often off New England. Thunderstorms are most frequent from June through August. They are most likely south of Cape Hatteras, where they occur on about 40 to 80 days annually, increasing toward the south. North of Cape Hatteras to New York, thunderstorms are reported on about 30 to 35 days. Off New England, this figure drops to 20 or less.

9. Ice. Ice is not a problem to shipping in the coastal waters off New England, nor do icebergs penetrate these waters. Furthermore, all the major ports and harbors along the New England coast are kept open to shipping even during the most severe winters. In bays and harbors, ice formation is mostly of a local nature. In principal harbors, steamers and tugs usually keep a channel open.

10. Storm Tides.. Extratropical and tropical storms generate storm tides which can cause severe destruction along North Atlantic coasts. The storm tide is a combination of the astronomical tide and a storm surge, which is the effect of the storm upon sea level. If the maximum storm surge coincides with high tide, the results can be disastrous. This is particularly true of spring tides, when astronomical tides are higher than usual.

Hurricane or tropical storm surges have a destructive period of several hours; extratropical storm surges have a destructive period of hours to days. The most destructive element of the tropical cyclone surge is the amplitude; the most destructive element of the extratropical storm surge is its persistence. The extratropical surge is no more than several feet in height, but with time, the pounding wave (surf) and near-shore currents erode the coast.

Storm surges for the same storm vary considerably at different locations, since storm surge amplitude is a function of the distance from the coast and the physical characteristics of the location. If the immediate coastal waters are shallow, the magnitude of the storm surge will be greater relative to deeper coastal waters.38/ Generally, the closer to shore, the higher the storm surge. If an FNPP site is relatively distant from the shore, then wind waves will be of greater concern than storm surge.

Along the Florida coast, where storm tides are mainly the result of hurricanes, maximum tide heights 8 to 10 feet above mean sea level have been recorded, while in the Keys 15- 18-foot tides have occurred. From Jacksonville north to Cape Hatteras, maximum tide heights have resulted mainly from tropical cyclones, and range from 6 to 12 feet above mean sea level. From Cape Hatteras to New England, both extratropical and tropical cyclones have generated extreme tides. The range of these extreme storm tides is from about 6 to 14 feet above mean sea level. Virtually no measurements of offshore storm tides have been made.

Storm surge computations can be made accurately only for outer coasts and seaward where the local bathymetry has been adequately surveyed. To provide definitive information on storm surge for deployment of FNPP's, it would also be necessary to make comprehensive studies of the specific proposed sites. These would involve local storm characteristics, frequency, and vector storm motions.

11. Resonance. In addition to the primary effects of storm surges and waves, there are important secondary effects to be considered, such as resonance, overtopping, and refraction. All three are functions of the FNPP site's geometry, bathymetry, wave climatology, and, where applicable, near shoreline configuration.

Because of resonance, the waves around the exterior of an FNPP facility can become much larger than waves in the surrounding ocean. Under critical situations, this can lead to overtopping of the breakwaters protecting the FNPP's, which in turn can create severe problems inside the breakwaters. Furthermore, if there are openings, severe resonance could exist inside the breakwaters. Because of the fixed geometry of the FNPP facility, there can be certain wave frequencies that are excited, resulting in standing waves of substantial magnitude inside the breakwater. Further, refraction could complicate the situation even more, by focusing waves at the entrances of FNPP enclosures.

To determine the possible susceptibility of the FNPP to waves and overtopping aggravated by resonance and refraction, a careful study of the specific geometry, bathymetry, and wave climatology should be made at each individual site.

EARTHQUAKES AND SEISMIC SEA WAVES

1. Earthquakes. The northeastern region of the United States contains zones of relatively high seismic activity (fig. 13 and table 4). This region is affected by large

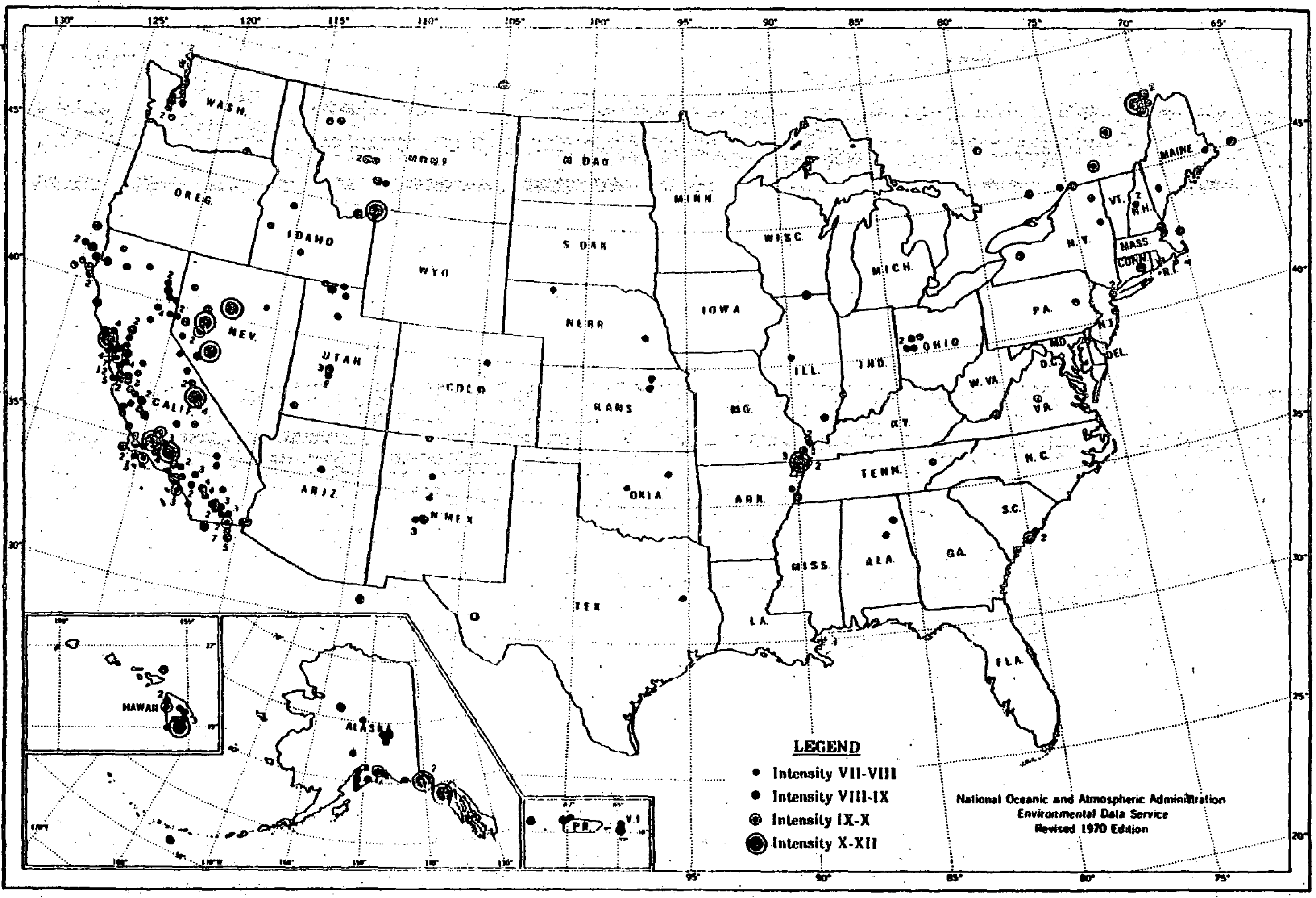


Figure 13.—Damaging earthquakes (modified Mercalli intensity VII and above) in the United States from earliest history through 1970.

Source: Coffman and von Hake, 1972: U.S. Earthquakes, 1970, Environmental Data Service, NOAA, U.S. Department of Commerce, Washington, D.C.

Date	Locality	N. Lat.	W. Long.	Felt area	Modified Mercalli intensity
		degrees	*degrees*	*sq. mi.*	
1663 Feb. 5	St. Lawrence River region	47.6	70.1	750,000	X
1755 Nov. 18	East of Cape Ann, Mass	42.5	70.0	300,000	VIII
1811 Dec. 16 1812 Jan. 23 1812 Feb. 7	Near New Madrid, Mo	36.6	89.6	2,000,000	XII
1812 Dec. 21	Off coast of southern California	34	120	......	X
1836 June 10	San Francisco Bay	38	122	......	IX-X
1838 June	San Francisco region	37½	122½	......	X
1852 Nov. 9	Near Fort Yuma, Ariz	33	114½	......	VIII-IX
1857 Jan. 9	Near Fort Tejon, Calif	35	119	......	X-XI
1865 Oct. 1	Fort Humboldt and Eureka, Calif	41	124½	......	VIII-IX
1865 Oct. 8	Santa Cruz Mts., Calif	37	122	......	VIII-IX
1868 Apr. 2	Near south coast of Hawaii	19	155½	......	X
1868 Oct. 21	Hayward, Calif	37½	122	......	IX-X
1872 Mar. 26	Owens Valley, Calif	36½	118	125,000	X-XI
1886 Aug. 31	Northwest of Charleston, S.C	32.9	80.0	2,000,000	IX-X
1892 Feb. 23	Northern Baja California	31½	116½	......	VIII-IX (U.S.)
1892 Apr. 19	Vacaville, Calif	38½	122½	......	IX
1892 Apr. 21	Winters, Calif	38½	122	......	IX
1893 Apr. 4	Northwest of Los Angeles, Calif	34½	118½	......	VIII-IX
1895 Oct. 31	Charleston, Mo	37.0	89.4	1,000,000	VIII
1898 Apr. 14	Mendocino County, Calif	39	124	......	VIII-IX
1899 Sept. 3	Yakutat Bay, Alaska	60	142	......	XI
1899 Sept. 10	. . . . do	60	140	......	XI
1899 Dec. 25	San Jacinto and Hemet, Calif	33½	116½	100,000	IX
1906 Apr. 18	Northwest of San Francisco, Calif	38	123	375,000	XI
1915 Oct. 2	Pleasant Valley, Nev	40½	117½	500,000	X
1918 Apr. 21	Riverside County, Calif	33¾	117	150,000	IX
1921 Sept. 29 1921 Oct. 1	Elsinore, Utah	38.8	112.2	......	VIII
1922 Mar. 10	Cholame Valley, Calif	35¾	120¼	100,000	IX
1925 Feb. 28	St. Lawrence River region	47.6	70.1	2,000,000	VIII
1925 June 27	Helena, Mont	46.0	111.2	310,000	VIII
1925 June 29	Santa Barbara, Calif	34.3	119.8	......	VIII-IX
1927 Nov. 4	West of Point Arguello, Calif	34½	121½	......	IX-X
1931 Aug. 16	Western Texas	30.6	104.1	450,000	VIII
1932 Dec. 20	Western Nevada	38.7	117.8	500,000	X
1933 Mar. 10	Long Beach, Calif	33.6	118.0	100,000	IX
1934 Jan. 30	Southeast of Hawthorne, Nev	38.3	118.4	110,000	VIII-IX
1934 Mar. 12	Near Kosmo, Utah	41.7	112.8	170,000	VIII
1935 Oct. 18	Northeast of Helena, Mont	46.6	112.0	230,000	VIII
1935 Oct. 31	. . . . do	46.6	112.0	140,000	VIII
1940 May 18	Southeast of El Centro, Calif	32.7	115.5	60,000	X
1949 Apr. 13	Western Washington	47.1	122.7	150,000	VIII
1952 July 21	Kern County, Calif	35.0	119.0	160,000	XI
1954 July 6	East of Fallon, Nev	39.4	118.5	130,000	IX
1954 Aug. 23	. . . . do	39.6	118.5	150,000	IX
1954 Dec. 16	Dixie Valley, Nev	39.3	118.2	200,000	X
1958 July 9	Southeastern Alaska	58.6	137.1	100,000	XI
1959 Aug. 17	Near Hebgen Lake, Mont	44.8	111.1	60,000	X
1964 Mar. 27	Southern Alaska	61.0	147.8	700,000	IX-X
1965 Apr. 29	Northwestern Washington	47.4	122.3	130,000	VIII
1971 Feb. 9	San Fernando, Calif	34.4	118.4	80,000	XI

Table 4.--Prominent earthquakes of the United States through 1971.

Source: Coffman and von Hake, U.S. Earthquakes, 1970, Department of Commerce, National Oceanic and Atmospheric Administration, Environ-earthquakes orginating in adjacent Canada, principally in the St. Lawrence Valley and the Laurentian Trough. New York and Massachusetts have experienced numerous shocks, several quite severe. A coastal area extending from Richmond, Virginia, to Portland, Maine, and inland as far as northwestern Pennsylvania, was shaken on August 10, 1884. by an earthquake that apparently originated near the edge of the Continental Shelf off the mouth of the Hudson River. On Long Island, walls and plaster were cracked at many places. On November 18, 1929, all of New England was shaken by a strong (Richter magnitude 7.2) submarine earthquake off the Grand Banks of Newfoundland. Greatest damage done was the shearing of 12 Atlantic cables. A seismic seawave (tsunami) resulting from displacement of the ocean floor caused considerable damage and loss of life at Placentia Bay, Newfoundland. Small seawaves were recorded along the United States east coast as far as Charleston, South Carolina, and ships within 50 to 300 miles (80 to 480 km) of the earthquake were shaken severely.[39]

A paper by B. C. Heezen and M. Ewing in 1952[40] advanced a theory that the 1929 Grand Banks earthquake "set in motion slides and slumps which, with the incorporation of water, were transformed into turbidity currents of high density. These converged to form a gigantic turbidity current which swept down the continental slope and across the sea floor for well over 350 nautical miles, breaking each succeeding submarine cable." All the main submarine cables across the North Atlantic traverse the epicentral area. Six cables were broken almost at once at the time of the earthquake, followed by an orderly sequence of breaks of each succeeding cable lying in increasingly deeper water for over 300 miles (480 km) south of the earthquake area.

Since turbidity currents of this type generally orginate on the Continental Slope and flow downhill, they would not normally constitute a threat to FNPP transmission cables located on the Continental Shelf.

In New Jersey, Pennsylvania, and States to the south, occasional strong but nondestructive shocks are believed to be the result of the settling of the coastal plain sediments on the underlying basement rock that structurally represents the base of the Appalachian mountain range. The greatest shock in the east was the Charleston, South Carolina earthquake of August 31, 1886. It was felt as far away as Chicago and Boston. The coastal areas of Alabama and northwestern Florida experienced modified Mercalli intensity V and VI effects (table 5) during this earthquake. In Charleston, 60 persons were killed and many buildings were ruined or severely damaged. In the surrounding country, bridges were wrecked, railroad tracks were twisted, and sand and water ejected

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage *negligible* in buildings of good design and construction; *slight to moderate* in well-built ordinary structures; *considerable* in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motorcars. (VIII- Rossi-Forel Scale.)

VIII. Damage *slight* in specially designed structures; *considerable* in ordinary substantial buildings, with partial collapse; *great* in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX Rossi-Forel Scale.)

IX. Damage *considerable* in specially designed structures; well-designed frame structures thrown out of plumb; *great* in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale.)

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Table 5.—Modified Mercalli intensity (damage) scale of 1931 (abridged).

Source: Wood, H.O., and F. Neumann, 1931: Modified Mercalli Intensity Scale of 1931, Bulletin of the Seismological Society of America, Vol. 21, pp. 277-283.

from numerous craterlets.[41]

2. Seismic Sea Waves. Although seismic sea waves can be considered some sort of hazard on the Atlantic Coast, other phenomena such as hurricanes and storm surges will be more important in the design criteria of floating power plants. A seismic sea wave, also knows as a tsunami, is a gravitational sea wave produced by any large scale, short-duration disturbance of the ocean floor, principally by a shallow submarine earthquake, but also by submarine earth movement, subsidence, or volcanic eruption. It is characterized by great speed of propagation (up to 950 km/hr), long wavelength (up to 200 km), long period (varying from 5 minutes to a few hours, generally 10-60 min), and low observable amplitude on the open sea. On entering shallow water along an exposed coast, (often thousands of miles from the source) however, a seismic sea wave may pile up to great heights (30 m or more), and cause considerable damage.[42]

It is the usual practice to divide tsunami hazards into two categories, remotely and locally generated. Possible remote sources for the Atlantic Coast include some of the earthquake-prone areas west of longitude 60° and approximately along latitude 20°N (fig. 14). Another source region occasionally mentioned is Portugal.

Fig. 15 shows earthquake (epicenter) distribution for the United States. There is relatively little chance of local tsunami generation on the east coast as compared to the west coast.

The 1929 Grand Banks earthquake (above) did produce a submarine landslide or turbidity current which in turn induced a tsunami. As discussed previously, this would not be likely to occur on the Continental Shelf. Also, according to model studies, submarine landslides and especially turbidity currents are relatively ineffective tsunami producers.

A tsunami warning system does not exist in the Atlantic and provisions have not been made for any safety measures to be taken. From the area west of longitude 60°W. and latitude 20°N., warning times would be shorter than for tsunamis generated on the European side of the Atlantic. For example, representative tsunami travel time from the November 18, 1929 Grand Banks earthquake are [43] as follows:

to: Ocean City, Maryland, 3 hours 48 minutes (distance approx. 1700 km)

to: Charleston, South Carolina, 5 hours 52 minutes (distance approx. 2450 km)

An earthquake near Hispaniola on August 4, 1946, generated a slight tsunami; no damage

WORLD SEISMICITY, 1961-1969

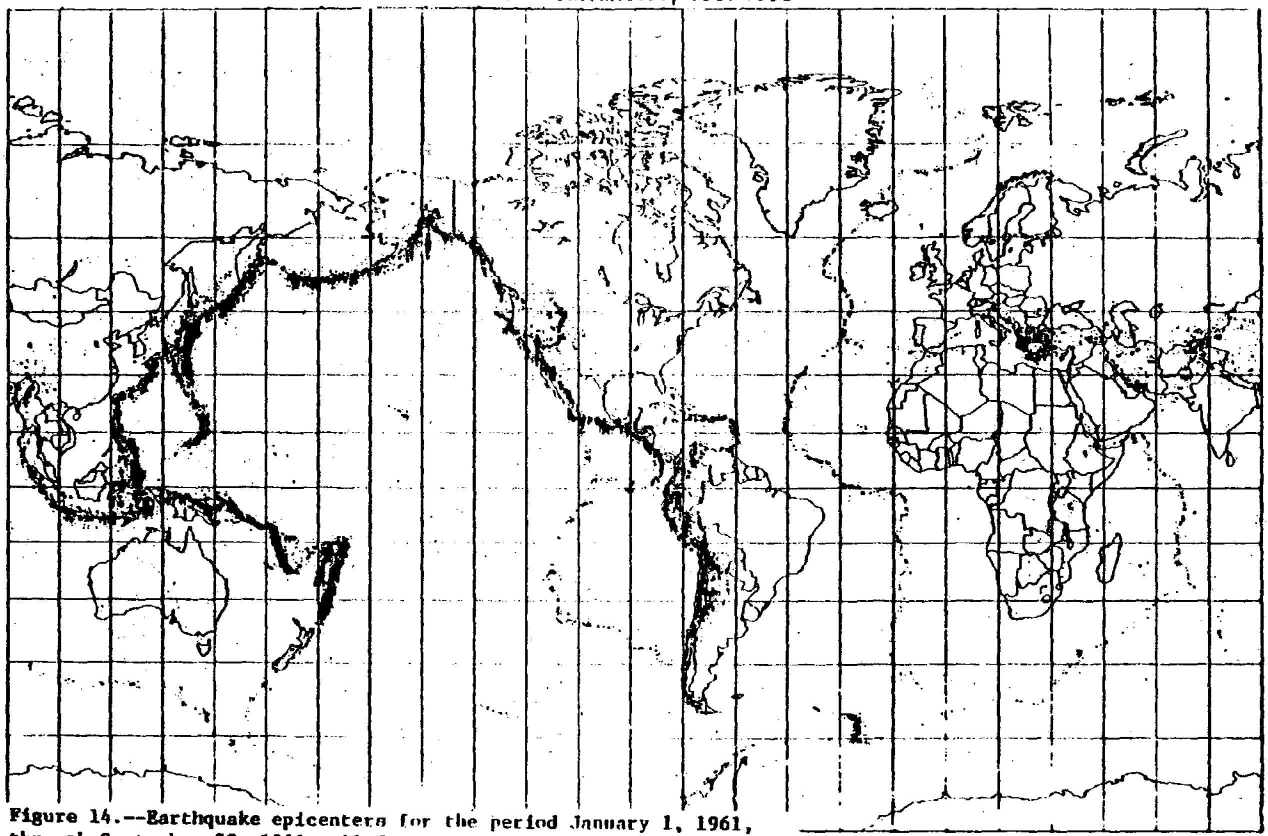


Figure 14.--Earthquake epicenters for the period January 1, 1961, through September 30, 1969, all depths. Epicenter clusters indicate major seismic zones. From west: the circum-Pacific seismic belt, the earth's most active seismic feature; the mid-Atlantic Ridge, and, the Alpide Belt, which links up with the circum-Pacific belt at New Guinea.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

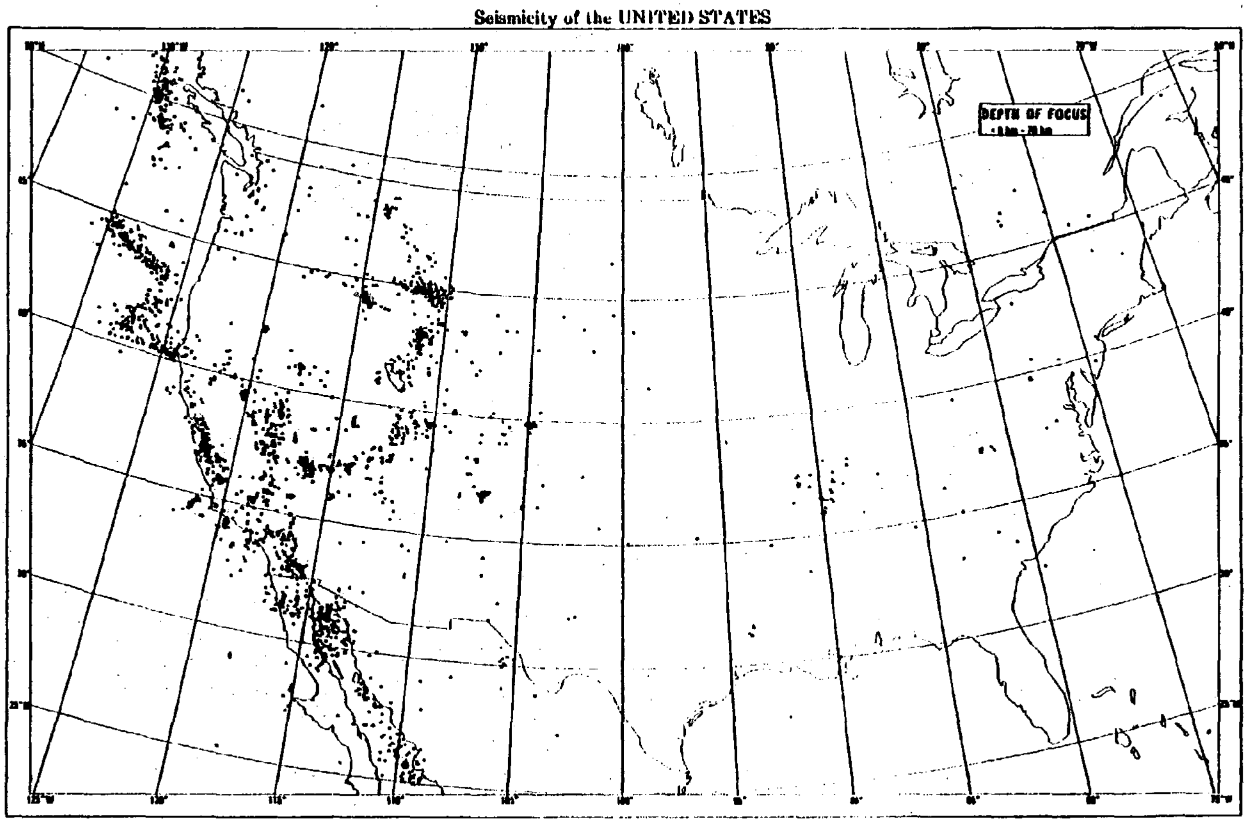


Figure 15.--U.S. earthquake (epicenter) distribution.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

was reported from the wave. Representative travel times from this event were 44/:

to: Daytona Beach, Florida, 3 hours 59 minutes (distance approx. 1650 km)

to: Atlantic City, New Jersey, 4 hours 49 minutes (distance approx. 2400 km).

For the east coast, storm surges and the effects of hurricanes will produce fluctuations in water level which will be as large as the largest expected tsunami on any reasonable time scale. At least from the water elevation point of view, tsunamis will not be the limiting factor in the construction FNPP's in the Atlantic.

Also, if we consider the water particle velocity associated with progressive waves such as tsunamis, a wave with one meter amplitude, even in shoal water of 10 meters, has a current of only about 1 m/sec associated with it. The orbital or particle velocity of severe storm waves of relatively high frequency and much larger amplitude would be a far more important consideration.

LIVING RESOURCES

1. <u>Estuarine and Coastal Wetlands</u>. The estuarine zone of the Atlantic Coast encompasses about 5.2 million acres. Of this, about 2.2 million acres are coastal wetlands, while the remainder is open shoal water. Coastal wetlands consist of about 400,000 acres of freshwater marsh, 1,700,000 acres of slat marsh, and 100,000 acres of mangroves.45/

Estuarine areas are important because they function as sort of a nutrient trap, slowing down the flow of valuable nutrients as they move seaward by incorporating them into the food web. Tidal flats with varying mixtures of mud, sand, and silts support a variety of mollusks, crustaceans, and worms. Filter feeders such as clams and oysters depend upon plankton and other food carried by the water from a much larger support area than that covered by the tidal flat itself. Algae and eel grass plant communities on mud and sand flats are extremely important in all estuarine zones. These plant communities produce a vast amount of organic material and provide an environment for an immense number of snails, worms, insects, crustaceans which are fed upon by a variety of fish and birds.

Alteration of the estuarine zone could have adverse impacts on the value of these areas for the propagation and production of shellfish, fish, and wildlife. Artificial deepening of estuarine areas by dredging reduces productivity and precludes growth of aquatic plants. Deposition of dredged soil directly over productive bottoms or in marsh areas obliterates vegetative habitat and may result in the smothering of benthic organisms.

Upland vegetation of the Atlantic coastal zone is dominated by hardwood and conifer forests, except in southern Florida, where palmettos are abundant. Interspersed along the coastal zone are large tracts of swamp forests whose compositions vary with the region.

In the estuarine zone, smooth cordgrass, salt meadow cordgrass and rushes (*Spartina alteralflora*, *Spartina patens*, and *Juncus roemericanus*) are the dominant primary producers. In lower peninsular Florida and the Keys, red and black mangroves are the major source of natural particulate organic matter. Sea grasses are present in coastal waters of most states and contribute measurably to productivity of coastal waters.

2. *Birds*. Over 400 game and non-game bird species occur in the Atlantic coastal estuarine zone. Important birds include various species of loons and grebes; sea birds such as the petrels and shearwaters; pelicans, herons, egrets, ibis swans, geese, ducks, raptors, shorebirds, and song birds.

The tidal marshes, riverine swamps, wetlands, and nearshore waters are important habitat components of the Atlantic Flyway. Waterfowl, shore birds, and marsh birds are dependent upon these areas for resting and feeding during migration periods.

3. *Land Mammals*. The Atlantic coastal zone supports a diverse array of animals whose habitats range from the severe environmental conditions of northern Maine through the tropical regions of Florida. Noteworthy animals include a wide variety of small non-game mammals,--fur-bearing animals such as beaver, otter, and raccoons,--and big game species such as white-tailed deer.

4. *Marine Life: Cape Hatteras to the Bay of Fundy*.

(a) General. The waters of the North Atlantic coast from Cape Hatteras to the Bay of Fundy are inhabited by an abundant and extremely diverse flora and fauna. This diversity results from the interaction between components of the warm Gulf Stream sweeping northward at the surface and remnants of the cold Labrador Current moving southward along the bottom. The Gulf Stream presses close to the coast at Cape Hatteras, then is deflected offshore northeasterly to the southern tip of the Grand Bank. The Labrador Current flows past southeast Newfoundland and forms a "cold wall" between the Gulf Stream and the coast. The two currents intermix wherever they come in contact and the coastal water is progressively warmer toward the south. The influence of the cold northern water persists as far as Cape Hatteras, but south of there bottom temperatures are significantly warmer.

Although Cape Hatteras is a prominent environmental boundary, its influence varies seasonally. Parr [46/] observed that a warm-water barrier is established in the region of Cape Hatteras (35°N Lat.) during the winter, while a cold-water barrier develops at Cape Cod (42°N Lat.) in the summer, but in neither locality is the barrier a permanent feature during all seasons. In the waters between Cape Hatteras and Cape Cod, seasonal fluctuations in the mixing of nutrient-laden warm and cold water offshore provides an ideal environment for the reproduction and growth of small oceanic planktonic plants and animals and the larger oceanic animals that feed upon them. Inshore, fresh water draining from the land carries high concentrations of nutrients into the estuaries, where salt and fresh water mix to provide an environment that supports numerous species of small plants and animals that are different from those that occur farther offshore in saltier oceanic waters.

(b) Plankton. Microscopic single-celled plants (phytoplankton) are the basic component of the food chain and are perhaps the most numerous organisms in ocean waters. These tiny plants grow most abundantly in sunlight where upwelling of bottom water brings nutrients to the surface. In the Atlantic Ocean, phytoplankton is more abundant in the waters between 40° and 50°W Lat. than it is in the waters south of there. Although hundreds of species have been described, Bigelow, et al, [47/] notes that the species occurring regularly in the plankton are comparatively few. In the Gulf of Maine he found the planktonic plant community at its lowest ebb in February, followed quickly with a luxuriant "bloom" during the spring months. Often there are secondary blooms of individual species at other times of the year. His observations for Gulf of Maine phytoplankton apply, with minor variations, to the whole coast under discussion here.

Small planktonic animals (zooplankton) feed upon the phytoplankton and consequently are most numerous where phytoplankton is abundant. In the Gulf of Maine, Bigelow, et al, [48/] found copepods and euphausiids (two groups of small Crustaceans) to be the most numerous animals in the plankton. Several species of copepods are common south of Cape Hatteras which are virtually absent north of there, and the reverse is also true. The large red copepod, <u>Calanus finmarchicus</u>, is representative of a group of copepods that occur from Cape Hatteras northward across the North Atlantic Ocean. The euphausiid, <u>Meganyctiphanes novegica</u> (a small shrimp), is distributed over a similar area. Both species are very abundant along the north Atlantic coast of the United States and are heavily preyed upon by many species of sportfish, commercial fish, marine mammals and large invertebrates.

(c) Benthic organisms. This section is based on Gosner.[49/] There are numerous communities of bottom-dwelling (benthic) organisms inhabiting the coastal regions of both the northern and southern shores of the U.S. east coast. Very few of these communities have been described qualitatively or quantitatively. These bottom-dwelling organisms are intimately related to that particular type of bottom substrate that sustains them best. Four main types of bottom fauna are identified by the type of substrate they inhabit. The substrate are: sand, silty sand, silt-clay, and rocky. The sand fauna type is characteristic of the shore zone, often extending offshore 10 to 20 miles, from New England southward to Florida. Rocky fauna is most common in southern Florida and north of Cape Cod to Eastport, Me.

A major division in the benthic invertebrate fauna occurs in the vicinity of Cape Hatteras, N.C. The fauna north of there is characterized by a larger standing crop composed of fewer species. The southern fauna is characterized by a greater variety of species, especially those having calcareous skeletons, and a smaller standing crop. A few commercial species characteristic of the northern region are: American lobster (*Homarus americanus*), surf clam (*Spinsula solidissima*), ocean quahog (*Arctica islandica*), and sea scallop (*Placopecten magellanicus*); several species typical of the southern region are: Calico shrimp (*Aequipecten gibbus*), several species of penaeid shrimp (*Penaeus spp.*), and the stone crab (*Menippe mercinaria*).

(d) Finfish. More than a hundred species of finfish are common in the coastal waters north of Cape Hatteras. Most species feed upon the planktonic plants and animals or benthic invertebrates and therefore are most abundant where these forms abound. Some of the more carnivorous species feed upon the larger invertebrates or on other fishes. The most abundant of these are the species that have supported substantial commercial or sport fisheries for many years.

Species like cod, haddock, silver hake, sea herring, redfish, and yellowtail flounder are very common in the Gulf of Maine and on Georges Bank but are scarce in the latitude of Cape Hatteras. Migratory species such as menhaden, mackerel, striped bass, bluefish, and bluefin tuna are abundant in inshore waters during the summer months, but move south of Cape Hatteras or offshore into deeper waters in the fall.

Many of the offshore species are closely dependent on the near shore or estuarine area during some part of their life cycle. Young menhaden and fluke move into sandy estuaries for food and protection. Young cod seek haven in the rocky shores of the Maine coast. Blackback flounders, striped bass, and alewives enter fresh water to spawn. All of the fishes are dependent on some portion of the food chain, whether as filter feeders eating plankton or as carnivores eating large fishes.

(e) Biological productivity. Reliable measures of biological productivity can be obtained from detailed surveys and analyses. Such data are available for confined areas of the coast and for selected groups of organisms, but not for the whole area from Cape Hatteras to the Bay of Fundy. A gross index of overall productivity for these waters exists in the annual summaries of commercial catch of all species of finfish and shellfish for all countries that fish in these waters. Statistics compiled by the International Commission for the Northwest Atlantic Fisheries are in this form for 1971 and 1972, but earlier years do not include shellfish nor all of the species caught inshore. The catch increased from less than 500 metric tons in 1960 to 2,000 metric tons in 1972.[50] This increase does not reflect an increasing abundance of fish, but rather increasingly intensive exploitation of fish stocks that were previously fished at very low levels of intensity or not fished at all.

(f) Marine mammals. Marine mammals are highly visible but extremely difficult to census. Some species are migratory, their paths dictated by severity of the weather or abundance of food. According to Dr. William E. Schevill (personal communication), an expert on whales and dolphins at Woods Hole Oceanographic Institute, large whales such as humpback, finback, and right whales are more numerous north of Cape Hatteras, while the smaller dolphins are about equally abundant along the entire coast. Little is known of the life-history of the marine mammals that occur here except for their frequent appearance where shoals of plankton, sea herring, and other fishes are concentrated. More research is necessary to better understand the role of these giant animals in the dynamics of marine animal populations.

5. Marine life: Cape Hatteras to the Florida Keys.

(a) General. This area differs from the middle Atlantic coast in being bathed by the warm, northward flowing Florida Current and Gulf Stream. Two different zoogeographic regions occur along the coast: 1) the Tropical Region, in the south, which extends through the Florida Keys north to Miami; and 2) the Warm-Temperate Region, in the north, which extends from Miami north to Cape Hatteras. The continental shelf is extremely narrow north to Palm Beach, Fla., from whence it considerably broadens, and again narrows off North Carolina.

Currents and atmospheric conditions affect oceanic water temperatures which in turn influence the environment and the fauna. The Florida Current, derived from the Yucatan Current to the south, becomes the Gulf stream when it flows out of the Straits of Florida. When the axis of the current meanders in over the continental shelf intrusion of cold slope water (10°C) occurs far inshore on the shelf. Cold fronts which move south during the fall, winter and spring cause the inshore water temperatures to drop below 15°C as far south as Miami. Winds blowing from off the land during the summer push the warm marine surface waters offshore, which causes upwelling of cold slope water on the shelf.[51]

(b) Fauna types. The fauna found along the coast consists primarily of four types: 1) Warm-Water, species which live and reproduce in both tropical and warm-temperate conditions and have minimum temperature tolerances of 10° to 18°C; 2) Tropical, species that cannot sustain growth at 18° to 19°C and are dependent upon temperatures greater than 20°C for reproduction [52]; 3) Subtropical, species that can survive less than one season at temperatures exceeding 25°C , that have minimum tolerances of 15°C , and require temperatures of 21°C or less for reproduction; and 4) Warm-Temperature, species that can survive temperatures of 25°C for only short periods of time, that have a minimum tolerance of 10°C , and that reproduce at temperatures from 10° to 20°C.

(c) Zonal distribution. The coast consists of six zones: 1) Estuarine; 2) Coastal; 3) Open Shelf; 4) Shelf-Edge; 5) Lower Shelf; and 6) Slope.

The Estuarine Zone consists of the shallow embayments, lagoons, and river deltas along the coast. The estuaries are bordered by mangrove trees in the tropics and by grassy marshlands in the temperature section. Estuaries are extremely important as they are a nursery area for fish and crustaceans, and they support large commercial and recreational fisheries. Marine species exploited are the white, brown, and pink shrimp, blue crab, spotted sea trout, grey snapper, mullet,and shad. The estuarine environment is continually threatened by man.

The Coastal Zone extends from the shore to 10 fathoms and consists primarily of a sand-mud bottom habitat. The fauna of the zone is primarily warm-temperate because water temperatures in the temperate section are tropical only in summer, and generally below 18°C. the other seasons. A large trawl fishery operates on pink, white, and brown shrimp, and on the croaker (Scianenidae) species. Black seabass are a common recreational and commercial fish on the inshore reefs. Migrations of young black seabass, grouper, grey snapper, and red snapper occur from the inshore reefs (8 to 10 fathoms) to the intermediate (14 to 26 fathoms) and offshore reefs (greater than 30 fathoms). Migrations of adult mullet and pompano occur offshore for spawning with the juveniles returning to the inshore nursery area. In the Tropical Region, the coastal zone supports large fisheries for spiny lobsters, stone crabs, pink shrimp, and mackerel.[53/]

The Open-Shelf Zone, from 10 to 30 fathoms, consists primarily of a sand bottom habitat, however, there are large areas of reef and live shell-rubble habitat. The most stable area on the shelf, in relation to temperatures, occurs within this zone. The subtropical fauna is found most abundant in 14 to 22 fathoms. Commercial fish trawlers harvest pink, brown, and rock shrimp on sandy bottoms. A large calico scallop resource occurs in the live shell-rubble habitat and is fished commercially. Black seabass, red and grey snappers, and groupers are fished by commercial and sport fishermen on the reefs.

The Shelf-Edge Zone from 30 to 60 fathoms, and the Lower Shelf Zone from 60 to 100 fathoms are poorly known. The bottom consists of a sand-shell, mud, and reef habitat. Intrusions of cold and tropical water affect the fauna in these zones because conditions are generally warm-temperate. Species such as groupers and snappers may move about on the shelf from one zone to another by season. Groupers and snappers are the commercial species sought on the offshore reefs.

The Slope Zone from 100 to 500 fathoms consists primarily of a mud bottom habitat. The bottom temperature in the zone is generally less than 12°C. Commercially exploitable species are royal red and scarlet shrimp, geryon crabs, Danish lobsters, whiting, tilefish, and groupers. Man's activities in, on and near this environment must be carefully watched for adverse effects.[54/]

(d) Plankton. The plankton biomass of the fertile inshore waters decreases in quantity offshore towards the warm tropical waters of the Gulf Stream. When stratification of warm tropical water occurs on the shelf during the summer, the plankton decrease may be seen in the decreased growth of calico scallops. Although the eggs and larvae of more than 1000 fish species may occur in the plankton, only a very few species have had their larval development and early life history investigated. The larval stages and development of the tunas have been investigated and the small juveniles were most abundant in the straits of Florida from May to October.

(e) Migration. Pelagic fishes (living in the open sea) migrate along the coast with the seasonal shift of the isotherms (water temperature) north and south.

Species taking part in migrations are the tunas, mackerel, bill fishes, cobia, dolphin, bluefish, spiny dogfish shark, and cownose rays. Extensive commercial and sport fisheries are conducted on these species during their migration. A cluepeoid pelagic species taken commercially by large purse seines is the menhaden.[55]

(f) Marine mammals. Marine mammals commonly occurring along the coast are the blackfish or pilot whale, spotted dolphin, and bottle-nosed dolphin, while off Florida the manatee is seen. Whales and dolphins may be captured commercially only by permit issued by the National Marine Fisheries Service, for research or exhibition in aquarium shows. As no tuna purse seine fishery occurs along the south Atlantic coast, the death of dolphins in seines is not a problem. Manatees, however, in living in clear water springs of Florida are increasingly subject to mortal injury by recreational small boat operators.

6. Threatened Species. Threatened species associated with the Atlantic Coast include the shortnose sturgeon, Maryland darter, southern bald eagle, arctic peregrine falcon, American peregrine falcon, redcockaded woodpecker, Bachman's warbler, eastern brown pelican, dusky seaside sparrow, Cape Sable sparrow, American alligator, and the Florida panther, as well as the green turtle and the Florida great white heron. Marine mammals whose populations have been determined threatened include the Florida mantatee, Caribbean Monk seal, right whale, sei whale, sperm whale, blue whale and humpback whale.[56]

THE GULF COAST

GEOLOGY AND TOPOGRAPHY

1. Beaches and Shoreline. The area's typically gentle beach profiles are shown in figure 1. The average width of the beach is about 70 meters.[57] Gaps in the line of beaches exist off Louisiana and Western Florida, where mangroves and marshes are found instead of beaches. Most profiles on the beaches include sand both above and below the mid-tidal line.[58]

2. The Continental Shelf. The shelf forms an almost continuous terrace around the margin of the Gulf of Mexico. The major breaks occur in the Straits of Florida and the Yucatan Channel, which form outlets from the Gulf to the Atlantic Ocean and Caribbean Sea, respectively. This terrace has numerous depressions, troughs, ridges, minor knobs, coral heads, escarpments, and two known submarine canyons (Campeche Canyon off Carmen, Mexico, and De Soto Canyon south of the Alabama-Florida state line). The widest parts are off Texas and the peninsulas of Yucatan and Florida. Shelf width varies from 8 to 17

miles in the northern Gulf, the maximum width being off western Florida.[59]

The greater part of the shelf west of the Florida peninsula is covered by about 40 fathoms of water, and the slope out to the 100-fathom contour is for the most part gradual. Because the Mississippi River discharges a daily load of about 2 million tons of sediment, the delta has been built out on the Continental Shelf to form a prominent fan extending nearly 1,000 km. seaward. The total thickness of the generally fine-grained sedimentary rock may be more than 10 km. within the Gulf.[60] The shelf off Louisiana and Texas is somewhat uniform and has a gentle slope to about the 50-fathom contour. From this point the slope increases to the 70-fathom line where it has an increase in gradient to the 100-fathom depth. The location of the various named segments of the Gulf coast is given in figure 2. The chief factors in the development of the individual shelf segments are:

West Florida Shelf--Calcareous reef growth and marine deposition.

Mississippi Delta--Deltaic deposition.

Texas-Louisiana Shelf--Marine deposition and diapiric (sediment) intrusion.

The West Florida shelf contains a broad, shallow (less than 3 meters deep) area of mud bottom that is rapidly being encroached by a mangrove shore. Lowwave energy permits the mangroves to trap sediments and prograde (build outward) the shore as islands that gradually merge to enclose very shallow, isolated swamps. The bay floor is divided by numerous mud banks which are eventually covered by mangroves. Northward along the coast, depths are slightly greater close to the shore and wave energy is high. Small fine-grained sand waves prograde into mud-floored bays.[61]

On the Texas-Louisiana shelf, the nearshore part contains many sand waves, usually parallel, but some at deep angles to the shore. About 160 prominences, probably salt domes capped by algal reefs, dot this shelf area.[62]

3. Shelf Sediments. The distribution of sediments has been studied by many workers, and is shown in figure 3. The subsurface sedimental structure consists of southward-dipping beds to about 60 km. offshore, where the beds reverse in slope. This line is the axis of a giant fold, where maximum sediment thickness occurs. Except on the Mississippi Delta, the beds consist mainly of sand-sized particles, including many lenses of reconsolidated sands.[63]

4. Sediment Movement. The physical agents active in the Gulf which affect the distribution of bottom sediments are semipermanent currents, normal wind waves, hurricane

waves, tidal currents, and currents associated with hurricane tides. These agents affect the sediments in two ways--first, in the distribution of sediment from the source rivers to the place of deposition; and second, in the reworking and post-depositional modification of the sediments on the shelf.

The agents active in the dispersal of sediments on the shelf are semipermanent currents, longshore currents due to the oblique approach of waves to the shore line, and tidal currents reinforcing the semipermanent currents. The combined effect of these agents is to transport both fine sediment in suspension and sands westward along the Louisiana and east Texas coasts to an area of general convergence near the central Texas coast. Semipermanent currents are also capable of transporting fine sediment in suspension northward past the Rio Grande to this same area. A seaward return current in this area of convergence, postulated to maintain the water balance, probably carries suspended sediments out from the shore to the shelf off the central Texas coast.[64/]

The principal agent in reworking sediments on the shelf is the surge of hurricane waves, reinforced by semipermanent and tidal currents. All parts of the shelf are subject to sufficiently intense hurricane wave action to move fine sand off the bottom at least once in five years, and more frequently than this on the middle and inner shelf. This wave motion by itself does not result in net transportation of sediment, but when superimposed upon the unidirectional or longer period oscillatory currents, it can contribute to short distance net transport. Some short distance net transport probably does occur, but the rate appears to be too slow to have destroyed the pattern of surface sediment distribution relict from lowered sea level.[65/]

The directions and intensities of some of the physical agents are dependent upon the seasonal wind patterns. Variations in the wind patterns associated with climatic changes could, therefore, result in significant changes in the dispersal of sediments.[66/]

Data obtained with current meters located 3 meters above the seabed in 50 to 80 meters of water indicate that sediment transport occurs only during storms. Bedload sediment transport is negligible compared to suspended load transport.[67/] Calculations suggest that severe storm occurring every few years might have more geological significance than a number of less severe storms.[68/]

5. <u>Engineering Properties</u>. Sand-size particles exist almost everywhere on the Gulf shelf except on the Mississippi Delta and accordingly bottom strength is quite good although detailed measurements are uncommon. The stratigraphy as revealed in cores can be extrapolated by geophysical measurements which show sand strata and the relatively

rare places where sand is replaced by fines of less predictable engineering characteristics.[69/]

OCEANOGRAPHY

1. Tides. Tides along the Gulf coast in general are uniformly small, but the type of tide differs considerably. At Pensacola, Fla., the tides are diurnal, with one high and one low water per day while at Galveston, Tex., the tides are semidiurnal around the times the moon is on the Equator, but become diurnal during the times of maximum north or south declination of the moon.

Tidal ranges along the Florida peninsula tend to be higher, with diurnal mean ranges between 2 and 4.5 feet. The northern coast of the Gulf exhibits diurnal mean ranges (the difference in height between mean higher high water and mean lower low water) of less than 2 feet. The following are diurnal mean ranges for selected locations starting from southern Florida in an arc to southern Texas: Shark River entrance, Fla., 4.5 feet; St. Petersburg, Fla., 2.3 feet; Cedar Key, Fla., 3.5 feet; Fort Gaines, Ala., 1.3 feet; Pascagoula River entrance, Miss., 1.6 feet; Galveston Bay entrance, 2.0 feet; Brazos Santiago, Tex., 1.4 feet.[70/]

Along the northern Gulf Coast, water levels are greatly influenced by the wind conditions; fluctuations in water levels ranging from 3.5 feet below to 4 feet above the plane of reference are not uncommon. During severe storms that pass through this region, high water from 10 to 12 feet above the plane of reference have been reported at Galveston and Port O'Connor, Tex.[71/]

Offshore tidal measurements are not available to establish tidal ranges on the Continental Shelf, but tidal ranges in the offshore region should be less than the tidal ranges observed at nearby shore stations (<2.0 ft.).

Tidal currents of the reversing type, found in the inlets and embayments along the coast, are relatively weak, exhibiting speeds at most locations of less than 1 knot. However, in restricted channels current speeds can exceed 2 knots. Rotary tidal currents found in offshore positions are generally weak (<1.0 knots) and depending on the type of tide may exhibit one or two complete cycles in a lunar day.

2. Circulation.

(a) General. The dominant feature of the circulation in the Gulf of Mexico is the Loop Current of the eastern Gulf (figure 16). Although the broad Continental Shelf separates coastal waters from the deep water, Loop-Current-related flow, evidence

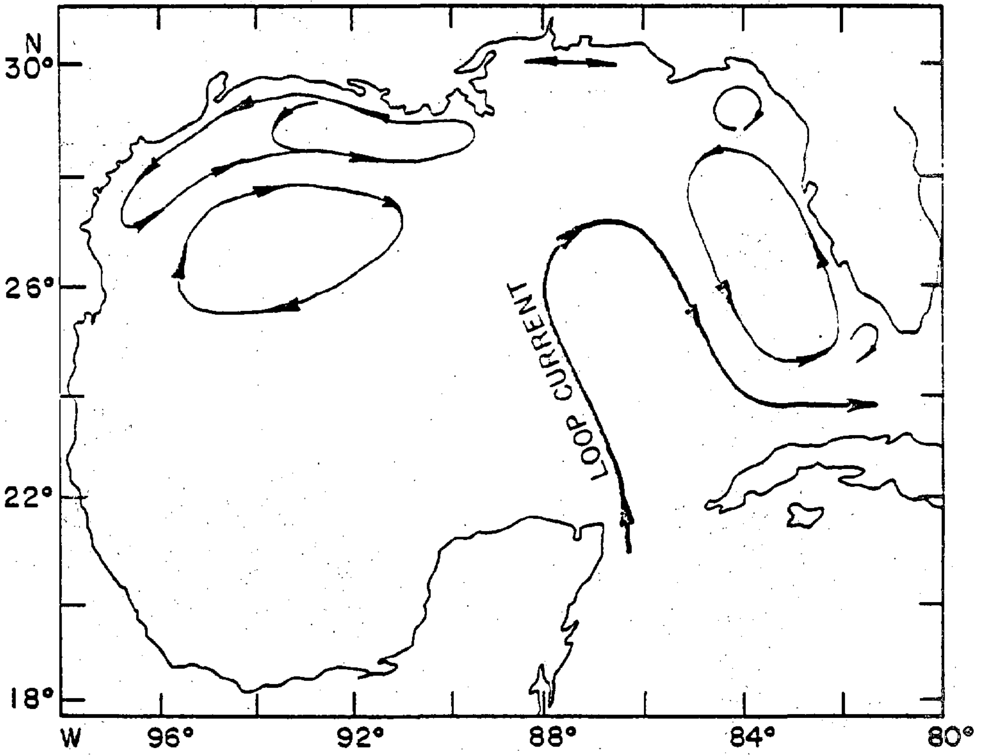


Figure 16.—General circulation pattern along the U.S. coast of the Gulf of Mexico.

Source: Armstrong, R.S., and J.R. Grady, 1967: Geronimo Cruises Entire Gulf of Mexico in Later Winter. Commercial Fishery Review 29(10).

indicates that general circulation patterns in the coastal region are also associated with the offshore currents.

Local winds may alter patterns significantly, but the effects are generally of short duration. In the case of hurricanes, however, the field of flow can be altered for periods up to a few weeks. Circulation in the extensive, almost continuous network of bays and estuaries is controlled by local winds, river discharge, density gradients (including salt wedge intrusions) and, occasionally, by branches from shelf currents. For the most part, the small tides of the Gulf are significant to the circulation only around tidal passes. Hence, the motion is highly variable from bay to bay and from time to time.72/

(b) Eastern Gulf States -- Key West to the Mississippi Delta.

(i) Surface Circulation. The general tendency of the coastal currents in the eastern Gulf seem to be associated with a cyclonic gyre on the Florida Continental Shelf (figure 16) which, in turn, is set up by the southerly flowing leg of the Loop Current. In the nearshore zone this gyre transports water northward most of the year off western Florida. From northern Florida westward to Louisiana the flow pattern seems variable, depending on direct or indirect effects of the Loop Current. Except in winter, little of the discharge from the Mississippi River seems to move toward the east.73/

(ii) Subsurface Circulation. The subsurface circulation is probably influenced by the Loop Current, but few detailed data are available.

(c) Western Gulf States -- Mississippi Delta to Brownsville.

(i) Surface Circulation. Currents in the offshore waters of the western Gulf are generated from large, persistent anticyclonic eddies that break off the Loop Current and migrate westward, and from streams that at times branch off the Loop Current, setting up direct exchange of water between the eastern and western Gulf. Both mechanisms tend to establish anticyclonic flow in the offshore waters of the northwestern Gulf. Easterly currents develop over the continental slope which generate cyclonic circulation on the Texas-Louisiana Shelf, producing prevailing westerly currents along the coast (see fig. 16). The westward motion draws low salinity water from the Mississippi River with it. In winter the westward current is strongest, with the freshening influence of the Mississippi River discharge traceable as far as the Texas-Mexican border. Beginning in spring the westward flow diminishes, extending no further than about Galveston, Texas.74/

Drift bottle studies conducted on the Texas-Louisiana continental shelf reveal a westerly flow along the Louisiana coast and southwesterly along the Texas coast during the months of September through April. Speeds ranging between 8 and 13 miles per day were observed during the month of February.

In March a northeasterly current is noted converging with the southwesterly drift off Brownsville. This northeasterly component is also observed off central Texas and Louisiana between 65 and 100 meter bottom contours. Drifters released into this northeasterly flow have been recovered on eastern Florida beaches.

During the months of May and June, the southwesterly flow parallel to the coast begins to break down under the influence of southerly winds. Surface drift is directly onshore off central Texas and obliquely onshore (NNE.) along the Louisiana coast.

By July, the surface currents between Brownsville and the Mississippi River Delta are northeasterly. This northeasterly drift is of short duration and by September the surface drift is again to the southwest off the Texas coast. This reversal appears to be the product of the southerly winds which prevail during this period.[75/]

(ii) Subsurface circulation. When a westerly flowing surface current is observed along the Texas coast there is a downwelling effect along the coast with bottom waters moving offshore. When currents are in an easterly direction, surface waters flow offshore and bottom waters move inshore.[76/]

3. Water Mass Characteristics.

(a) General. The temperature and salinity regimes for the Gulf coastal waters reflect the seasonal fluctuations of solar heating, fresh water discharge and coastal current patterns. The degree of change decreases with increased depth and distance from shore. Surface temperatures reach a maximum during August-September and a minimum during January. Salinities are lowest during April and June and reflect the increased volumes of fresh water discharge from Alabama westward.[77/] Along the eastern Gulf, however, river discharge reaches a maximum during late summer and early fall, affecting the coastal salinities during this period.[78/]

(b) Eastern Gulf States -- Key West to the Mississippi Delta.

(i) Temperature. Minimum temperatures occur in January along this section of the coast, with mean values of 15-16°C along the northern coast increasing to 23°C at the southern tip of Florida. Maximum values occur in August and are quite homogenous, ranging between 30-31°C. Surface isotherms generally parallel the northern coast and intersect the Florida peninsula obliquely during the months October-May. During the remaining portion of the year, isotherms are somewhat random isolating areas of colder or warmer water.[79/] Vertically, the water column over the continental shelf appears to be isothermal during all months [80/]; however, this probably reflects the lack of data for the shelf area. The coastal waters off Panama City are isothermal during the months of October to April as far as 30 miles offshore. With increased solar heating during April and May a thermocline develops initially offshore and eventually extends to the coast. By June a well developed thermocline exists and can be traced to within a few hundred yards of the shoreline. The thermocline will persist until early fall when it migrates seaward and the shelf waters are again isothermal.[81/]

(ii) Salinity. Salinities of <36.0 °/oo are generally found in the shallow waters off the west coast of Florida. Salinity values off Panama City generally range between 34 °/oo and 35 °/oo nearshore and increase in both the upper and lower layers. There is usually a slight increase in salinity with depth. During the months October through January, strong winds tend to make the water column isohaline out to 11 miles from shore. The largest gradients occur during the summer months, May through August. The salinities in the lower layer remain high, occasionally reading 36 °/oo, and are typical of the central Gulf region. The surface waters undergo considerable dilution, because precipitation is at a maximum during the summer months.[82/]

(iii) Oxygen. Very little oxygen data is available for the shelf waters of this area. For the entire northeastern Gulf, surface oxygen values range between 4 and 6 ml/l for all months. There is a decrease with depth and values of not less than 2.5 ml/l are recorded to a depth of 100 m.

(c) Western Gulf States -- Mississippi Delta to Brownsville.

(i) Temperature. Surface temperature values show the largest annual temperature range off Galveston, with a spread of 21.0°C ranging from 10°C to 31°C. The annual range of surface temperatures decreases seaward and southward from the coast. At the shelf edge an annual range of 11°C can be expected (19.0°C to 30.0°C). Fig. 17 shows the typical distribution of surface temperatures for the coldest and warmest months. Isotherms parallel the coast in winter (see fig. 17) with temperatures increasing seaward from about 10°C along the shore to about 20°C over the outer shelf. During spring, temperatures of inshore waters increase at a greater rate than those of offshore waters. Isotherms become irregular with a spread of only 2° to 6°C over the entire shelf. During the summer the isotherms remain irregular with average surface temperatures ranging between 29° and 31°C. However, a tongue of colder water is evident along the southern Texas coast (figure 17). By early fall the isotherms again parallel the coast with only

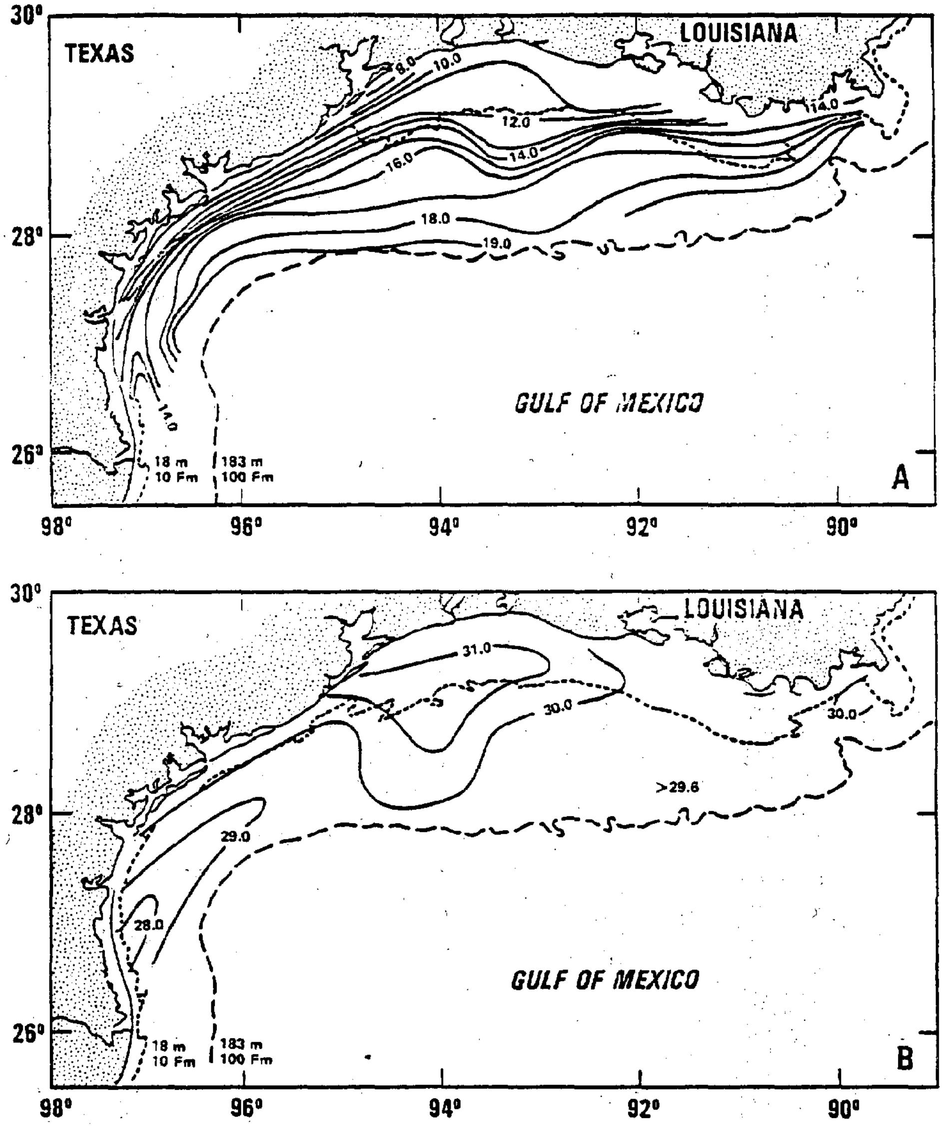


Figure 17.--Typical distributions of lowest (A, January 1964) and highest (b, August 1963) surface temperatures (°C).

Source: Harrington, D.L., 1965b: Oceanographic Observations on the Northwest Continental Shelf of the Gulf of Mexico, unpublished manuscript, National Marine Fisheries Service, Biological Laboratory, Galveston, Tex.

a slight gradient. Increased cooling of the inshore water during the later part of fall results in a steeper gradient typical of the winter pattern.[83/]

The vertical temperature structure is characterized, in general, by two distinct periods--one in which the waters are isothermal and the other when the waters are stratified. The isothermal period can last from 9 to 10 months in the inshore waters, but gradually shortens with increased distance offshore, becoming almost nonexistent over the outer shelf.

Warming and cooling at the bottom do not display the steady seasonal progressions seen at the surface. Bottom values reach a maximum during late summer in shallower waters and later in the offshore waters. During September and December, when offshore bottom temperatures are still increasing, coastal waters are cooling, consequently, cooler temperatures prevail inshore and seaward of a zone of warmer waters located between the 30 meter and 45 meter contours.[84/]

(ii) Salinity. From September through April, offshore surface isohalines (contours of equal salinities) parallel the northern Texas and Louisiana coast and intersect the coastline off southern Texas. Salinities range between 30.0 °/oo off Galveston to 36.0 °/oo off Brownsville out to the 20 m. contour.[85/]

Surface salinities along the upper Texas and Louisiana coast begin to decrease during April-May with increased river discharge carried westward from the Mississippi Delta region. Salinities over the Continental Shelf are as low as 32.0 °/oo 60 miles offshore in the Galveston area and gradually increase seaward and southward along the Texas coast.

In June a tongue of high salinity water (36.5 °/oo) appears along the southern Texas coast which corresponds with the shift in the current pattern and the tongue of cooler water located in this same area. By August the entire Texas coast from Brownsville to Galveston exhibits salinities of 36.5 °/oo. By September the current regime reverses and the isohalines again parallel the coast.

Only in shallow depths do bottom salinities undergo the variations seen at the surface. Along the 7 m. contour, bottom salinities approximate those of the surface. Seaward from this point the bottom salinities show narrower annual ranges, with values of >36.0 °/oo found outside the 70 m. contour during all months.[86/]

(iii) Dissolved Oxygen. Based on seasonal summaries (compiled from Nansen-cast observations held by the National Oceanographic Data Center for the northwestern third of the Gulf of Mexico), oxygen values are highest at the surface during the winter (January-March) and also exhibit the widest range (3.36-7.35 ml/1). During this period there is a steady decrease with depth. During other months (April-December), oxygen values show a narrower range (4.09-5.44 ml/1) at the surface. With depth there is a slight decrease just below the surface and then a gradual increase to the 50 meter level with values generally exceeding the surface values. Below the 50-meter level there is a general decrease with depth.

Oxygen values measured along the beaches of Mustang Island in 1959 and 1960 ranged between 3.50 to 6.30 ml/1 and in general were high from November to March and low in the summer season.87/

4. Hurricane Effects. Tropical storms which pass over this area produce large scale temporal changes to the circulation and temperature characteristics of the waters along its path. Based on a survey immediately after hurricane Hilda, 1964, which came ashore on the Louisiana coast, vertical temperature structures after the storm indicated that the warm surface layers were transported outward from the hurricane center, cooling and mixing as they moved. These waters then converged outside the central storm area, resulting in downwelling to depths of 80 to 100 meters. Cold waters upwelled along the hurricane path from depths of approximately 60 meters. Sea surface temperatures decreased by more than 5°C over an area of some 70 to 200 miles. A cyclonic current system was reported around the area of greatest hurricane intensity.88/

Hurricane Betsy, which came ashore on the Louisiana coast in September of 1965, modified the waters over the northern Gulf shelf. The typical surface waters next to shore were removed and replaced by waters with oceanic characteristics. The influence of the hurricane extended to the greatest depths of the Continental Shelf (75 meters) so that water temperatures on the shelf floor were as much as 6°C warmer after the storm than before. Upwelling in the upper 30 meters of the water column was evident at distances of about 70 km. on either side of the path of the hurricane eye. A 50-meter thick layer of isothermal water lay on the surface at distances of about 150 km. on either side of the path. A strong divergence developed seaward of the Mississippi Delta. Surface currents flowed to the east and west on respective sides of the delta.89/

CLIMATOLOGY

1. General. The climate of the Gulf coast varies from humid and subtropical over southern Florida and southern Texas to a more variable but warm marine climate along the northern coast. The weather patterns are essentially those which prevail in a transition zone between a temperature and tropical area. Extended periods of stable humidity and

temperature frequently occur. The Gulf of Mexico is a source of warm, moist air, which generally flows northward during the warmer months.

The general circulation of air near the surface of the Gulf and along the Gulf coast follows the western extension of the Bermuda High during the spring and summer. During the winter months, the pressure patterns and frontal activity from the north and west have a more dominant influence. During the winter the highest frequency of winds have a northern component, and during the summer, a southern component. The vast majority of wind speeds are in the 5- to 15-knot category.

2. Extratropical Cyclones. Extratropical cyclones generally occur in the late fall, winter, and early spring. The area is subjected alternately to maritime tropical and polar continental air masses in periods of varying length. This region is usually south of the average track of winter cyclones, but occasionally one will move this far south. Westerly systems at times make their influence felt as cold fronts from the northwest push southward into the Gulf of Mexico. The cold air behind these fronts, though modified by the southward journey, brings sudden and occasionally large drops in the temperature. These are often referred to as "Northers," and can bring strong, cold winds. Winds up to 60 knots have been known to occur, but speeds of 30 knots are more common.[90/]

The Gulf of Mexico, with its relatively warm waters, introduces retarding and modifying effects upon cold fronts. As the invading cold air mass pushes out over the Gulf, it moves against a strong flow of maritime tropical air moving in the opposite direction, causing the front to become quasistationary. At these times, the Northern Gulf area becomes a favored region for cyclogenesis. When waves develop on the front, they are usually associated with an eastward-moving upper air trough. The principal track of the associated low center parallels the Gulf coast or moves inland, producing persistent low stratus ceilings and rain in the Northern Gulf area. These conditions usually persist ahead of the low centers.

3. Tropical Cyclones. The hurricane season generally begins in June and closes with November. The months of greatest frequency are August, September, and October. Tropical cyclones are most likely to be severe during August, September, and October. The June hurricanes which form in the West Indian region usually move in a direction between west and north, while they are south of the 25°N latitude. In late September, October, and November, hurricanes of this region are more likely to move in a direction between north and east, passing through the Yucatan Channel, or over Cuba, Florida, or

the Bahamas. Of the hurricanes that come from the Atlantic into the West Indies, the majority occur in August and September, and move on a west-northwesterly course in low latitudes, reaching the coast before curving toward the north and northeast. Late in the season, October or November, the movement of hurricanes that form east of the West Indies is often toward the north in the open Atlantic.

The average speed of movement of West Indian hurricanes is about 10 to 13 knots. The highest rates of progression usually occur when the storm is moving northward or northeastward in the middle or higher latitudes.[91/]

Gulf coast tropical cyclones are most likely to occur in August and September from Texas to the Florida Panhandle, and in September and October, along the Florida Gulf Coast. June is also an active month, particularly off Texas. Each season, an average of one or two tropical cyclones travels through the Gulf of Mexico and strikes the U.S. Gulf coast. Less than half of these reach hurricane strength (45 percent).[92/] Hurricanes have reached severe proportions in the Gulf of Mexico and winds up to 175 knots have been estimated off Mississippi and 100 knot plus winds can occur all along the Gulf coast.

4. Winds. Near the Gulf coast, winds are more viable than over the open waters of the Gulf, since the coastal winds fall more directly under the influence of the moving cyclonic storms that are characteristic of the continent. In coastal areas, about 30 to 40 percent of midwinter winds are from the northern quadrant and 40 to 50 percent of the summer winds are from the southern directions. On the Florida coast, wind speeds average 9 knots in March, which is generally the month with highest velocities. At most locations the wind drops to below 7 knots in August. Along the Alabama and Louisiana coasts, wind speeds average 8 or 9 knots in August. On the Texas coast, wind speeds average 12 knots in April, dropping to 9 knots in August.

Along the Gulf coast, land and sea breezes prevail, although over the open waters offshore, little difference between daytime and nighttime winds is noticed. Winds over the northwestern portion of the Gulf, on the whole, blow slightly more from a southerly direction throughout the year than over the eastern portions. In combination with the change in direction of the coastline, this leads to more persistent onshore winds throughout the year over the western portion of the Gulf.

Some 30 or 40 polar air masses penetrate from the North American continent to the Gulf of Mexico each winter. During the year, some 15 or 20 of these bring strong northerly winds to the Gulf, and are called northers. Occasionally, local usage has corrupted the term norther to apply to any wind shift to northerly, if accompanied by a temperature drop. Winds from 25 up to 50 knots or more may occur in severe northers of the Gulf. From 1 to 6 northers are likely to be severe over the Gulf during individual years. Northers ordinarily occur from November to March. Severe northers usually occur from December to February, but occasionally later. January or February, sometimes March, will be the month having the most northers for individual years. Northers generally last about a day and a half, but severe storms may endure for 3 or 4 days. Gale-force winds may also occur in tropical cyclones, but these are infrequent at any one location.93/

5. High Waves. High waves along the U.S. Gulf coast can be generated by extratropical or tropical cyclones. While seas of 12 to 25 feet occur most commonly in winter, with the more frequent extratropical storms, wave heights greater than 25 feet are more likely with hurricanes in summer or fall. Waves of 25 to 30 feet have been generated along this coast by Carla in 1961 and by Audrey in 1957.94/

Waves ≥12 feet occur about 2 to 4 percent of the time from November through March, all along the Gulf coast, and in September, east of Texas. They are most frequent in January and February. Waves ≥20 feet never occur more than 1 percent of the time, but can be observed somewhere in every month. They hardly ever occur in May, July, or August.95/

6. Visibility. Warm, moist Gulf air blowing slowly over chilled land surfaces brings about the formation of fog at the ground. From November through April, fog is encountered occasionally at points throughout the Gulf coast region. It is most frequent in the vicinity of harbor entrances and over land areas extending into the Gulf, such as Cape San Blas. Fog forms with southerly winds and dissipates during northerly winds.

Fog is relatively infrequent at most Florida coastal points, with the exception of Tampa in the winter. There is a greater frequency along the Alabama and Louisiana coasts and the Texas coastal bend, with lesser amounts on the southwest Texas coast. Fog is generally at a maximum in winter.

In general, visibilities drop below 2 miles around 1 percent of the time during winter and spring from the west coast of Florida to Louisiana. Off Louisiana and the Texas coast, frequencies range from 1 to 4 percent in these seasons. During summer and fall, visibilities drop below 2 miles less than 1 percent of the time everywhere.96/

7. Air Temperatures. Air temperature extremes at coastal land stations range from isolated cases of freezing (32°F) during extreme cold outbreaks from the north, to the high nineties during the summer. These extremes are quickly modified by the Gulf

water within a short distance offshore. The near offshore mean air temperature ranges from a minimum of 60°F during the winter months to a maximum of 82°F during the summer. The coastal air temperatures average 2° to 4° cooler in the eastern part of the east-west coast, and the temperature increases southward along the north-south coasts.[97]

8. Precipitation. Along the Gulf Coast, precipitation tends to fall periodically during the late autumn, winter, and spring months, and is generally associated with extratropical cyclones. In summer and early autumn, scattered shower and thunderstorm activity is high. The gentle coastal slopes do not, however, give rise to persistent areas of concentrated thunderstorm activity day after day. In general, the greatest rainfall occurs in summer and early autumn, with some of the heaviest falls associated with tropical cyclones during the months of August, September, and October.

New Orleans has some of the heaviest rainfall amounts along the coast. The wettest month is usually July, with an average of 6.72 inches. The heaviest monthly rainfall of record at that location was 25.11 inches in October, 1937.[98]

Thunderstorms occur all year, but the most severe are in the early summer. Hail is a rare occurrence. Tornadoes and waterspouts are also rare. Lightning will be associated with all thunderstorms.

9. Storm Tides. Tropical and extratropical storms generate storm tides which can cause severe destruction along the Gulf coast. The storm tide is a combination of a normal astronomical tide and a storm surge (the effect of the storm upon sea level). Storm surges on the open coast, in conjunction with high tides, have been known to raise the water level as much as 25 feet.[99]

The storm surge generated by hurricane Camille in 1969 flooded coastal areas from lower Plaquemines Parish in Louisiana to Perido Pass, Alabama. Flooding was most severe in the Pass Christian-Long Beach, Miss., area, where tides up to 24.2 feet above mean sea level were measured. In the St. Louis Bay, maximum tides ran about 18 feet above mean sea level, while in the Back Bay of Biloxi, they were about 15 feet above mean sea level.[100]

EARTHQUAKES AND SEISMIC SEA WAVES

1. Earthquakes. The Gulf coast area has a very low level of seismic activity. Reports of seiche (standing wave oscillation) action in rivers, lakes, bayous, and protected harbors and waterways all along the Louisiana Gulf coast and along the Texas Gulf coast as far west as Freeport, Tex., followed the great Prince William Sound, Alaska,

earthquake of 1964.[101] These surges commenced between 30 and 49 minutes after the earthquake, or about the time the Love and Raleigh waves from the earthquake were passing through the area. Damage, although generally minor, was widespread along the Gulf coast. The area in which damage was reported extended from the Lake Borgne, Louisiana, area on the east to Houston, Texas, on the west, and as far inland as Baton Rouge, Louisiana.

On October 19, 1930, a moderate earthquake (maximum intensity VI—see table 5), centered about 60 miles (95 km) west of New Orleans, awakened many people throughout eastern Louisiana. The total "felt" area was estimated at 15,000 square miles (39,000 sq. km). Portions of the Gulf coast were also within the felt area of the 1886 Charleston, South Carolina, earthquake. This earthquake was felt with intensity II-IV along the Mississippi coastal areas and intensity IV-V along the Alabama coast. The great series of earthquakes near New Madrid, Missouri, in 1811-1812 were felt over two-thirds of the country. Effects south to the Gulf coast were minimal.[102]

2. Seismic Sea Waves. The distribution of earthquakes in the Gulf of Mexico has not produced a significant tsunami hazard along the shoreline in the past. There exists an account of the grounding of a battleship in the Caribbean (not the Gulf) in the early 1900's in which the tsunami source was of such small horizontal extent that the wave-train was dispersive. First arriving waves were of up to a 2-minute period; later breaking waves were of less than a 1-minute period and 15 meters in height, grounding and destroying the ship in less than an hour. The occurrence of damaging tsunamis is not very likely in the Gulf coast region.

LIVING RESOURCES

1. General. The following discussion draws considerably from Galtsoff, Gunther, and Heald.[103] The five Gulf Coast States—Texas, Louisiana, Mississippi, Alabama, and Florida—accounted for 1.6 billion pounds, or 34 percent of the weight and 32 percent of the value of the total seafood landings in the United States in 1972.

2. Estuarine and Coastal Wetlands. There are 12.7 million acres of estuaries and coastal marshes in the five States bordering the Gulf of Mexico. This constitutes two-thirds of our Nation's coastal marshes and more than one-third of our estuarine water area. It is this tremendous area of coastal marsh and shallow estuaries which makes the Gulf of Mexico so productive of fishery resources.

The estuarine zone extends from Corpus Christi, Texas, to the southern tip of Florida. Excluded from this zone are the Laguna Madre of Texas, a hypersaline lagoon, and Florida Bay in the Keys area, because these are not estuarine as defined in terms of low-salinity water. Bay systems, sounds, and associated brackish water bodies comprise these estuarine waters. They vary considerably in size and shape according to climate and season, but they are all coastal bodies into which fresh water high in nutrients is discharged from rivers and streams and into which sea water flows rhythmically with the tide. Maximum depth of the large bays is about 20 feet, except in channels, and the average depths are about 6-8 feet. Smaller bays may be shallower. Marsh fringes or submerged grasslands characterize the more productive estuaries.

Marshes adjacent to the Gulf of Mexico are divided into three general classes, depending on water quality. Salt marshes are characterized by high salinity waters; brackish marshes are those inundated by very low salinity waters; and fresh marshes are those inundated by fresh water. The demarcation between brackish and fresh marshes is often difficult to determine because of seasonal and annual variations in rainfall and salinity. Near its upper limits, a brackish marsh grades into a fresh marsh, and near its lower limits, into a salt marsh. Vegetation of the fresh marsh includes sacahuista, spartinas, cattails, and rushes, which change to the more salt-tolerant spartinas, saltgrass and rushes of the brackish water marsh.

Brackish and fresh water marshes provide a large variety of food, heavier cover, and more high ground than the salt marsh. Primary aquatic consumers in these marshes include zooplankton, clams, various worms, crabs, grass shrimp and amphipods. Preying on these animals are other worms, larval and juvenile decopod crustaceans, grass shrimp, larval fish, small predatory fish and filter feeding fish. Secondary and tertiary aquatic consumers are the predatory fishes and larger invertebrates. Nonaquatic or semi-aquatic consumers include many species of waterfowl, shorebirds, predaceous diving birds, muskrats, raccoons, alligators, nutria, rabbits, deer, frogs, snakes, turtles, mink, and wild hogs.

Salt cordgrass, glasswort, seepweek, maritime saltwort, sea oxaye, salt grass, and saltflat grass are the dominant plant species in a salt marsh. Most of the primary level of food production (vegetation) is channeled through the detrital food chain to higher levels. Salt marsh consumers include waterfowl, marine snails, crabs, grass shrimp, and large populations of larval marine fishes and crustaceans.

In lower peninsular Florida, mangrove swamps provide an important source of nutrient material to estuarine and inshore waters.

The outflow of the Mississippi River greatly affects the waters of the northern

Gulf. Though the fertility of the central Gulf estuaries has probably been reduced by man's activities along the Mississippi, the area between Pascagoula, Mississippi, and Port Arthur, Texas, remains second only to the coast of Peru among the most productive fishery areas of the world. The catch of fish and shellfish from Louisiana exceeds that of any other state, primarily as a result of high production of two estuary-dependent species: menhaden and shrimp. Almost 68 percent of the total seafood landings of the Gulf states was represented by Louisiana landings in 1972.

3. Birds. Two major migratory routes of birds, the Mississippi Flyway and the Central Flyway transect the Gulf of Mexico. The coastal zone provides a wide variety of bird habitat. The long expanse of mud flats and beaches are inhabited by shorebirds, while the shallow bays and wetlands provide habitat for wading birds.

(a) Waterfowl. Nearly all waterfolw which occur along the northwestern Gulf coast are produced in the far north and migrate to the Gulf Coast after the onset of shorter days and cold weather. These birds become extremely numerous during the peak of migration. Most geese spend the winter in the coastal lagoons and marshes, feeding on submerged aquatic vegetation. The Canada goose and to some extent the blue goose, have learned to utilize grain fields for food and may also spend time inland on fresh water.

Surface feeding ducks (dabbling ducks), including the mallards, pintails, black and wood duck, teals, gadwalls, and shovelers exhibit a wide variety of feeding and nesting habits. Several species have adapted to farm ponds and grain fields, but others remain completely dependent on the coastal salt marshes for their winter home, dwelling there and feeding on aquatic insects, mollusks, marine plants, and marsh grass.

Of the diving ducks, only redheads, coots, canvasback, and scaups spend much time on inland waters and grain fields. The remainder of these species, which include the buffleheads, hooded mergansers, and goldeneyes, pass the winter either in coastal Texas or far out in the open Gulf.

(b) Shore birds. All but a few species of shore birds are dependent on wetland habitats for most of the year. Even species that perform spectacular over-water migrations, such as the golden plover, are dependent on the marshes and mud flats of the Gulf Coast. Plovers, small to medium-sized shore birds, spend summer in the Arctic and winters in South America, stopping over in mud flats along the Texas Coast during both migrations. Sandpipers, including both shore and wading birds, occur along the Gulf Coast where they feed on small invertebrates. Avocets and phalaropes, including upland, shore, and pelagic species are also present in the coastal area.

(c) Large, fish-eating birds. These long-legged waders include the cattle egret, white-faced ibis, white ibis, snowy egret, roseate spoonbill, common egret, Louisiana heron, lesser blue heron, black-crowned night heron, white pelican, olivaceous cormorant, reddish egret, green heron, yellow-crowned night heron, anhinga, least bittern, and the brown pelican. Each of these species are dependent upon the coastal zone during portions of their life history.

(d) Other birds. Colonial birds, such as gulls and terns use the Gulf's barrier islands extensively for nesting and feeding. Large populations of rails and gallinules nest in the marshes during the summer. Scattered pairs of bald eagles and osprey may be found nesting along the Texas Coast.

4. Land Mammals. Noteworthy animals living in the coastal zone and depending largely on the swamp and salt marsh communities for food include the armadillo, bobcat, deer, gray fox, mink, muskrat, nutria, opossum, river otter, eastern and swamp cottontails, raccoon, striped skunk, and red wolf. Deer and rabbit are taken by hunters. Mink, muskrat, nutria, raccoon, and opossum populations are utilized extensively by trappers.

5. Benthic Communities. At the margin of coastal bays, shoal areas support extensive marine algal and grass beds. Algal and grass production in these areas is regulated by water temperature, salinity, turbidity, and bottom types. Widgeon grass, shoal grass and turtle grass are common in shoal waters. The most common algae found in shoal waters are blue-green, green, and red. These areas serve as an important nursery, offering a sheltered environment to many species of larval fish and crustaceans.

6. Fisheries. Nearly 98 percent of the commercial catch is made up of estuarine species. In terms of weight landed, the major commercial species are the pelagic large-scale menhaden, and the benthic shrimp (brown, white, pink, and others), Atlantic croaker, spot, striped mullet, blue crab, and American oyster. The major sport fish species are the pelagic tarpon and the benthic spotted seatrout, red drum, sand sea trout, black drum, sea catfishes and croakers. Important high-salinity species are groupers, king mackerel, Spanish mackerel, and red snapper.

(a) Menhanden (Pelagic). The Gulf menhaden and two other menhaden species that occur occasionally in the catches support an important fishery conducted with purse seines from western Florida to eastern Texas. The fishery is centered in Louisiana, particularly west of the Mississippi delta. Large quantities are also taken in

Breton Sound, Louisiana.

(b) Brown Shrimp (Benthic). The brown shrimp fishery is an important trawl fishery west of Mobile Bay, Alabama. Highest catches are taken off the Texas coast from 10 to 30 fathoms. Large catches also are made off Louisiana in 10 to 20 fathoms, and in many Louisiana bays. This species along with white and pink shrimp supports the most valuable commercial fishery in the United States.

(c) White Shrimp (Benthic). This species is important from northern Florida to Texas. Major fishing areas are west of the Mississippi River to San Antonio Bay, Texas. Most catches come from inshore areas to 10 fathoms, and from bays.

(d) Pink Shrimp (Benthic). The pink shrimp fishery is conducted principally in offshore waters off Florida. Most catches are taken from 10 to 20 fathoms.

(e) Atlantic Croaker (Benthic). The Atlantic croaker makes up about 50 percent of the catch of "industrial bottomfish" by trawlers. It is becoming more important as food and sport fish. The "industrial bottomfish" fishery is important in Mississippi and Louisiana and is conducted in waters up to 20 fathoms. The bulk of the catch is reduced to fish meal used in feeds for livestock, etc.

(f) Spot (Benthic). The spot makes up about 25 percent of the "industrial bottomfish" catch by trawlers. It is also taken by haul seines, gill nets, and trammel nets from inshore waters of Florida. It is becoming more important as a food fish.

(g) Striped Mullet (Pelagic). Striped mullet is an important species in Florida. It is taken in most bays and coastal areas of that area. Casual fishermen probably take large quantities which go unreported. It is also a bait species sought after by sport fishermen.

(h) Blue Crab (Benthic). The blue crab supports an important commercial fishery in most bays and sounds as far west as Corpus Christi Bay, Texas.

(i) American Oyster (Benthic). The American oyster provides a major fishery resource over the coast, but it is relatively unimportant in Florida except for the Apalachicola Bay and St. George Sound areas. Large quantities are taken from Breton Sound, Mississippi Sound, Chandeleur Sound, Barataria Bay and East Bay in the delta region. In Texas, Galveston Bay and East Bay are important oyster producing areas.

(j) Groupers (Benthic). Groupers are caught commercially by handlines, mainly on offshore banks throughout the northern Gulf. They are more important in Florida than elsewhere in the Gulf. This fishery is combined with that of red snapper. Groupers are also of importance as sport fish.

(k) Mackerel (Pelagic). King mackerel and Spanish mackerel, important sport fish, also are taken commercially in large quantities. King mackerel are taken by gill nets close to shore on the lower coast of Florida. Spanish mackerel are important in the commercial fishery along the Florida coast as far west as Escambia Bay. They also are taken in quantity by Florida fishermen off Perdido Bay, Alabama.

(l) Red Snapper (Benthic). Red snapper are taken by handlines on offshore banks in 5 to 10 fathoms. A few are also taken in trawls. Several other valuable species are taken incidentally in the red snapper fishery. It is also an important game fish.

(m) Tarpon (Pelagic). The tarpon is an important sport fish of the region, though its numbers apparently have declined in the northern Gulf. Its populations are sufficiently depressed to warrant its status as a potentially endangered species. There are some signs, however, that its populations may be recovering.

(n) Sea Trout (Benthic). Spotted sea trout is a widely distributed sport and commercial species in the northern Gulf. It is taken commercially will gill nets, haul seines and trammel nets in most inshore areas. Some are also taken by shrimp trawlers in shallow waters off Louisiana and Alabama. The sand sea trout, an important sportfish, is taken in small quantities by hand seines and gill nets in the Tampa Bay area, and a few are caught on hand lines offshore of Tampa Bay. This species is also taken in shrimp trawls and trammel nets in shallow waters of the Mississippi Delta.

(o) Red Drum (Benthic). Red drum is an important sport and commercial species in all the Gulf states. It is taken commercially by haul seines, gill nets and trammel nets in most bays from Florida to Texas, and it is also taken by red snapper fishermen. Some are caught by inshore shrimp trawlers in Louisiana.

(p) Black Drum (Benthic). Though black drum is an important sport fish, especially in the northern Gulf, it is important commercially only in Texas where it is taken by set lines and trammel nets in most bays. Small quantities are taken in bays and sounds in the Mississippi Delta area.

(q) Sea Catfishes (Benthic). Sea catfishes, especially the gafftopsail catfish, are sport fish of some importance in the northern Gulf.

7. Life History. The general life history of most motile (capable of movement) estuarine animals of the Gulf coastal states follows a similar pattern. Adults spawn in the Gulf and larvae make their way into the low-salinity waters of the estuaries. The young develop in the estuaries and then return to or toward the sea. This is generally

true of the major commercial species including large-scale menhaden, shrimp, Atlantic croaker and spot, striped mullet and blue crab. The American oyster apparently will live and reproduce at sea-water salinities, but it grows, lives and reproduces best under estuarine conditions. The major sport fishes follow a similar life history pattern, but spotted sea trout and the sea catfishes usually spawn inside the estuaries, often close to the bay entrances. It has been suggested that organisms with a marine-estuarine life history have a distinct advantage of avoiding most of their predators and parasites during the early stages of life in the estuaries.

The shrimp resource, like the other major commercial and sport fishery resources of the Gulf states, is dependent upon the coastal shallow-water environment. The estuaries provide nursery areas rich in nutrients for the development of young of animals supporting these fisheries, and in several cases support adult populations. Though the harvest of some of these resources takes place outside the estuaries, the resources are nonetheless estuary-dependent.

8. Environmental Influences. Extremes of salinity variation in bays bordering the Gulf are not common. A salinity gradient extends from sea water to fresh water over a relatively short distance, and the entire bay may vary from high salinity to almost fresh water over a period of years. Great influxes of fresh water (floods) are not known to kill the motile organisms, but sometimes they kill large oyster reefs completely, and it takes a few years for living reefs to become re-established. Under these conditions, other sessile and non-motile organisms are also killed. Such happenings are not long-term catastrophes, because the enemies of oysters are killed or driven seaward, and apparently the nutrients brought in from the rivers lead to a higher production of oysters and shrimp in the following years.

Conditions leading to sudden influxes of fresh water were created artificially on the Louisiana coast by the leveeing of the Mississippi River; the instability of the estuarine system around the mouth of the river has increased and probably the fertility of the region has decreased.

The greatest numbers of marine species are found in high-salinity waters of the upper Gulf offshore from bays and estuaries. As the salinity declines through the bays and into fresh water, the numbers of species decline.

Certain shallow, protected and semi-enclosed parts of the estuarine system of the northern Gulf attain a water temperature of approximately 104°F in the summer. Water seldom freezes in the central Gulf, but on the south Texas coast, mush ice forms in large quantities along the shores of the bays. These extreme cold waves cause catastrophic mortalities of aquatic organisms. The mean annual open-water temperature of the estuarine surface approximates 79°F.

On the central Gulf coast, bay waters are always muddy and rather turbulent. In most cases, salinity is higher on the surface than on the bottom, caused in part by high evaporation. Circulation and exchange of water are good in most instances and oxygenation is sufficient from top to bottom. Immediately below the surface of the mud, where the organic content is high, conditions are often anaerobic with hydrogen sulfide present.

On the northeast shore of Mobile Bay, a great deal of plant debris and other organic matter is deposited just offshore, and during periods of little wind and limited tidal exchange, dissolved oxygen is consumed. Winds from the east to northeast force surface water offshore and a minor upwelling takes place when deoxygenated deeper offshore water invades the shallows. When this occurs, fish, crabs and shrimp come close to shore and some even crawl or hop out on the beach. Such an event is called a "Jubilee."

A similar phenomenon may occur during periods of flood along the Louisiana coast. Vast quantities of turbid fresh water overlay colder high-salinity water, and oxygenation is prevented by thermal and chemical stratification. Bottom waters devoid of oxygen were observed along the Louisiana coast during the spring floods of 1973, and many marine animals were concentrated near the shore.

9. Seasonal Cycles. In the spring, many motile species, which are taken only in the Gulf during the winter or which are absent entirely, begin to enter the bays. Some go only into the seaward bays and many that go into the landward bays are taken only rarely in the summer and fall. This influx continues through warm months, and some species are not found in the bays until summer or fall.

Many species begin to leave the bays in the early fall and winter, and some of these are found in the Gulf during periods varying from 1 to 3 months in midwinter. Some disappear from the bays entirely, as well as from the shallow Gulf. The general movement to the Gulf starts in October and continues into December. Most estuarine species return to the bays from February to April. The large general exodus of estuarine species from the bays in the fall is the most noticeable aspect of the seasonal cycle.

It appears that the temperature cycle is chiefly responsible for the seasonal movements and other recurrent cyclic activities of estuarine species, since the temperature cycle is definite while the general salinity changes are not nearly so regular.

10. Marine Mammals. The mammalian fauna of the Gulf of Mexico consists of the West Indian seal, the manatee and various cetaceans. The apparent former range of the West Indian seal was the Bahamas and southern Florida through the West Indies to Honduras and Yucatan. Single individuals and small herds are reported to have visited the western Gulf as far north as Galveston, Texas, on occasion as late as 1932.

Manatees, while having been reported in the past from the northern Gulf, are extremely sensitive to cold, and they are continuous residents in the United States only in Florida.

The sperm whales, pigmy sperm whale, beaked whales, long-snouted dolphin, and bottlenose dolphin are cetaceans that have been reported from the Gulf. The long-snouted dolphin is common in offshore waters and the bottlenose inhabits shallow coastal waters and bays.

11. Threatened Species. Wildlife species which are threatened include the whooping crane, Eastern brown pelican, Southern bald eagle, Eskimo curlew, prairie falcon, Arctic peregrine falcon, American peregrine falcon, Attwater's greater prairie chicken, greater sandhill crane, Cape Sable sparrow, red-cockade woodpecker, Bachman's warbler, American alligator, red wolf, Florida manatee, gopher tortoise, Key blacksnake, indigo snake, Florida pine snake, Florida scrub lizard, and striped red-tailed skunk. Peripheral species include the roseate spoonbill, northern black-bellied tree duck and the Eastern reddish egret.104/

THE PACIFIC COAST

GEOLOGY AND TOPOGRAPHY

1. General. Compared to the Gulf and Atlantic coasts the entire Pacific Coast of the U.S. is geologically young, very narrow, and tectonically active (subject to earth movement). Tectonic activity is particularly pronounced from Cape Mendocino to Mexico, where many destructive earthquakes occur and where faults that are active or suspected of being active can be traced onto the narrow Continental Shelf and landward regions.

2. Beaches and Shoreline. The shores of California, Oregon and Washington include many rocky areas and long sandy beaches. Some of these beaches are adjacent to the Columbia River and near Monterey, Oxnard, Santa Monica, Long Beach and San Diego. 105/

3. The Continental Shelf. The continental margin off southern California is complex and characterized by islands, basins, ridges and banks that are more or less parallel to the coastline. In this area the shelf is narrow, averaging only about 10 to 15 miles in width; in some sections it is practically nonexistent. The shelf break occurs at about 50 fathoms. 106/

The shelf widens a bit north of San Francisco and loses the variability in width which characterizes it to the south. Along the Oregon and Washington coasts the shelf break is about 100 fathoms deep and the width of the shelf is about 20 miles. In this part of the coast (north of the California border), the outer portion of the shelf has a number of banks.

4. Shelf Sediments. Sediments vary in composition along the shelf off the western United States, especially off the California coast where the basin and trough topography causes a number of different mechanisms to deposit sediment. In southern California there is a considerable local variation in the thickness of sediment and this is related to the topography and proximity to sources. Typically in this region most of the midportions of the shelf have about 30 to 50 feet of sediment, except off La Jolla, where the shelf is nearly barren of sediment. 107/ In the Oregon and Washington area many of the banks are composed of rock or hard clay at the shelf edge, while the shelf topography is relatively smooth, with the exception of local rock knolls. Oil company reports show that in these northerly parts the shelf has only

a thin veneer of sediment. The sediments are frequently alternating sand and mud deposits without any significant relationship in grain size to depth or distance from shore. 108/

5. Sediment Movement. The physical agents active along the Pacific Coast which affect the distribution of bottom sediments are longshore currents, normal wind waves, and storm action. Along the California coast where estimates of the volumes and areas of change have been made it has been noted that sand is lost from the shelf during times of large wave action, presumably by southward lateral transport and accumulation in the head of La Jolla Canyon. During times of small wave action it is believed that sand is replenished by southward lateral transport of nearshore sediments. The coarsest sediments moved fastest near shore. Farther offshore movement is less rapid, generally involving progressively finer sediments. Longshore movement occurs past coastal barriers such as Point Conception and Point Dome. 109/

Farther north silt from the Columbia River is transported generally northward and to a lesser extent westward. Measurements indicate that the transport generally occurs during a few storms each winter when it moves as suspended load. At other times this material is trapped in the nearshore region by wave-driven bottom currents that have a net onshore direction. 110/

Data obtained with current meters located 3 meters above the seabed in 50 to 80 meters of water indicate that sediment transport occurs only during storms. Bedload sediment transport is negligible compared to suspended load transport. 111/ Calculations suggest that a severe storm occurring every few years might have more geological significance than a number of less severe storms. 112/

6. Engineering Properties. Detrital sediments of mostly sand to sand-silt sizes predominate on the narrow shelves of the Pacific Coast and correspond closely to the sediment composition of adjacent beaches. 113/ Accordingly, bottom strengths may be considered good although detailed measurements are uncommon.

Uncertain engineering conditions exist in areas of submarine canyons, in areas of anomalous sedimentary patters resulting from bottom currents and exposures to large waves. Areas of submarine basins and also areas of recent explosive volcanism would require reconnaissance before siting structures. Areas of abundant calcareous organisms should provide stable sand conditions.

The seaward extension of the San Andreas fault leaves the coast at Point Arena but its position on the shelf is not known with certainty. Faults occur elsewhere on the shelf, best developed between Monterey and Point Arena, but the area north of Monterey is also thoroughly cut up by faults. 114/ Careful siting of structures to avoid fault lines would be necessary.

OCEANOGRAPHY

1. Tides. A characteristic of the tides along the west coast of the United States is the large inequality in the heights of the two high waters and of the two low waters of each day. This variation in tidal heights during a lunar day (24.84 solar hrs.) is known as diurnal inequality. Along the coast the average difference between the heights of the two high waters of the day is from 1 to 2 feet, and the difference in the heights of the low waters averages from 2 to 3 feet. At some locations along the coast the inequality becomes so great that the tides exhibit diurnal characteristics, with only one high and low water per day.

On the coast the mean rise of the tide above the plane of reference (mean of lower low waters) varies from 5 feet off southern California to about 7.5 feet off the coast of Washington. Extreme variations from 3 feet below to 10 feet above the datum may reasonably be expected. 115/ The following diurnal ranges (the difference in height between mean higher high water and mean lower low water) for selected sites along the coast: San Diego, California, 5.6 ft.; San Francisco (Golden Gate), California, 5.7 ft.; Crescent City, California, 6.9 ft.; Columbia River entrance, 7.5 ft.; Westport, Washington, 8.5 ft. 116/

The inequality of the tidal heights is reflected in the equally variable tidal currents. The Pacific Coast experiences generally two floods and two ebbs each day, but one of the floods or ebbs has a greater speed and larger duration than the other. The inequality varies with the declination of the moon. At some locations along the coast the inequality becomes so great that the tidal currents exhibit diurnal characteristics, with only one flood and ebb per day.

Tidal currents of the rotary type (found in offshore positions) are weak, with maximum mean speeds of less than one knot. Speeds increase northward with mean maximum speeds of 0.4 knots at San Francisco Lightship increasing to 0.9 knots at Swiftsure Bank (off northern Washington). The direction of flow changes continuously throughout the lunar day.

Tidal currents of the reversing type found at inshore locations are generally weak with mean speeds of about one knot. At coastal locations adjacent to inlets and river mouths, current speeds are somewhat higher (about 2.0 knots). The direction of flow is variable and is influenced by the coastal land and seabed configuration. [117]

2. Circulation. The California Current flows southeast nearly parallel to the Pacific Coast of the United States the year round. Along the eastern boundary of the current, near the shoreline, eddies and countercurrents complicate the pattern. During the winter months (November through February) the Davidson countercurrent flows north between the coast and the eastern edge of the California Current from southern California to British Columbia. From March through June the California Current dominates the coast, with southerly flow along the entire coast. In July the current continues southeast from Washington to central California, but at this time the Southern California Eddy appears and dominates the circulation off southern California in a large counter-clockwise gyre containing scattered small eddies. [118] See Figure 18 for general circulation patterns for winter and summer seasons.

3. Water Mass Characteristics.

(a) Point Conception to Northern Washington. The physical and chemical water mass characteristics along this section of the Pacific coast are greatly influenced by the Davidson countercurrent, the California Current, and northerly winds which induce coastal upwelling.

Coastal upwelling begins in May along the Oregon coast, earlier to the south, and brings water typically found at depths of 183 meters. [119] The water is cold, and has a high salinity and a low oxygen content. [120] Throughout the summer this upwelling tends to lengthen the cold-water period of the year (mean temperature range from the surface to 20 meters is 10-20° C), by holding the now warmer waters of the California current in an offshore position. [121] Fig. 19 shows these cold surface waters along the coast in August surrounded by warmer offshore waters.

In the fall the Davidson countercurrent appears in the coastal region bringing with it warmer and more saline waters from the south extending the warm water period along the coast well into fall. The highest surface temperature off Oregon may occur in early fall with maximum surface temperatures of 19°C. [122]

The salinities of the waters brought into this area by the California Current system are typically less than 33.0‰. These waters mix seasonally with higher salinity waters of about 34.0‰, brought into the coastal area by

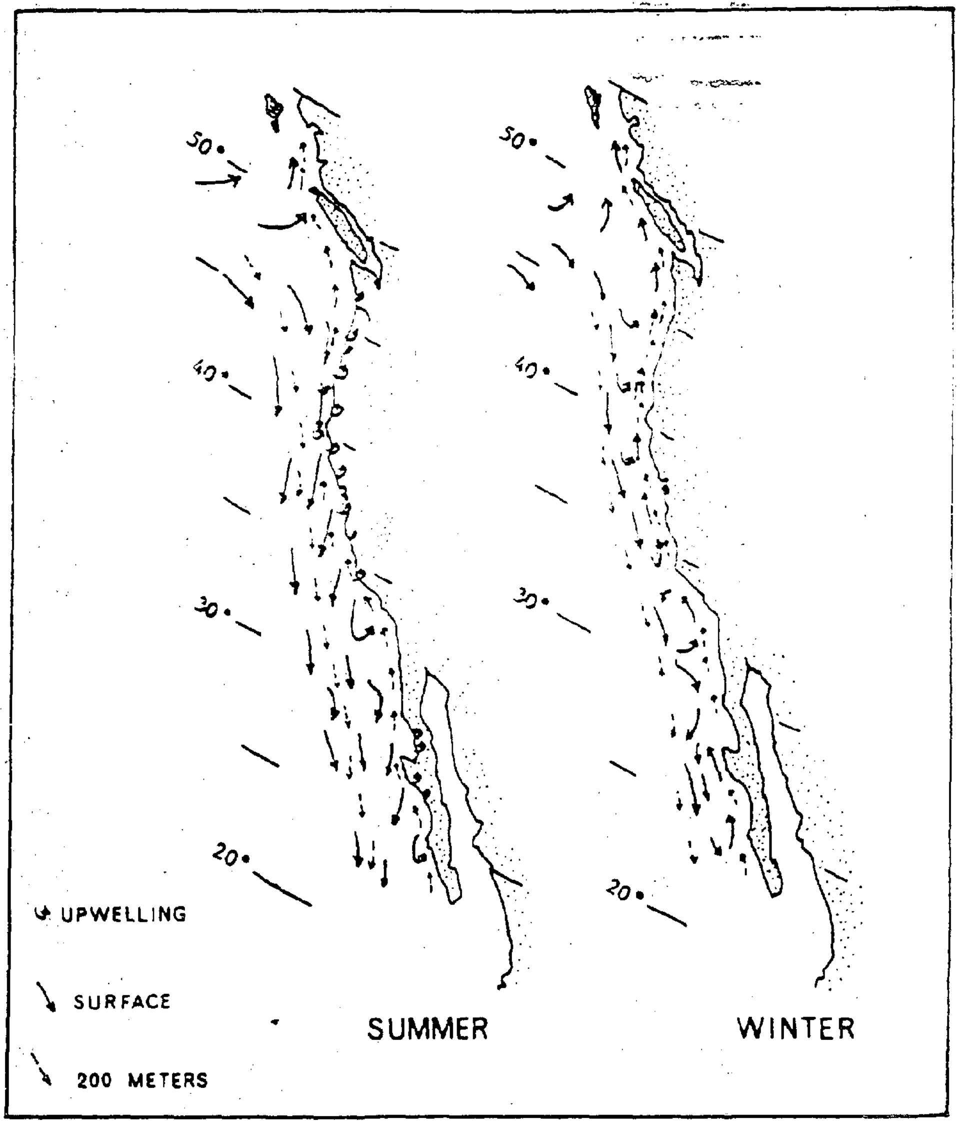


Figure 18.--General circulation patterns along the Pacific Coast.

Source: Ricketts, E.V., and J. Calvin, 1962: Between Pacific Tides (3d ed., rev. by Joel W. Hedgepeth). Stanford University Press, Calif.

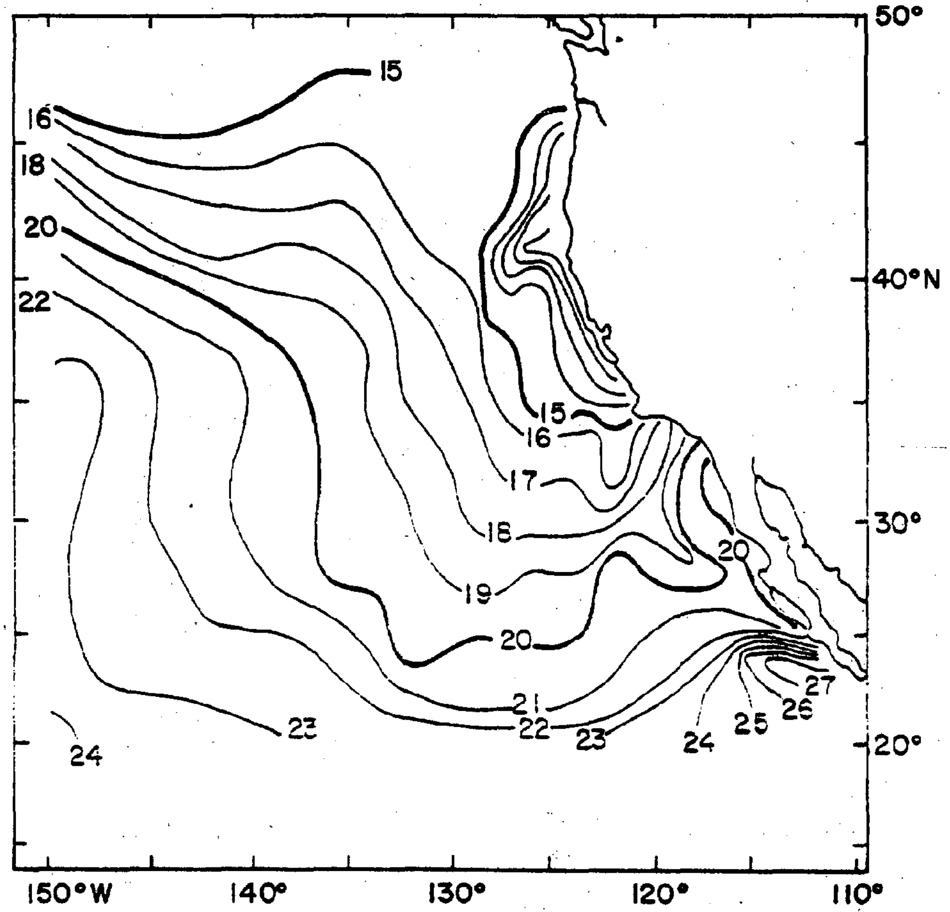


Figure 19.—Ocean temperature 10 m (°C), August.

Source: Reid, J.L., G.I. Roden, and J.G. Wyllie, 1958: Studies of the California Current Systems. Contributions from the Scripps Institution of Oceanography, New Series No. 998.

upwelling in the spring and summer and from the south by the Davidson countercurrent during the fall and winter. As a result, salinities with depth along the coast will range between 34 and 33‰.[123]

Regionally, the spring discharge of the Columbia River greatly affects the surface salinity characteristics (upper 10 meters). The fresh water discharge spreads over the surface to the south and its influence can be detected 250 miles offshore and south of 40° North by mid-summer with salinities of less than 32.0‰. [124]

The main feature of oxygen distribution along this section of coast is the wide ranges found in the near surface waters during the spring and summer seasons. For example, the surface range off the Oregon coast is 2.15 - 9.67 ml/l. This variance can be attributed to coastal upwelling.

(b) South of Point Conception. The waters adjacent to this section of the California coast experience considerable mixing while over the shelf because of wave action and differential currents. Despite this, they normally remain quite thermally stratified in the upper layers, especially in the summer, when the surface warms to temperatures 5 to 10°C above the temperature at 60 meters. In winter the stability is less, and occasionally high winds will produce a condition of almost complete mixing in places where the water is not over 60m deep.[125]

In general, salinity increases with depth, but the range is not large, and in the summer there is often an inversion near the surface due to evaporation, accompanied by enough heating of the surface layers to preserve stability. [126]

Figure 20 is a location chart. Table 6 shows the minimum and maximum values of temperature and salinity corresponding to the areas depicted in fig. 20.

Concentrations of dissolved oxygen are in the neighborhood of saturation at the surface. There is a normal decline with depth, but in no season is the average oxygen content at 60m less than 2.8 ml/l. Upwelled waters are characterized by lower oxygen concentrations. [127]

CLIMATOLOGY

1. General. The Pacific coastal region of the United States and the adjacent ocean areas are located along the eastern portion of the Pacific high pressure system. This high, when well developed, forms the principal circulation control, forcing most of the lows that develop to follow a course northward of the United States. This action damps out weather changes that might otherwise occur and brings to the weather along the

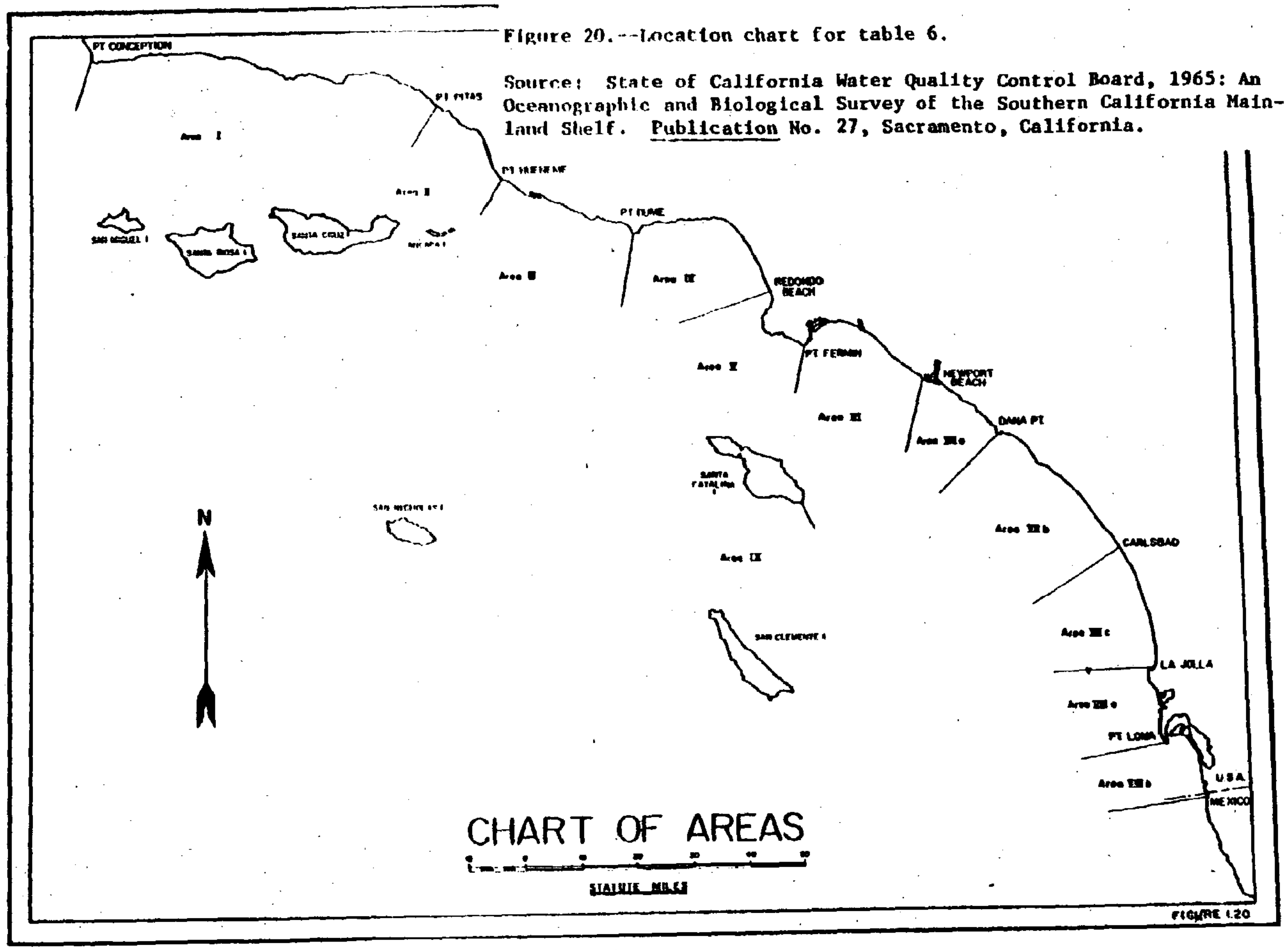


Figure 20.--Location chart for table 6.

Source: State of California Water Quality Control Board, 1965: An Oceanographic and Biological Survey of the Southern California Mainland Shelf. Publication No. 27, Sacramento, California.

Table 6.--Minimum and maximum values of temperature, salinity, and density for the areas shown in figure 20.

Area	*Depth (ft.)*	*Temperature (°F)*	*Salinity (‰)*	*Density (gms/cm³)*
I	0	54.0–68.2	33.26–33.85	1.02370–1.02540
	50	52.5–67.0	33.14–33.85	1.02393–1.02558
	100	51.0–65.4	33.22–33.96	1.02382–1.02589
	200	50.0–58.3	33.36–34.00	1.02486–1.02620
IIa	0	55.3–69.1	33.22–33.85	1.02340–1.02535
	50	50.6–67.2	33.20–33.96	1.02391–1.02520
	100	49.0–64.9	33.20–33.79	1.02428–1.02597
	200	46.1–59.9	33.41–33.90	1.02493–1.02600
IIb	0	55.0–68.8	33.36–33.97	1.02364–1.02515
	50	53.4–67.0	33.27–33.78	1.02393–1.02532
	100	50.5–64.0	33.08–33.78	1.02435–1.02566
	200	50.3–56.8	33.51–33.84	1.02405–1.02565
III	0	53.2–70.2	32.78–32.98	1.02365–1.02540
	50	50.3–69.0	33.26–33.96	1.02362–1.02573
	100	50.3–65.2	33.20–34.00	1.02397–1.02584
	200	50.0–58.5	33.44–34.08	1.02446–1.02610
IV	0	56.0–65.1	33.00–33.64	1.02380–1.02512
	50	54.1–65.1	33.27–33.60	1.02404–1.02531
	100	52.4–64.3	33.20–33.58	1.02415–1.02561
	200	50.2–57.7	33.34–33.70	1.02505–1.02568
V	0	56.0–65.8	33.18–33.31	1.02396–1.02527
	50	53.8–65.6	33.15–33.30	1.02408–1.02528
	100	54.2–63.2	33.40–33.32	1.02447–1.02551
	200	51.9–58.8	33.38–33.36	1.02449–1.02608
VI	0	53.0–73.6	32.94–33.70	1.02347–1.02515
	50	54.8–68.0	33.20–33.72	1.02355–1.02516
	100	53.6–62.2	33.25–33.86	1.02446–1.02547
	200	50.4–57.0	33.40–33.82	1.02510–1.02590
VIIa	0	56.6–73.6	33.08–33.94	1.02304–1.02513
	50	55.8–72.7	33.29–34.15	1.02382–1.02537
	100	52.4–66.0	33.37–33.22	1.02434–1.02551
	200	51.0–61.3	33.40–33.96	1.02468–1.02570
VIIb	0	57.8–77.9	33.28–34.05	1.02305–1.02514
	50	50.9–72.2	33.26–34.08	1.02344–1.02537
	100	52.3–62.6	33.37–34.01	1.02401–1.02570
	200	50.4–62.2	33.40–34.06	1.02495–1.02628
VIIc	0	58.0–70.7	33.42–33.93	1.02338–1.02510
	50	56.2–64.9	33.37–33.93	1.02410–1.02535
	100	53.6–61.0	33.38–34.06	1.02459–1.02552
	200	55.3–56.2	33.42–33.96	1.02528–1.02584
VIIIa	0	58.8–71.3	33.42–33.93	1.02325–1.02502
	50	54.3–67.3	33.42–33.91	1.02386–1.02531
	100	52.4–63.3	33.40–33.92	1.02430–1.02573
	200	50.8–60.6	33.45–34.03	1.02460–1.02617
VIIIb	0	57.9–72.0	33.33–33.88	1.02313–1.02514
	50	53.6–66.6	33.38–33.83	1.02365–1.02570
	100	51.9–62.6	33.42–33.88	1.02450–1.02587
	200	49.5–53.4	33.42–34.15	1.02504–1.02615

Source: State of California Water Quality Control Board, 1965: An Oceanographic and Biological Survey of the Southern California Mainland Shelf, Publication No. 27, Sacramento, Calif.

coast a stability factor that would not otherwise exist. Air which reaches the coast as a result of the prevailing westerly winds has acquired much water vapor during its passage over the ocean, with resultant high humidities over the coastal regions. The marine influence is also evidenced in a cooling effect in summer and warming influence in winter.

During the summer, the North Pacific High reaches its greatest development. In July, the center, with highest pressure about 1025 millibars, is located in the latitude of San Francisco near 150°W. Average pressure in excess of 1015 millibars prevails over most of the ocean area north of 20°N almost to Alaska and west from the Pacific coast to about 160°E. At this season of the year, the Aleutian Low is almost non-existant.

By October, the High has contracted, particularly on the north in the direction of the Aleutian Low, which has formed over Alaska and the Bering Sea with pressures of 1002.5 millibars and below prevailing over southwestern Alaska including the Aleutian Islands. This low-pressure area, which appears as a permanent system on the charts, is actually the result of frequent migratory lows that move through the area during the winter season.

In October, the Pacific High extends from the U.S. coast across the Pacific Ocean and into the Asiatic Continent, and reaches a maximum of 1020 millibars in the vicinity of 30° to 35°N and 135° to 140°W. Weakening of the High continues with the approach of the winter season, and by November, it is little more than a weak belt of high pressure lying between the Aleutian Low and the equatorial belt of low pressure. Lows continue to form along the polar front and tend to make their path through the area covered by the Aleutian Low. In winter these traveling depressions moving eastward cause considerable day-to-day variation in pressure, particularly in the area north of 40°N.

During the spring months, there is a gradual return to the summer pattern, with the High spreading northward and the Low becoming further contracted. Migratory Lows become less frequent and enter the continent farther north. Day-to-day fluctuations in pressure are much smaller than in the winter months. 128/

2. Extratropical cyclones. Extratropical cyclones frequent the northern sector, particularly the Gulf of Alaska, throughout the year. These storms derive their energy from contrasting air masses and form on fronts. It is not unusual in severe

extratropical storms to have winds of hurricane force (≥ 64 knots). Fall, winter, and spring are the seasons of highest frequency. During most of the cool season, the Gulf of Alaska has the highest frequency of extratropical cyclones in the Northern Hemisphere. 129/

In winter months, there are four areas of cyclogenesis (formation and intensification of lows) in the Northeastern Pacific, and cyclones move into the area from the west or southwest. Two primary tracks converge on the Gulf of Alaska, and another primary track approaches Vancouver Island. A secondary track moves from the Gulf of Alaska toward Vancouver Island.

In spring, the primary storm tracks entering the Gulf of Alaska remain, but only a secondary track approaches Vancouver Island from the southwest. Areas of cyclogenesis are roughly the same as in winter, but they are considerably smaller.

In summer, one primary cyclone track enters the Gulf of Alaska. There are two areas of cyclogenesis during this season: one in the Gulf of Alaska and one centered near 47°N, 165°W. Fall conditions are essentially the same as those encountered in spring.

3. Tropical cyclones. The hurricane season in the eastern North Pacific runs from late May through November, when an average of 15 tropical cyclones form. About six or seven usually become hurricanes. As in all tropical cyclone regions, however, it is possible for these storms to form in any month. The 1951 season was the longest on record, beginning on May 18 and ending on December 1. Thirty-two tropical cyclones have occurred during August from 1966-72--an average of 4.6 storms each August. Two or more tropical cyclones per months form on an average, from July through October. One or more of these become hurricanes each month, from July through October. Maximum wind speeds in these hurricanes have been recorded at 130 kt, as during Ava in June 1973. 130/

Tropical cyclones of this region usually form in an area between 10°N and 25°N, extending from 90°W to 160°W. In general, early and late season tropical cyclones form close to the coast and farther south, while mid-season storms form anywhere in a wide band from the Mexican and Central American coast to the Hawaiian Islands. One notable exception was hurricane Nina, which formed 8°N, 162°W, late in November of 1957. 131/

Tracks of most storms generally parallel the coast moving in a west-northwesterly direction. Movement is more regular during the mid-season months, when the easterly steering current aloft is most steady and located farthest north. Many storms, particularly early and late season ones, recurve toward the northeast. Some move northward or northeastward for their entire lives. A few have been tracked into the western Pacific.

Forward speeds of tropical cyclones in the eastern North Pacific, as in other tropical regions, are variable. However, since storms in this region usually remain below 30°N, the range of forward speeds is less, and they do not vary as much with latitude as in other regions. Average forward speeds range from 7 to 12 knots; extremes range from stationary to 25 knots. Tropical cyclones rarely move faster than 15 knots, below 15°N. Slowest speeds are found during recurvature or tight turns. Average forward speeds are highest during August (10 to 12 knots) and lowest in June (7 to 8 knots). It is very rare for one of these storms to strike the Southern California coastline. A tropical cyclone hit the Southern California region in September 1939. This storm moved inland near Los Angeles with winds of 34 to 47 knots and waves of 30 feet. 132/ In 1972, the remains of hurricane Hyacinth moved inland between San Diego and Los Angeles.

4. Winds. The prevailing winds in late fall and winter north of 40°N are westerly to southwesterly. The coast south of 40°N has northwesterly anticyclonic winds year round. Average wind speeds are highest in the north, diminishing with latitude. Off the coast from Washington to northern California, mean speeds in winter range from 14 to 17 knots. South of San Francisco, winter mean speeds drop off to 9 to 14 knots. 133/

The spring wind regime consists of westerly to southwesterly winds over the open ocean, becoming northwesterly south of Vancouver Island. Mean wind speeds are fairly uniform north of San Francisco; April speeds range from 13 to 17 knots near the coast and are strongest off northern California. South of San Francisco, speeds average 10 to 15 knots.

In summer, winds are northwesterly to northerly along the entire coast, and mean wind speeds are generally 10 to 15 knots. The land-sea breeze effect is often important during this season, particularly in the south. The land heats up, creating a sea breeze during the afternoon, and cools at night, resulting in a land breeze. This is most likely when pressure gradients are weak.

In early fall, winds are westerly to northerly, and speeds are generally 10 to 14 knots. Wind speeds increase and winds with a southerly component become more frequent, particularly north of San Francisco, as fall turns toward winter.

The frequencies of gales (winds $\geq$ 34 kt) over the area vary with both season and latitude. In general, most gales come from the same direction as the prevailing wind. The area south of San Francisco seldom experiences a frequency of gales greater than 2 percent. Gale frequencies are highest off Oregon in winter (5 to 8 percent); they decrease significantly with latitude. Late fall and early winter are the seasons of maximum occurrence in the northern waters, except off northern and central California, where a spring maximum of 3 to 6 percent occurs.

The Santa Ana is an offshore desert wind usually occurring over or close to San Pedro Bay (near the port of Long Beach.[134] While infrequent, it may be violent. These winds are most apt to occur in late autumn or winter, and at times may reach a speed greater than 50 kt. Meteorological conditions are favorable for a desert wind whenever a strong area of high barometric gradient calls for northeast or east winds over southern California. The air moving outward from this high-pressure area streams through Cajon Pass into the lower lands of southern California. If the pressure difference between Nevada and southern California is only moderate, the desert winds are usually confined to rather narrow belts extending from the mouths of the passes to the ocean by the lowest and least obstructed routes. Airstreams from Cajon Pass usually maintain their identity in a remarkable manner. They move out over the valley floor, swing toward the southwest, and either follow the Santa Ana River Canyon through the Santa Ana Mountains or move directly over the low mountains south of the canyon and then follow a well-defined path over the almost level plains of Orange County to reach the ocean in the vicinity of Newport. The stream may shift its position slightly from time to time, but appears to change but little in width or velocity as it follows its path to the ocean. The wind often flows over the south foothills at the western entrance to Santa Ana Canyon, appearing to come down the hillsides in strong gusts directly along the ground.

These winds diminish little, if any, immediately after passing over water, and some reports credit them with blowing considerable distances at sea. However, beyond 50 miles from shore, they are usually of no particular concern. Aside from weather forecasts broadcast by radio, the mariner has only short notice of the approach of a

Santa Ana. The barometer is almost useless when its readings are taken alone, for there is little pressure variation, although a gale may spring up and blow for hours. For some hours before a Santa Ana, there is usually a period of good visibility and unusually low humidity. Shortly before its arrival on the coast, the Santa Ana may be observed as an approaching darkbrown dust cloud. This will often give from 10 to 30 minutes warning, and is always one of the positive indications.

The Santa Ana may come at any time during the 24 hours, but its strength is reinforced or opposed by the ordinary land and sea breezes. The reinforcement by the land breeze tends to produce the greatest velocity between 0700 and 0900 PST (Pacific Standard Time) and its force can be expected to lessen after 1000 PST.

5. <u>High waves</u>. High waves generally decrease in frequency southward. North of the area, in Queen Charlotte Sound, British Columbia, an anchored drilling rig reported an extreme wave of 100 feet in 1968.[135] Waves $\geq$ 20 feet occur about 2.5 percent of the time off the Washington coast in December, falling to less than 1 percent off Southern California. Waves $\geq$ 12 feet occur 15 to 20 percent of the time in fall and winter, from northern California to northern Washington.

Southern California sea-state and surf problems fall into two categories, depending on the different distant source regions of swells affecting local waters. During the winter season, storms traversing the temperate latitudes of the North Pacific, with extensive bands of westerly winds south of the 40th parallel, may direct heavy swells into Southern California coastal waters. Seas or swells originating north of that parallel do not affect Southern California coastal waters, as they are blocked by Point Arguello and Point Conception.

As spring approaches in the Northern Hemisphere, storms decrease in intensity and move to more northerly latitudes. At the same time, Southern Hemisphere autumn storms become more vigorous. By late May or early June, intense storms spawned off the Antarctic ice sheet may become nearly stationary for days at a time in the southern latitudes. Forty-to-fifty-knot winds may blow from the same direction, and over the same stretch of water, for extended periods of time. As a result, heavy swells will be propagated. These swells, traveling along great circle paths and carrying abundant energy, may traverse thousands of miles of ocean completely undetected, dissipating their energy on the coast of Southern California.

6. Visibility. Both summer-and winter-type fogs are common along the Pacific coast, with the summer type being more frequent and extensive. The generally light anticyclonic winds which prevail during the warm months, when the North Pacific high remains stable, are conducive to both the formation and maintenance of fog.

During most of the year the temperature of the water off the coast is lower than that of the ocean farther to the west, the greatest differences occurring in July, August, and September. The cooling effect of these coastal waters upon the easterly-moving air above it is a primary factor in the prevalence of summer fogs. Under these conditions, the warm, moist air from the west easily attains its dewpoint, and the resulting fog drifts toward the coast and moves inland.

Winter fog is more local in character, and although it may extend over a considerable range in latitude, it seldom extends any great distance to sea. However, when the so-called summer or advection type of fog, which may also occur in winter, unites with fog which has formed over the land, a sheet of fog may extend a considerable distance to sea.

The seaward extent of fog varies greatly. The band of densest and most frequent fog occurs over the narrow stream of colder water just off the coast, and is frequently limited to a band of 50 miles or less. At other times, fog covers large areas both in latitude and in longitude, and may extend for hundreds of miles to sea.

The months of maximum occurrence of fog off the Pacific coast vary somewhat with the different localities and, of course, with the individual year. Fog is most prevalent over Puget Sound in the late summer and fall months. Over the Strait of Juan de Fuca, sea fog predominates and its greatest frequency is in August and September. Fog occurs with almost equal frequency over the Strait throughout the other months. Along the coast proper, from Tatoosh Island to the lower California coast, the period of most frequent fog is from July to October, and that of least frequent, from December to May. On the lower coast of California, that is, from Los Angeles southward, the foggiest months are those from September to February, and the least foggy, from May to August. In the San Francisco Bay region, the incidence of low visibility (less than 2 miles) rises sharply in the fall months, rather than in the summer, because of the occurrence of radiation fog.

The maximum frequency of visibilities below 2 miles along the coast of Washington and Oregon is 10 percent, off southern Oregon, occurring in August, In general, visibilities drop below 2 miles 5 to 10 percent of the time, from July through November along these coasts. In the vicinity of Eureka, where there are coastal plains, maximum frequency of fog is in the fall, and is of the radiation type. Humboldt Bay, the harbor of Eureka, however, is an area of dense sea fog, and the shoals near there are dangerous to vessels in thick weather. Between Blunts Reef and San Francisco are two of the most foggy spots on the Pacific coast: Point Arena and Point Reyes. Point Reyes is often spoken of as being the actual center of heaviest and most frequent fogs on the Pacific coast; this is true when an average over a long period of record is considered. Owing to the persistence of the fog cover, through which it is said the sun's rays sometimes fail to penetrate for 3 or even 4 weeks at a time, Point Reyes has close to the lowest midsummer temperature of any observing station in the United States. Visibilities off northern California drop below 2 miles 7 to 15 percent of the time from July through November.

Golden Gate, the entrance to San Francisco Bay, is a region of frequent fog, and shipwrecks have been numerous there. Often a sheet of fog forms in early forenoon off the bold headlands on either side of the Golden Gate and becomes more formidable in size as the day wears on. As the temperature rises in the warm inland valleys, a steadily increasing indraft takes place. Then the fog, perhaps 1,500 or more feet in height, approaches the shore and enshrouds a good portion of all of San Francisco Bay. Under favorable termperature conditions, the fog will overspread the shore and rise up the more than half-mile height of Mount Tamalpais. 136/

Between San Franscisco and Monterey, warm-winter eddies are interposed between the cold waters and the coast, and a band of less frequent fog results. Estero Bay, just a few miles south of Point Piedras Blancas, is also one of the foggiest spots along the coast. Visibilities in this region drop below 2 miles about 5 to 8 percent of the time from July through February.

Surface fogs are not a common phenomenon over the waters of Southern California below Point Arguello, since warm-water eddies lie between the coast and the cool California current. This condition results in a preponderance of low stratus clouds, rather than surface fog. The minimum occurrence is at San Diego Bay. Point Arguello is the southernmost point in the band of maximum occurrence of fog. There the cool water lies close inshore and the maximum frequency of 14 percent visibilities less than 2 miles occurs in October and frequencies of 7 to 14 percent occur from April through November. Fogs at Point Arguello are invariably thick, and this point is recognized by mariners as one of the most dangerous on the coast. While the coast of Southern California has a minimum frequency of fog, there are two very foggy spots off the coast of Los Angeles. These are San Miguel Island and Buffalo Springs on Catalina Island.

7. Air Temperatures. The warmest temperatures and lowest seasonal ranges are observed in the Southern California ocean areas; temperatures seldom rise above 85°F. Freezing temperatures are almost never encountered south of 45°N. Near 50°N, freezing temperatures are recorded 1 to 2 percent of the time in winter months.

Surface air temperatures reach their peak during the summer months. The average temperatures during July range from 59°F off Washington to 64°F in Southern California. 137/ By November, mean temperatures have declined about 10°F in the northern areas, while the southern areas remain within 5°F of their summer values. Minimum temperatures are reached in January or February; they represent a difference of 10° to 15°F from the summer values in the northern sector. The Washington coastal area has an average temperature of 44°F in January, while Southern California has a mean of 58°F in this month. March brings a gradual warming of the surface air as summer conditions return.

8. Precipitation. The percentage frequency of observations that include precipitation usually attain maximum values over most of the northern areas in November through January and south of San Francisco in January. The frequency of precipitation is lowest over the Southern California marine areas, increasing to a maximum off northern Washington.

Winter precipitation frequencies are 15 to 30 percent north of San Francisco, decreasing to 6 to 15 percent between Los Angeles and San Francisco. South of Los Angeles, precipitation occurs less than 5 percent of the time. Significant frozen precipitation is rare even in northern waters, where snow falls less than 2 percent of the time.

Spring brings a gradual reduction of the frequency of precipitation throughout the area. During summer, coastal waters off Washington and Oregon record precipitation about 4 to 10 percent of the time. The coastal areas in California observe precipitation between 1 and 4 percent of the time in the summer months. Fall brings a gradual return to winter frequencies.

Thunderstorms, which are most likely to occur during the fall season, are observed less than 1 percent of the time in offshore waters. Close to shore, they are more likely in winter, north of Los Angeles. Along the Washington and Oregon coasts, the average is about 7 to 9 thunderstorms a year, while at San Francisco this drops to an average of 2 per year. 138/

9. Storm tides. See Atlantic coast discussions. Tropical and extratropical storms can generate storm tides off the North Pacific coast but they are not too significant. Fortunately, the rugged Pacific coast is generally not noticeably affected by the storm surges of several feet that are generated by extratropical storms. Tropical cyclones are a rarity on this coast, with the last damaging tropical storm that moved inland in 1939 (near Los Angeles) having only gale force winds.

EARTHQUAKE AND SEISMIC SEA WAVES

1. Earthquakes. Much of the seismic activity of the country is centered in this area, principally in the Coast Ranges of California. Earthquakes of destructive magnitude have occurred in California on an average of about once a year for the past 50 years. The state is interlaced with hundreds of faults, some of which extend offshore. The most dominant is the San Andreas Fault, a continuous belt extending some 650 miles (1000 km) through southern and central California. The fault zone continues northward beyond Point Arena, following an underwater course close to the coastline.

Some of the most outstanding historic earthquakes include one in 1812 in the Santa Barbara-Ventura-northern Los Angeles County region (maximum intensity X, Modified Mercalli Scale); one in 1838 along the San Andreas Fault near San Francisco (X); another in 1857 in the northwest corner of Los Angeles County (X-XI); one in 1872 in Owens Valley in the Sierras (X-XI); the great earthquake of 1906 which resulted in the destruction of a large part of San Francisco by fire (XI); a series of damaging earthquakes in Kern County in 1952 (XI); and the earthquake near San Fernando in 1971 (XI), which resulted in 65 deaths and over $500 million damage.

Most of the notable earthquakes have been centered near the coastline or on land and the major effects have been to the built-up areas of large population centers. However, on November 17, 1949, a minor disturbance centering on Terminal Island in San Pedro Bay sheared 200 oil wells near the 1,800-foot (550 meters) level, causing more than $9 million damage. In 1951, 1955 and 1961, earthquakes barely perceptible at the surface caused additional subsurface damage ($3.0, $3.0, and $4.5 million, respectively) to oil wells on Terminal Island and the adjacent mainland.

A dense cluster of epicenters occurs at Cape Mendocino and on the prominent Gorda escarpment to the west. An 1853 earthquake in Humboldt Bay caused the wharf to sink 4 feet. An earthquake with a magnitude of 6+ in 1909 caused extensive damage (intensity VIII) in Humboldt County, California. The total felt area was about 100,000 square miles (260,000 sq km); the shock was also felt onboard a ship 25 miles (40 km) southwest of Cape Mendocino. An earthquake in 1922 northwest of Cape Mendocino was measured at 7.6 on the Richter magnitude scale. The shock was so far from land that the greatest intensity onshore was IV at Eureka. A magnitude 7.3 shock in 1923 was also centered off Cape Mendocino, although closer to shore. Damage reached intensity VI-VIII at some coastal towns; the shock was also felt on a number of ships at sea.

Another zone of high seismic activity is associated with the Blanco fracture zone, off the Oregon coast. The earthquake of 1873, centered off the coast near the California - Oregon border, was one of the largest known shocks north of the Mendocino escarpment; but it may not have exceeded that of 1922, previously noted. In 1873 nearly every building in Crescent City, California was damaged. The shock was felt from Portland, Oregon, to San Francisco and onboard ships at sea.

The Puget Sound area has always been known to be moderately seismic, with a record of a few hard jolts at long intervals, but an increase in activity during recent years was climaxed by a strong shock on April 13, 1949. More than $25 million damage was sustained in cities bordering the Sound and several people were killed. Another strong earthquake, on April 29, 1965, caused several deaths in the area and an estimated property damage of $12.5 million.[139/] Figure 12 and table 4 (see Atlantic coast section) include the significant earthquakes which have occurred near the coasts of California, Washington and Oregon. The prominent earthquakes in California are shown in fig. 21 and table 7.

2. Seismic Sea Waves. Tsunamis generated by local earthquakes are rare on the California coast, but the 1812 earthquake was followed by a wave that entered Refugio Harbor, west of Santa Barbara; it is believed to have risen to 30 feet (9 meters) or more, and possibly to 50 feet (15 meters) at Gaviota, about 20 miles (32 km) west. A recent examination of evidence indicated that available reports on this tsunami did not provide adequate proof for such an occurrence. Although no tsunami was reported after the great San Francisco earthquake of 1906, water in the harbor was disturbed,

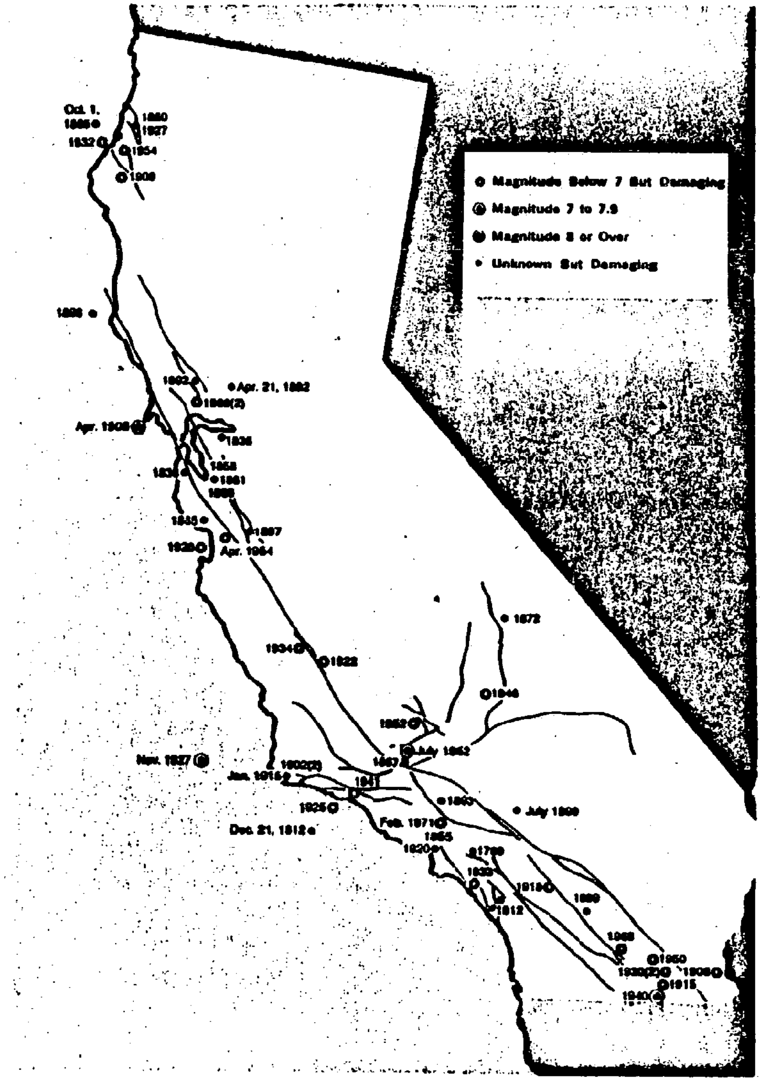


Figure 21.--Prominent California earthquakes.

Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1971: Earthquake History of California. Earthquake Information Bulletin, 3(2).

Table 7.--Prominent earthquakes in California, 1769 through December 1970 (Intensity VIII and above).

Date		Region	Modified Mercalli Intensity
1769	July 28	Los Angeles region	
1812	Dec. 8	Southern California	VIII-IX
	Dec. 21	Off coast of southern California	X
1836	June 10	San Francisco Bay	IX-X
1838	June	San Francisco region	X
1855	July 10 or 11	Los Angeles County	VIII
1857	Jan. 9*	Near Fort Tejon	X-XI
1858	Nov. 26	San Jose	VIII
1860	Nov. 12	Humboldt Bay	VIII
1861	July 3	Near Livermore	VIII
1865	Oct. 1	Fort Humboldt-Eureka area	VIII-IX
	Oct. 8	Santa Cruz Mountains	VIII-IX
1868	Oct. 21	Hayward	IX-X
1872	Mar. 26*	Near Lone Pine	X-XI
1892	Apr. 19	Vacaville	IX
	Apr. 21	Winters	IX
1893	Apr. 4	Northwest of Los Angeles	VIII-IX
1897	June 20	Near Hollister	VIII
1898	Apr. 14	Mendocino area	VIII-IX
1899	July 22	San Bernardino County	VIII
	Dec. 25	San Jacinto-Hemet area	IX
1902	July 27 and 31	Santa Barbara County	VIII
1906	Apr. 18**	San Francisco region	XI
	Apr. 18‡	Brawley, Imperial Valley	VIII
1909	Oct. 28‡	Humboldt County	VIII
1915	Jan. 11	Los Alamos	VIII
	June 22‡	El Centro-Calexico-Mexicali area	VIII
1918	Apr. 21‡	San Jacinto-Hemet area	IX
1920	June 21	Inglewood	VIII
1922	Mar. 10‡	Cholame Valley	IX
1925	June 29‡	Santa Barbara area	VIII-IX
1926	Oct. 22‡	Monterey Bay	VIII
1927	Aug. 20	Humboldt Bay	VIII
	Nov. 4†	West of Point Arguello	IX-X
1930	Feb. 26	Westmorland	VIII
	Mar. 1	Brawley	VIII
1932	June 6‡	Humboldt County	VIII
1933	Mar. 10‡	Near Long Beach	IX
1934	June 7‡	Parkfield	VIII
1940	May 18†	Imperial Valley	X
1941	June 30	Santa Barbara-Carpinteria area	VIII
1946	Mar. 15‡	North of Walker Pass	VIII
1950	July 29	Imperial Valley	VIII
1952	July 21†	Kern County	XI
	Aug. 22	Bakersfield	VIII
1954	Apr. 25	East of Watsonville	VIII
	Dec. 21‡	Eureka	VII
1968	Apr. 8‡	Northeast San Diego County	VII
1969	Oct. 1	Santa Rosa	VII-VIII

* Possibly Magnitude 8 ** Magnitude 8 or above. † Magnitude 7 to 7.9. ‡ Magnitude 6 to 6.9. § See Modified Mercalli Intensity Scale in the May-June 1970 Earthquake Information Bulletin.

Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1971: Earthquake History of California, Earthquake Information Bulletin, 3(2), Rockville, Md.

and vibrations from the shock were felt on offshore vessels.140/

On November 4, 1972, an earthquake of magnitude 7.3 caused a tsunami about 6 feet high at Surf. Heavy shocks from this event were felt on two vessels 27 and 14 miles, respectively, from Point Arguello.

Two tsunamis from distant sources have affected the California coast. On April 1, 1946, an Aleutian Islands earthquake, magnitude 7.4, set off a tsunami that caused great damage on Unimak Island and in Hawaii. The wave rose to 11 feet (3.4 meters) at Halfmoon Bay, California, and 12 feet (3.7 meters) at Santa Cruz, where one person was drowned.141/

The Prince William Sound, Alaska, earthquake of March 27, 1964, produced one of the largest shocks ever recorded on the North American Continent. It generated a major tsunami of record size which caused damage along the Washington and Oregon coast and reached disasterous proportions at Crescent City, Calif. (11 killed and about $9 million damage). Other areas of the California coast suffered damage in excess of $1 million.142/

The entire west coast of the U.S. is exposed to the possibility of major tsunamis generated around the borders of the Pacific Ocean. From the historical evidence and experience within the last 100 years, tsunami hazard should be a significant design consideration for all coastal structures. On the basis of recent history, there is no particular reason to distinguish between one area and another of the coasts of Washington, Oregon, and California. The probability of a tsunami occurring which will have noticeable effect on existing coastal structures certainly is within the range of 10 to 25 years. Over the last 30 years the April 1946, November 1952, March 1957, May 1960, and March 1964 earthquakes have induced major, Pacific-wide tsunamis.

Pacific coastlines have been exposed to these waves to varying degrees. The most notable example is the Crescent City, California, area. A broad area extending north and somewhat to the south of Crescent City had wave heights up to 20 feet (6 meters) above sea level caused by the Great Alaskan Earthquake of 1964. The tsunami-generation area in this case was elliptical in form, with the broad side of the ellipse directing the major wave energy toward the north coast of California and Oregon.

A Chilean earthquake in May 1960 produced a Pacific-wide tsunami in which a major portion of the energy was directed perpendicular to the coastline. Hawaii and Japan suffered the greatest damage, while the west coast of the U.S. was somewhat protected from the direct impact of the waves, even though the amplitude was over 1 meter in Southern California.

With the exception of Alaska, earthquakes around the Pacific Basin are generally more concentrated in areas distant from the United States (fig. 23). Thus, warning times are of the order of hours in most cases. It would be quite reasonable to assume that for remote tsunamis any particular area along the coast of the U.S. might be subjected to several feet of wave amplitude in the immediate offshore areas. In certain areas—due to local refractive effects or resonance effects or combinations of these—one could expect significantly higher wave heights. Similarly, in certain locations the currents due to tsunamis could reach speeds of several knots, even from modest amplitude waves.

Locally generated tsunamis, especially off that portion of Southern California from San Francisco southward, probably present the greatest hazard to the proposed atoll and barge power plants. Studies for shore-based nuclear power plants and the Bolsa Island proposal study produce design heights of up to 10 meters.

Tsunami warning times for earthquakes occurring along the U.S. Pacific Coast will vary from only a few minutes for sites close to the earthquake, to about 3-1/2 hours for sites at the opposite end of the coastline.

Each individual location has a local fault and seismicity pattern associated with it, thus, no general rule can be formed. However, an upper value can perhaps be reached or stated for which other factors than tsunamis are limiting. For example, a magnitude 7 earthquake with large vertical ground displacement at the site of a power plant would in itself be the major hazard.

LIVING RESOURCES

1. General. The waters and adjacent nearshore areas along the Pacific Coast are inhabited by an abundant and extremely diverse flora and fauna that reflect the dynamic physical and chemical factors which occur throughout this wide range of climatic zones. The combination of current movements bringing either warmer or colder waters into the region, areas of upwelling, and the coastal substrate regulate the abundance, diversity, and variety of plants and animals associated with the area. Point Conception, California, is generally acknowledged as the area of biological transition of warmwater to coldwater forms. Also, south of Point Conception, coastal lands and adjacent waters are influenced by metropolitan developments which affect not only the terrestrial flora and fauna but those of the marine environment as well.

Coastal currents are an overriding factor in the life of flora and fauna along the Pacific Coast. The California current system is southward moving and tends to bring colder waters into nearshore areas. During the winter, the Davidson current carries warmer water northward along the coast. Very frequently thse currents interact or have excursions which bring abnormally warm or cold waters to nearshore areas. For example, in some years the Davidson current allows more tropical forms of organisms to populate in northern reaches, with the accompanying decline in temperate water forms.

Many of the plant species associated with shallow water areas are temperature sensitive and during periods when temperatures are high, biomass is greatly reduced.[143] Grazing animals such as abalones and sea urchins are affected by reduction in herbaceous material and under certain conditions fail to reproduce.[144] Temperature is a key regulating factors of the marine flora and fauna along the California coast in that temperatures over 66°F are undesirable for many of the temperate water forms. Further north temperature sensitives of plant and animal populations have not been well defined, although there is no doubt that large variations in temperature would have an adverse effect upon indigenous flora and fauna of this region.[145]

2. Estuarine and Coastal Wetlands. The coastal zone area along the Oregon-Washington coast is characterized by forests extending to the edge of the sea. Numerous rivers flow into the sea, causing relatively small estuarine areas to become established. These northern estuarine areas provide important habitat for a wide variety of bird species and shellfish which have high sport and commercial value, and also provide an important spawning-rearing area for a wide variety of fishes, some of which, like the salmon, migrate up rivers from the sea to breed in fresh water.

In California coastal wetlands and estuarine areas comprise only about 422,000 acres, less thant one-half of one percent of the State land area. And only about 31,000 acres of this is found in southern California from Morro Bay south to the Mexican border. Of these, less than 13,000 acres are marsh lands and tide lands. The remaining 18,000 acres are open waters.[146]

Estuarine and coastal wetlands of the Pacific coast are essential resting places, feeding areas and wintering grounds for important segments of the migratory bird population of the Pacific flyway. Marsh lands, tide flats, and open protected waters are their major habitats, but sand spits, beaches, grass lands, shrub-covered dunes and bordering bluffs are also important to the total life of such ecosystems.

3. Birds. Water associated birds visiting or resident to the bays and wetlands of the estuarine areas include water fowl such as black brant, American wigeon, mallard, pintail, green-winged teal, lesser scaup, greater scaup, bufflehead, surf scooter, and mergansers. Shore birds include the western sandpiper, marble godwit, least sandpiper, sanderling, long-billed curlew, black-necked stilts, avisets, black-bellied plover, light-footed clapper rail; sea birds include gulls and terns; marsh birds include gray-blue herons, snowy and American egrets and the American bittern. Duck, sandpipers and sanderlings are present seasonally in tremendous numbers. Species such as herons, bitterns, and egrets, although common, are not considered abundant in the Pacific flyway.

Pelagic sea birds are an important part of the marine biota of the Pacific coast. More than 62 species of sea birds regularly occur in sub-Arctic Pacific and transitional domains. Although many are important in the overall marine food chain, little is known about the population level, standing stock or environmental interactions of important sea birds.[147]

4. Land Mammals. Coastal upland areas are populated by game and non-game animals including blacktailed deer, Roosevelt elk, quails and grouse. Certain areas of the coastal zone provide essential habitat for wildlife. For example, the coastal strand north of the Klamath River is the range of a small but important herd of Roosevelt elk.

5. Benthic Communities. The substrate of shallow nearshore areas along the Pacific coast north of Point Conception is composed primarily of rock, although there are fairly short expanses of sandy beach areas. The rocky areas provide a substrate to which kelp and other algae forms attach. In these areas, kelp forms a basic food substance for the animals which inhabit the area. Several of these, including abalone, are of special economic interest to man.

(a) Marine plants. The Southern California shoreline is dominated primarily by sandy beach areas with rocky areas occurring infrequently. Where they do occur, rocky reef areas provide holdfasts for kelp including the Giant Kelp (*Macrocystis pyriferia*). Growth of kelp in this area is reduced at temperatures greater than 66°F. Degeneration of plants occur at temperatures 68°F or greater.[148]

Kelp, a form of brown algae, has been harvested in coastal waters for more than 60 years. The largest beds are found in protected waters in depths of 20 meters or less. Growth is most rapid during the summer. Grazing animals such as sea urchins can make vast inroads into kelp and under favorable conditions they can entirely eliminate kelp from an area. Frey[149] points out that heated water discharges also pose a special threat to kelp, which requires temperatures below 66°F for growth. Kelp and other marine plants provide food and protection, and play an essential role in the reproduction of fish, birds, and marine mammals, especially sea otters, and their depletion may seriously affect the survival of animals associated with them.

The kelp harvest in California has ranged from 395,000 wet tons in 1918 to a low of 260 wet tons in 1931. The average harvest from 1960-1969 was 129,000 wet tons.

(b) Invertebrates. The biomass of benthic animals, as represented by the abundance of trawl-caught invertebrates, varies with ocean depth. Off the Columbia River,[150] researchers found that the weight of catch per unit of time in depths between 175 and 700 meters is three times that in lesser and greater depths. The composition of the biomass also changed with depth. Prominent animals in the trawl catches were sea urchins, crabs, and various mollusks.

Ocean shrimp are found mainly at depths between 50 and 400 meters. They tend to remain in well defined beds throughout the year with little mixing of adults between beds. Shrimp tend to be found on green mud bottoms. Adults swim upward during hours of darkness to feed on plankton. Shrimp breed in the autumn and the female carries the developing eggs through the winter until they hatch in the spring. The young spend about 2 months as planktonic animals before settling to the bottom to begin maturation. Most economically valuable shrimp mature first as males and after one or two seasons change into females for the remainder of their lives. Ocean shrimp are valuable commercially and have been the object of much research designed to perpetuate a high level of yield. Shrimp are also food for many fishes and invertebrates.

About 25 million pounds of shrimp were captured in 1972 in the coastal waters from Washington to central California. Oregon catches account for about 80% of the total. In 1969, the coastal shrimp catch amounted to about 15.4 million pounds, with a value of over $1.83 million.

Crabs of the genus Cancer, and in particular the Dungeness crab (C. magister) are an important component of the West Coast fishery. These crabs prefer sandy bottoms and their main abundance in adult form occurs within the 100-meter depth contour. Frey[151] notes that the geographical distribution of the Dungeness crab is delimited by the 38° and 65°F surface isotherms.

The reproductive cycle of this species takes nearly a full year, with fertilization of the females occurring in the spring, spawning in the fall, and hatching of larvae in the winter. Larvae spend as much as 5 months in planktonic form before taking up life as small adults on the bottom. Legal size for commercial fishing in reached in about 4 years. Food of the Dungeness crab includes fish, clams, and a variety of other small animals found in the bottom.

In the past, Dungeness crab populations have occurred as far south as central California. During recent years the crab fishery of San Francisco has drastically declined as a result of unknown factors. Populations of Dungeness crab from Eureka north are also exhibiting variability in numbers. These fluctuations appear to be independent of commercial fishing pressure, and suggest that environmental factors play an important role in maintaining and regulating the population levels.

The Dungeness crab catch on the west coast in 1969 was nearly 37 million pounds worth almost $9.5 million. The catch in 1972-73 declined to about half the 1969 total.

The spiny lobster is harvested mostly along the rocky coastal areas of southern California in depths to about 65 meters although most of the fishing occurs in depth of less than about 20 meters. As with other crustaceans, the reproductive cycle is lengthy, with mating occurring early in the year, followed by fertilization of the eggs in May and June. The female carries the eggs for nearly 10 weeks as the embryos develop; during the period they occupy warm, shallow, inshore waters with depths generally of less than 10 meters. Food of the adults is varied, and includes snails, sea urchins, sponges, hydroids, rock scallops, algae, mussels, annelid worms, crabs, barnacles, and fish.

In 1969 nearly 310,000 pounds of spiny lobster, worth $347,000 were taken in Southern California waters.

Mollusks are an important group of invertebrate animals along the Pacific coast and include clams and oysters, as well as abalone, snails, octopi, and squids. Mollusks are especially numerous and varied in habit and habitat. Many mollusks are important as sources of food and recreation while others serve as food for crabs, fur seals, and fishes utilized by man.

Clams and oysters are important throughout the Pacific coastal areas with most sport and commercial fishing activity occurring along the coast of Oregon and Washington. Most of the clams taken by man are found either in the intertidal zone or in shallow waters. Oysters are produced commercially in mariculture enterprises, providing an important industry in Washington and Oregon, whose managed beds occupy a large expanse of shallow water bays and estuarine areas.

The most important large group of invertebrates in California is the abalone. Various species of abalone occur but the black abalone and the red abalone are the principal species sought for both commercial and sport use. Abalone are captured as deep as 50 meters by commercial and sports divers,

Snails, octopi, and squid are presently little utilized on the American side of the Pacific Ocean, but are likely to become increasingly valuable as sources of protein. Recent clam and scallop surveys along the inner shelf off Oregon and Washington did not reveal any extensive concentrations of these forms.

Mollusks ordinarily have a well defined habitat and population changes are readily apparent. Mollusks are preyed upon by a host of mammals, fish, birds, and other invertebrates so that any condition that increases the number of predators may be expected to have a detrimental effect on the mollusks. The aggregate catch of all mollusks in the coastal states in 1969 was over 29 million pounds valued at over $4.7 million.

6. <u>Pelagic (living in the open sea) Communities</u>.

(a) Plankton. The phytoplankton (plant plankton) of the region as listed by Anderson[152] cannot be enumerated beyond the large groupings -- the diatoms and the flagellates. These are the primary members of the food chain of the sea and may be the first to be affected by environmental changes. Diatoms form the main component in the plankton plant community, with green and blue-green algaes occurring either locally or very infrequently. In Southern California waters periodic blooms of dinoflagellate occur which have in the past caused extensive mortalities in the fish fauna.

As with the phytoplankters, the smaller zooplankters are numerous and they are only one step removed from the primary producers of the food chain. Little is known concerning their life histories or how they might react to environmental alterations.

Among the larger zooplankton occurring in the region are jellyfishes, comb jellies, arrow-worms (an important group, being both predators on smaller plankters and prey for larger forms), segmented worms, and the large and important group of crustaceans (shrimp, crabs, etc.).

This latter group is one of the most important groups of animals in the sea (comprising some 70 percent of the marine zooplankton) and often forms the majority of plankton collections. It is comprised of diverse forms, some of which feed directly upon diatoms and flagellates and other which feed upon small zooplankters. Almost all form part of the diet of fishes, both forage fishes which in turn are eaten by larger, commercially important fish, or in some instances the commercially valuable fish which feed directly upon the crustaceans.

Within this group (crustaceans) the following rank high in the food chain: copepods, isopods, amphipods, euphausiids (krill), decapods, and stomatopods. The copepods are an extremely large group, some being small enough to be included in the microplankton, while others are classed as macroplankton. The species are much too numerous to be listed, but species listed and life history accounts are available.

The amphipods are not as important as the copepods in the economy of the sea, but do form part of the diet of many fishes, including yellowfin tuna.

Euphausiids (or krill) are perhaps next to the copepods[153] in importance among marine crustaceans. Their occurrence has been studied by Ponomareva and Vinogradov. They are found in the stomachs of many fish, including yellowfin tuna, hake, and ocean perch, and they rank high in the catches of micronekton (small free swimming marine organisms). Additionally they are fed upon by many whales.

Longhurst[154] reports decapod crustaceans, such as the pelagic red crab, rank high as food organisms utilized by larger fish, including tuna, and are an important link in the food chain.

The mollusks (squid, snails, etc.) also form an important segment of the marine food chain.[155] Squids and octopuses have been found in tuna stomachs,[156] and because of their larger size rank higher in volume than do the numerous but smaller crustaceans.

Another group of mollusks found in the oceanic areas is the marine pelagic snails, which are also found in tuna stomachs.

The tunicate (or salpa) are chordates which often form a large part of plankton catches. These too have been found in fish stomachs, particularly in yellowfin tuna.

(b) Fishes. The extensive coastal and oceanic area extending from Washington to the California-Mexico border (extending to 400 miles offshore) contains about 160 families of fishes with over 500 species.[157] Deepwater fishes account for nearly 48% of the number of species, but nearly 80% of these species also are found in waters shallower than 400 feet.[158]

Many of these fishes are quite small and have no present commercial value, but still are exceedingly important in the food web. For example, one gonostomatid bristlemouth seldom exceeds three inches in length at maturity, yet it may well be the most numerous fish in the ocean.[159]

Even though many of these fishes as adults are demersal or deepwater inhabitants, most have planktonic eggs and/or larvae which, during development, are found primarily in the upper 200 meters of the ocean. Hence, these early stages are very susceptible to deleterious changes in the environment.[160]

The fish fauna differ in the various regions, with tropical forms occurring off Southern California. For convenience, the California fish fauna will be considered first, followed by that of Oregon and Washington.

Based on extensive plankton surveys in the California Current Region, larvae of the northern anchovy ranked first in relative abundance, followed by hake and rockfish. Other species ranking among the top 12 in abundance were sand dabs, gonostomatid light fish, jack mackeral, bathylagid smelts (2 species), lanternfishes (3 species) and sardines. These 12 kinds of larvae accounted for between 90 and 93% of the larvae collected. The anchovy and hake larvae together accounted for 46-65% of the total larvae captured each year.[161]

The fishery resources of Oregon have been less intensively studied than those of California. Based on Plankton surveys in Oregon waters from May to October 1969, 98% of all larvae in combined samples were in four families. Anchovy accounted for 68% of the catch, lanternfishes 25%, rockfishes 4.2%, and smelts 0.4%. Other fishes included in the 10 most abundant larvae were pleuronectid flatfishes, lumpsuckers, deep-sea smelts, bothid flatfishes, viperfish, and ribbon barracudina.[162]

Similar plankton surveys off coastal Washington in April and May 1967, indicated that rockfish larvae were the dominant form, accounting for nearly 40% of the total catch, followed by lanternfishes (32%) and flatfishes (14%). Sandlances, deep-sea smelt, osmerid smelt, cods, sculpins, blennies, and greenlings made up the bulk of the remaining catches.[163]

This coastal region supports a very large commercial fishery which also varies in substance and magnitude. In 1971, 10,181 licensed commercial fishermen landed nearly 641 million pounds of finfish in California, valued at over $110 million. Based on poundage landed, yellowfin tuna was the dominant species (168 million pounds), followed by skipjack tuna (155 million pounds), anchovy (98 million pounds), albacore tuna (68 million pounds), and jack mackeral (60 million pounds). (Commercial salmon landings are of less economic importance, although a substantial ocean sport fishery for these fishes does exist.) Tuna, collectively, were the most valuable, with a worth of some $95 million. The total landings of finfishes in 1971 was about 15% less than in 1970, but the value of the catch was greater in 1971 by about 3%.[164]

It should be noted that the principal constituents of the California landings occur as tropical forms that spend portions of their life history in waters adjacent to California but are not resident on a year around basis.

The commercial landings of all finfish and shellfish in Oregon in 1972 amounted to 93 million pounds valued at $24 million. This represented an increase in catch over 1971 of nearly 18% and an increase in value of nearly 33%. Dominant species in the catch were albacore tuna, sole and flounders, salmon, and rockfishes.[165]

The 1969 commercial fish catch in Washington amounted to 117 million pounds valued at nearly $21 million. Nearly 30 million pounds of rockfishes were landed with a value of $1.7 million, followed by salmon (32 million pounds valued at over $12 million), halibut (10 million pounds worth over $3.3 million), flatfish (9.8 million pounds worth $740 thousand) and hake (8.5 million pounds valued at $68 thousand).

The present catch and species composition of the commercial fisheries of the Pacific coast does not necessarily reflect the dominant forms available nor their future potential. In the California area those species considered underutilized and hence potentially available for increased harvest include anchovy, hake, saury, rockfishes, sablefish, jack mackeral, and bonito.[167]

In waters off Oregon and Washington, underutilized species include Pacific ocean perch, hake, spiny dogfish, arrowtooth flounder, and Dover sole.[168]

It should be noted that certain of these abundant, but underutilized, species are presently being heavily fishes by foreign fishing fleets.

The coastal region also supports an extensive and economically valuable marine sport fishery. An estimated 2.2 million anglers fished in salt water from the southern California border to the northern Washington border in 1970. Estimated expenditures by these anglers amounted to $183 million.[169] The species dominating the marine sport catch varies as to area and season, but generally rockfish, sea bass, albacore tuna, salmon, and flatfishes form the bulk of the catch.[170]

Many fish species, especially those indigenous to areas adjacent to highly urbanized or metropolitan areas, have shown a trend of being reduced in numbers or disappearing entirely. This downward trend appears to be caused by overfishing, habitat destruction, and perhaps poor water quality. In southern California sport fishing is

10 times as important economically as the present commercial fishing industry. It appears that the condition of sport fishery is steadily worsening, with a severe reduction of fish that occur on a year around basis in the area.

Sport fishing is also important off major ports and river systems such as San Francisco Bay, Eureka, Coos Bay, Newport (Oregon), the Columbia River, Willipa Bay, and in the Puget Sound.

Along the Pacific coast the transition area between tropical and cold temperature regions is characterized by a relative fish population which includes a number of eurythermal, temperate, and tropical forms. Eury thermal forms are fishes which can adapt to a wide range of temperatures. Few species are limited to this geographic area in their distribution, though most southern California fish have their center of abundance here. The southern limit of fish fauna is apparently sharper than that to the north, as many San Diegan species occasionally range into central or northern California, while few northern species are taken in the tropics. The significance of water temperature as a limiting factor on these distributions has been documented by Secretary of the Interior and Radovitch.[171]

7. Marine Mammals. Pinnipeds occurring off the coast include the California sea lion, Northern sea lion, Northern fur seal, harbor seal, Northern elephant seal. Among larger cetaceans, gray, minke, sei, fin, blue, humpback, killer, and sperm whales are commonly or occasionally seen; smaller cetaceans observed include Risso's dolphin, Dall porpoise, Pacific whitesided dolphin, and harbor porpoise. Sea otters are also found along the coast.

(a) Pinnipeds. California sea lions are mostly adult and sub-adult males, moving northward after the breeding season in California; from 1968 to 1970, 2,500 animals were estimated in Oregon, and another 1,000 estimated traveling farther north to Washington and British Columbia (of a total U.S. population of 40,000). Estimates of northern sea lions off Oregon in 1970, and Washington from 1949 to 1959, were 1,078 and 500 respectively, from a total world population of 240,000 to 300,000. Female fur seals and young of both sexes are common off the Pacific coast during winter and spring, migrating north for the summer. Harbor seals have no established migratory pattern and appear to be sedentary; the populations in Oregon and Washington are estimated at 500 and 2,100, respectively. Non-breeding northern elephant seals are occasionally seen offshore, though their rookeries are off California and Baja, California.

(b) Cetaceans. Of the large cetaceans seen along the coast, gray and killer whales are seen most often. Rice and Wolman[172] report that gray whales numbering about

11,000 can be seen in the fall and spring on their migration route along the shore from the colder seas to lagoons in Baja, California; a small number seem to be residential. Killer whales in groups of two to twenty or more may be seen along the coast and in waters of Puget Sound, sometimes taking advantage of fish runs for feeding. Minke whales, the smallest of the "large" whales, not exceeding about 35 feet, are seen occasionally off the coast and even in Puget Sound. Sei and fin whales may appear off the coast from spring to fall, usually singly or in small groups of from two to five animals. Blue whales, the largest animal ever known, reaching 100 feet and 136 tons, can occasionally be seen off the coast during the summer, moving farther south in winter. Pike[173/] notes that small groups of humpback whales may also be seen migrating south in winter. Sperm whales, estimated at 700,000 in the North Pacific, are seen offshore from spring through early fall. Other whales, such as beaked whales occur occasionally, but are rarely seen or recognized by Oregon and Washington residents.

Fiscus[174/] reports that Risso's dolphin, once thought rare, is probably an offshore species; a group of approximately 200 was sighted off Washington in the spring of 1972. The Pacific whitesided dolphin is seen year round off Washington in large schools of up to thousands and may be the most abundant dolphin off the coast. Dall porpoises are also commonly seen off the coast and in the Strait of Juan de Fuca, though in small groups; they are fast-swimming animals with a highly conspicuous color pattern. The harbor porpoise is an inshore species frequenting coastal and inland waters; it is abundant in Washington waters.

(c) Wilde and Ames[175/] estimate the sea otter population at 1600 to 1800 off the California coast as of mid-1973, while Garrison[176/] estimates the population of this species at less than 75 off the Washington and Oregon coasts.

8. Threatened Species. No species of fish or amphibians are considered threatened in estuarine and marine habitats along the Pacific coast. Bird species which are considered threatened include the California brown pelican, which ranges from Washington to South America and breeds locally on islands off the southern California coast, Aleutian Canada goose, California condor, American peregrin falcon, California clapper rail, light-footed clapper rail, California black rail, and California least tern. Some experts believe that the short-tailed albatross, which ranges throughout the temperate and sub-Arctic Pacific, should be considered rare and endangered. Threatened mammals listed in the U.S. Department of Interior's "Threatened Wildlife of the United States," 1973 include the Morro Bay kangaroo rat, salt marsh harvest mouse,

sperm whale, gray whale, blue whale, finback whale, sei whale, humpback whale, right whale, Guadalupe fur sea and southern sea otter, a population of the sea otter occurring off the California coast. This population was decimated as a result of fur harvests in the 18th and 19th centuries, but now appears to be making a substantial comeback.[177/]

THE GREAT LAKES

GEOLOGY AND TOPOGRAPHY

1. General. Representing the largest store of fresh water in the world, the Great Lakes were sculpted out during the last glacial period and now covers 95,000 sq mi along the Canadian - U.S. border. The shoreline of the lakes, including both mainland and islands, totals about 9,600 mi. Table 8 gives the dimensions of the five lakes, which vary widely in size, morphology (fig. 22), and water quality.

The upper three lakes, Superior, Michigan, and Huron, are characterized by complicated bottom topography trending north-south while the two lower lakes exhibit smooth basins running from east to west. Table 9 summarizes Great Lakes sediment samplings.

In general, Great Lakes beaches show a variety of composition comparable to that found on either of the oceanic coasts. The sand grains average .25 mm in diameter and are similar to those found on beaches in southeast United States. In many places, the Great Lakes beaches are backed by clay and glacial till bluffs left by earlier stages of lake development. These bluffs, particularly the ones composed of glacial outwash, are subject to considerable erosion at high water, as are the smaller gravel beaches of the lake.

2. Lakes Topography and Structure.

(a) Lake Superior. Lake Superior, the deepest of the Great Lakes, is separated into two basins by a north-south ridge extending from the Keweenaw Peninsula at a depth of about 510 feet. The western basin has a maximum depth of 925 feet. Although irregular in shape it exhibits a generally smooth topography, interrputed by a trough which plunges 840 feet off the western shore and by a series of islands and shoals to the north. The eastern basin is dominated by north-south valleys and ridges, with depths averaging 480 feet on the ridges and 1200 feet in the valleys. Slopes average 4 1/2°. The Lake's maximum depth, 1333 feet, is reached in one of these valleys.

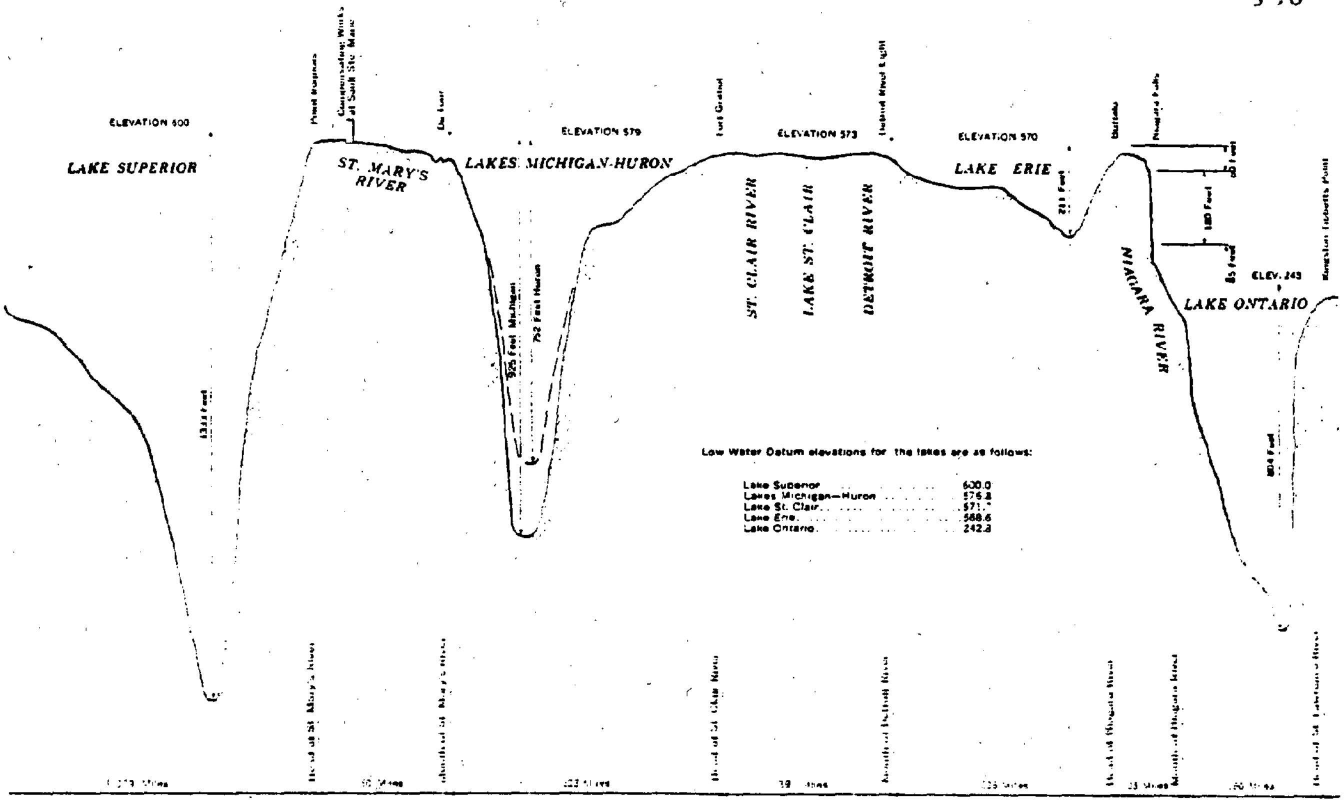


Figure 22.—Topography of the Great Lakes.

Source: Department of the Army, Lake Survey District, Corps of Engineers 630 Federal Bldg. and U.S. Courthouse, Detroit, Mich.

Table 8.—Dimensions of the Great Lakes.

Lake	Length (mi)	Breadth (mi)	Area: Water surface (mi^2)	Area: Drainage basin (mi^2)	Average surface elevation above mean sea level since 1860 (ft)	Mean discharge (cfs)	Maximum depth (ft)	Mean depth (ft)
Superior	350	160	31,820	80,000	602.20	73,300	1,333	487
Michigan	307	118	22,400	67,860	580.54	55,000	923	276
Huron	206	183	23,010	72,620	580.54	177,900	750	195
St. Clair	26	24	490	7,430	574.88	178,000	21	10
Erie	241	57	9,930	32,490	572.34	195,800	210	58
Ontario	193	53	7,520	34,800	246.03	233,900	802	283

Source: Great Lakes Basin Commission, 1972: Limnology of Lakes and Embayments, Great Lakes Basin Framework Study, Appendix No. 4, December.

Table 9.--Great Lakes sediment samplings.

LAKE	SHALLOW WATER	DEEP WATER
Superior	Thin veneer of sand - approx. 10 cm	Silt-clay 2-150 cm, over deep valleys thin cover of sandy silt over 350 cm of clay
Michigan	Unconsolidated sand	No deep water
Huron	Silty sand	Yellow to red layers of clay 280 cm thick
Erie	58% mud, semifluid silt & clay, 14% sand, 3% limestone & dolomite bedrock, 12% mud and sand mixtures, 7% sand and gravel, 3% locustrine clay. Sediment has been recorded with depths of 34 meters.	No deep water
Ontario	75% glacial fill, 10% bedrock, 15% sand and gravel	Organic & glacial clays with a maximum thickness of 6 1/2 meters

Source: Derived from Hough, J.L., 1958: *Geology of the Great Lakes*, University of Illinois Press.

The western shores are steep, rocky bluffs which become gentle low-lying clay and gravel banks at Duluth. East of Duluth along the Minnesota and Michigan coasts, the shoreline may be characterized as wave-cut terraces[178/] with gravel-sized sediments in the west gradually grading to sand in the east.[179/]

(b) Lake Michigan. Lake Michigan is divided into three distinct basins. The southern basin, which reaches a maximum depth of 540 feet, is broad and regular in shape. This basin, delineated on the north by an escarpment running from Frankfort, Michigan to Fort Washington, Wisconsin, is built on an eroded shale bed which provides the even, fine-grained sediment found on this section of the lake floor.[180/] The mid-basin is bordered on the north by a ridge that runs northeast from Sheboygan, Wisconsin. Here the lake floor has an irregular limestone base. Although many of the bottom depressions are filled with cohesive clays, deepwater currents have left the limestone exposed in many areas.

The western side of the northern basin slopes gently towards the center attaining the lake-wide maximum depth of 925 feet. Bottom topography in the east becomes much more rugged as north-south oriented ridges and troughs vary bottom depths from as little as 36 to as much as 510 feet. The sediment in the north is fine to medium grained sand with reddish-brown clay and gray-green mud in the deeper troughs. The shoreline ranges from precipitous cliffs on the north and west to broad sandy beaches with large dunes in the east.[181/]

(c) Lake Huron. This lake is also comprised of three sub-basins. The deep eastern basin, Georgian Bay, is separated from the main lake by the Niagara Escarpment. The basin bottom slopes smoothly from the east and relatively sharply from the west to a maximum depth of 507 feet near the straits north of Bruce Peninsula. Lake Huron proper is divided into two sandstone-floor basins by a limestone ridge that extends northwest from Kincardine, Ontario. The northern basin is distinguished by a trough running south from Georgian Bay in which the lake's greatest depth (750 ft) is found. The southern basin is much more regular with a depth of about 390 ft. The floor is relatively smooth because deep layers of sediment fill depressions among the scattered bedrock outcroppings.[182] Turbidity currents have resulted in finer sediments being found further east in the lake. As a rule, cores tend to change from yellow to red clay as they reach a sediment thickness of 7 feet.[183] The Huron shoreline is varied, ranging from marshes above Saginaw Bay to sheer cliffs and rocky beaches in the north. The U.S. beaches may be characterized on the whole as more gravelly and somewhat narrower than those at the other lakes (40-60 ft average).[184]

(d) Lake Erie. This is the shallowest and smoothest of the Great Lakes. Depths are less than 120 ft, except in the eastern basin where they reach a maximum of 570 ft. The western basin is a shallow platform with a depth of approximately 42 ft and is covered by fine-grained and organic sediments. As the floor becomes deeper in the east the sedimentary cover changes from mud to a silty clay at Niagara. The Erie shoreline starts as marshland in the west, then develops into 30-foot high glacial till bluffs, with fine narrow beaches.[185] These, in turn, evolve into much higher silty clay bluffs fronted by 150-200 foot beaches in Pennsylvania, and then back to a glacial till bluff pattern in New York State.

(e) Lake Ontario. The lake consists of one large basin divided by a sill that extends north from Rochester, New York. The lake floor drops sharply to a maximum depth of 798 ft off the New York shore, but slopes gently down from Canada. The shore around Ontario consists of cliffs broken by various embayments leading to drowned valleys. The beaches are poorly developed and are significant only within silty embayments.

The Ontario bottom sediment follows the pattern of glacial till found on the beach out to a depth of 66 ft. From there, nearshore sediments become fine out to a depth of 150 ft, where very fine clays begin.

3. Sediment Movement. There have been numerous studies in the lakes to develop techniques to distinguish depositional environments, local sources, and direction of

sediment transport. For example, the impressive beaches, dunes, and nearshore bar complexes along the eastern and southeastern Lake Michigan coastline have been studied for years. Cressey[186/] delineates beach variations, erosion problems and direction of sediment transport along some Michigan beaches and describes nature of wind activity, dune forms, etc. Other studies show changes in direction of littoral drift and the relationship of sand-bottom geometrics with time, and the effects of hydrologic and meteorologic variables to some of these changes.

Such studies show a cyclic pattern of these variables occurring as a result of changes in barometric pressure.[187/] Low energy conditions developed during times of high pressure allows construction of shallow, discontinuous sand bars with sinuous, cusped shorelines behind, and development of small embayments adjacent to occasional rip channels cutting the bars. Slight shoreward migration of bars also occurs. More rapid longshore currents are produced by higher waves during times of falling barometric pressure. Subsequent deflection of those higher velocity currents by the sinuous shoreline produces rip currents which erode channels in the bars. Sites of sand accumulation are shifted to new areas between these rip channels. With a return to low energy conditions, there is reconstruction of the original discontinuous bar system which has been displayed along the shore from its original position.

4. Engineering Properties. Foundation conditions on the floor of the Great Lakes are greatly varied and uncertain. Sediments are generally soft and fine grained silts and clays of glacial origin. Sands occur nearshore generally. In places where bedrock is exposed or sand occurs, conditions would be good. Siting would require prior detailed measurements. Existing measurements are rare.

LIMNOLOGY

1. Circulation. The general circulation of the Great Lakes is controlled by (a) the wind, (b) the flowthrough of drainage from watersheds, (c) the rotation of the earth (Coriolis force), and (d) local topographic and/or hydrodynamic influences. Of these factors, the rotation of the earth is constant, while flowthrough of drainage and local influences are relatively slow to change. These latter three factors comprise a relatively "steady state" condition of current-determining tendency, upon which the winds superimpose quite rapid short-period variations in current pattern.[188/] The general surface circulation is shown in fig. 23, which is taken from the classic drift-bottle study of Harrington[189/] for the warm months. This study is still one of the most complete and comprehensive works on surface currents in the Great Lakes.

2. Water Mass Characteristics.

(a) Ice. Ice generally hinders navigation on the lakes from mid-December

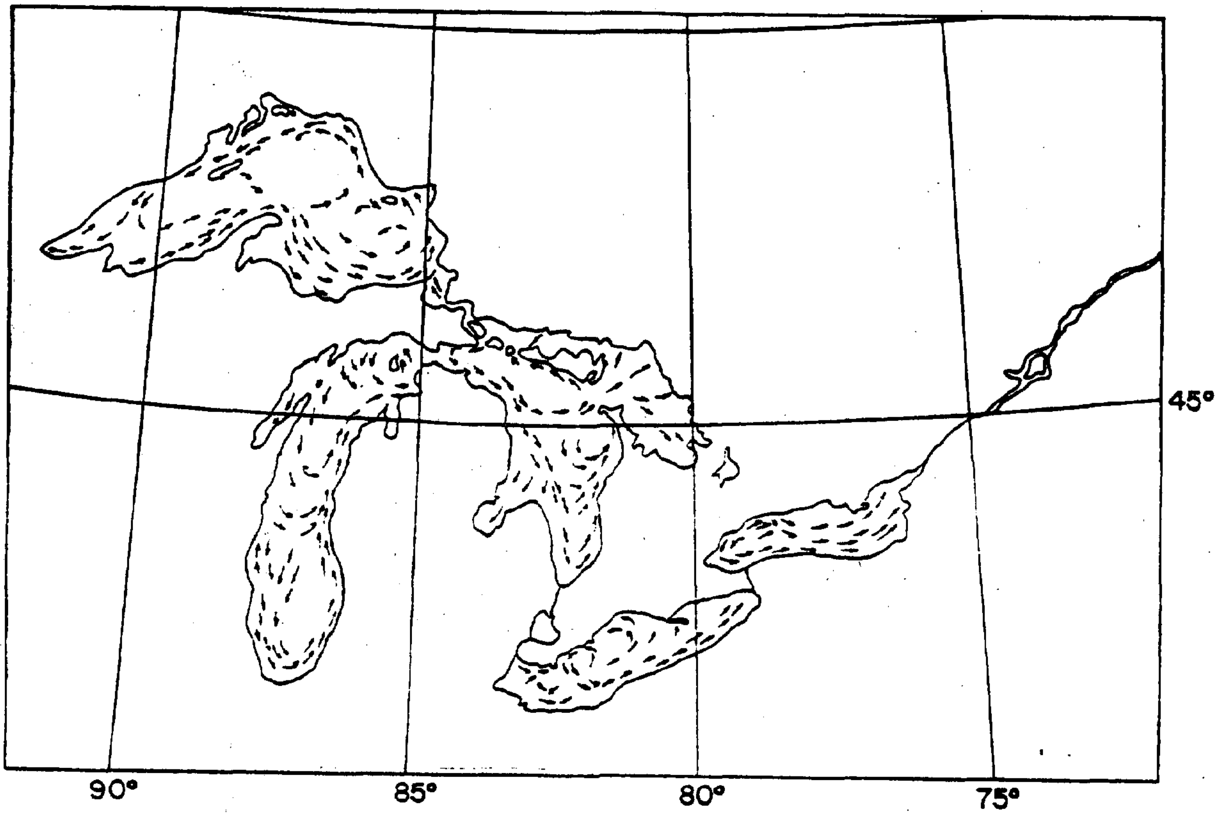


Figure 23.—General surface circulation of the Great Lakes.

Source: Harrington, M.W., 1895, Currents of the Great Lakes. U.S. Department of Agriculture, Weather Bureau, Bulletin B.

to mid-April. Full ice coverage is rare; due to combined effects of wind and waves partial coverage often takes the form of windrows along one shore. During long cold periods, ice up to 3 ft thick may form in shallow, protected bays and harbors. Wind and currents break up the ice and carry it to bottlenecks where it builds up. Pressure ridges may form and extend 10 to 20 ft above the surface, and 30 to 35 ft below.

(i) Lake Superior. Ice in Lake Superior is more subject to the influence of wind, waves, and currents than in any of the other lakes. Even when air temperatures are at or below freezing, ice is melted by the upwelling of warm water. Ice forms initially in the north and west and covers 60% of the surface in a normal winter. The ice resembles and acts as an arctic ice pack.

(ii) Lake Michigan. The lake has a 40% ice cover during a normal winter. The northwest bays are the first to freeze, followed by the Straits of Mackinac and the island region. In the south, drifting ice flows, collected along the shore due to the circular current pattern, may consolidate from the shore outwards to a distance of 10 to 15 miles. Because of the north-south orientation of the lake, freezing and thawing often occur simultaneously.

(iii) Lake Huron. Ice cover in a normal winter is approximately 60%. The first areas to freeze are the east shore of Georgian Bay, the North Channel, St. Mary's River, Straits of Mackinac, Thunder Bay, and Saginaw Bay. The deep north central basin is rarely covered. Because of the lake's north-south orientation, ice forms and deteriorates simultaneously.

(iv) Lake Erie. The most shallow of the Great Lakes, the relatively small Lake Erie has the least thermal stability and in a normal winter has a 95% ice cover. The shallow west basin is the first to freeze over, followed by the inner bay at Long Point in the east. The ice clears rapidly, except at Buffalo where prevailing winds and currents concentrate drifting ice.

(v) Lake Ontario. Although many harbors are closed by ice from mid-December to mid-April, the lake itself has only a 15% ice cover in a normal winter. Most ice forms near land, with the first appearing in Bay Quinte and the approaches to the St. Lawrence River. Ice is concentrated at the northeast end by winds and currents.

(b) Surface Temperature.

(i) Lake Superior. The annual variation of mean water surface temperature in Lake Superior between Thunder Cape and Gros Cap (Ft. William and Sault Ste. Marie), ranges from about 2°C (36°F) in the open water and 0°C (32°F) along the shores during winter to over 10°C (50°F) in the open water and up to 15°C (59°F) along the shores during summer. In the open water, the winter minimum temperature is reached in mid-March and the summer maximum in early September. Along the shores these extremes are reached approximately a month earlier. This northernmost and deepest of the Great Lakes is very cold, with offshore temperatures exceeding 10°C (50°F) only 2 months of the year.

(ii) Lake Michigan. Mean water temperature in Lake Michigan between Milwaukee and White Shoal (north of Beaver Island), varies from the winter low of about 2°C (36°F) to the summer high of about 21°C (70°F) around Milwaukee, and 18°C (64°F) elsewhere. The winter minimum is generally reached during early March and the summer maximum during mid-August. Water temperature exceeds 10°C (50°F) from 4 to 5 months of the year, for mid-lake and coastal waters.

(iii) Lake Huron. The mean water surface temperature variation in Lake Huron, between Detour Passage and Huron Lightship (mouth of St. Marys River and Port Huron), ranges from about 2°C (36°F) during winter to about 18°C (64°F) during summer in most of the lake, except near Port Huron, where it reaches 21°C (70°F). The winter minimum is reached during mid-February along the shores and in mid-March in the open lake. The summer maximum is reached during mid-August. Water temperature exceeds 10°C (50°F) during 5 months in the south and about 4 months in mid-lake and the north.

(iv) Lake Erie. The mean water temperature in Lake Erie, between Detroit River Buoy and Port Colborne varies from a winter low of about 2°C (36°F) to a summer high of about 21°C (70°F). The winter minimum occurs progressively later from mid-February in the west to early March in the east, reflecting the general deepening of water to the east. The summer maximum occurs during the first half of August. In this southernmost and shallowest of the Great Lakes, water temperature exceeds 10°C (50°F) approximately 6 months of the year.

(v) Lake Ontario. In Lake Ontario, between Cobourg and Charlotte, the mean annual surface temperature varies from about 2°C (36°F) during winter to about 21°C (70°F) in the south and 18°C (64°F) in the north during summer. The winter minimum is reached during mid-February along the shores and during mid-March in the deep open lake. The summer maximum is reached during early August in the south and mid-August elsewhere. Water temperature exceeds 10°C (50°F) for approximately 5 months of the year, except in the south where it includes a slightly longer period.

(c) Vertical Temperature Structure. Deep lakes in temperate climates undergo a cyclic annual variation in thermal structure, as shown in fig. 24. As the warming season progresses, the upper layers absorb heat from the atmosphere, becoming warmer, with the thermocline deepening through conduction and wind-induced mixing. The thermocline separates the warm upper water (epilimnion) from the cold deeper water (hypolimnion). The epilimnion, being less dense, literally floats on the top of the hypolimnion. In the early stages, the thermocline is rather weak and is easily broken down by wind action. This mixes the warm surface layer with the colder water below, producing further development and deepening of the thermocline. As the thermocline approaches its maximum normal depth, the mixing activity diminishes. With stabilization of a strong thermocline at constant depth, heat conduction is negligible. The maximum depth of the thermocline during this period of peak heat content is about 15 meters in all the Great Lakes.

In the fall, substantial heat loss results from convection of heat to the atmosphere by evaporation and, to a lesser extent, by conduction. The cooled surface water becomes denser than the underlying water of the epilimnion and sinks toward the thermocline. Vertical mixing and cooling of the epilimnion by these convection currents continues until epilimnion density essentially matches that of the hypolimnion. A homogeneous state is achieved at a temperature a little warmer than the 4°C temperature of maximum water density. Further cooling at the surface sets in motion vertical convective currents involving the entire water mass of the lake. The cooling process continues until a homogeneous lake of maximum water density is attained. With the loss of the thermocline, the entire water column becomes isothermal. Wind-induced stirring is enhanced during isothermal conditions.

Continued cooling of the surface in winter results in the possible development of a reversed temperature gradient and the formation of ice. As the surface water cools below 4°C, its density decreases and it floats as a surface layer, as does warm water in summer, although the density difference between surface and deepwater is much less than in summer.

The spring overturn completes the cycle. As the surface water is warmed toward the temperature of maximum density, vertical convective currents are initiated and the entire water mass is again mixed to an isothermal state. Wind-stirring and the warming of the surface water increase the temperature of the entire water mass.[190]

(d) Water Quality. The five Great Lakes can be ranked in order of their level of chemical quality (see table 10). Lake Superior, because it has a small population in its drainage basin and a large volume, is the purest. Lake Huron is next in order of decreasing water quality. It has a low population density in the Canadian portion of the basin, a large volume, and receives inflow from Lake Superior, so quality is maintained in spite of inflows from Lake Michigan and Saginaw Bay. Lake Michigan is third in order of decreasing quality. The southern basin of Lake Michigan shows signs of eutrophication, due to nutrient input from the rural and urban complexes adjacent to the basin. The northern half of the lake receives much higher-quality tributary

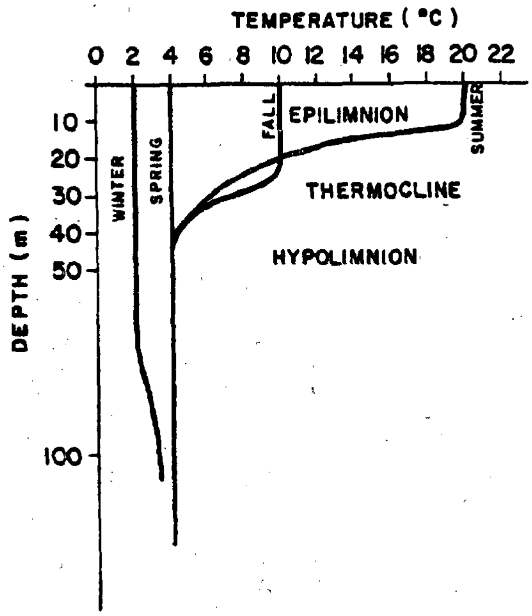


Figure 24.—Seasonal changes in the vertical temperature structure of a deep lake.

Source: Great Lakes Basin Commission, 1972: Limnology of Lakes and Embayments. Great Lakes Basic Framework Study, Appendix No. 4, December.

Table 10.—Estimated chemical loads of the Great Lakes, exclusive of loading from upstream Great Lakes.

	Dissolved Solids*	Cl^-	PO_4^{-3}	NO_3^{-1}	Ca^{+2}	SoP_{2aq}
Lake Superior	450	11	0.44	4.5	74	29
Lake Michigan	980	82	1.10	2.9	170	22
Lake Huron	580	170	1.00	26.0	insufficient data	
Lake Erie (include Lake St. Clair)	1700	400	6.70	12.0	230	11
Lake Ontario	1100	290	0.26	4.5	210	7.6

*Units 10^7 kg/yr

Source: Derived from Great Lakes Basin Commission, 1972: Limnology of Lakes and Embayments, Great Lakes Basin Framework Study, Appendix No. 4, December.

water than the southern basin, and is somewhat isolated from the southern basin by the circulation pattern in the lake. Low outflow prevents Lake Michigan from causing more deterioration in Lake Huron water quality. Lake Ontario receives poor quality water from Lake Erie, in addition to inputs from within its own basin. Owing to its larger volume, however, Lake Ontario water is of somewhat higher quality than Lake Erie water. Due to the dense population and high degree of industrialization in its drainage basin, and to the low volume of water, Lake Erie has the highest level of chemical loading and the lowest quality of all the lakes.191/

(i) Oxygen. Dissolved oxygen is required for the metabolic activity of most aquatic organisms. The solubility of oxygen in water is low and is dependent upon pressure and temperature. Oxygen is more soluble in cold water than warm, so hypolimnetic water normally serves as an oxygen reservoir. Replenishment of oxygen to the hypolimnion is dependent on exchange with the atmosphere and on photosynthetic activity. The hypolimnion, therefore, is oxygenated primarily during fall and spring periods of overturn and/or isothermal water. In the summer the hypolimnion furnishes oxygen to the biota and, because mixing and exchange with the atmosphere are retarded by thermal stratification, the hypolimnion is slightly deoxygenated.

Bacteria and oxidizable organic constituents are more efficient at removing oxygen from water than most macroorganisms, so the introduction of sewage or other easily oxidized material short circuits the oxygen cycle, encourages development of oxidizing bacterial populations, increases dissolved oxygen demand, accelerates oxygen depletion, and may lead to destruction of the normal biota. Tolerances to low oxygen levels vary, but most Great Lakes fauna cannot tolerate extremely low levels. In most organisms juvenile forms are less tolerant than adults to low oxygen levels, so repopulation may be prevented even though a breeding stock is present in an area of oxygen depletion.

Oxygen supplies in Great Lakes water have been thoroughly studied and regions of oxygen depletion identified. The only major region in the Great Lakes where oxygen depletion is known to be critical is in Lake Erie.

Low oxygen levels have been present from time to time in Lake Erie's central basin since the late 1920's. These low levels occur during periods of summer stagnation, when high levels of Biological Oxygen Demand (BOD) in the central basin of the lake exceed oxygen supply.

Oxygen depletion in the western basin is less common because it is shallow and wave agitated, so the oxygen supply is generally abundant. When oxygen depletion does occur in the western basin, it is due to unusual meteorological conditions which result in minimal wave action. The deeper central basin is a trap for high BOD material swept in from the western basin and from the municipalities that adjoin the basin itself.

Recent studies indicate that the oxygen demand in Lake Erie exceeds the BOD of material known to enter from cultural sources. The annual organic waste load into Lake Erie has a BOD equivalent to 82 million kilograms (180 million pounds) of oxygen and one recent period of oxygen depletion had an estimated deficit of 122 million kilograms (270 million pounds) of oxygen. BOD directly from cultural inputs, therefore, cannot account for the total oxygen depletion. The answer lies in the increased production of algae in response to nutrient discharge into Lake Erie. The algae bloom, die, and algal material that is not consumed or decomposed in the water column are deposited in the central basin where their decay increases BOD and oxygen consumption.

Low oxygen levels occur near the bottom of Lake Erie throughout much of the summer, but in the absence of thermal stratification, mixing prevents complete deoxygenation. Thermal stratification leads to rapid depletion because the volume of the hypolimnion is small and the oxygen cannot be effectively replenished. Low oxygen leads to the release of nutrients that have been previously removed from the system by sediment interaction. The release of nutrients accelerates algal production and further deoxygenation, thus creating a cyclical flux of materials that may become self-maintaining under some circumstances.

The other Great Lakes have not as yet shown major deoxygenation problems. However, Lakes Michigan and Ontario receive sufficient loading to cause deoxygenation if it were not for the large reservoirs of oxygen in the hypolimnion of the two lakes. Continued release of BOD materials and nutrients in these lakes may cause problems similar to those of Lake Erie, due to build-up of natural BOD from accelerated algal productivity.[192/]

(ii) Phosphorus. Phosphorus is a nutrient used in the production of protoplasm. The only natural source of phosphorus is limited weathering of phosphatic minerals in the drainage basin. Therefore, in an undisturbed ecosystem phosphorus compounds are scarce and the growth of plants and animals is limited.

When phosphates are added to the ecosystem from other sources, and there is no other limitation on algal production, by nutrients or other factors such as light or temperature, then increased primary production and nuisance algal blooms result. The overproduction of algae leads to increased turbidity, increased oxygen demand (when the algae decompose), loss of valuable consumers (especially predacious fish), and finally, degradation of overall water quality.

The major sources of phosphates in the Great Lakes are the metropolitan areas. The rapid hydrolysis of phosphates from detergents and the assimilation of phosphates by the biota and sediment cause phosphate concentrations to decline rapidly with distance from their sources. Consequently, it is only in restricted embayments and areas of overloading of phosphate that significant phosphate concentrations occur. Notable regions of phosphate overloading are near Chicago, Green Bay, Saginaw Bay, Detroit, Toledo, Long Point, Buffalo and the Niagara River outlet, Toronto, Cobourg, and Oswego.

If the main sources of phosphate are urban, then sewage treatment and nonphosphatic detergents may be feasible solutions to the phosphate problem. However, phosphorus may not be the limiting nutrient in the Great Lakes, and nitrogen or BOD may be more appropriately controlled to limit eutrophication and algal production.

Lakes Erie and Ontario are subject to the greatest stress from phosphate pollution. Concentrations are sometimes high enough to approach saturation with respect to the mineral hydroxyapatite. Western Lake Erie is supersaturated and regions near urbanized areas approach saturation. A positive correlation has been found between plankton abundance and hydroxyapatite saturation in Lake Erie.[193/]

CLIMATOLOGY

1. General.[194/] The climatology of the area is a result of the passage of many cyclones and anticyclones over or near the Great Lakes. The paths of these systems are in general controlled by the upper-air, long wave pattern. Although storms may approach from any direction, the vast majority come from a southwesterly to westerly direction. Since the basic movement of weather systems is west to east, anticyclones also move into the area from a westerly direction.

The approach and passage of a cyclonic storm may result in major and rapid changes in the weather, depending on the season and severity of the storm. The most severe storms historically occur in the fall, with the greatest frequency in November.

Wind directions are highly variable, but in general favor a westerly component. With the passage of a storm system, the winds may shift nearly 180 degrees within a few hours.

2. Extratropical Cyclones. The location of the Great Lakes in the interior of the North American Continent, between the source regions of contrasting polar and tropical air masses, results in more rapidly changing and complex weather patterns than those of more maritime locations. The interaction of the air masses along the polar front produces LOWS or cyclonic storms, which usually move toward the Great Lakes under the influence of the general westerly circulation. Larger seasonal changes in the heat and moisture characteristics of the land surface, and, consequently, greater modification of air mass properties as compared with ocean areas, produce more variable areas of cyclogenesis over land. In addition, the complex relationships of, and sharper contrasts between, southward-moving polar air and northward-moving tropical air over the continent can produce extremely rapid deepening of low-pressure systems over the Midwest. The development of a storm of major proportions sometimes occurs within less than 24 hr.

The Great Lakes area is at the juncture of the paths of storms from several areas of cyclogenesis in the western portion of the continent. November is usually the month of the most frequent severe weather, as sharper contrasts between the polar and tropical air over the continent develop. A secondary factor in the intensity of November storms is the heat energy supplied by the relatively warm, open waters of the Great Lakes.

The more destructive storms on the Great Lakes usually come from the southwest. These lows form in three areas: Texas and New Mexico, the Central Rocky Mountains and Great Plains, and the Pacific Southwest. The movement of storms from all three regions is similar, from the Middle West to the Great Lakes. The season for storms from these regions is generally from October through May.

One of the worst storms occurred November 11 to 12, 1940, when three large ships sank.[195] A November 17 to 18, 1958 storm sank a large freighter. Storms in other months have been severe enough to sink large lake carriers.

3. Winds. Observations on the lakes are provided by cooperating ships. These observations are generally lacking from January through March, when ice restricts the ships' movements. Many reporting stations are located on the lake shores. Over water,

winds are generally stronger than land winds. The highest ship-measured winds were 95 kt from the west-northwest, on Lake Huron on August 6, 1965.[196] Records for the other lakes are: Lake Erie, 87 kt; Lake Superior, 81 kt; St. Clair, 61 kt; Lake Michigan, 58 kt; and Lake Ontario, 50 kt. The higher winds are usually associated with squall lines, which are more prevalent in late spring, summer, and fall. November is the worst month for extreme winds. The winter months have the highest frequency of steady winds over 28 kt.[197] The stronger winds have a highest frequency out of the west, but can occur from any direction.

4. High Waves.[198] Waves over 20 ft have occurred on all the lakes, with 24 ft the general maximum; but 33 ft waves were reported on Lake Michigan in October 1969. The higher waves occur on the larger and deeper lakes. Lake Superior has the highest frequency of high waves, but even there the frequency of waves over 20 ft is only approximately 0.05 percent. High waves will be associated with high winds and the fall months. The frequency in the winter months is less, partially due to ice.

5. Visibility.[199] Fog occurs throughout the year, but is more prevalent during early summer and fall. Advection fog occurs in the spring and early summer, when the lake water is colder than the air moving off the land. Steam fog occurs in the fall, when the water is warmer than the air. Lake Superior has the highest frequency of fog, but is not consistent in the time of year from one end to the other. Each location would have to be evaluated individually.

6. Thunderstorms.[200] Thunderstorms with lightning and hail have a spring and summer frequency maximum. The frequency is highest along the western shore of Lake Michigan and southern shore of Lake Erie. Frontal and squall line thunderstorms are generally the most severe, with strong and gusty winds. Depending on the time of year and time of day, the lakes may enhance or suppress the thunderstorm activity. Tornadoes occur with the more severe thunderstorms, but tend to dissipate or develop into less intense waterspouts, once over the lakes.

7. Seiches. Seiches (usually caused by extratropical storms passing north of Lake Erie, with strong southwest and west winds) setup water at the eastern end of the lake, resulting in low water levels in the western end. In one such case on November 20, 1970, water rose 5.0 ft above normal at Buffalo and fell 4.6 below normal at Toledo.[201] Other lakes can be affected when the wind blows across their length for a period of time, but, because of their greater depths, usually not as severely as Lake Erie.

8. Air Temperature.[202] Air temperature varies greatly with season and latitude. Wind direction in any season has a great effect on the mean temperature. With cold arctic outbreaks, temperatures may vary 50° to 60°F over a 24 hour period. The lakes themselves have a definite modifying effect on the air temperature on the lee side.

The daily range of mean temperature isopleths follow the outlines of the lakes, being smaller toward the centers. This daily range is fairly constant during a given season, and is greater in the summer. During the cold months, the mean air temperature is warmer toward the centers of the lakes, and during the warm months is cooler toward the centers.

The northwest shore of Lake Superior has the coldest average temperatures, and the southern shore of Lake Erie, the warmest average temperatures. The mean daily temperature along the shore of Lake Superior averages 15° to 25°F below freezing during January, while the mean temperature of Lake Erie averages about 5°F below freezing. The daily mean temperature over the lakes during July ranges from 52°F over central Lake Superior to 74°F over southern Lake Michigan and western Lake Erie.

9. Water Level. Lake levels vary with the season, and, also, the years. Currently (and for the last several years) all lakes are above normal. Lakes Erie and St. Clair set new records in 1973. The lake levels are highest in late spring and early summer, due to spring rains and snow runoff. They are lowest in mid-winter, generally during February.

(a) Lake Superior. Over a recent 5-year period, the maximum monthly mean was 0.99 to 1.82 ft above Low Water Datum, and the minimum monthly mean was from 0.32 ft below to 0.42 ft above Low Water Datum. The greatest fluctuation in a single year was 2.14 ft, and the greatest difference over the entire 111-year period of observation was 3.83 ft. Elevation is now regulated by compensating works in the St. Mary's river which vary the outflow; under an agreement between the United States and Canada, the elevation of Lake Superior is maintained between 600.5 and 602.0 ft above the International Great Lakes Datum.

(b) Lake Michigan. The maximum monthly mean for a recent 5-year period was 0.88 to 3.04 ft above the Low Water Datum; the maximum monthly mean for the same period was 0.08 ft below to 1.70 ft above the Low Water Datum. The greatest annual fluctuation was 2.23 ft. The greatest difference in levels for the entire 111-year period of observation was 6.59 ft.

(c) Lake Huron. The maximum monthly mean over a recent 5-year period was 0.88 to 3.04 ft above the Low Water Datum; the minimum monthly mean was 0.08 ft below to 1.70 ft above the Low Water Datum. The greatest fluctuation in a single year was 2.23 ft and the greatest total difference between high and low water was 6.59 ft in the 111-year period of observation.

(d) Lake Erie. The maximum monthly mean over a recent 5-year period was 1.97 to 3.93 ft above the Low Water Datum. The minimum monthly mean for the same period was 0.44 to 1.87 ft above the Low Water Datum. The greatest annual fluctuation was 2.75 ft and the greatest total difference during the 111-years of observation was 5.25 ft. Low water in spring and fall coincides with the greatest frequency and severity of storms.

Because of the shallow depth, the wind causes great fluctuations in water level; the effects are most marked at the ends of the lake and less at intermediate points, with variations from normal along the south shore seldom greater than 1 foot either way. At Buffalo, however, levels 10.5 ft above and 4.4 ft below Low Water Datum have been recorded. Fluctuations of 6 ft above and 2.5 ft below Low Water Datum have been observed at Sandusky in the west.

(e) Lake Ontario. In recent years, the maximum monthly mean was between 2.5 and 3.25 feet above the Low Water Datum; the minimum monthly mean was 0.87 to 1.25 above the Low Water Datum. The greatest annual fluctuation was 3.58 feet and the greatest difference in level for the 111-year period of observation was 6.61 feet. Wind-induced fluctuations are limited by the great depth of the lake.

EARTHQUAKES AND TSUNAMIS

1. Earthquakes. The Great Lakes area has a very low level of seismic activity. A 1935 earthquake, estimated at magnitude 6 1/4 on the Richter scale, occurred near Timiskaming, Quebec, Canada, about 100 miles (160 km) from the northern shores of Lake Huron. Damage was slight in the epicentral region, largely because of the sparsity of population. The earthquake was felt over an area of nearly 1,000,000 square miles (2,600,000 sq km) in the United States and Canada.[203/]

The series of great earthquakes near New Madrid, Missouri in 1811-1812 were felt over two-thirds of the United States. Effects in the Great Lakes area were minimal. Portions of the Great Lakes were also within the felt area of the 1886 Charleston, S.C., earthquake (intensity I-IV).

The effects of even an extremely small recent (magnitude 3.7, September 15, 1972) earthquake in northern Illinois were well noted by a widespread population.

2. Seismic Sea Waves. Large magnitude earthquakes sufficient to produce a major tsunami in the Great Lakes area are not known to have occurred historically. A point which has not been examined is the possibility of a large submarine landslide producing a tsunami. Although submarine landslides are not efficient wave generators in an open basin or ocean, that may not be equally true if a major portion of a lake bed were to slip. Warning times for nonweather induced tsunami-like waves in the Great Lakes would be essentially zero.

LIVING RESOURCES

1. General.[204/] Approximately 40% of the U.S. population lives in Great Lakes states and 10% in counties bordering the lakes. Consequently, the lake waters are used for domestic and industrial purposes, including waste disposal. Extensive commercial and sport fisheries have existed for many years, and the lakes are used for boating, bathing, and other recreation.

Human activities have affected even these large bodies of water, and there is evidence of accelerated eutrophication. The fish populations, bottom fauna, and chemical content of the waters of Lake Erie have changed markedly during the past years, and the standing crop of plankton in southern Lake Michigan has increased significantly over past years.

2. Estuarine and Wetland Areas. Upland areas include flood plains, as well as swamp forests and stands of beech-maple, sugar-maple-red oak, and hemlock-hardwood. Numerous large and small tributary streams carry surface water runoff from upland areas into smaller creeks and marshes, which in turn drain into the lakes. These wetland areas provide important habitat for many fish and wildlife species.

3. Birds. Predatory birds indigenous to the area include the sparrow hawk, red-tailed hawk, marsh hawk, and broad-winged hawk. Various species of game birds, including ruffed grouse, woodcock, and pheasant, also occur, and non-game bird species are abundant during the summer period.

The Great Lakes are located on major migration routes for waterfowl, and some species of ducks concentrate along the shores of the southern lakes during winter periods. Dabbling ducks, such as the wood duck, black duck, mallard, and blue-winged teal, utilize the marshes and wetland areas for breeding purposes.

4. Land Mammals. Wildlife species found in the area are typical of those of the northern United States. Common mammals include the cottontail rabbit, fox, raccoon, chipmunk, and gray squirrel. In some locations, white-tailed deer are common. Moose occur around the periphery of Lake Superior and Lake Michigan.

5. Commercial and Sport Fisheries. Prior to 1950, eleven species contributed significantly to the U.S. commercial fishery: lake sturgeon, lake trout, lake herring, blue pike, chubs, lake whitefish, carp, suckers, catfish, yellow perch, and walleye. Of these, only the last eight have played a substantial role in the commercial fishery of the last two decades. Reduction of stocks due to inroads of the sea lamprey, and invasion by smelt and alewives, accelerated in some cases by over-fishing, have resulted in the virtual elimination of the first four from the commercial fishery, although they still remain as considerations in a future restored fishery. Four other species, northern pike, bullhead, sheepshead and quillback, have contributed to the commercial fishery right up to the present but their total combined catch has represented only 1.56% of the total over the last 20 years.

The present fishery of all the Great Lakes is almost entirely supported by medium and low-value species such as the yellow perch and carp, although chubs continue to be important in Lakes Michigan and Superior, and the alewife in the former.

In addition to the commercial fishery, the introduction of salmon into Lake Michigan in 1966 and in the other lakes in following years has produced a highly successful sport fishery, particularly in the upper Great Lakes (Superior-Michigan-Huron). The major factors in this program included sea lamprey control, an abundant forage base, restrictions on the commercial catch of salmonids, and massive stocking programs. The net result has been an increase from almost no sport fishing in the 50's and early 60's to approximately 2,000,000 angler days for trout-salmon fishermen in 1971 on Lake Michigan, 645,000 days on Lake Huron, and 401,000 days on Lake Superior.

A discussion of the resource base that supports these fisheries follows.

6. Benthic Communities. The Benthic Communities found in the Great Lakes region as a whole are typical of those found in clean, cold, deep lakes. Although studies of the group have been limited in the majority of the lakes, the following composite picture for the region emerges. In cold, deeper waters of all the lakes (excluding southern Green Bay, Saginaw Bay, the western and central basins of Lake Erie and many areas adjacent to river mouths) the amphipod *Pontoporeia sp* and the mysid *Mysis sp* are

the most numerous components of the main basins. Other groups found in substantial numbers are clean water forms of sphaeriid clams, oligochaetes, mayflys, snails, leeches and caddisfly larvae. Of special interest is the loss of mayfly populations from southern Green Bay, Saginaw Bay, and western Lake Erie due to the polluted conditions.

7. Pelagic Communities.

(a) Phytoplankton. The phytoplankton populations of the Great Lakes region are dominated by the common clean water diatom species with the more pollution-tolerant blue-green algae species appearing in the western and central basins of Lake Erie, areas of Saginaw Bay, southern Green Bay, and at various locations along the lake shore where high nutrient loading occurs. Apart from a shift toward the more pollution-tolerant forms, there have also been shifts in population pulses and in relation abundance. In Lake Huron the seasonal peaks occur during November, January, and April. In Lake Erie the major pulses occur in the spring and fall and are estimated to be at least twenty times greater now than those occurring in the 1920's. These pulses have also increased in duration as well as size.

(b) Zooplankton. With the exception of Lakes Superior, Huron, and Ontario — about which little is known — the zooplankton populations of the Great Lakes have changed significantly. (With the analysis of data gathered during the International Field Year for the Great Lakes, 1972-73, the picture on Lake Ontario should be improved.)

In Lake Michigan the alewife was likely responsible for the sharp reduction in numbers of some of the largest zooplankton, causing an increase in abundance of the remaining species. In addition there is a marked difference in species composition and abundance in crustacean zooplankton between southern Green Bay and the rest of Lake Michigan. There has also been a documented difference in the zooplankton populations of the various basins of Lake Erie, with abundances distinctly highest in the western basin and lowest in the eastern.

(c) Fish. Because the Great Lakes represent such a varied group of habitats, it is convenient to divide the fish into two groups: cold-water forms, and warm-water forms.

- Cold-Water Forms:

Lake Trout. The lake trout was the single most sought after sport and commercial fish in the Great Lakes region until its populations collapsed during the late 40's and early 50's. Through stocking programs and restrictive commercial fishing regulations it is once again increasing in abundance in the upper Great Lakes (Superior, Michigan, Huron).

Depth distribution in the upper lakes varies from lake to lake, and also according to season within each lake. Lake trout are dispersed over a wide area in the shallows during spring, migrating to the deeper cool (temp. 4.4-18.3°C) strata during summer. Spawning generally occurs anywhere from June through December on rocky shoals and gravelly beaches. Available information indicates that in Lake Huron proper spawning took place from October 20 to November 10. Young lake trout feed on a variety of invertebrates, then move up to the juvenile smelt and alewife, and finally to the adults of these species.

Deepwater Chubs, Whitefish, and Lake Herring. The fish belonging to this group makeup the second most important complex in the Great Lakes. It was this group which bore the brunt of commercial fishing pressure as other stocks declined. As a result of this pressure and of competition with exotic introductions, only three of this group remain in any numbers. They are the lake herring, whitefish, and bloater.

The lake herring is a gregarious, school-forming species spawning over shoal areas either inshore or offshore in late autumn and early winter. Fry hatch the following spring, with recent experimental work indicating that temperatures in the range of 2-8°C are optimum for normal development. Tagging studies have also indicated that movement is over very small areas, with populations forming local, quasi-discrete stocks.

The lake whitefish is also a gregarious species, spawning on sand, gravel, stone, or honeycomb rock at depths of 2-18 meters during October and the first half of November. Incubation takes place from November to the following April, with constant temperatures of around 0.5°C important for normal development. Seasonal movements include spring and early summer concentrations in water less than 18 m deep. During July and August they move to deeper water. In the fall they return to the shallow water where they likely remain until the ice breaks up. In addition there were groups of whitefish that spawn in various river systems, but these have largely been lost due to pollution.

The bloater, smallest of the chub group, is the only species of this group (deepwater chubs) of commercial importance and new fishing regulations and limitations designed to preserve these stocks may reduce the catch still further. The bloater spawns in January-March in water 40-60 fathoms deep and is found in areas of high alewife abundance at this time. Young bloaters up to a length of several inches feed heavily on zooplankton. During 1968, 1969, and again 1970, young-of-the-year and yearling bloaters appeared in far greater numbers in experimental catches. This success follows the severe alewife reduction in the spring of 1967 and the subsequent zooplankton shift. It appears then that the alewife abundance and commercial pressure are the key factors in bloater abundance.

Salmon. Only Lake Ontario had a native population of salmon (Atlantic) which are now extinct. As mentioned earlier under sport fishing, new populations of Pacific salmon have been successfully introduced into the upper Great Lakes. These consist mainly of coho and chinook, with some test plants of other species. Small scale plants have also been made in Lakes Erie and Ontario with a much larger program planned for Ontario upon completion of the Lamprey-Control Program. In Lake Michigan the salmon congregate in the southern basin during the winter and during spring are often found near Chicago. As spring progresses, they move up the east side of the lake, going progressively deeper as the inshore waters warm. Starting in September, they begin to congregate in the lake near their spawning streams and the runs continue into December. Abundance at this point depends on an adequate forage base, numbers stocked (little in any natural reproduction) and Lamprey Control.

Splake. Splake, a brook trout-lake trout hybrid was planted in Lake Huron with the hope of rehabilitation of that lake's trout fishery. At this time insufficient data are available to evaluate this species.

Other Trout. At this time various lakes support populations of rainbow, brown, and brook trout, all providing important sport fisheries. Of these, the rainbow (steelhead) supports the largest fishery.

Alewives. The alewife, a relatively recent invader of the Great Lakes, has been responsible for some of the fisheries problems of the past, but today provides the forage base upon which the successful salmon fishery is based.

Alewives form dense schools during late winter and early spring prior to moving from their deepwater wintering area to the inshore spawning sites. Spawning takes place during June and July, with the juveniles remaining in the area for sometime. The young alewives are found at intermediate depths during fall and winter. Alewives feed on plankton, aquatic insects and crustaceans.

Smelt. In the Great Lakes smelt are found in the 14-64m zone, being most abundant in the 18-36m zone. Adults congregate in schools in April prior to spawning in the inshore area. At this time a sport fishery exists, although they are also taken commercially. Young smelt feed on invertebrates and the adults feed on invertebrates and fish.

Sea Lamprey. The life history of the sea lamprey in the Great Lakes includes a larval existence of about 4 years in silt beds of tributary streams, and a subsequent parasitic life of 12 to 18 months in the lakes. Parasitic life is terminated by a spawning migration beginning in early April and continuing until mid-June. Adults die after spawning.

Although it has no sport or commercial value of its own, the lamprey, perhaps more than any other single factor, has influenced the fish populations of the Great Lakes. Its successful control is essential to viable fishery programs in the region.

- Warm-Water Forms

The following warm-water forms will be discussed briefly since they provide some level of sport or commercial fishery today.

Walleye. Populations of walleye have existed in all the Great Lakes, but have been particularly important in Lake Erie. The species spawns in the spring in tributary streams and in some cases on shoals. Tagging studies have indicated migrations from both Lakes Huron and Erie into Lake St. Clair during spawning. Pollution and destruction of spawning sites have limited this species in the past and likely will control future abundance. In Lake Michigan only the Muskegon River has had a significant walleye spawning run in the last several decades.

Yellow Perch. This species was primarily a sport fish over most of the Great Lakes until the decline of high-value commercial species. Since then, however, fishing effort for yellow perch has increased significantly. In Lake Erie alone, the catch has risen from 2.5 million pounds in 1920 to over 15 million pounds in 1971 (down from the record production of 33.7 million pounds in 1969). Perch spawn in the spring in shallow areas within the inshore zone. One limiting factor for this species may be the alewife, which seems to inhibit reproduction.

Carp. Carp are now distributed throughout the littoral waters of the Great Lakes. During the spring the fish migrate from the deeper water of the lakes into marsh areas to spawn. Adults are in the upper regions during the summer months, occupying marginal areas of deeper water during the late summer early fall, and move into deeper water and remain there during the winter.[205/]

At this time there appear to be no factors limiting the abundance of this species to any great extent.

Other species, such as freshwater drum, suckers, catfish, and buffalo fish would also have to be considered in any detailed evaluation of the living resources of the Great Lakes.

8. Threatened Species. Threatened wildlife species include lake sturgeon, longjaw cisco, deepwater cisco, blackfin cisco, blue pike, Kintland's warbler, dusky seaside sparrow, and eastern timber wolf.[206/]

Part 2: Detailed Environmental Analyses for Selected Atlantic Coast Areas

INTRODUCTION

The following sections detail environmental descriptions of four selected Atlantic coast areas, namely: (1) from the Canadian border to Portsmouth, N.H., (2) Sandy Hook to Atlantic City, N.J., (3) Chincoteague to Cape Charles, Va., and (4) Cape Kennedy to Key West, Fla. The width of the areas considered is from the coast 60 miles seaward (fig. 25.)

The organization of the sections is similar to those of Part 1, so that the detailed descriptions may be fitted into the larger-scale picture provided by the general discussions of the Atlantic Coast in that chapter. Some general comments are necessary in several of the discipline categories before proceeding to the discussions.

OCEANOGRAPHY

Because coastal areas and waters between Sandy Hook, N.J., and Cape Henry, Va., are physically homogeneous in oceanographic characteristics, they have been treated as a unit to avoid repetition. Specifically, the discussion of tides, tidal currents, circulation, and water mass characteristics for area 2 (Sandy Hook to Atlantic City) also applies to area 3 (Chincoteague to Cape Charles).

CLIMATOLOGY

1. General. A general discussion of the climatology of the Atlantic Coast of an extratropical and tropical cyclones was given in Part 1. However, because extratropical and tropical storms are the primary weather producers, and because one storm can affect several or all four areas of consideration, a more detailed discussion of storm climatology for the Atlantic coast follows.

Extratropical and tropical cyclone statistics were obtained from Weather Bureau Technical Paper No. 55,[207/] and from the Environmental Data Service's Mariners Weather Log.

The mean recurrence intervals for wind and wave extremes were provided by the National Climatic Center (NCC), based on the work of H.C.S. Thom,[208/] formerly of the Environmental Data Service. Significant waves represent the average height of one-third of all waves visually observed. Extreme wave heights are 1.8 times the significant wave height. The wave heights recurrence values could only occur where water depths are sufficient to maintain such heights. A given water depth will support a maximum wave equal to approximately 78 percent of the given depth.

The Consolidated Tables of Meteorological Elements and the wind, wave, and visibility frequency distributions following the climatology section of each area description are all based on information obtained from the U.S. Navy's "Summary of Synoptic Meteorological Observations"[209] (SSMO), and apply specifically to the four areas shown in fig. 26 which differ slightly (larger in area) from the four areas of consideration. This difference, however, should not be climatologically significant. Where coastal data were available, a coastal subsection was added to the discussion. Tables for the coastal land stations were produced from the Normals, Means, and Extremes Table of the "Local Climatological Data"[210] for each station.

A special computer run was required for Area 2, and for potential superstructure icing tables. The data used in these tables were obtained from the National Climatic Center's tape data Family 11 (TDF-11), Marine Surface Observations. It should be noted that these data are based upon observations made by ships in passage. Such ships tend to avoid bad weather when possible, thus biasing the data toward good weather samples.

In the wave height vs. wave period section, if both sea and swell waves are present in the observation, the higher of the two values is used. If both waves are the same height, the longer period is used. That is, if a ship reported a sea of 13 feet and a swell of 8 feet, the 13-foot sea was used in the wave summary. If the vessel reported both sea and swell of 13 feet with a period of 8 seconds for sea and a period of 15 seconds for swell, the 15-second swell observation was used in the summary. These procedures are based on the World Meteorological Organization specifications for wave summaries. When only one of the wave groups was observed, it was used in the summary. The maximum seas appearing in the wave table were obtained from the wave height vs. wave period section of the SSMO summary.

In the count of tropical and extratropical cyclones, each of the areas shown in fig. 2 was enlarged by one degree of latitude and longitude: This was done to insure that storms passing close enough to the areas to affect them were included. In addition, special counts of tropical cyclones passing within 60 mi of the coast are also included.

2. Extratropical Cyclones. Although the annual number of extratropical storms visiting the Atlantic Coast is far greater than the number of tropical storms, only a relative few cause serious damage. The following descriptions of severe extratropical storms that have affected several of the FNPP areas are examples of what damage such relatively rare extratropical cyclones are examples of what damage such relatively rare

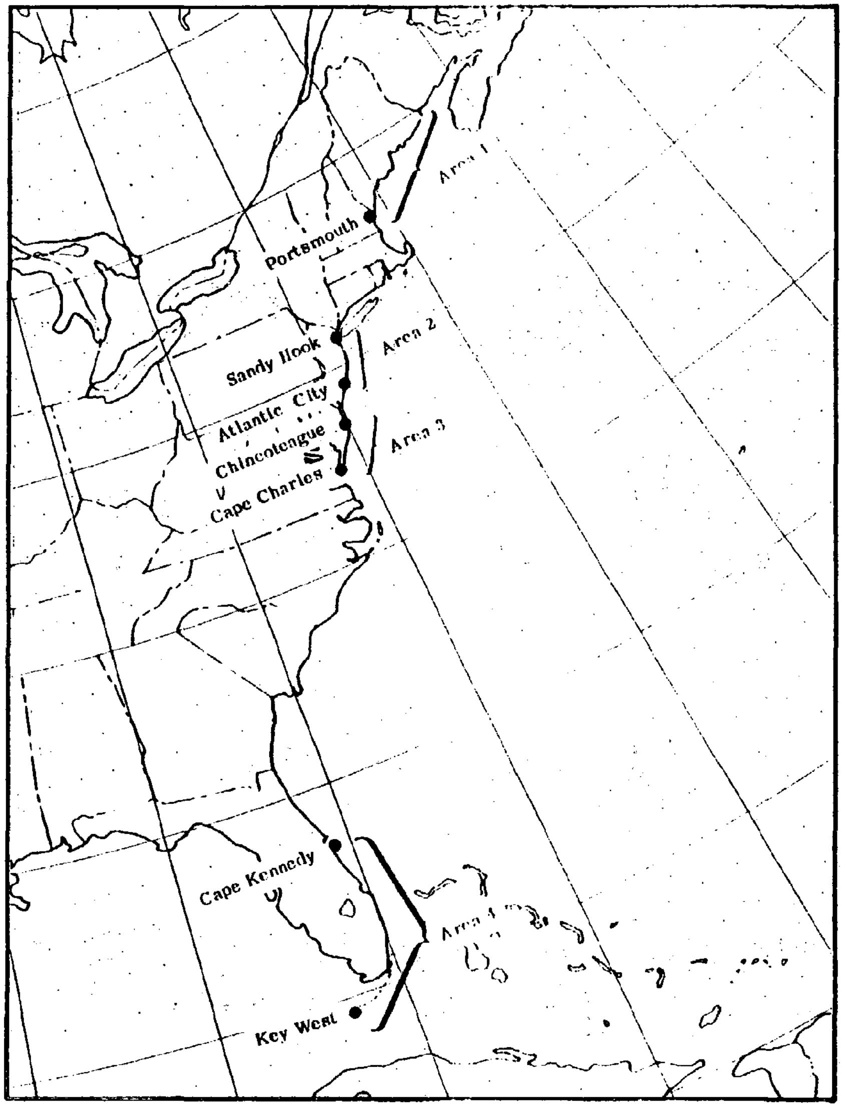


Figure 25.--Selected Atlantic coast areas.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

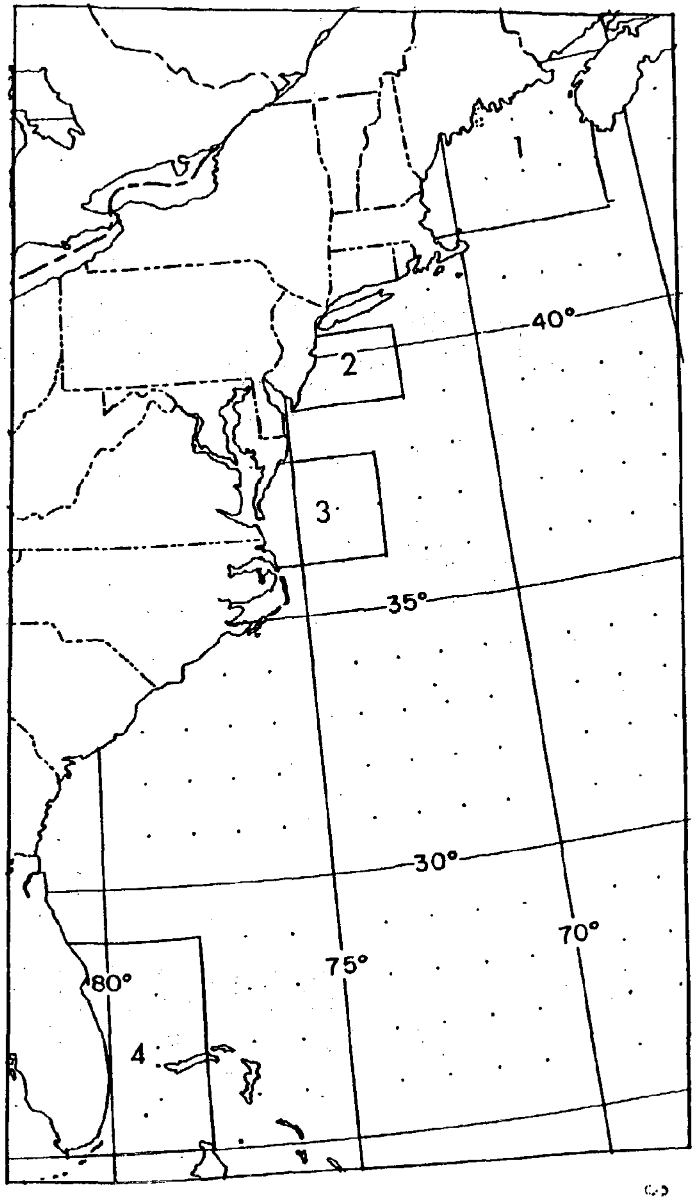


Figure 26.--Areas described in Climatology sections.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

extratropical cyclones can bring.

(a) November 11-14, 1968. The Veterans Day Storm of 1968 was particularly severe for a storm occurring so early in the season. The 980-mb cyclone whipped coastal areas from Florida to Maine with 50- to 60-kt winds and high tides. It also dumped an early season snow, with some totals up to 16 inches, from South Carolina to Maine, and as far west as Illinois and Missouri. Destruction was worst from New Jersey to Long Island, where tides, gales, and breakers eroded beaches, sank small boats, and flooded lowlands. Total insurable fixed damage was estimated at $20 million.211/

(b) Great Atlantic Coast Storm, March 5-9, 1962. A slow-moving, late winter coastal storm combined with spring tides (maximum range) to bring tremendous destruction to coastal installations from southern New England to Florida on March 6-9. This storm, which consisted of a series of LOWS, has been described as the most damaging extratropical cyclone to hit the U.S. coastline. Although gale-force winds and at time hurricane-force winds accompanied this storm, this is not usual for a North Atlantic winter extratropical cyclone. It was the long fetch and the persistence of these strong northeasterly winds which raised the spring tides to near-record levels. The tidal flooding which attended this storm was in many ways more disastrous than that which accompanies hurricanes. The storm surge in tropical cyclones generally recedes rapidly after one or two high tides, but the surge accompanying this storm occurred in many locations on four and five successive high tides. In addition, many places reported run-up of waves 20 to 30 feet high, while wave heights at sea reached 60 feet.

This successive onslaught of wave and tidal action for over 2 days weakened and undetermined even the more permanent shoreline structures and, after a period of time, some suffered structural damage and collapsed. Many of the less sturdy summer cottages on exposed coast were washed away completely.

The probability of having an easterly flow of the magnitude experienced during the March 1962 storm, for which the return period was computed as 11 years, is 60 percent within a 10-year period, and 84 percent within a 20-year period.

Another important factor was that the March 1962 storm occurred at the maximum spring tide for the month. If the return period for the easterly flow is considered to be 11 years for the March storm, and if this flow is assumed independent of the lunar cycle, the return period for similar flow occurring during a maximum spring tide is about 60 years. Therefore, the probability of an easterly flow of the March 6-10, 1962 magnitude occurring in conjunction with a maximum spring tide is 15 percent for 10 years and 28 percent for 20 years.[212]

(c) January 8-12, 1956. The first major storm of 1956 affecting the northern Atlantic Coastal States was an intense one of the "northeaster" type, which caused an extensive area of freezing precipitation. On January 7, the weather patterns of the storm were developing both at the surface and aloft over the Atlantic Ocean and North America. A strong High south of Greenland prevented the movement of an intense Low east of Hatteras. These combined to produce an area of glaze which began as sleet and freezing rain shortly before midnight on the 7th in eastern Maine, and spread rapidly westward and southward. The southern limit of these hydrometeors was reached on the 10th in the Carolinas and Tennessee, with the westernmost limit occurring in Michigan on the same data. The duration at any one station was quite variable, ranging from 5 to 15 hours in the coastal States to over 75 hours (intermittently) in portions of Ohio. Only the rapid transition of temperatures from below freezing to thawing conditions kept this storm from causing major ice damage. From onset to the very end, freezing precipitation persisted for 7 days over some portions of the northeastern States.

At the Mt. Washington Observatory , N.H., solid ice was built up to a maximum thickness of 6 feet on the northeast corner of the rampart, but with an average thickness of 1 foot on the walls.

The storm's long, easterly fetch produced high tides from Delaware northward, inflicting considerable damage on shore property and installations. At Atlantic City, N.J., tides of 4.5 feet above normal were recorded, and described as farther above normal than those of the 1954 and 1955 hurricanes. Philadelphia reported considerable damage from strong and gusty winds on the 10th. Blue Hill Observatory reported a peak gust of 65 m.p.h. on January 9, and a total rainfall that day of 3 inches. The arrival of the warm air and its persistence, in attendance with warm rains and melting of ice and snow, brought considerable flooding from ice-jammed streams.[213]

The return period for an easterly flow situation of the duration and magnitude of this storm is 18 years. The return period for this flow occurring with a maximum spring tide is 99 years.[214]

(d) November 24-26, 1950. During this period, the eastern Atlantic States experienced one of the worst extratropical storms on record. From Mississippi to Indiana and from Georgia to Maine, subzero temperatures, gales, snow, high tides, and floods caused more than $70 million in damages. At many points sustained gale-force winds continued for 12 hours or more. At coastal stations such as Newark and Boston, one-minute wind speeds were in excess of 80 m.p.h. Peak gusts reached 110 m.p.h. at Concord, N.H., 108 m.p.h. at Newark, N.J., and 100 m.p.h. at Hartford, Conn. Atop Mt. Washington, a wind gust reached 160 m.p.h.[215/]

3. Tropical Cyclones. The following discussion details the meteorological characteristics of hurricanes, the most intense stage of tropical cyclones.

(a) Wind. Wind records in a hurricane are often interrupted before the maximum speed is recorded. Because of the delicate design required of instruments for accurate readings at average speeds, anemometers have frequently failed or been blown away when speeds reached the vicinity of 100 kt. With the spacing necessary between observatories and with the strongest winds confined to a relatively narrow band around the eye, it would be fortuitous to have the maximum winds occur at a first order weather station. Nevertheless, a few readings of over 130 kt have been obtained.

From theoretical calculations based on pressure gradients and structural damage, it is estimated that sustained winds in a few of the most severe hurricanes have exceeded 175 kt. It is possible for momentary gusts to be as much as 25 to 50 percent higher than sustained winds. Therefore, in a storm with sustained 100-kt winds, there could be gusts of 150 kt; and in one with 150-kt sustained winds, maximum gusts might be over 200 kt. Since the gustiness is responsible for damaging intermittent pressure pulses and wrenching effects, the speed of the peak gusts must be considered in designing structures to withstand hurricanes.

The rapid rise in the actual force of the wind at higher speeds is another important factor in relation to construction and wind damage. The force exerted by the wind does not increase proportionally with the speed, but with the square of the speed, thus doubling the speed results in approximately four times the force. A wind of 50 kt produces a pressure of about 15 lb/sq ft, but a wind of 110 kt exerts a pressure of 78 lb/sq ft, and results in a several-fold increase in destructive capacity over that of the 50-kt storm.[216/]

At Havana, Cuba, in October 1944, a velocity of 141 kt was measured. In the Florida hurricane of September 1947, a reliable one-minute wind velocity of 135-kt was measured at Hillsboro Light near Pompano Beach.[217/] Earlier this same storm had passed over Hope Town in the Bahamas, and the maximum wind was estimated at 140 kt. Probably neither of these extremes represents the actual maximum winds in the storm.

Wind estimates varied from 110 to 130 kt for several points between Cape Fear, North Carolina and Myrtle Beach, South Carolina, when the destructive Hazel passed over them in October 1954.[218] In San Juan, Puerto Rico, on September 13, 1928, the wind averaged 117 kt for a five-minute period, and the one-minute maximum was estimated at more than 125 kt. During the hurricane of August 1949, the wind instrument at West Palm Beach, Florida was blown away when the velocity reached 96 kt, with gusts to 109. The highest wind was estimated at 104 kt with gusts to 113.[219] A privately-owned anemometer, the accuracy of which is unknown, recorded gusts to 135 kt. The anemometer at the airport terminal building at Chetumal, Mexico, registered 152 kt before it collapsed with the approach of hurricane Janet, September 28, 1955. The wind continued to increase and was estimated at more than 175 kt.

Even these speeds were undoubtedly exceeded in the Labor Day storm that struck the Florida Keys in 1935. Engineers have calculated that winds of 175 to 200 kt would have been required for some of the damage done during this severe hurricane.[220] Winds of 130 kt probably occur not infrequently, but they are not often measured, because few anemometers withstand winds of such force and, too, the centers of hurricanes frequently pass inland at isolated points and the maximum winds seldom occur at locations where wind-measuring equipment is installed. There are some indications the winds within the 130- to 140-kt class struck Cameron, Louisiana, during hurricane Audrey in June 1957.

Hurricane Camille (1969) generated extreme winds. Based on reconnaissance flight level winds and measured surface pressure, maximum surface winds were calculated at 175 kt close to the center, early on the afternoon of August 17. This calculation represents the maximum winds ever observed in a hurricane based on anything other than pure estimation.[221] The highest actual measurement on a wind instrument was found on an Easterline Angus wind speed recorder which had been left running on a Transworld Drilling Co. rig located east of Boothville (Maine Pass Block 29). The recorder had been switched to double scale before evacuation and recorded an extreme gust of 149-kt before the paper jammed and the trace was lost.[222]

(b) Pressure. The lowest sea-level pressure of record in the Western Hemisphere occurred in the 1935 Florida Keys hurricane, when a reading of 26.35 inches (892 mb) was recorded at Craig, Florida.[223] The second lowest recorded pressure occurred in hurricane Camille (1969) off the Mississippi coast, measured at 26.73 inches (905 mb). Central pressure in Hurricane Donna dropped to 27.46 inches (930 mb) in the

Florida Keys in 1960).[224/]

EARTHQUAKES AND SEISMIC SEA WAVES

See Chapter VII for a general discussion of Earthquakes and Seismic Sea Waves as they affect the Atlantic Coast. The additional discussion below applies to all four areas of consideration, and is as detailed as available data permit. There will be no further discussion of these subjects in the individual area descriptions.

1. Earthquakes. The relationships commonly used to relate earthquake magnitude and expected intensity are not applicable to this study, since only one of the significant earthquakes that have occurred near the four areas had a computer magnitude. The maximum intensity for each of the sites during the past 300 years would probably have been near VI (Table 5, Part 1), corresponding to a maximum ground acceleration of approximately 0.05g. Offshore effects equivalent to intensity VII (maximum acceleration approximately 0.1g) might be expected in the future from earthquakes in the same areas as those of 1727 and 1957.

Table 11summarizes the significant earthquakes that have affected the east coast. Fig. 27relates these earthquakes to the four areas studies. Figs.28 through 33 are isoseismal (felt area) maps for six significant east coast earthquakes.

2. Seismic Sea Waves (Tsunamis). The floating powerplants presumably would be located offshore in water at least 20 meters deep. Clearly, from the point of view of tsunami hazard, it would be advantageous to anchor the powerplants in relatively deeper water, since tsunami wave amplitude is a function of water depth, with wave amplitude increasing as the wave progresses into shoal water and shortens in wave length.

These are only general considerations and would be modified greatly by the local topography. For example, a shoreline which is a good reflector can double the local water particle velocities, while a shoreline that is an excellent absorber of energy would not have this property. In many instances, a typical tsunami with perhaps an amplitude of 1 meter will be largely describable by a linear theory assuming a very slowly, very gently sloping bottom topography and a depth of, say, 60 or 100 meters. This would depend, of course, on the wave period and other factors. On the east coast, where there is a broad shoal Continental Shelf, dissipation due to bottom friction of a tsunami would be worth considerable, although the expected occurrence of tsunamis is probably not the limiting factor in design criteria for east coast locations, where hurricanes and storm surges pose greater threats (see Part 1).

Table 11.--Prominent East Coast U.S. earthquakes.

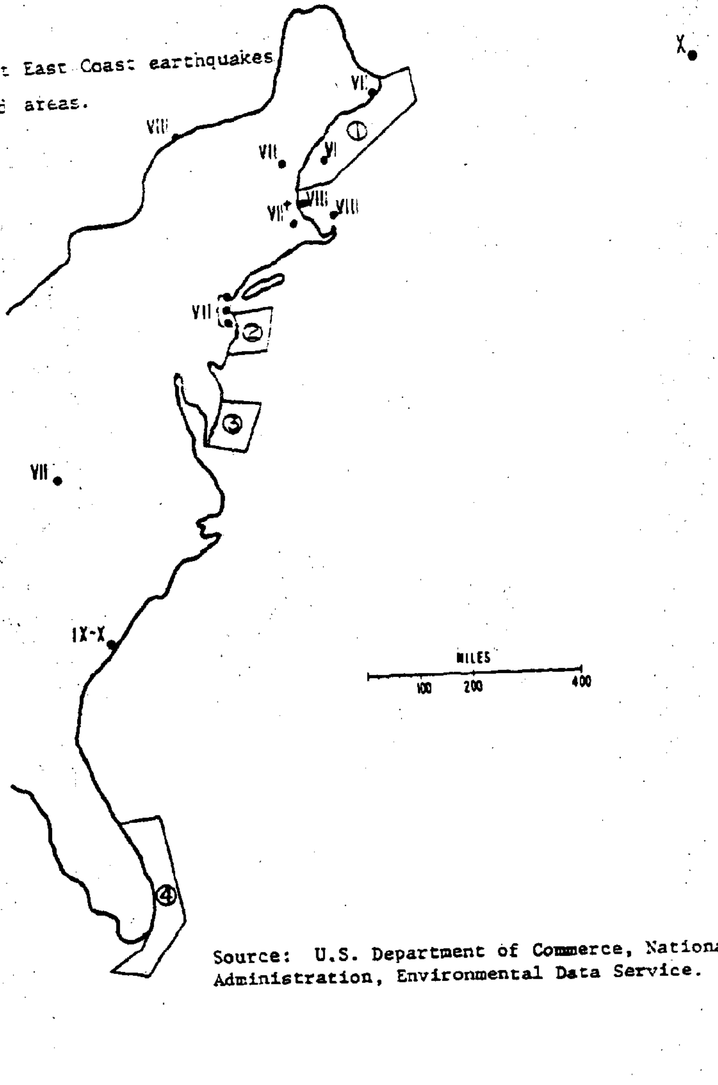
DATE	LAT. N	LONG. W	MAX. INT.	FELT AREA SQ. MILES	DISTANCE TO NEAREST AREA MILES	#
1727 NOV. 9	42.8°	70.8°	VIII	75,000	30	1
1737 DEC. 18	40.8	74.0	VII		30	2
1755 NOV. 18	42.5	70.0	VIII	300,000	60	1
1817 OCT. 5	42.5	71.2	VII-VIII		60	1
1880 JAN. 2	22.8	80.8 (CUBA)	VIII	65,000 (U.S.)	100	4
1884 AUG. 10	40.6	74.0	VII	70,000	20	2
*1886 AUG. 31	32.9	80.0	IX-X	2,000,000	300	4
*1897 MAY 31	37.3	80.7	VII	280,000	280	3
1904 MAR. 21	45.0	67.2	VII	150,000	20	1
1927 JUN. 1	40.3	74.0	VII	3,000	10	2
*1929 NOV. 18'	44.0	56.0 (GRAND BANKS)	X	80,000 (U.S.)	580	1
*1940 DEC. 20	43.8	71.3	VII	150,000	60	1
*1944 SEP. 4	45.0	74.8	VIII	175,000	230	1
*1957 APR. 26	43.6	69.8	VI	31,500	IN ZONE	1

'MAGNITUDE 7.2

*ISOSEISMAL MAP FOLLOWS

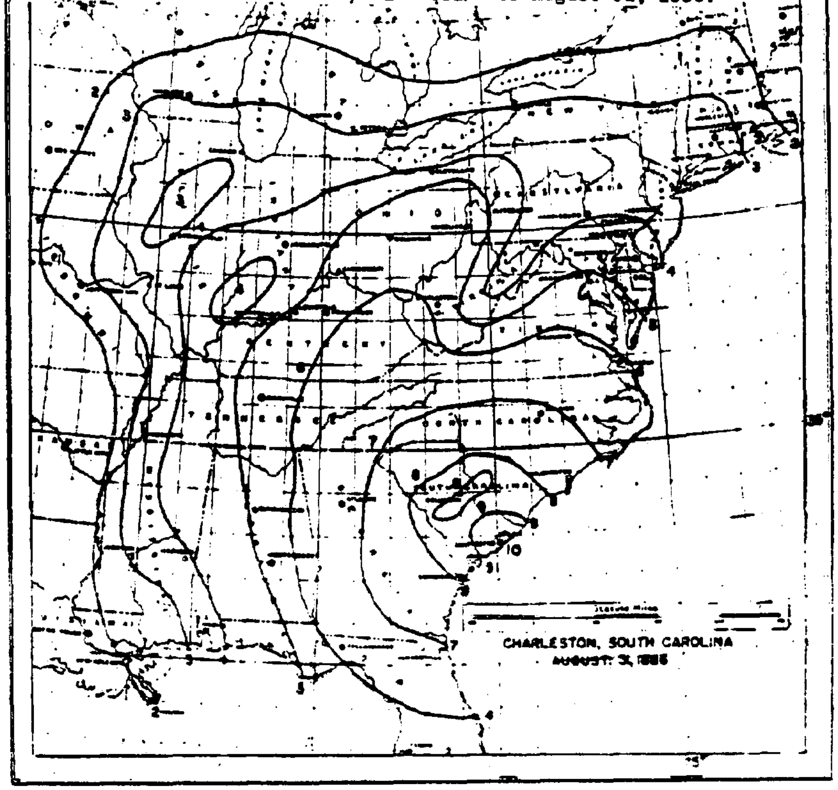
Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

Figure 27.--Significant East Coast earthquakes in relation to selected areas.



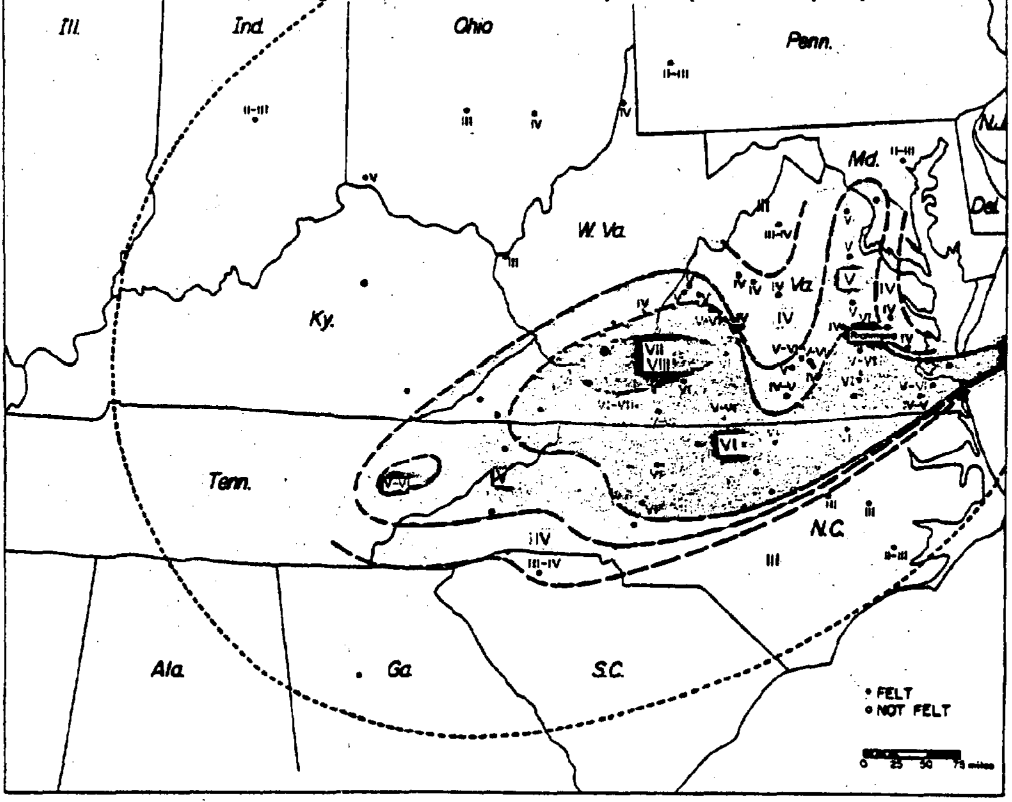
Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

Figure 28.—Area affected by earthquake of August 31, 1886.



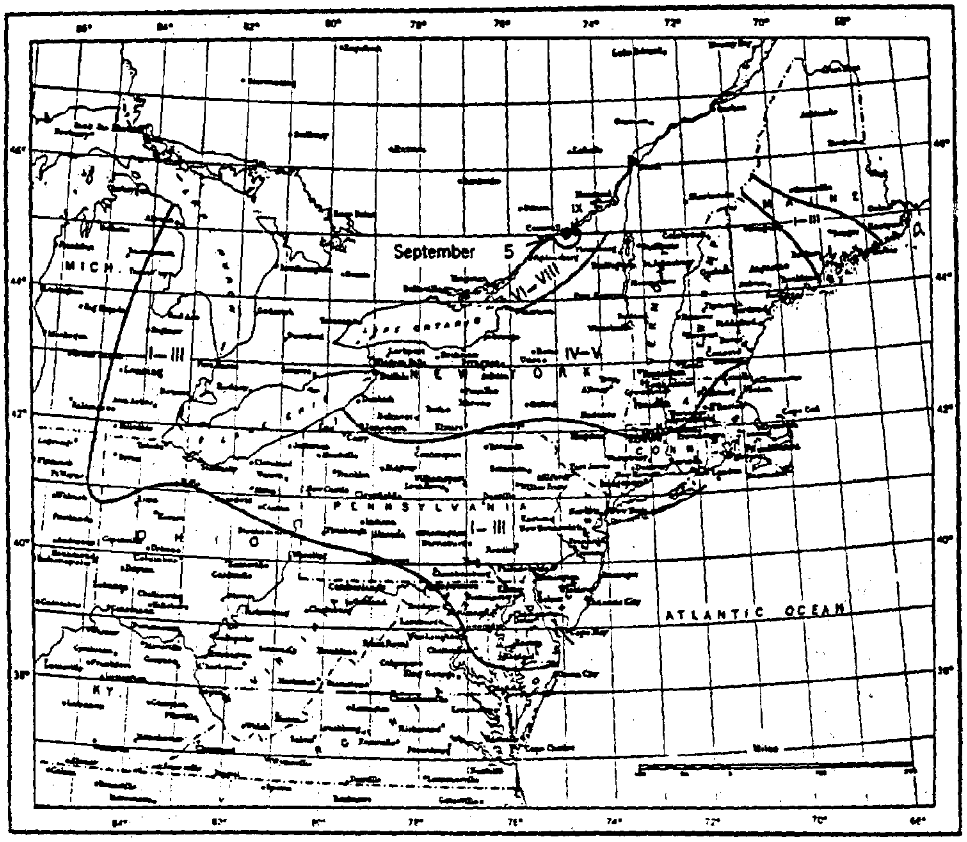
Source: Dutton, Clarence E., 1889: "The Charleston Earthquake of August 31, 1886." Ninth Annual Report, 1887-88, U.S. Geological Survey, Washington, D.C., pp. 203-528.

Figure 29.—Area affected by earthquake of May 31, 1897.



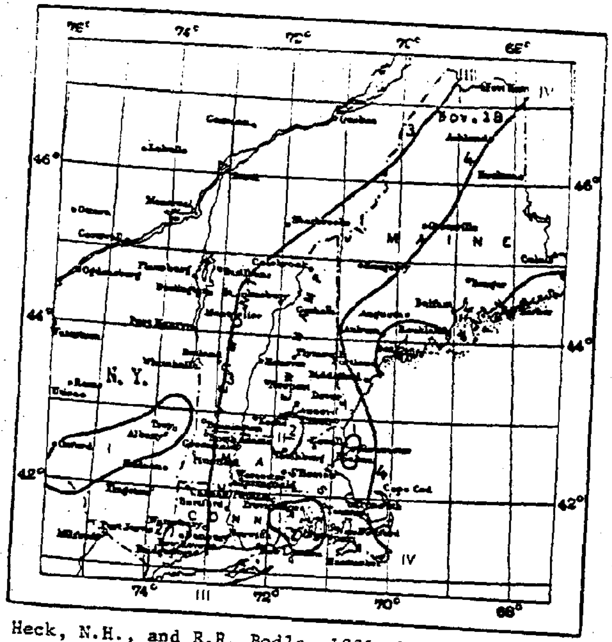
Source: Hopper, Margaret G., and G.A. Bollinger, 1971: The Earthquake History of Virginia, 1774 to 1900. Department of Geological Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Va., 97—

Figure 30.--Area affected by earthquake of September 5, 1944.



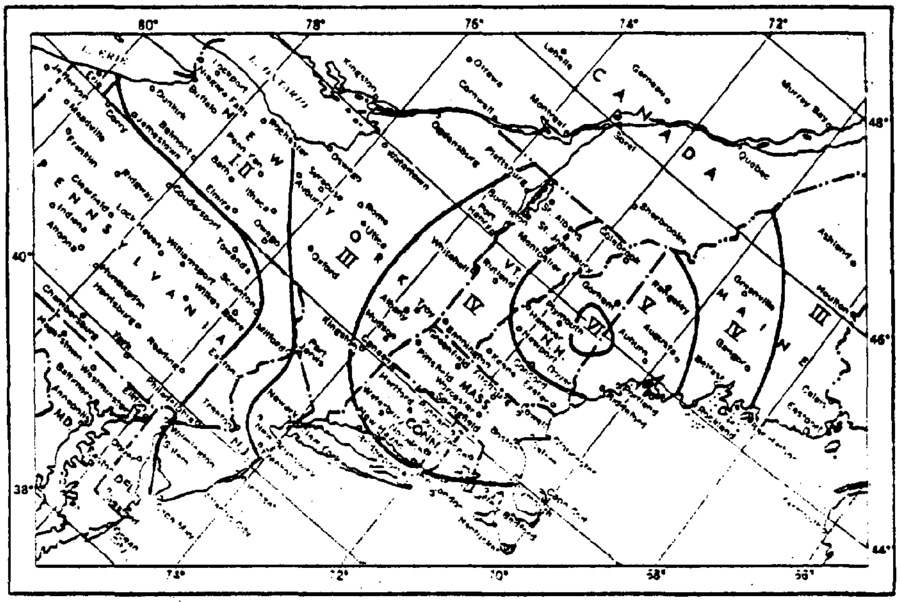
Source: Bodle, Ralph R., 1946: United States Earthquakes, 1944. Serial No. 682, U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C.

Figure 31.--U.S. areas affected by Grand Banks earthquake, November 18, 1929.



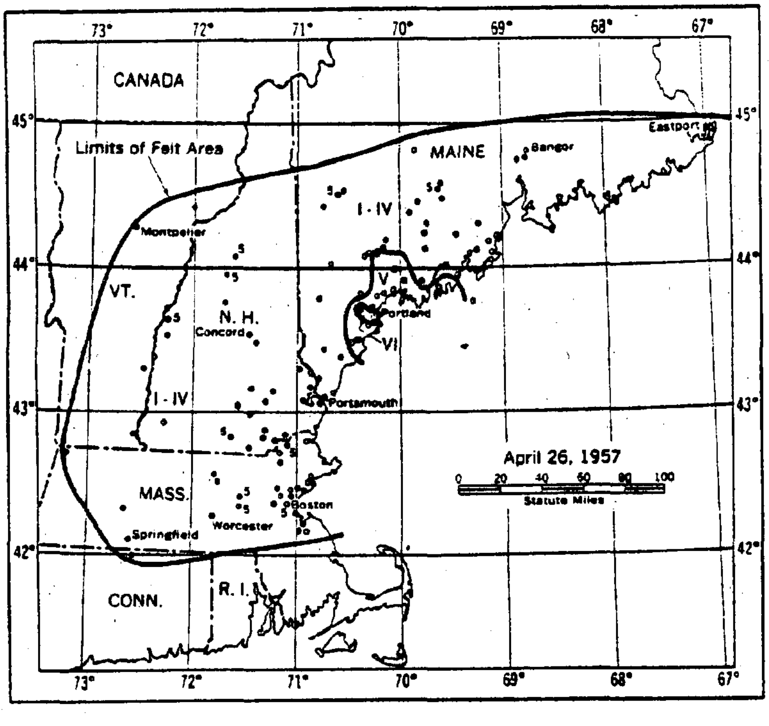
Source: Heck, N.H., and R.R. Bodle, 1931: United States Earthquake 1929. Serial No. 11, U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C.

Figure 32.--Area affected by earthquakes of December 20 and 24, 1940.



Source: Neumann, Frank, 1942: United States Earthquakes 1940, Serial No. 647, U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C.

Figure 33.--Area affected by earthquake of April 26, 1957.



Source: Brazee, Rutlage J., and William K. Cloud, 1959: United States Earthquakes 1957. U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C.

AREA 1: CANADIAN BORDER TO PORTSMOUTH, N.H.

GEOLOGY AND TOPOGRAPHY

1. General. From the Canadian border to Portland, the heavily indented coast features a complex mixture of shoal grounds and islands interspersed with deepwater estuaries extending far inland. From Portland to Portsmouth, the area is characterized by a moderately indented coast, with few offshore islands.[225/]

This area (see fig. 34) includes the Northwestern Gulf of Maine and the entrance to its northern arm, the Bay of Fundy. The Gulf of Maine is a rectangular depression; the Bay of Fundy, a shallow, U-shaped trough. The Gulf is defined by Georges Bank off the New England Shelf, Cape Cod, and southern Nova Scotia. The floor of the Gulf consists of a series of fairly deep northwest and northeast trending basins separated by low swells, some capped by flat-topped banks. Basins included within 60 miles from shore include the Owen, Grand Manan, Murr, Jordan, Matincus, and Platts Basins. Some of these continue beyond 60 miles offshore. Altogether these basins occupy 30% of the Gulf area and 76% of its volume. Most are compound, enclosing several separate deep areas which appear as flat plains that contrast with the undulate basin floors and the gently sloping basin sides. Between the basins, in addition to the flat-topped banks, irregular surfaces are common, owing in part to outcrops of bedrock, locally granite, and to concentrations of boulders. The Bay of Fundy is relatively flat floored.[226/]

In recent years extensive and improved sounding of the sea floor and geologic mapping of the adjacent land have provided new information for determining the origin of the topography. Earlier beliefs of stream erosion followed by submergence, of areas separated by banks built as end moraines, have been supplanted by the general acceptance of a glacial-erosion theory. Most of the ice entered the Gulf of Main directly from the north-northwest and through the Bay of Fundy. The U-shaped cross section of the bottom, its smoothly curving trend, and its deep, somewhat hummocky floor are typical of glacial troughs. The Gulf of Maine appears to have been free of ice for the past 11,000 years, as indicated by the presence of nonglacial sediments.[227/]

The Bay of Fundy is about 50 miles wide, separating Maine and Nova Scotia. It includes the Grand Manan Island. Depths are less than 200 meters over most of the area, except in basins where depths may reach 300 meters. Within the Gulf of Main depths are also less than 200 meters, except in basins where they rarely exceed 300 meters.[228/]

The most recent topographic maps show no evidence of submarine canyons off the Maine Coast, although channels that were part of a drainage system during the late Tertiary and early Pleistocene occur in the south of the area. No major faults transect the area.[229/] There are faults (Fundian Fault Zone), however, inshore along the coast.[230/]

2. Sediments. The basins within the Gulf of Maine have sediments which are high in silt and clay but also have a scattering of gravel and boulders of various sizes. Deep cores are not available so that it is not known whether the poor sorting with numerous erratics of glacial origin extend deep in the sediments or is merely a surface expression. Thicknesses are generally less than 100 meters except at the entrance of the Bay of Fundy where they may be somewhat greater.[231/]

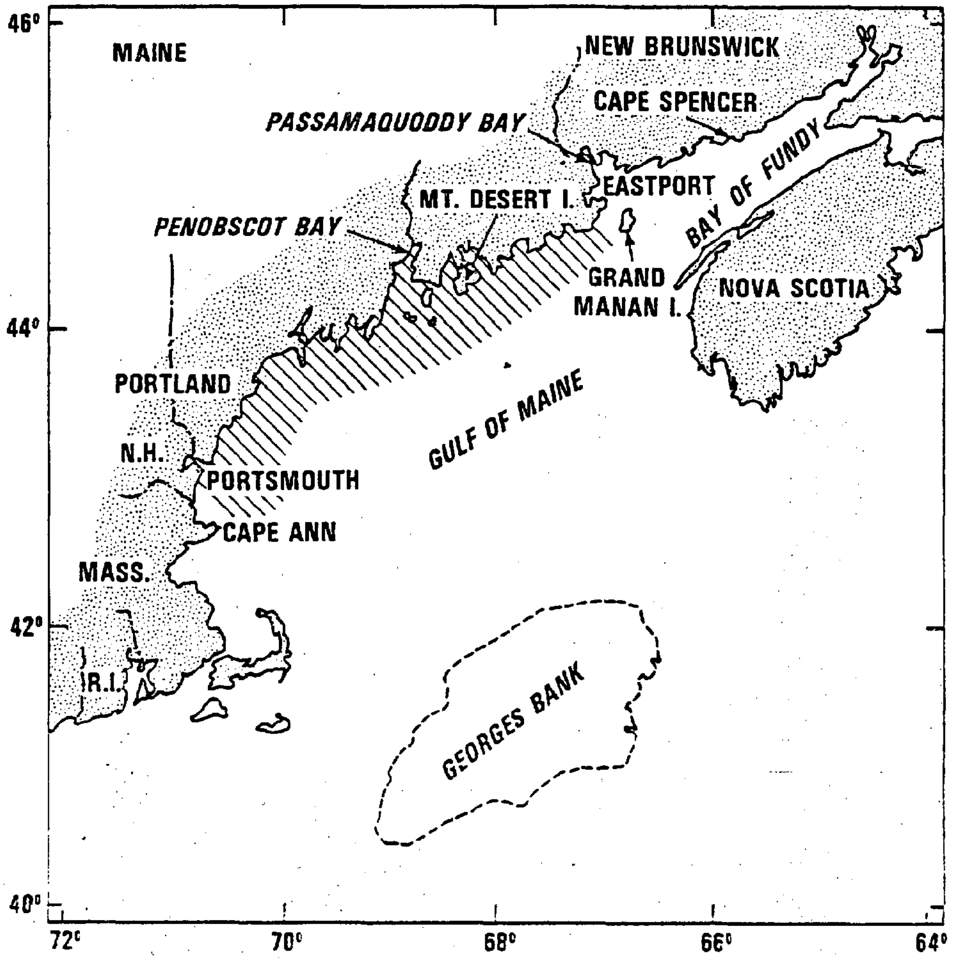
The age of the sediments are Recent (Holocent) or Pleistocent. No older sediments are present; presumably they were eroded by glacial scour. The basement consists of igneous and metamorphic rocks of pre-Triassic to Jurassic age.[232/]

3. Turbidity Currents. A major turbidity current was reported just to the east of the area, on the Grand Banks, set off by the earthquake of November 18, 1929. Cores from the area in 1952 showed the presence of a widespread blanket of silt and sand beyond the foot of the continental slope. The main point of interest is that about a dozen telegraphic cables were broken in a systematic and progressive manner during a period of 13 hours after the earthquake. Estimates of the speed of the turbidity current responsible for the cable breaks vary from 101 to 37 km per hour.[233/] However, there is little chance of turbidity current activity in the nearshore (60 mile zone) area.

OCEANOGRAPHY

1. General. The general circulation along the Maine coast is to the southwest under the influence of the counterclockwise Gulf eddy. Local wind conditions will alter this southwesterly drift. Tidal ranges are quite large with extremely high tidal ranges in the Eastport, Maine area. The resultant mixing caused by the high tides creates a near homogenous condition throughout the water column along the northern section of the coast. Salinities generally do not exceed 33% and the spring river discharge is quite evident in the coastal surface waters. The general southwesterly drift carries these low surface salinity waters parallel to the coast. Maximum temperatures occur in August, however, latitudinally the southern section will exhibit maximum temperatures 4 to 5°C higher than the northern section.

Figure 34.--Area 1 (shaded): Canadian Border to Portsmouth, N.H.



Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

Table 12.--Rotary tidal currents.

Georges Bank Lat. 41°48' N., long. 67°34' W.			
Time		Direction (true)	Velocity
		Degrees	Knots
Hours after maximum flood at Pollock Rip Channel	0	325	1.5
	1	332	2.1
	2	342	2.0
	3	356	1.3
	4	35	0.7
	5	99	0.8
	6	126	1.3
	7	150	2.0
	8	159	1.9
	9	169	1.7
	10	197	1.2
	11	275	0.9

Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1972: Tidal Current Tables, 1972 -- Atlantic Coast of North America, Rockville, Md.

2. Tides. Tides along the coast of Maine are semidiurnal, with nearly equal highs and lows occurring each lunar day. One complete tidal cycle occurs about every 12 1/2 hours. The highest tidal ranges for the United States occur along this section of the coast, with mean ranges of 18.2 feet at Eastport, Me., decreasing to 9.0 feet at Portland, Me., Lightship, and 8.1 feet in Portsmouth Harbor, N.H.[234/]

3. Tidal Currents. Tidal currents in the offshore region are rotary in character, the direction of flow varying continuously in a clockwise direction over a tidal cycle (12 1/2 hours). Speeds vary from hour to hour, with no period of slack water. Table 12 documents the rotary nature of the tidal currents at the surface for a location on Georges Bank.

Tidal currents inshore along the Maine coast are reversing in nature and are controlled by the configuration of the coastline and seabed. At the entrance to the Bay of Fundy, the flood current has an average velocity at strength of about 2.5 knots and sets 040 degrees. The ebb has an average velocity of about 4 knots and sets 230 degrees.

Along the axis of the Bay of Fundy from Grand Manan Island to Cape Spencer the currents have an average velocity of from 1.5 to 2 knots. The flood sets northeastward and the ebb southwestward.

East of Mount Desert Island the tidal currents along the coast are stronger and more regular than those farther west. Between Mount Desert Island and Portland there is a resultant westward drift along the coast.

At Portland Lightship the tidal current is weak, being on the average less than 0.3 knots at time of strength, setting 335 degrees on the flood and 140 degrees on the ebb.

At the Boston Lightship the tidal current is even weaker, averaging less than only 0.2 knots at strength.

4. Circulation. The Gulf of Maine Eddy* is the major circulation feature directly influencing water movements along the Maine coast. This counterclockwise eddy develops in early spring, strengthened by the spring river runoff, and dominates the circulation in the entire Gulf of Maine by May. Water enters this system from the east across the Scotian Shelf and either turns north into the Bay of Fundy or west toward the Maine coast. Less saline waters move from the Bay of Fundy and join with the westward moving gyre. The flow continues southwesterly paralleling the coast of Maine, turning eastward at Cape Ann and moving either into Cape Cod or continuing eastward and then north across Georges Bank. This eddy slows in June and by autumn the southern side diverts

into an easterly drift across Georges Bank.

A small counterclockwise eddy remains in the northeastern section of the Gulf during the autumn/winter seasons, maintaining an offshore component to the surface drift in the area off Penobscot Bay during the period.[235/] Figs. 35 thru 38 illustrate the seasonal surface circulation in the area, as inferred from drift bottle recoveries.

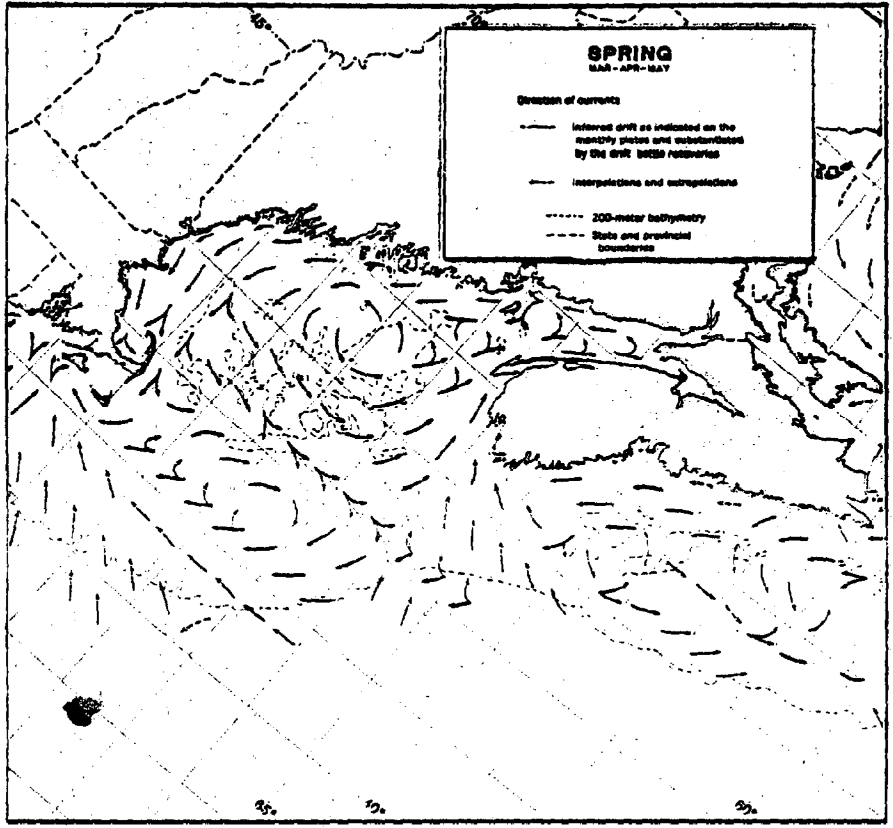
(a) Surface Circulation. The circulation in Maine's coastal waters, under the influence of the Gulf eddy, is predominantly southwesterly during all seasons. This southwesterly flow paralleling the coast is modified or strengthened by local wind conditions, density gradient reflected in the spring runoff, and the migratory nature of the Gulf Eddy. Surface currents are weak, with speeds ranging between 0.1 and 1.1 knots reported from all points of the compass.[236/]

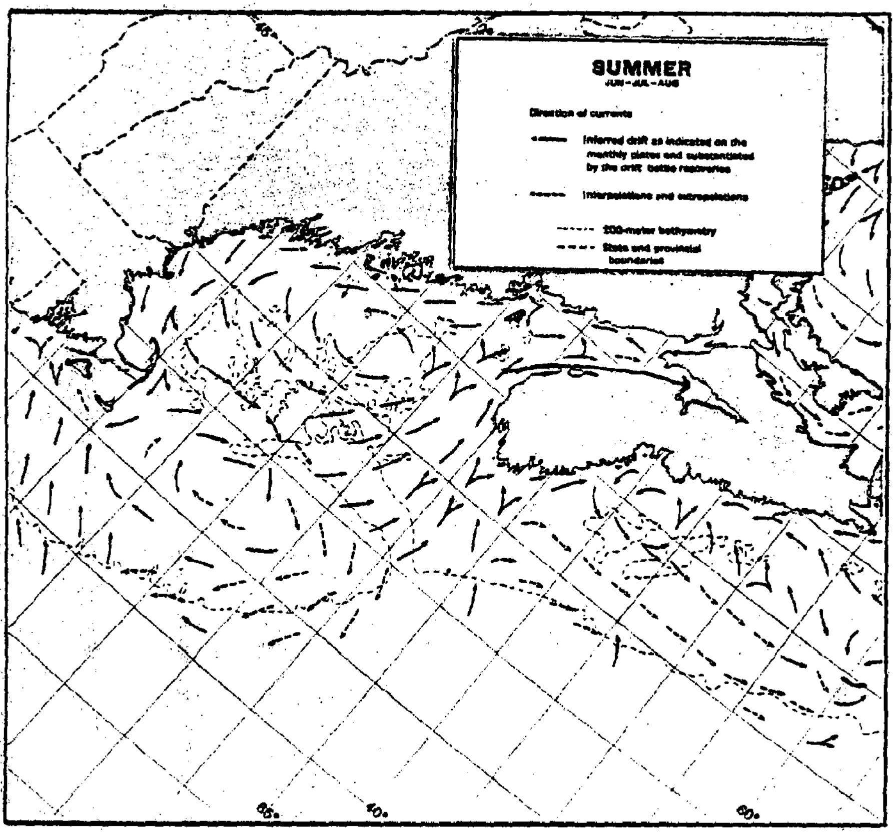
During a 1962-65 investigation, correlations between drift bottle recoveries (released from the Portland Lightship at 43°32'N and 70°06'W) and prevailing wind conditions showed the following pattern: In autumn, winds were mostly from north to west, and recoveries were made to the southwest and along the coast. In winter easterly winds were less and southwest winds were slightly greater than in the autumn, presumably leading to a greater loss of bottles to offshore waters. In spring, winds were more variable and so were the directions of recovery. Northern and western wind components still drove some bottles southwest, but a relative increase in southerly and easterly winds increased recoveries to the northeast. In summer, a comparatively greater frequency of winds from the southwest to southeast increased recoveries to the northeast.[237/] Fig. 39 shows the relationship to prevailing winds and straight line drift of bottles released from the Portland Lightship.

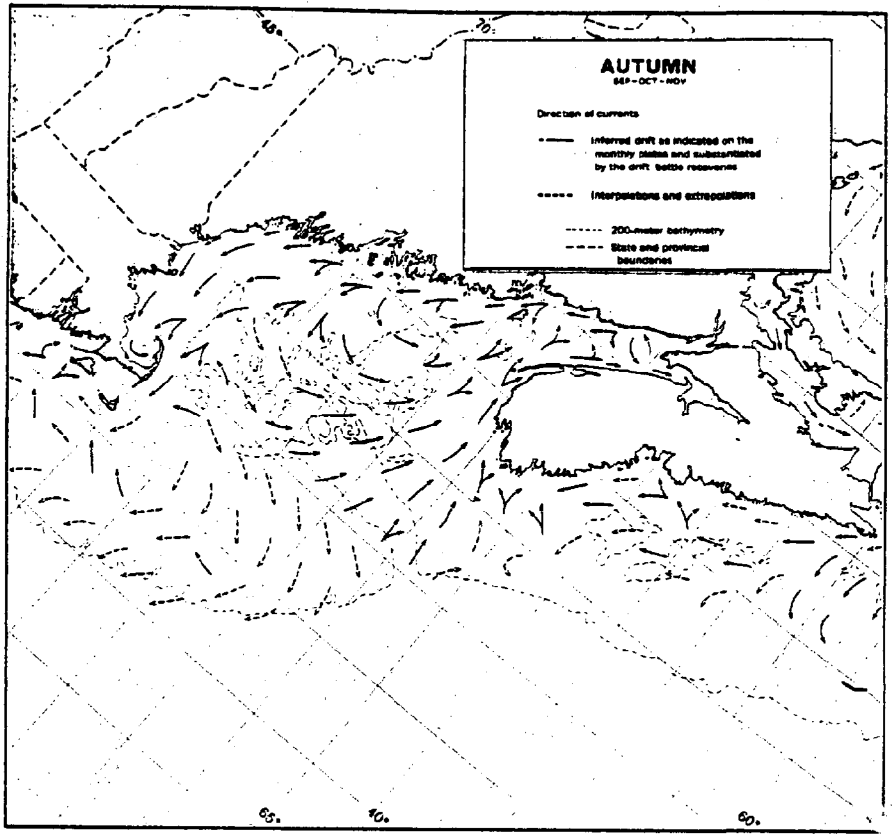
The Coriolis force deflects wind-driven currents to the right, and measurements made at the Portland Lightship showed that northerly winds produced surface currents deflected slightly to the right of the wind. Southerly winds blowing against the south-setting surface drift at times reversed the resultant surface drift either to the right or slightly to the left of the wind, depending on the interaction of wind direction and strength, original direction of the current, and configuration of the coast.[238/] Table 13 shows the expected amount of deflection for wind-generated surface currents at Portland and Boston Lightships.

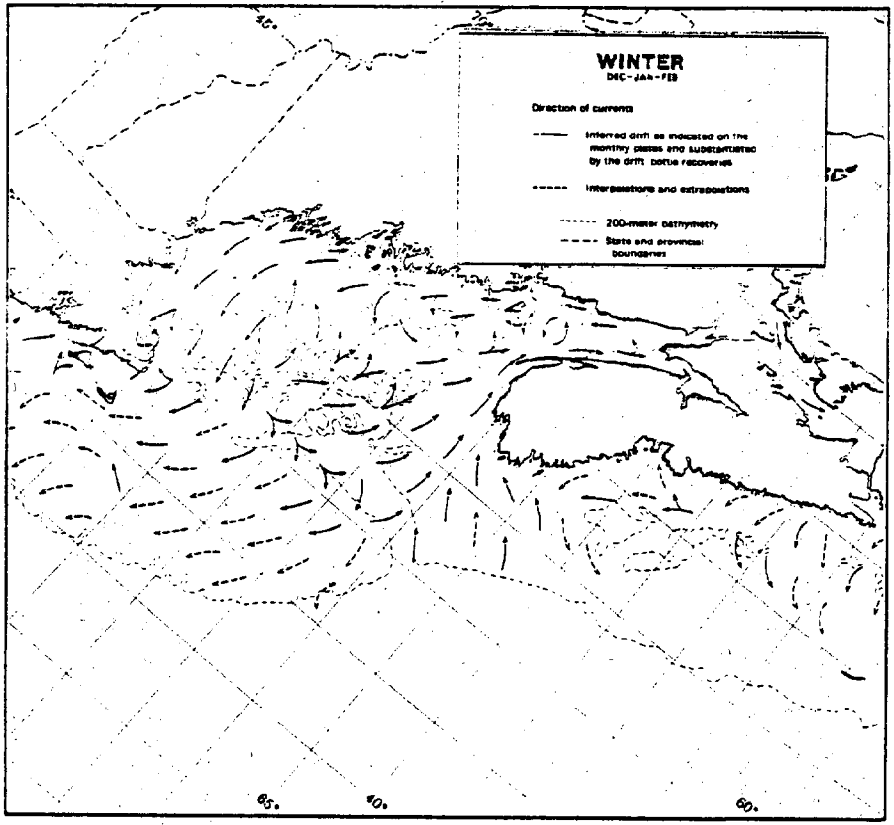
(b) Subsurface Drift. Based on seabed drifter recoveries, bottom waters tend to move shoreward and into the bays and estuaries during all seasons. This shore-

Figures 35-38.--Gulf of Maine surface circulation.



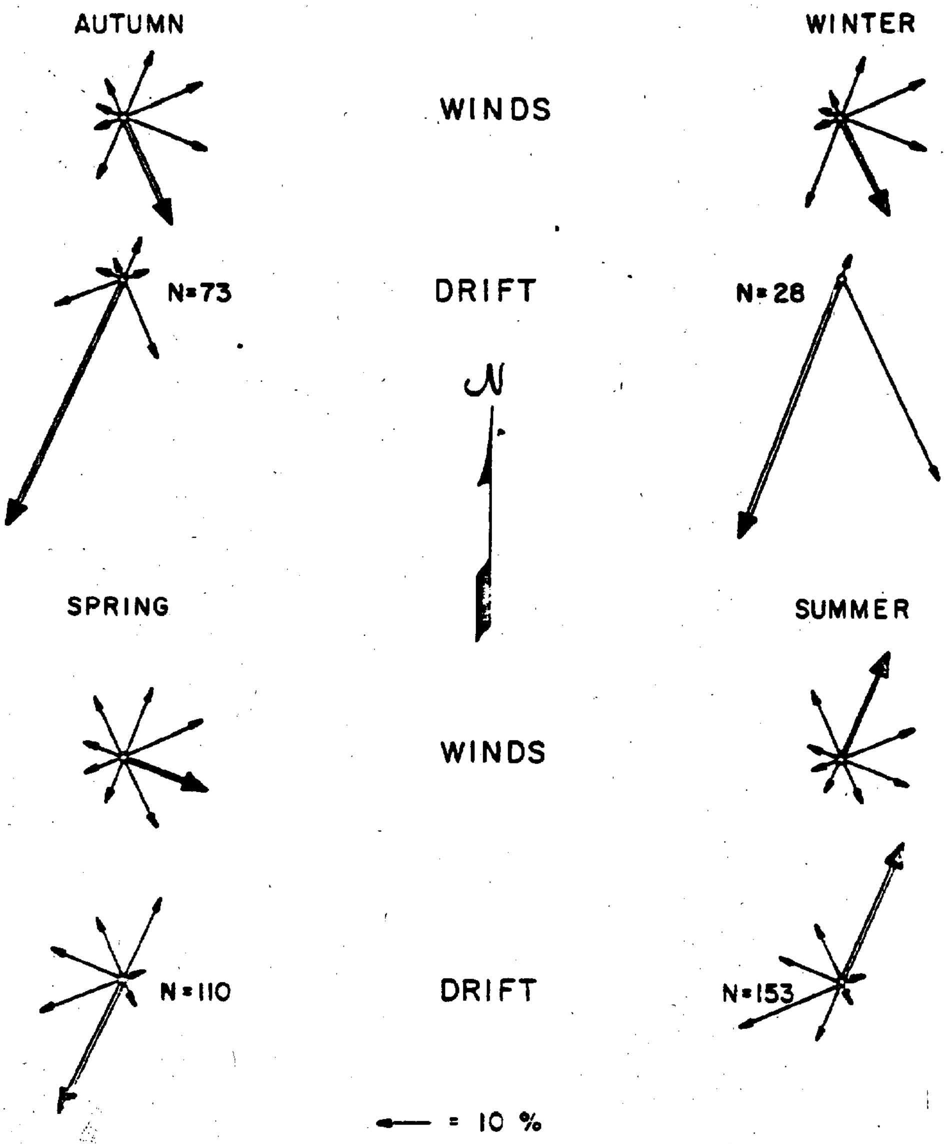






Source: Bumpus, D.F., and L.M. Lauzier, 1965: Surface Circulation on the Continental Shelf off Eastern North America Between Newfoundland and Florida. Serial Atlas of the Marine Environment, Folio 7, American Geographical Society.

Figure 39.--Frequencies of prevailing wind directions and the straight-line drift of bottles released from Portland Lightship. A double-line arrow indicates the largest percentage for each rosette of frequencies.



Source: Graham, J.J., 1970: Coastal Currents of the Western Gulf of Maine. International Commission for the Northwest Atlantic Fisheries, Research Bulletin No. 7.

Table 13.--Average deviation of current to right of wind direction. A minus sign (-) indicates that the current sets to the left of the wind.

Wind from			N.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.
Old Lightship Stations	Lat. ° '	Long. ° '	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Portland	43 32	70 06	24	14	9	8	-2	-14	0	26	15	18	18	24	15	34	13	18
Boston	42 20	70 45	--	-1	--	21	--	32	--	29	--	20	--	2	--	19	--	15

Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1972: Tidal Current Tables, 1972 -- Atlantic Coast of North America, Rockville, Md.

ward bottom component appears to reflect the removal of less saline waters along the surface. Movements along the coast are in a general southerly direction paralleling the coast and reflect the general surface circulation.

5. Water Mass Characteristics.

(a) General. The distribution of temperature and salinity in the Gulf of Maine already has been described in considerable detail (see Atlantic Coast, Part 1). The following discussion focuses on the coastal waters of Maine.

Tidal mixing is an important component in determining the vertical distributions of temperature and salinity during all seasons along the Maine coast. Progressively greater tidal mixing occurs eastward along the coast, and consequently, water characteristics along the eastern section are quite homogeneous with depth during all seasons. The western section, however, reflects lower tidal mixing, and exhibits seasonal ranges between surface and bottom conditions.[239]

(b) Temperature. Wide seasonal temperature ranges (4°C - 16°, August) occur between surface and bottom waters in central and western sections, however, temperatures at 20 meters are relatively uniform along the entire coast. During the fall and winter seasons, temperatures are quite uniform from top to bottom. Within surface water, temperature gradients are usually perpendicular to the coastline with temperatures generally increasing with distance from the coast.[240]

Annual and 5-year mean surface-temperature values recorded at Eastport, Bar Harbor, Portland, and Portsmouth show cyclic trends of heating and cooling. This cyclic range amounts to about 2°C for the mean annual values and can be traced to variations in weather conditions. The maximum and minimum surface values recorded at Eastport and Portland, for the period 1965-71, were -1.0°C to 14°C and -2.0°C to 19°C respectively.[241] Fig. 40 shows the monthly ranges of temperature at the surface for Mt. Desert Rock Light Station and Portland Lightship. Temperature ranges for the Gulf of Maine as a whole to depths of 300 meters are shown in Table 14.

(c) Salinity. As with temperatures, salinities along the eastern section are quite homogeneous throughout the water column. Southwestward along the coast, tidal mixing is not as great and salinities increase with depth. The spring river discharge is quite evident in the general lowering of salinities along the entire coast from March to May. Surface salinities are much lower along the western section (<30.5 ‰) and also show wider ranges between surface and bottom waters during this period. These higher bottom salinities can be attributed to lower levels of tidal

Figure 40.--Sea-surface temperatures by month at Mt. Desert Rock Light Station and Portland Lightship. The solid lines represent the temperature for 1970. The dashed lines represent the maxima, means, and minima for the periods 1957-68 (Mt. Desert Rock) and 1956-69 (Portland).

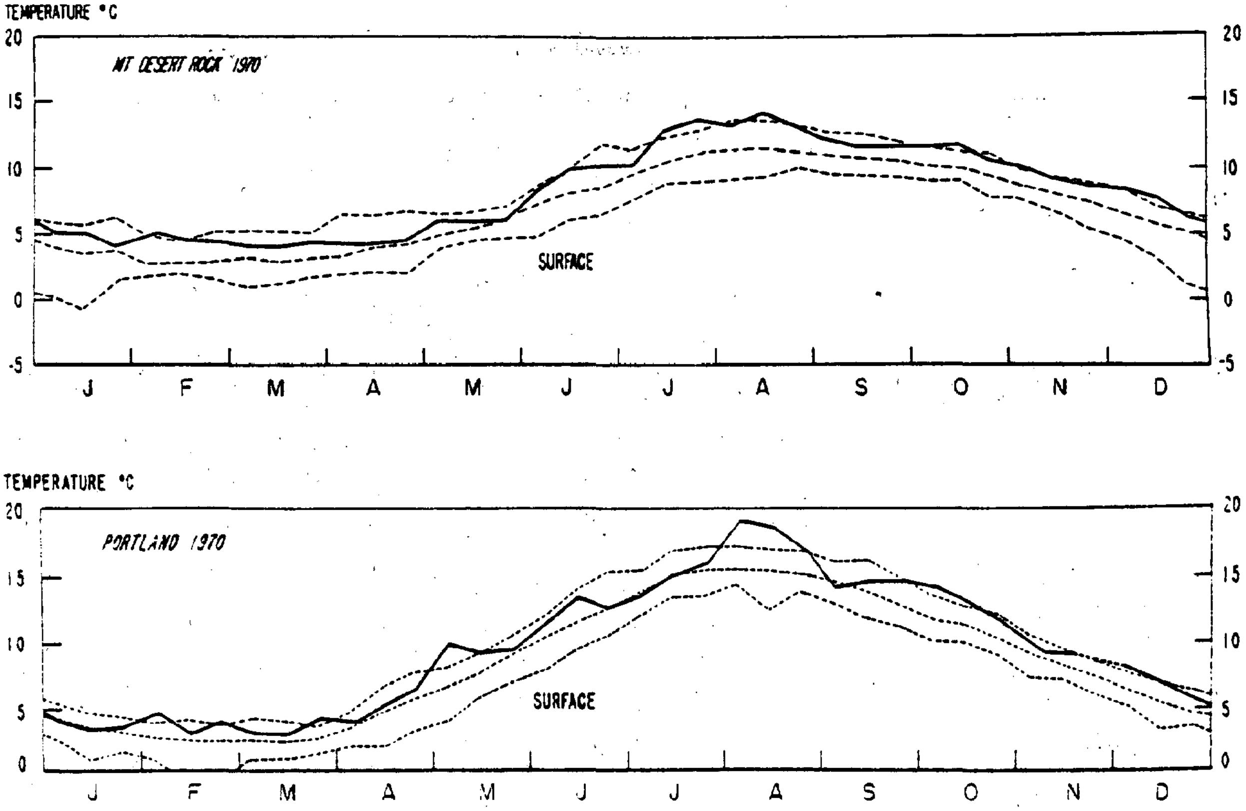
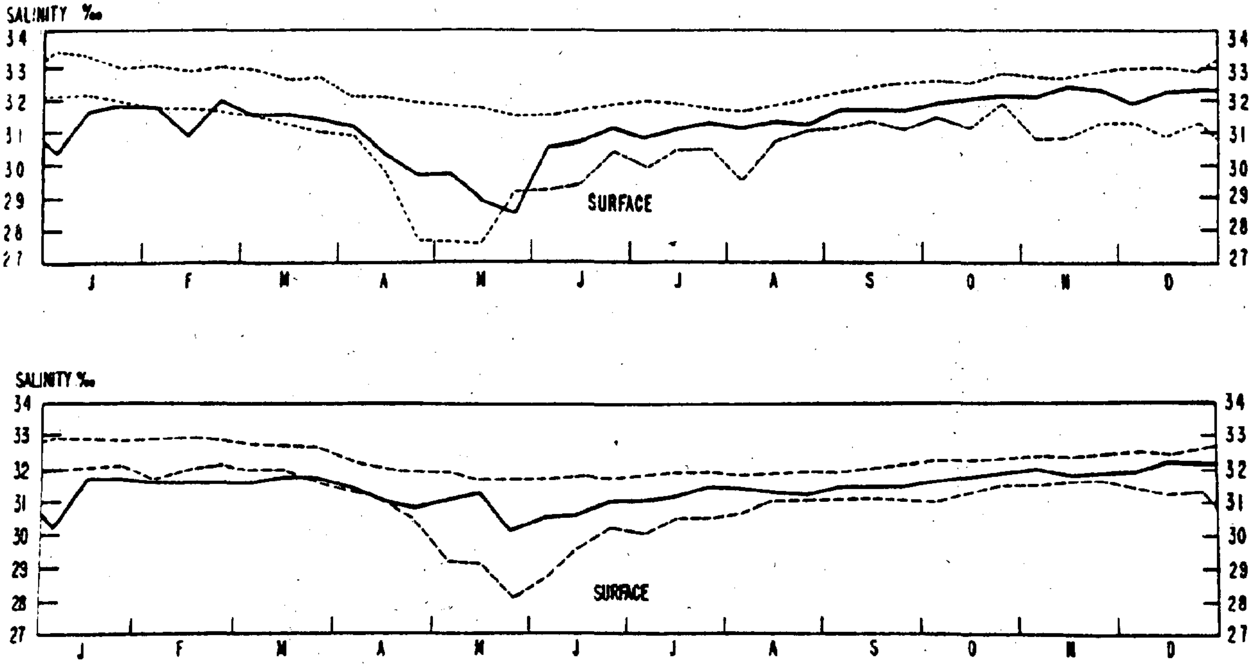


Figure 41.--Surface salinities by month at Portland (top) and Boston (bottom) Lightships. The solid lines represent salinity for 1970. The dashed lines are maxima and minima for the period 1956-69.



Source: Chase, J., 1972: Oceanographic Observations Along the East Coast of the United States -- January - December 1970. Oceanographic Report No. 53, U.S. Coast Guard.

Table 14.--Seasonal water temperature vs. depth, 42-45°N, 66-72°W.

MONTHS 1 - 3 NUMBER MONTHS PRESENT 1, 2, 3

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	5.83	2.82	-0.50	257	1.27
10	5.95	2.81	-0.42	259	1.29
20	6.28	2.83	-0.22	254	1.27
30	6.54	2.93	-0.17	241	1.27
50	6.71	3.10	0.0	203	1.28
75	7.23	3.70	0.0	160	1.33
100	7.94	4.47	1.77	125	1.49
125	8.08	5.21	2.00	107	1.40
150	8.15	5.79	3.23	99	1.24
200	7.83	6.33	4.32	54	0.86
250	7.27	6.26	4.27	16	0.78
300	6.48	5.78	4.14	4	1.11

MONTHS 4 - 6 NUMBER MONTHS PRESENT 4, 5, 6

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	17.05	7.37	2.36	596	3.83
10	15.43	6.45	1.92	596	3.17
20	12.54	5.33	1.79	589	2.23
30	10.79	4.54	1.71	569	1.62
50	9.34	3.89	1.52	510	1.20
75	8.16	3.78	1.35	373	1.09
100	8.15	4.03	1.67	276	1.11
125	9.11	4.50	1.85	239	1.16
150	8.68	5.09	2.42	207	1.13
200	8.31	5.99	3.96	128	0.90
250	8.56	5.97	3.83	26	1.10
300	6.43	5.01	4.08	8	1.13

MONTHS 7 - 9 NUMBER MONTHS PRESENT 7, 8, 9

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	21.99	15.30	8.80	474	2.53
10	21.09	13.92	7.68	476	2.50
20	18.76	11.41	5.90	473	2.36
30	16.44	9.32	3.99	462	2.25
50	15.59	7.14	2.89	422	2.06
75	13.76	5.93	3.11	342	1.78
100	9.53	5.41	2.81	292	1.49
125	9.70	5.41	2.91	256	1.31
150	9.73	5.64	2.96	220	1.23
200	8.70	6.11	4.61	117	1.04
250	8.12	6.67	4.74	27	0.90
300	7.10	6.60	6.16	6	0.34

MONTHS 10 - 12 NUMBER MONTHS PRESENT 10, 11, 12

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	15.22	8.77	2.50	240	2.66
10	14.66	8.70	2.59	240	2.48
20	14.59	8.58	3.80	239	2.28
30	12.86	8.57	3.50	213	1.92
50	11.38	7.96	4.03	179	1.48
75	11.00	7.14	3.66	138	1.38
100	10.26	6.67	3.75	114	1.26
125	9.73	6.36	3.99	97	1.17
150	9.15	6.40	4.26	87	1.08
200	7.98	6.58	4.99	43	0.85
250	7.63	6.73	5.14	12	0.74
300	6.16	6.16	6.16	1	0.0

Source: Churgin, J., and S.J. Halminski, 1974: Temperature, Salinity, Oxygen, and Phosphate in Waters Off United States. Key to Oceanographic Records Documentation No. 2, Vol. I, Western North Atlantic, Environmental Data Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C. In press.

mixing and to bottom indrafts of higher saline waters to compensate for the large volumes of fresh water removed at the surface.[242] Fig. 41 shows the range of surface salinities by month for the Portland and Boston Lightships. The single feature that stands out in both locations is the lower surface salinities that result from the spring river runoff.

(d) Oxygen. Oxygen values for the entire Gulf of Maine generally show high concentrations with depth during the winter (Jan.-Mar.) and spring (Apr.-June) seasons, with mean surface values of 7.43 and 7.85 ml/l respectively. Mean surface values for the summer (July-Sept.) and winter (Oct.-Dec.) seasons are somewhat lower at 6.17 and 6.50 ml/l, respectively. The spread of values is greatest during the spring, the highest surface oxygen concentration also appearing at this period, with surface values between 6.22 and 9.96 ml/l. Oxygen values decrease slowly with depth; and relatively high values are found at 125 meters. The annual mean range at 125 meters is 5.56-6.28 ml/l. These values are based on unpublished summaries of data prepared by the National Oceanographic Data Center.

(e) Other.

(i) Phosphate. For the Gulf of Maine in general, phosphate values increase with depth. Maximum surface values occur during the fall and winter months (Oct.-Mar.), with values reaching 1.37 microgram-atoms/liter (µg-at/l).

Mean surface values for the fall (Oct.-Dec.) and winter (Jan.-Mar.) show seasonal highs at 0.93 and 0.85 (µg-at/l), respectively. Mean surface values for spring (Apr.-June) and summer (July-Aug.) show seasonal lows at 0.48 and 0.29 (µg-at/l), respectively.

At depths of 100 m, phosphate values display some uniformity, with seasonal means ranging between 0.99 and 1.09 (µg-at/l). These values are based on unpublished summaries prepared by the National Oceanographic Data Center.

(ii) Nitrate. Nitrate data are limited. Values recorded off Grand Manan, Me.[243] showed values ranging between 8 and 10 (µg-at/l) with depth during all months. The distribution of nitrates over the Gulf of Maine are very similar to that found for phosphate.[244]

(iii) Transparency. Transparency generally increases from inshore to offshore, and at times the distribution of transparency isolines agree closely with that of surface temperature. The coastal waters showed higher transparency during the spring and the least during the fall.[245]

(iv) pH. Surface pH values range between 7.9 and 8.19 for the Gulf of Maine. Subsurface readings tend to group around 7.9.[246]

CLIMATOLOGY

1. General. The Gulf of Maine lies in the region of most frequent movement of cyclonic storms.[247] It is in the general zone of west to east motion on which are superimposed northward and southward movements of large air masses from tropical and polar regions. The Labrador Current flows southward along the Nova Scotia coast; branching to bring cold water into the Gulf of Maine, it exerts a moderating influence on the immediate coastal and near offshore regions.

2. Extratropical cyclones. Lying along paths most frequently followed by extratropical cyclones, the area experiences frequent wind shifts and rapid weather changes in the cooler seasons. These depressions generally enter the area from the west or from the southwest, the latter (nor'easters) normally being of greater severity due to a considerable passage over water. Heavy rain or snow before the passage of the storm center may be extensive and winds of hurricane force sometimes accompany them. After the storm center passes, the northwesterly winds, coming directly from the interior, are often bitterly cold.

The classical "nor'easter" is so-called because winds over the coastal area are from the northeast. Such storms may occur at any time, but are most frequent and violent between September and April. They usually develop in the area 30° to 40°N, within about 100 mi of the coast, and move north to northeastward, attaining maximum intensity near New England and the Maritime Provinces. They nearly always bring precipitation and frequently gale-force winds to the coastal area.

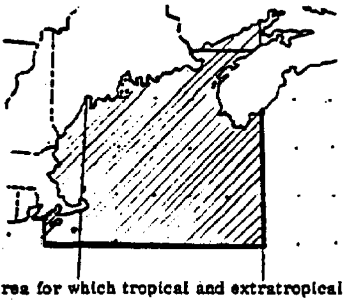
(a) Coast. The coast from Cape Cod northward is vulnerable to storms. From 1963 to 1972, a total of 325 storms has affected this area (passed within 1°). Most were not severe. Frequencies of wind speeds show that from November through March, winds ≥ 34 knots occur on over 4 percent of the observations, reaching 7.7 percent in February. Table 15 contains a monthly count of extratropical cyclone activity over a 10-year period.[248]

3. Tropical cyclones. Tropical cyclones, although much rarer than the extratropical variety, occasionally move northward in late summer and autumn. A total of 57 tropical cyclones has affected this region since 1900.[249] The storm centers

Table 15.--Climatological summaries for area 1.

TROPICAL CYCLONE AND EXTRATROPICAL CYCLONE ACTIVITY

COASTAL AREA 41°N TO COAST, 65°W TO COAST



Area for which tropical and extratropical cyclone statistics appear below.

Tropical Cyclone Activity 1900-1972

	Feb.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tropical Storm Stage (34 to 63 kt)			1	2	4	5	2			14
Hurricane Stage (≥ 64 kt)					9	13	4			26
Extratropical Stage	1		2		1	7	5	1		17
Total	1		3	2	14	25	11	1		57

Extratropical Cyclones Affecting Area 1963-1972

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
37	35	31	27	23	19	18	18	18	25	36	38	325

Tropical Cyclones Striking within 50 Mi of the Coast, Northern Maine to Portsmouth, N. H., 1900-72

	Feb.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tropical Storm Stage (34 to 63 kt)				1		3				4
Hurricane Stage (≥ 64 kt)					1	1	2			4
Extratropical Stage	1		1	1	1	4	1			9
Total	1		1	2	2	8	3			17

METEOROLOGICAL TABLES FOR AREA 1 -- 42°N TO COAST, 66°W TO COAST

Mean Recurrence Intervals

	5 yr	10 yr	25 yr	50 yr	100 yr
Maximum Sustained Wind (kt)	72	80	92	103	117
Maximum Significant Wave Height (ft)	41	46	54	61	69
Extreme Wave Height (ft)	74	84	98	110	124

Percentage Frequency of Wind Direction by Speed

January

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.3	5.2	4.4	1.3	.4	327	12.8	18.0
NE	1.1	3.3	1.9	1.4	.2	175	6.8	18.7
E	.7	2.4	2.3	1.2	.2	170	6.6	19.2
SE	.6	2.8	2.3	.9	*	166	6.4	17.8
S	.9	3.7	2.6	1.1	.1	216	8.4	18.8
SW	1.3	5.8	4.8	1.8	.4	351	13.7	17.2
W	2.2	6.5	8.6	4.6	.4	563	22.0	19.7
NW	.9	7.8	9.7	4.4	.3	574	22.4	20.8
VAR	*	.0	.0	.0	.0	1	*	3.0
CALM	.7					17	.7	.0
TOT	241	900	786	429	46	2559	100.0	18.8
PCT	9.4	35.4	30.6	16.6	1.8	100.0		

February

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.3	5.4	4.1	1.3	.2	261	12.4	17.1
NE	.9	3.3	1.8	.7	.2	144	6.8	16.6
E	.7	2.9	2.1	.9	.6	150	7.1	18.6
SE	.6	2.6	2.4	.2	.1	120	5.7	17.3
S	.6	3.4	3.0	.7	.1	171	8.1	16.9
SW	1.0	5.6	4.3	1.2	.2	262	12.4	17.2
W	1.4	9.2	8.9	3.9	.6	507	24.0	19.2
NW	1.3	7.3	9.0	4.6	.8	480	22.7	20.3
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	.9					18	.9	.0
TOT	180	836	759	281	57	2113	100.0	18.3
PCT	8.5	39.6	35.9	13.3	2.7	100.0		

March

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.1	5.6	4.9	1.3	.1	319	13.0	17.3
NE	1.2	3.8	2.6	.8	*	207	8.5	15.9
E	1.0	3.0	2.0	.7	*	164	6.7	15.9
SE	1.0	3.6	1.9	.8	*	175	7.2	15.5
S	1.1	5.1	2.3	.5	.0	221	9.0	14.4
SW	1.9	5.5	3.9	1.1	.1	306	12.5	15.8
W	1.8	8.1	9.2	4.4	.2	576	23.6	19.2
NW	1.8	6.3	8.3	2.2	.1	449	18.4	18.1
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	1.1					28	1.1	.0
TOT	284	996	858	291	16	2443	100.0	16.9
PCT	11.6	40.7	35.1	11.9	.7	100.0		

April

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.4	5.1	2.4	1.0	.2	270	11.2	14.9
NE	1.0	3.7	1.4	.4	.0	159	6.6	14.1
E	1.8	4.9	1.0	.3	.0	190	7.8	11.3
SE	1.8	5.8	2.3	.4	.0	236	9.8	13.0
S	3.0	8.8	4.0	1.0	.0	398	16.5	13.7
SW	2.5	8.1	4.0	.7	*	372	15.4	13.8
W	2.5	9.2	4.2	.7	.1	404	16.7	13.9
NW	1.8	7.3	3.8	.9	*	332	13.7	14.6
VAR	.1	.0	.0	.0	.0	2	.1	2.0
CALM	2.2					54	2.2	.0
TOT	469	1250	561	128	10	2417	100.0	13.5
PCT	19.4	52.0	23.2	5.3	.4	100.0		

May

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.0	4.0	1.0	.2	.0	194	7.2	11.0
NE	1.5	4.1	2.2	.3	.0	215	8.0	13.3
E	2.3	4.3	1.5	.3	.0	220	8.4	11.9
SE	2.5	5.1	1.9	.1	.0	254	9.3	11.5
S	4.4	10.3	4.9	.8	*	550	20.3	13.0
SW	2.5	10.4	5.4	.8	.0	514	19.2	14.1
W	2.9	9.0	2.2	.2	.0	385	14.4	11.7
NW	1.6	4.9	1.6	.2	.0	221	8.2	12.3
VAR	*	.0	.0	.0	.0	1	*	2.0
CALM	4.5					120	4.5	.0
TOT	644	1400	555	80	1	2680	100.0	12.0
PCT	24.0	52.2	20.7	3.0	*	100.0		

June

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.9	4.2	1.5	.2	.0	197	7.7	11.6
NE	1.3	3.3	1.0	.1	.0	146	5.7	11.4
E	2.0	2.7	.8	.2	.0	161	6.3	10.2
SE	2.5	4.3	.9	.0	.0	198	7.7	10.0
S	4.3	14.1	7.0	.2	.0	657	25.6	13.0
SW	3.9	14.7	5.1	.3	.0	617	24.0	12.4
W	3.0	8.1	1.8	*	.0	335	13.1	11.1
NW	1.6	3.5	1.1	.1	*	163	6.3	11.7
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	3.6					93	3.6	.0
TOT	636	1411	492	28	1	2567	100.0	11.4
PCT	24.7	55.0	19.2	1.1	*	100.0		

Percentage Frequency of Wind Direction by Speed (Area 1 cont.)

July

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.0	3.3	.3	.1	.0	155	5.7	9.5
NE	2.1	2.5	.4	.0	.0	136	5.0	8.4
E	2.3	2.0	.2	.0	.0	144	5.3	7.7
SE	3.0	5.5	.6	.0	.0	247	9.0	9.0
S	5.7	16.1	4.5	.1	.0	720	26.4	11.5
SW	4.9	17.7	3.9	.1	.0	725	26.5	12.5
W	3.6	7.2	.7	.0	.0	315	11.5	9.3
NW	1.9	3.1	.3	.1	.0	148	5.4	9.4
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	5.0					136	5.0	.0
TOT	841	1582	298	11	0	2732	100.0	9.9
PCT	30.8	57.9	10.9	.4	.0	100.0		

August

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.7	3.9	1.4	.1	*	201	7.2	11.7
NE	1.2	1.6	1.1	.2	.1	175	6.2	12.5
E	1.6	3.2	.6	.2	.0	157	5.6	10.0
SE	2.1	6.0	1.2	.1	.0	265	9.5	10.8
S	4.7	15.7	4.0	.4	*	697	24.9	11.7
SW	4.5	14.8	3.8	.1	.0	652	23.3	11.7
W	2.7	7.3	1.4	.2	.0	328	11.7	10.9
NW	2.8	4.4	.9	.1	.0	206	7.3	10.7
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	4.4					123	4.4	.0
TOT	703	1655	407	35	4	2804	100.0	10.9
PCT	25.1	59.0	14.5	1.2	.1	100.0		

September

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.1	6.4	3.2	.4	*	319	12.2	13.7
NE	2.9	5.1	1.6	.3	.0	265	10.1	11.7
E	2.1	3.4	.7	.2	*	171	6.5	11.4
SE	1.4	4.1	1.5	.2	.0	198	7.6	11.8
S	2.8	8.2	4.5	.3	.1	420	16.1	13.5
SW	3.3	9.5	3.7	.2	.1	439	16.8	12.7
W	3.4	8.5	2.4	.1	.0	377	14.4	11.3
NW	2.4	7.7	2.6	.1	.0	335	12.8	12.1
VAR	.1	*	.0	.0	.0	4	.2	3.8
CALM	3.4					90	3.4	.0
TOT	634	1388	539	55	6	2616	100.0	12.0
PCT	24.2	53.1	20.6	2.1	.2	100.0		

October

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.7	5.5	3.1	1.0	*	246	11.3	15.0
NE	1.4	4.6	3.0	.7	.2	192	8.8	14.9
E	1.1	4.6	1.8	.9	*	188	8.7	14.9
SE	1.8	5.0	1.2	.2	.0	180	8.3	11.4
S	2.4	8.8	4.1	.5	.0	343	15.8	13.5
SW	2.8	9.9	4.1	.8	.0	382	17.6	12.1
W	1.7	7.6	5.0	1.7	.1	336	15.5	16.3
NW	1.0	6.2	3.2	.9	.3	252	11.6	16.2
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	2.4					53	2.4	.0
TOT	353	1124	535	144	15	2171	100.0	14.1
PCT	16.3	51.8	24.6	6.6	.7	100.0		

November

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.2	5.8	3.8	1.1	.0	273	12.0	15.9
NE	.8	4.2	2.1	.4	.2	176	7.7	16.2
E	1.1	2.2	1.9	1.0	.3	148	6.5	17.8
SE	.9	3.3	3.0	.7	.2	186	8.2	17.0
S	1.4	6.4	4.1	.7	*	288	12.6	15.4
SW	1.5	6.9	4.5	1.0	*	318	14.0	15.6
W	1.5	7.7	7.6	2.1	.5	443	19.4	18.4
NW	1.6	7.2	6.5	2.8	.3	419	18.4	18.3
VAR	*	.0	.0	.0	.0	1	*	2.0
CALM	1.2					28	1.2	.0
TOT	280	996	765	221	36	2278	100.0	16.8
PCT	12.3	43.7	33.6	9.7	1.6	100.0		

December

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.1	3.8	4.4	2.2	.4	262	11.9	19.9
NE	.9	2.7	3.1	1.4	.1	181	8.2	18.9
E	.8	2.5	1.2	.3	.0	105	4.8	14.0
SE	1.0	3.1	1.9	.8	.2	152	6.9	16.1
S	1.1	4.5	4.1	.7	.2	232	10.6	16.3
SW	1.3	6.8	5.0	1.6	.2	331	15.1	16.8
W	1.6	7.0	9.2	4.2	.5	501	22.8	20.4
NW	1.7	5.9	7.6	3.1	.4	411	18.7	19.3
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	1.0					23	1.0	.0
TOT	235	796	801	316	50	2198	100.0	18.3
PCT	10.7	36.2	36.4	14.4	2.3	100.0		

Annual

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.7	4.8	2.8	.8	.1	3024	10.2	15.1
NE	1.4	3.6	1.8	.5	.1	2169	7.3	14.4
E	1.6	3.2	1.3	.5	.1	1974	6.7	13.5
SE	1.6	4.2	1.7	.3	.1	2373	8.0	13.0
S	2.8	9.0	4.1	.6	*	4915	16.6	13.4
SW	2.7	9.9	4.4	.8	.1	5269	17.8	13.8
W	2.6	7.9	4.9	1.7	.2	5070	17.1	15.9
NW	1.6	5.8	4.4	1.5	.2	3990	13.5	16.8
VAR	*	*	.0	.0	.0	9	*	2.9
CALM	2.7					784	2.7	.0
TOT	5469	14340	7500	2020	242	29579	100.0	14.2
PCT	18.5	48.5	25.4	6.8	.8	100.0		

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Winds ≥34 kt	7.4	7.7	4.3	1.5	.6	.2	.1	.4	.9	2.3	4.5	7.3	3.0
Winds ≥48 kt	.4	.9	.2	.1	0	0	0	*	.1	*	1.0	.9	.3

Percentage Frequency of Visibility (Nautical Miles) by Hour

January

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.4	.6	.6	1.3	7.1	11.6	429
06&09	.6	.2	.3	1.0	7.1	8.0	335
12&15	.9	.9	1.0	2.4	9.1	15.5	589
18&21	1.2	1.0	1.1	3.1	9.4	15.7	623
TOT	61	47	53	160	647	1006	1976
PCT	3.1	2.4	2.7	8.1	32.7	50.9	100.0

February

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.4	.5	.5	1.5	7.6	12.7	377
06&09	.4	.5	.3	1.5	6.8	7.7	279
12&15	1.2	.8	1.4	2.5	7.1	15.1	494
18&21	1.6	.6	.9	2.8	8.9	17.5	516
TOT	51	38	51	131	492	863	1626
PCT	3.1	2.3	3.1	8.1	30.3	53.1	100.0

March

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.3	.2	.8	1.8	8.0	13.6	436
06&09	.6	.2	.1	.5	8.3	9.0	343
12&15	.6	.5	.5	1.8	7.3	13.1	483
18&21	.5	.6	.9	2.5	8.8	17.4	570
TOT	35	24	41	128	605	1019	1852
PCT	1.9	1.3	2.2	6.9	32.7	55.0	100.0

April

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.8	.2	.5	1.0	6.8	12.2	394
06&09	.6	.3	.1	1.1	5.6	9.1	314
12&15	1.5	.6	.8	2.4	7.1	16.3	522
18&21	1.1	.8	1.0	2.3	8.7	18.4	597
TOT	77	35	45	131	516	1023	1827
PCT	4.2	1.9	2.5	7.2	28.2	56.0	100.0

May

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	2.5	.4	.3	1.2	7.3	11.4	449
06&09	2.3	.6	.5	.8	6.3	8.2	381
12&15	1.4	.6	.8	1.3	8.4	15.1	543
18&21	1.8	.8	.4	2.4	10.1	15.3	601
TOT	159	45	34	112	628	976	1994
PCT	8.1	2.3	1.7	5.7	32.1	49.9	100.0

June

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	2.9	.7	.6	2.7	7.6	9.6	455
06&09	2.3	.4	.5	.5	7.0	7.2	330
12&15	2.6	1.2	.7	3.6	6.7	12.1	491
18&21	2.9	1.0	1.3	3.4	9.1	13.4	536
TOT	189	59	57	193	548	766	1812
PCT	10.4	3.3	3.1	10.7	30.2	42.3	100.0

July

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	3.5	.8	1.0	2.6	8.7	9.0	483
06&09	3.7	.6	.5	.9	6.7	5.6	344
12&15	4.9	.9	.9	2.4	7.6	8.4	480
18&21	3.3	.6	1.6	3.1	10.7	11.6	592
TOT	294	58	77	170	641	659	1899
PCT	15.5	3.1	4.1	9.0	33.8	34.7	100.0

August

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	3.1	.6	.5	2.5	8.4	11.2	521
06&09	3.3	.3	.3	1.0	7.0	8.2	399
12&15	3.0	.4	1.5	1.9	7.3	10.7	491
18&21	1.6	.9	1.0	2.5	9.6	12.4	575
TOT	237	43	65	156	641	844	1986
PCT	11.9	2.2	3.3	7.9	32.3	42.5	100.0

September

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	1.4	.3	.5	.9	6.7	15.1	479
06&09	1.7	.4	.2	1.1	6.0	10.8	388
12&15	1.7	.6	.8	1.1	6.2	15.8	503
18&21	1.2	.4	.8	1.7	7.2	17.3	551
TOT	116	31	44	92	503	1133	1921
PCT	6.0	1.7	2.3	4.8	26.2	59.0	100.0

October

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	1.0	.2	.3	1.0	7.6	13.0	378
06&09	1.4	.3	.2	.4	6.8	14.3	380
12&15	.9	.2	.2	1.4	8.4	14.5	416
18&21	.5	.2	.3	1.4	10.6	14.5	451
TOT	65	17	18	68	542	915	1625
PCT	4.0	1.0	1.1	4.2	33.4	56.3	100.0

November

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.4	.3	.2	1.2	7.3	12.0	366
06&09	.2	.1	.3	.9	8.1	10.3	344
12&15	.9	.3	1.0	2.3	7.7	16.7	498
18&21	.5	.5	.6	1.8	9.1	17.3	512
TOT	35	21	35	107	553	969	1720
PCT	2.0	1.2	2.0	6.2	32.2	56.3	100.0

December

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.5	.2	.5	2.0	7.5	11.5	365
06&09	.5	.2	.2	1.0	6.2	8.5	275
12&15	1.1	.6	.5	2.2	9.3	14.7	470
18&21	1.9	.4	.7	3.1	9.7	17.3	541
TOT	60	24	33	137	536	859	1651
PCT	3.6	1.5	2.0	8.3	32.5	52.0	100.0

Annual

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	1.9	.4	.5	1.7	7.6	11.9	5134
06&09	1.5	.4	.5	.9	6.8	8.8	4092
12&15	1.6	.6	.9	2.1	7.7	14.1	5938
18&21	1.6	.6	.9	2.6	9.3	15.6	6685
TOT	1381	443	553	1586	6854	11032	21849
PCT	6.3	2.0	2.5	7.3	31.4	50.5	100.0

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Percentage Frequency of Wave Height (Feet) vs. Wave Period (Seconds) for Area I

January

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.5	14.0	7.5	4.0	1.4	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	223	2
6-7	.0	.3	11.8	3.8	2.9	.6	1.4	.1	.3	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	151	5
8-9	.0	.0	.3	8.7	2.3	.3	.7	.9	1.9	.1	.3	.1	.0	.0	.0	.0	.0	.0	.0	108	7
10-11	.0	.0	.1	.3	11.0	1.3	.0	.1	.4	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	92	7
12-13	.0	.0	.1	.0	.1	5.6	1.6	.1	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	55	8
>13	.0	.0	.0	.0	.0	.3	1.6	1.7	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	32	10
INDET	2.5	.1	1.0	.6	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	31	1
TOTAL	41	106	145	120	125	62	37	21	27	3	4	1	0	0	0	0	0	0	0	692	5
PCT	5.9	15.3	21.0	17.3	18.1	9.0	5.3	3.0	3.9	.4	.6	.1	.0	.0	.0	.0	.0	.0	.0	100.0	

February

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.8	13.7	9.3	2.8	2.0	.0	.2	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	207	2
6-7	.0	.2	17.0	2.1	2.8	2.6	1.3	1.1	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	172	6
8-9	.0	.2	1.0	12.1	1.1	.2	1.0	1.0	1.6	.3	.0	.2	.0	.0	.0	.0	.0	.0	.0	114	6
10-11	.0	.0	.0	.3	4.7	1.8	.2	.0	.2	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	47	7
12-13	.0	.0	.0	.2	.2	2.5	.3	.2	.0	.0	.0	.0	.2	.0	.0	.0	.0	.0	.0	21	9
>13	.0	.2	.0	.0	.0	.0	1.8	1.1	2.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	32	11
INDET	2.8	.0	.2	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	19	0
TOTAL	40	99	172	108	66	43	29	21	28	4	0	1	1	0	0	0	0	0	0	612	5
PCT	6.5	16.2	28.1	17.6	10.8	7.0	4.7	3.4	4.6	.7	.0	.2	.2	.0	.0	.0	.0	.0	.0	100.0	

March

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	6.7	17.9	5.6	2.9	1.1	.2	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	229	2
6-7	.0	.5	18.5	3.2	3.5	2.1	.6	.5	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	172	4
8-9	.0	.0	.3	12.9	2.3	.5	.2	.3	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	110	5
10-11	.0	.3	.0	.6	6.4	3.0	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	70	7
12-13	.0	.0	.0	.0	.9	2.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	22	7
>13	.0	.0	.2	.0	.0	.0	.6	.8	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11	13
INDET	2.7	.5	.0	.2	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	24	1
TOTAL	62	126	162	130	95	54	14	11	3	1	0	0	0	0	0	0	0	0	0	658	4
PCT	9.4	19.1	24.6	19.8	14.4	8.2	2.1	1.7	.5	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

April

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	10.6	29.5	3.6	2.3	1.6	.5	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	342	2
6-7	.0	1.1	12.9	3.9	1.6	.8	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	131	3
8-9	.3	.0	1.1	4.6	.8	.3	.5	.3	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	52	[illegible]
10-11	.0	.0	.0	.0	2.2	.2	.2	.0	.0	.2	.0	.2	.0	.0	.0	.0	.0	.0	.0	18	[illegible]
12-13	.0	.0	.0	.2	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2	[illegible]
>13	.0	.0	.0	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1	[illegible]
INDET	11.1	1.2	2.3	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	95	[illegible]
TOTAL	141	204	159	69	40	16	6	2	0	1	2	1	0	0	0	0	0	0	0	641	[illegible]
PCT	22.0	31.8	24.8	10.8	6.2	2.5	.9	.3	.0	.2	.3	.2	.0	.0	.0	.0	.0	.0	.0	100.0	

May

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	11.9	27.1	10.3	1.7	1.0	.1	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	377	1
6-7	.0	1.3	20.4	2.4	1.5	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	190	3
8-9	.0	.1	.1	5.0	1.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	69	5
10-11	.0	.1	.0	.0	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4	6
12-13	.0	.1	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2	6
>13	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1	8
INDET	10.1	1.8	1.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	97	0
TOTAL	159	220	233	68	29	5	5	0	1	0	0	0	0	0	0	0	0	0	0	720	2
PCT	22.1	30.6	32.4	9.4	4.0	.7	.7	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

June

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	13.1	29.9	15.4	2.7	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	406	1
6-7	.0	1.6	9.5	2.6	.8	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	98	3
8-9	.0	.8	1.4	3.0	.8	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	40	4
10-11	.2	.2	.5	.2	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	9	4
12-13	.0	.0	.0	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2	8
>13	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4	7
INDET	14.0	1.1	.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	103	[illegible]
TOTAL	181	223	183	58	15	1	0	1	0	0	0	0	0	0	0	0	0	0	0	662	[illegible]
PCT	27.3	33.7	27.6	8.8	2.3	.2	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

July

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	19.3	35.3	9.7	1.5	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	455	1
6-7	.1	1.9	9.4	1.6	.9	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	98	3
8-9	.0	.3	.6	.6	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13	4
10-11	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1	3
12-13	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	
>13	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	
INDET	16.4	.7	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	121	0
TOTAL	247	263	139	26	10	3	0	0	0	0	0	0	0	0	0	0	0	0	0	688	1
PCT	35.9	38.2	20.2	3.8	1.5	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

August

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	14.7	33.8	11.3	1.9	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	473	1
6-7	.3	.4	9.9	2.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	97	3
8-9	.0	.0	.1	1.4	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	15	5
10-11	.0	.0	.1	.0	1.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10	6
12-13	.0	.0	.1	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3	6
>13	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	
INDET	18.7	.9	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	151	0
TOTAL	252	263	173	43	16	1	0	1	0	0	0	0	0	0	0	0	0	0	0	749	1
PCT	33.6	35.1	23.1	5.7	2.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

September

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	12.7	35.4	16.9	1.9	.6	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	448	2
6-7	.0	1.3	9.7	1.9	1.6	.1	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	109	3
8-9	.0	.1	.4	2.7	.7	.4	.3	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	35	6
10-11	.0	.0	.3	.3	.6	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10	6
12-13	.0	.0	.0	.0	.0	.6	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	8
>13	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1	2
INDET	9.7	.4	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	71	0
TOTAL	152	259	176	46	24	11	9	3	1	0	0	0	0	0	0	0	0	0	0	679	2
PCT	22.4	38.1	25.9	6.8	3.5	1.6	1.3	.4	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

Percentage Frequency of Wave Height (Feet) vs. Wave Period (Seconds) (Area 1 cont.)

October

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	4.3	26.5	16.2	6.6	1.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	215	2
6-7	.0	.5	9.9	5.4	3.1	.8	1.5	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	85	4
8-9	.3	.0	.3	6.6	1.0	.8	1.3	.3	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	43	6
10-11	.0	.0	.0	.0	.8	.0	.0	.0	.5	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	6	10
12-13	.0	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3	14
>13	.0	.0	.0	.0	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2	10
INDET	5.6	2.3	1.0	.0	.0	.3	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	37	1
TOTAL	40	115	108	73	24	7	13	2	9	1	0	0	0	0	0	0	0	0	0	392	3
PCT	10.2	29.3	27.6	18.6	6.1	1.8	3.3	.5	2.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

November

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.6	21.6	14.4	3.1	.9	1.7	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	241	2
6-7	.0	.4	14.0	2.9	1.5	.9	1.3	.7	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	120	4
8-9	.0	.0	.2	6.1	2.0	.9	.7	.7	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	60	6
10-11	.0	.0	.0	.4	5.5	1.5	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	44	7
12-13	.0	.0	.0	.0	.0	3.7	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	23	8
>13	.0	.0	.0	.0	.0	.2	1.5	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	14	10
INDET	1.4	.0	.9	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	41	0
TOTAL	49	118	160	68	54	49	22	16	7	0	0	0	0	0	0	0	0	0	0	543	4
PCT	9.0	21.7	29.5	12.5	9.9	9.0	4.1	2.9	1.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

December

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	6.3	13.9	7.5	1.7	1.7	.7	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	187	2
6-7	.0	.0	18.6	2.1	3.0	1.4	.5	1.7	.5	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	161	4
8-9	.0	.2	1.2	12.7	2.6	1.7	1.4	.0	1.4	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	124	6
10-11	.0	.0	.0	.0	5.7	2.1	.7	.2	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	53	8
12-13	.0	.0	.0	.0	.3	.3	.2	.2	.2	.2	.2	.3	.0	.0	.0	.0	.0	.0	.0	12	13
>13	.0	.0	.0	.0	.0	.0	.0	.0	1.6	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	11	15
INDET	3.7	.3	.2	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	26	0
TOTAL	57	83	158	97	77	37	18	14	21	6	1	5	0	0	0	0	0	0	0	574	4
PCT	9.9	14.5	27.5	16.9	13.4	6.4	3.1	2.4	3.7	1.0	.2	.9	.0	.0	.0	.0	.0	.0	.0	100.0	

Annual

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	9.6	23.5	10.8	2.6	1.0	.4	.1	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3804	2
6-7	*	.9	18.6	2.8	1.9	.8	.0	.3	.2	*	*	*	.0	.0	.0	.0	.0	.0	.0	1804	4
8-9	*	.1	.6	6.2	1.3	.4	.5	.3	.5	.1	.1	*	.0	.0	.0	.0	.0	.0	.0	763	6
10-11	*	.1	.1	.2	3.2	.8	.1	.1	.1	.1	.0	*	.0	.0	.0	.0	.0	.0	.0	364	7
12-13	.0	*	*	.1	.1	1.3	.2	.1	.1	*	*	*	*	.0	.0	.0	.0	.0	.0	150	8
>13	.0	*	.1	.0	.0	.1	.5	.4	.4	.0	.0	*	.0	.0	.0	.0	.0	.0	.0	109	12
INDET	9.0	.8	.7	.1	.1	*	.0	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	616	0
TOTAL	1421	2079	1966	906	575	289	153	92	97	16	7	4	1	0	0	0	0	0	0	7610	3
PCT	18.7	27.3	25.8	11.9	7.6	3.8	2.0	1.2	1.3	.2	.1	.1	*	.0	.0	.0	.0	.0	.0	100.0	

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Waves ≥12 ft	6.0	9.1	2.4	1.0	.1	.2	0	.1	.5	3.1	4.2	6.2	2.9
Waves ≥20 ft	.7	.4	0	.5	0	0	0	0	0	0	0	1.1	.2
Maximum Seas	23-25	26-32	17-19	23-25	13-16	12	8-9	12	13-16	17-19	13-16	23-25	26-32

Consolidated Table of Meteorological Elements (Area 1)

	Weather Elements	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
[illegible]	Visibility < 2 naut. mi.	6.2	6.5	5.4	8.6	12.1	16.8	22.7	17.4	10.6	6.1	5.2	7.1
	Precipitation	21.7	23.7	15.3	11.7	9.6	8.0	4.7	5.9	7.2	7.0	13.2	22.1
	Sky overcast or obscured	45.6	44.2	35.0	34.5	34.2	32.2	31.1	30.8	28.9	28.8	40.8	47.0
	Thunder and lightning	0.0	0.1	0.0	0.1	0.1	0.4	0.5	0.5	0.3	0.1	*	0.0
	Temperature ≥ 85°F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Temperature ≤ 32°F	40.9	45.8	22.3	2.9	0.0	0.0	0.0	0.0	0.0	0.1	1.7	28.8
	Mean temperature (°F)	34.1	32.7	36.4	41.5	47.3	54.8	61.2	62.0	58.8	53.1	45.7	37.9
	Mean relative humidity (%)	79	79	78	80	85	86	89	88	84	81	78	80
	Mean cloud cover (eighths)	6.0	5.8	4.7	4.5	4.7	4.6	4.7	4.4	4.6	4.2	5.3	5.9
Millibars	Mean sea-level pressure	1014	1013	1013	1015	1015	1014	1015	1015	1018	1017	1016	1016
	Extreme maximum sea-level pressure	1052	1042	1040	1042	1038	1033	1030	1037	1041	1039	1041	1045
	Extreme minimum sea-level pressure	976	970	977	980	990	994	994	992	985	973	980	971

*0.0-0.05%

These data are based upon observations made by ships in passage. Such ships tend to avoid bad weather when possible, thus biasing the data toward good weather samples.

Potential Superstructure Icing (% Frequency)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
oderate (Air temp. < -2°C, wind ≥13 kt)	23.3	24.2	8.6	.5	0	0	0	0	0	0	.6	13.5
Severe(Air temp. < -9°C, wind ≥30 kt)	.8	.7	.1	0	0	0	0	0	0	0	0	.5

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Area 1

PERCENT FREQUENCY OF OCCURRENCE OF SEA TEMP (DEG F) BY MONTH

SEA TMP DEG F	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	PCT
96+	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
95/96	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
93/94	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
91/92	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
89/90	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
87/88	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
85/86	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
83/84	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	3	*
81/82	.0	.0	.0	.0	.0	.0	.0	.2	.0	.0	.0	.0	4	*
79/80	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	2	*
77/78	.0	.0	.0	.0	.0	.0	.0	*	.0	.0	.0	.0	1	*
75/76	.0	.0	.3	.0	.0	.1	*	.3	*	.1	.0	.0	12	*
73/74	.0	.0	.0	.0	.0	*	.2	.7	.3	.0	.0	.0	29	.1
71/72	.0	.0	.0	.0	.0	.1	1.0	1.6	.6	.0	.0	.0	83	.3
69/70	.0	.0	.0	.0	.0	.1	3.4	4.8	1.2	.4	.0	.0	250	.9
67/68	.0	.0	.0	.0	.0	.7	5.1	8.0	3.0	.2	.0	.0	426	1.6
65/66	.0	.0	.0	.0	.0	1.2	7.6	10.7	5.1	.7	.0	.0	630	2.4
63/64	.0	.0	.0	.0	.0	2.0	10.2	9.9	9.0	1.4	.1	.0	801	3.0
61/62	.0	.0	.0	.0	.3	3.6	8.7	9.8	11.1	2.3	.1	.0	873	3.3
59/60	.0	.0	.0	.0	.6	4.3	11.3	9.0	14.7	5.6	.8	.1	1095	4.1
57/58	.0	.0	.0	.0	.8	6.1	6.7	6.3	11.7	11.8	2.2	.1	1045	4.0
55/56	*	.0	.0	.1	2.0	7.2	5.4	4.6	10.2	18.8	3.4	.4	1157	4.4
53/54	.3	.0	.0	.5	2.5	9.7	5.0	4.2	6.3	18.1	8.0	.9	1216	4.6
51/52	.4	.2	.1	1.1	3.8	9.4	5.0	5.1	6.4	13.6	11.5	2.3	1290	4.9
49/50	1.1	1.2	.7	1.3	6.8	10.5	8.9	13.0	10.3	11.7	21.5	6.7	2082	7.9
47/48	1.9	1.2	1.4	2.1	9.6	8.9	11.3	9.8	8.9	9.5	19.4	11.9	2125	8.0
45/46	6.6	2.4	1.4	3.7	16.5	10.6	8.0	1.7	.4	5.1	20.0	18.1	1995	7.5
43/44	13.8	4.2	3.5	8.5	15.1	11.5	1.9	.1	.2	.6	10.5	25.7	2042	7.7
41/42	23.1	12.1	9.1	16.8	18.0	11.7	.3	*	.2	.1	2.2	23.4	2509	9.5
39/40	25.3	15.6	16.4	17.6	14.5	2.0	.2	.0	.0	.1	.2	7.3	2136	8.1
37/38	16.4	21.4	23.7	28.4	10.0	.2	.0	.0	.0	.1	.1	1.9	2184	8.3
35/36	5.9	27.7	32.8	18.4	1.1	.0	.0	.0	.0	.1	.1	.8	1777	6.7
33/34	2.3	8.7	3.2	3.0	.3	.0	.0	.0	.0	.1	.0	.5	475	1.8
31/32	.4	3.1	2.1	.3	.3	.0	.0	.0	.0	.0	.0	.2	140	.5
29/30	.4	1.3	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	54	.2
27/28	.1	.2	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	7	*
<27	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
TOTAL	2256	1884	2158	2148	2344	2304	2493	2603	2387	1948	1983	1946	26452	100.0
MEAN	40.4	37.9	37.6	39.5	44.0	50.1	56.7	58.6	57.1	53.4	48.0	44.1	47.8	

LAND STATION DATA

STATION: MACHIAS, MAINE
POSITION: 44.7N 67.5W
ELEVATION: 40 FEET

MEANS AND EXTREMES FOR PERIOD [illegible]

	Temperature (°F)									Precipitation Totals (inches)								Mean number of days					
	Means			Extremes								Snow, Sleet							Temperatures Max.		Min.		
Month	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year	Mean degree days	Mean	Greatest daily	Year	Mean	Maximum monthly	Year	Greatest daily	Year	Precip .10 inch or more	90° and above	32° and below	32° and below	0° and below	Month
(a)	19	19	19	19		19		19	20	20		19	19		19		10	19	19	17	19	
JAN.	31.0	10.8	20.9	55	1953	-25	1961+	1360	4.21	2.49	1958	20.9	46.7	1952	15.3	1956	4	0	15	30	7	JAN.
FEB.	32.3	11.1	21.7	50	1966+	-26	1961	1225	4.19	3.73	1951	17.0	40.0	1967	13.9	1959	7	0	13	27	7	FEB.
MAR.	39.1	21.2	30.1	66	1955	-12	1956	1068	4.58	2.35	1961	13.4	42.4	1956	8.0	1967+	7	0	3	28	1	MAR.
APR.	50.3	30.9	40.6	80	1957	*	1950	725	3.81	2.77	1956	2.2	9.7	1959	6.7	1957	8	0	*	18	0	APR.
MAY	61.3	39.5	50.4	88	1944	27	1966	446	4.08	3.40	1961	.2	3.4	1963	2.4	1963	9	0	0	5	0	MAY
JUNE	69.3	48.4	58.9	89	1963+	32	1955	195	3.76	5.03	1962	0	0		0		8	0	0	*	0	JUNE
JULY	73.9	56.1	66.0	93	1968+	37	1965+	50	3.33	4.11	1958	0	0		0		6	4	0	0	0	JULY
AUG.	72.8	53.1	63.0	97	1961	36	1969	78	3.13	3.36	1951	0	0		0		6	0	0	0	0	AUG.
SEP.	64.6	46.4	56.0	99	1969	25	1965	272	4.01	4.22	1960	0	0		0		6	0	0	1	0	SEP.
OCT.	57.2	38.1	47.7	83	1963	18	1956	535	4.08	2.98	1952	.3	2.0	1968+	2.0	1969	7	0	0	8	0	OCT.
NOV.	46.3	29.6	38.0	70	1956	5	1951	801	5.38	2.86	1958	2.2	11.7	1962	6.0	1962	8	0	1	20	0	NOV.
DEC.	34.6	16.6	25.6	57	1962	-24	1951	1216	4.91	4.15	1950	15.8	43.5	1964	15.0	1964	9	0	13	28	3	DEC.
Year	52.8	33.3	43.1	99	July 1966+	-25	Feb. 1961+	7986	48.85	5.08	June 1962	73.4	46.7	Jan. 1952	15.3	Jan. 1956	86	*	47	167	18	Year

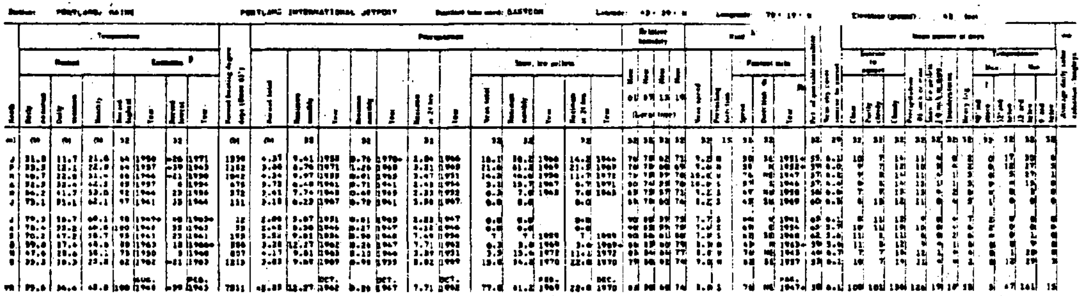
STATION: EASTPORT, MAINE
POSITION: 44.9N 67.0W
ELEVATION: 80 FEET

MEANS AND EXTREMES FOR PERIOD OF RECORD 1931-1960

	Temperature (°F)						Precipitation Totals (inches)					Mean number of days										Relative humidity					
	Means			Extremes					Snow, Sleet, Hail				Temperatures Max.		Min.		Sunrise to sunset										
Month	Daily maximum	Daily minimum	Monthly	Record highest	Record lowest	Mean degree days	Mean	Greatest daily	Mean	Maximum monthly	Greatest daily	Precipitation .10 inch or more	90° and above	32° and below	32° and below	0° and below	Clear	Partly cloudy	Cloudy	Thunderstorms	Heavy fog	1:30 AM EST	7:30 AM EST	1:30 PM EST	Pct. of possible sunshine	Avg. sky cover sunrise to sunset	Month
(a)	30	30	30	30	30	30	30	30	30	30	30	30	10	30	30	30	71	71	71	30	47	65	36	65	59	63	
Jan	30.6	15.1	22.8	50	-16	1303	4.12	2.42	18.0	32.7	10.0	8	0	16	29	3	8	8	15	*	8	76	72	71	45	6.0	Jan
Feb	31.8	15.9	23.3	54	-23	1172	3.44	1.94	18.0	41.4	17.7	7	0	15	27	3	8	7	13	*	8	76	70	71	50	6.2	Feb
Mar	37.4	24.2	30.8	76	-10	1057	3.48	1.93	13.7	39.7	10.7	7	0	8	28	*	8	9	14	*	3	75	69	73	52	6.3	Mar
Apr	47.0	33.2	40.1	81	16	742	3.38	2.22	4.6	27.0	10.3	7	0	*	13	0	7	9	14	1	4	77	71	77	52	6.6	Apr
May	56.6	40.8	48.7	90	26	503	3.09	2.96	T	0.4	0.4	7	*	0	1	0	7	11	13	1	6	79	71	70	52	6.4	May
Jun	64.4	47.2	55.0	92	30	179	3.33	1.65	0	0	0	7	*	0	0	0	6	12	12	3	8	82	75	68	54	6.6	Jun
Jul	70.3	52.6	61.3	89	44	123	3.07	1.63	0	0	0	6	0	0	0	0	7	13	11	4	12	83	77	82	56	6.2	Jul
Aug	70.6	53.6	61.9	93	42	112	2.86	4.28	0	0	0	5	*	0	0	0	8	11	11	3	10	83	76	83	57	6.0	Aug
Sep	64.8	49.3	56.7	92	33	233	3.33	1.66	0	0	*	6	*	0	0	0	9	9	12	1	6	84	79	81	55	6.0	Sep
Oct	55.2	42.0	46.6	80	22	500	3.62	1.89	0.1	1.6	1.5	6	0	0	3	0	8	8	14	1	4	81	72	79	50	6.2	Oct
Nov	43.2	32.0	39.0	71	4	776	4.40	3.89	3.0	14.0	9.8	8	0	3	14	0	5	8	17	*	2	80	75	76	38	7.2	Nov
Dec	36.0	19.3	20.0	60	-13	1162	3.76	3.13	10.7	35.2	12.8	8	0	12	27	2	7	8	16	*	1	77	73	75	40	5.9	Dec
Year	50.3	35.5	41.8	93 Aug. 1940	-23 Dec. 1933	8840	40.67	4.28 Aug. 1962	66.9	33.7 Jan. 1998	18.3 Apr. 1946	82	*	33	160	7	89	126	163	14	68	79	73	77	51	6.6	Year

(a) Average length of record, years.
T Trace, an amount too small to measure.
+ Also on later dates, months or years.
* Less than one half.

NORMALS, MEANS, AND EXTREMES



@ For period November 1940 through the current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Highest temperature 103 in July 1911; maximum monthly precipitation 12.29 in January 1931; minimum monthly precipitation 0.08 in October 1924; maximum snowfall in 24 hours 23.3 in January 1935.

[illegible]

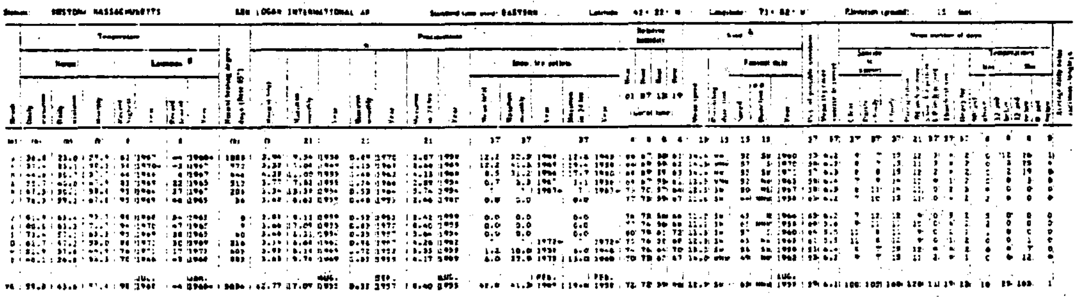
[illegible]

[illegible]

To 8 compass points only.

** The National Weather Service considers the accuracy of solar radiation data questionable; therefore, publication is suspended pending determination of corrected values.

NORMALS, MEANS, AND EXTREMES



@ For period April 1964 through current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Highest temperature 104 in July 1911, lowest temperature -18 in February 1934, maximum monthly precipitation 7 in March 1913, fastest mile wind 87 S in September 1938.

[illegible]

[illegible]

[illegible]

** Data for the year 1956 are fastest observed 1-minute speeds with directions to 16 compass points. Otherwise data are fastest mile with directions to 8 compass points.

To 8 compass points only.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

generally move through the area in a northeastward direction, and as a rule, are much more violent than the extratropical storms of the same season. Tropical cyclones tend to take on some characteristics of extratropical cyclones before reaching the area, and are less intense than in more southerly latitudes.

(a) Coast. From Portsmouth, N.H., to northern Maine, a total of 17 tropical cyclones have come within 60 miles of the coast since 1900. Four of these have been hurricanes.

In recent years, Carol (1954) and Donna (1960) have been the strongest hurricanes to affect the New England coast. Carol brought 70- to 90-kt winds and 7- to 13-ft tides to the southern Massachusetts and Rhode Island coasts, and 35- to 60-kt winds to northern New England. Gusts along the northern New England coast reached 78 kt. That same year (1954) hurricane Edna generated sustained winds up to 60 kt and gusts up to 80 kt along northern New England shores. In September 1960, hurricane Donna pounded the entire Atlantic seaboard, bringing winds up to 60 kt, and gusts up to 70 kt to northern New England. Tides up to 9 ft above mean low water were recorded.[250/]

4. Winds. The prevailing wind direction over the area from November to March is west through northwest, with average wind speeds of 18 to 20 kt. In spring and early fall, winds are variable, and wind speeds average between 12 and 14 kt, decreasing during spring and increasing in autumn. Summer winds have a more southerly component. From June through August, south and southwest winds blow about half of the time, and wind speeds are at their lowest, ranging from 10 to 11 kt.

Gales occur more than one percent of the time from October through April, and are associated mostly with extratropical storms and their associated fronts. Winter wind speeds are the highest [251/] (SSMO, 1970), so it's not surprising that the frequency of gales (winds ≥34 knots) is highest from December through February, when it ranges from 7.3 to 7.7 percent. The infrequent summer gales are usually due to thunderstorms, sometimes in squall lines, which occur most frequently in June, July, and August. Summer and fall gales may also be brought by a tropical cyclone.

(a) Coast. Along the shore, prevailing open ocean winds are modified by topography. Wind speeds are less, in general, because of surface friction. For example, average winter speeds range from 9 to 13 kt, well below open water averages. There also may be about one-half the number of gales as there are on the open sea.

The sea breeze is usually a summertime coastal phenomenon in this area, but can occur at other times, when the temperature gradient along the coast is pronounced.

When pressure gradients are weak and days warm, an afternoon onshore wind develops as the land heats up faster than the water. At night the flow is off the land, as it cools faster than the water. The sea breeze is the stronger of the two, and can reach 15 knots if conditions are right.

5. Extreme winds. Winds of more than 100 kt have occurred in "nor'easters" and tropical cyclones over this area. On land, Portland has a record fastest mile of 66 kt, while at Boston, the record is 57 kt. Gusts of 73 kt have been recorded at Falmouth. At Providence during hurricane Carol, sustained winds climbed to 78 kt, with gusts to 91 kt. Maximum sustained winds at Eastport occurred in December, and were easterly at 72 kt. It has been estimated that windstorms, generating winds of 50 kt or more, occur about four times each year somewhere along these shores.[252] Table 15 contains observed gale frequencies and sustained wind recurrence intervals. The mean recurrence value for maximum sustained wind for 10 yr is 80 kt, and for 50 yr, 103 kt.[253]

6. Wave heights. Since waves are generated by winds their distribution frequency is similar. High waves occur most frequently in winter and are infrequent from May through September. From November through May, waves of 3 to 4 ft occur most often (20-30 percent), while 1- to 2-ft waves are the rule in summer. Waves $\geq$12 ft are observed 8 to 9 percent of the time during December, January, and February. Waves $\geq$ 20 ft occur most often in December (1.1 percent).

Maximum seas of 26 to 32 ft have been observed in this area, occurring in February. Waves of 23 to 25 ft have occurred in December, January, and April.[254] The insufficient number of wave observations available does not give an accurate picture of what can be expected. Table 15 contains statistical estimates of expected wave height. It should be noted that high waves can only occur in deep water. As the water becomes more shallow, waves will break before reaching extreme heights. In the deep waters of this area, extreme wave heights of 124 ft could be expected every 100 yr, on an average. Maximum significant wave heights (an average of the one-third highest observed waves) of 69 ft can be expected in the same average period and could be supported in water approximately 88 or more feet deep.

7. Visibility. Poor visibility may be produced by fog, haze, rain, and snow. Summertime advection fog is the type most common in this area. These fogs often set in almost without warning, and have been known to persist for three weeks with little interruption.[255]

In general, visibilities less than 2 mi occur between 10 and 23 percent of the time from May through September. July is the worst month (22.7 percent). During the the remainder of the year, visibilities less than 2 mi are encountered 5 to 9 percent of the time.

Dense fog can drop visibilities to below 1/2 mi. This is most frequently caused by advection fog from May through August, when visibilities drop below 1/2 mi from 8 to 15 percent of the time. July is the worst month (15.5 percent).

(a) Coast. The areas along the coast, at the heads of bays and within the rivers, are often comparatively clear while fog is very thick outside. Most radiation fog occurs in winter, and most advection fog occurs in summer. Steam fog (sea smoke), sometimes encountered in winter, forms in very cold weather when the air temperature is much lower than that of the water. Fog is more likely to form with light to moderate winds.

A good indication of fog frequency along the coast, are the hours of operation of fog signals. Peak hours of operation occur in summer, mainly in July. During this month, averages range from about 100 hours around Boston up to 300 hours along the coast of eastern Maine. The best months seem to be November and April, when averages remain below 100 hours of operation.[256]

8. Storm tides. This phenomenon is strictly coastal, and is the result of a storm's wind and pressure effect on tide (surge) plus the normal astronomical tide. These storm tides occur in both extratropical and tropical cyclones. When the peak storm surge and the normal high tide occur simultaneously, the results can be disastrous. Most of the record high tides along this coast have been the result of extratropical storms. These record tides range from about 10 to 14 ft above mean sea level.[257] Eastport, Me. has an average return period of 50 years for a tide 14 ft above mean sea level. This 50 year value is good for tides of 9 to 10 ft above mean sea level at Portsmouth, N.H., Portland, Maine, Boston, Mass., and Bar Harbor, Maine.

9. Air temperature. Air temperatures in this area range from an average of just above freezing (32.7°F) in February to 62°F in August. Temperatures drop below freezing from October through April. Large temperature variations are not uncommon in winter. During February, temperatures fall below freezing 45.8 percent of the time. Summer temperatures never get above 85°F.

(a) Coast. Temperature variations become more apparent along the coast. Average January temperatures range from 23°F at Eastport to 30°F at Boston and 33°F at

Nantucket. Temperatures get lower in winter along the coast. An extreme of -23°F has been observed at Eastport and -18°F, at Boston. In summer, temperatures get warmer near the coast. July averages range from 74°F at Boston to 61°F at Eastport. Extremes of 104°F at Boston and 93°F at Eastport have been recorded.

During all seasons, changes in wind direction can cause large temperature fluctuations. In winter, southerly and southwesterly winds may bring mild weather, while northwesterly winds may be very cold. In summer, warm weather occurs with southwesterly and westerly winds, while northeast winds may be chilly. On the average, air temperatures at sea range about 4°F to 8°F higher in January and 2° to 6°F lower in July than along the coast.

10. Superstructure Icing. Ice accretion on ships or platforms is a complex process that depends on sea conditions, atmospheric conditions, and vessel or platform size.[258] While icing can be caused by freezing rain or fog, heavy sea spray is by far the most dangerous cause. Sea-spray icing can occur when air temperatures fall below the freezing temperature of sea water (usually about -2°C) and sea surface temperatures are below about 5°C.[259] Small ships (500-ton class) can accumulate 50 tons or more of ice in less than 24 hours in heavy seas.

Potential superstructure icing is based on wind speed and air temperature, and is necessarily subjective. Moderate icing, (1 to 4 tons buildup per hour on a 300 to 500 ton vessle or 1 1/2 to 2 1/2 inches per hour is most likely with air temperatures of -2°C or below and winds of 13 knots or more. Potential for severe icing exists when temperatures fall to -9°C or less and winds are greater than or equal to 30 knots.

In the open waters of Area 1 the potential for superstructure icing exists from November through April. It reaches a peak in January and February. During these months potential moderate superstructure icing exists nearly one-quarter of the time, while conditions for potentially severe icing occur close to one percent of the time.

LIVING RESOURCES

1. General. The coastal waters of the Gulf of Maine are rich with nutrients which support diverse and abundant stocks of marine plants and animals. Native upland vegetation includes swamp forests of spruce, tamarack, and arborvitae in northern sections, grading into conifers, maple, elm, and ash toward the southern edge of the area.[260]

2. Estuarine and coastal wetlands. The estuarine zone, both coastal wetlands and shoal water habitat, encompasses an area of about 87,000 acres. Shoal water

comprises about 52,000 acres, of which 23,000 are considered important open shoal water habitat for fish, shellfish, and wildlife.

There are about 35,000 acres of coastal wetlands in this region, of which about 12,000 acres are dominated by freshwater plant species affected by tides, while about 21,000 acres are dominated by salt grass and salt-meadow cordgrass. Salt marsh cordgrass dominates the remaining 2,000 acres of coastal wetlands.

Most of the larger tidal marshes in Maine are in the three counties south of the city of Portland. The salt marshes to the north are usually small, with a combined area of less than 50 acres, and are isolated at the head of the bays. The Maine Department of Inland Fishereis and Game owns the 2,200-acre Scarboro Marsh just south of Portland and also owns 500 acres of estuarine habitat in Merry meeting Bay, as well as marshes in the Weskeag and Pleasant River areas. The Coastal Maine National Wildlife Refuge, when completed, will include most of the salt marshes between the Scarboro Marsh and the New Hampshire line.

New Hampshire has only two areas of major importance from the marine resources standpoint: the Hampton Marshes and Great Bay. The Hampton Marshes contain about 4,000 acres of salt marsh and open water in the harbor and rivers. A small marsh of 139 acres is owned by the New Hampshire Audubon Society, and several hundred acres are owned by the State Fish and Game Department. There is some residential development on the eastern edge of the marsh at Hampton Beach.

The Great Bay is largely open brackish water with a few fringing marshes. Development on the borders of this 3,000-acre area is rapidly reducing its value to marine life.

There are seven other small coastal marshes north of the Hampton Marshes. These average about 200 acres in size and are composed largely of saltmeadow cordgrass. They are not of high value for waterfowl, but have a high value for other forms of wildlife.

The U.S. Fish and Wildlife Service maintains several National Wildlife Refugues within 2 miles of the coast of Maine. These refuges are Moosehorn at Calais; Petit Manan (a 9-acre island south of Whiting); Pond Island (a 10-acre island 16 miles northeast of Portland); Rachel Carson at Wells; and Sea Island (about 25 miles from Rockland--a 65-acre island). The National Park Service maintains Acadia National Park near Bar Harbor, Maine.

3. Birds. Predatory bird species include the sparrow hawk, marsh hawk, and redtailed hawk. Ruffed grouse, bob white quail and the woodcock are the principal

game-bird species and are abundant during summer periods. There are indications that certain species such as the cardinal are extending their winter range to this region.

The coastal marshes, estuarine, and near-shore areas provide important habitat for migratory waterfowl, shorebirds, and seabirds. Some species of diving ducks utilize marshes and wetland areas for breeding and nesting purposes. During the spring and fall, large numbers of migratory waterfowl concentrate in coastal wetlands and shallow water areas.

4. Land mammals. Mammals inhabiting the coastal zone and depending in large part on the wetland areas include the cottontail rabbit, raccoon, chipmunk, and gray squirrel. Whitetailed deer are common big game animals. Muskrat and other small mammals are common in open areas near water and a few beaver occur in coastal marshes. Gray fox and mink are common to upland areas.

5. Plankton. The plankton of the Gulf of Maine were surveyed intensively by Bigelow and reported in a monumental work.[261/] He found the plankton to be dominated by calanoid copepods, particularly the species *Calanus finmarchicus*. Major elements of the zooplankton included copepods, glass worms, euphausiids, amphipods, and ctenophores. Most of the species represented are found in the inshore waters of the Maine coast during some part of the year. More recently, Sherman [262/] examined seasonal variations in abundance of zooplankton in the Gulf of Maine. Copepods were the most abundant group in all seasons, reaching peak numbers in the summer.

The distribution of mysids (Crustacea) from bottom sediment samples from Nova Scotia to Florida was reported by Wigley and Burns.[263/] They identified 19 species of marine mysids from the entire coast, 15 of which were found off New England. Most of these are deep-water species and only a few are found inshore in the sand and gravel of the coast of Maine.

6. Invertebrates. On this coast, the most important species of invertebrates from the economic viewpoint are lobsters, northern shrimp, sea worms, and sea scallops. All of these species spend significant portions of their life cycle in inshore waters, and, on this coast, the major portion of the commercial catch of all except the northern shrimp is taken inside the 12-mile limit.

The literature on lobsters is too extensive for comments, except to offer a bibliography as a reference.[264/] Larval lobsters appear to be widely distributed and are not known to concentrate anywhere in Maine waters. This is Maine's most valuable fishery by far; landings in 1972 were 16.3 million pounds, worth $18.6 million. Second in value were soft clams, landing 6.1 million pounds, worth $3.7 million. The fishery for shrimp, ranked third in value in Maine, is described in a publication by Wigley.[265]

The wide tidal amplitude in Maine causes thousands of acres of mud flats to be exposed at low tide. This facilitates harvesting soft clams and sand and blood worms by hand methods. Southern Maine also contains some excellent hard clam territory. The importance of this species varies with the temperature of the ocean; a warmer temperature results in an increase in hard clam and a reduction, in soft clam production. Only a very small area produces oysters, and this species is not commercially important. Other estuarine species of importance in Maine's commercial fishery are lobsters, rock crabs, and blood and sand worms.[266]

Due to several factors, pollution being the most important, there is no commercial fishery in New hampshire for oysters and soft and hard clams. The lobster, and rock, and green crab are the major commercial species. There are, however, many recreational shellfishermen, and some of their catch finds its way illegally in local markets. The soft clam is of primary importance in Great Bay and Hampton Marshes, and some oysters and hard clams are taken in the Piscataqua River.[267]

7. Finfish. Of the 15 most important commercial species, only ocean perch and gray sole are not taken in significant quantities within the 12-mile limit. Cod, pollock, and whiting are taken both offshore and inside the 12-mile limit.

The biology of sea herring has been studied intensively along the Maine coast. The young of this species are marketed as the Maine sardine. The best general reference on the biology and distribution of Maine fishes, including sea herring, is the "Fishes of the Gulf of Maine." [268] Recent studies have shown the distribution of larval and 1-year-old herring along the coast.[269] The 1-year-old fish are found inshore and in recent years have been found north of Portland, Maine.

The abundance of groundfish outside the 60-meter contour along the coast of Maine has been measured for many years with seasonal surveys by NMFS R/V Albatross IV. Between 15 and 30 species of fish are usually sampled in varying abundance. The autumn distribution of the 20 most common species during the years 1955-1961 was summarized in the Serial Atlas of the Marine Environment.[270] Although the commercial stocks of the most important species are concentrated offshore in deeper water, the eggs, larvae or juveniles are often found inshore within the potential area of impact of the floating power plants.

The sportfish catch from the Maine coast is not as well documented as the

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Commercial catch. Cod, mackerel, and small "harbor" pollock are caught frequently by anglers around harbor wharves almost anywhere along the coast. Haddock, the American eel, winter flounder, and striped bass are also taken by anglers. Data included in the 1970 Saltwater Angling Survey [271] for these species reflect their relative abundance.

To summarize, this is a relatively unspoiled area with clean water predominating, except around the population centers, where harbor pollution is apparent. Various fisheries prosper in the unspoiled waters, and, aside from the problem of river pollution with regard to the decimated Atlantic salmon, no fish or invertebrate species appear to have been harmed significantly by deteriorating water quality.

8. Threatened species. Wildlife species threatened include the bog turtle, American peregrine falcon, Arctic peregrine falcon, Ipswich sparrow, beach meadow mole, sperm whale, blue whale, finback whale, sei whale, humpback, right whale, and barehead whale.[272]

AREA 2: SANDY HOOK TO ATLANTIC CITY, N.J.

GEOLOGY AND TOPOGRAPHY

1. General. This area (fig. 42) is bounded on the north by the south shore of Long Island and extends along the coast of New Jersey to the resort area of Atlantic City. The southern coast of Long Island is a glaciated coast and consists of coastal plains fringed by long sand barriers. The sand barriers locally connect with the mainland, but generally are separated from the shore by lagoons. The lagoons are partly filled, and large tracks of marsh exist where the in filling has been almost complete.[273]

The coast south of New York Harbor was not glaciated (although some of the glacial outwash extends into northern New Jersey, accounting for the numerous gravel deposits). The sea floor is relatively smooth, having the characteristics of an unglaciated topography. This area has, however, low ridges and troughs that extend roughly parallel to the coast. These longitudinal features have low relief, ordinarily not more than 7 to 10 meters. The ridges are usually sand covered, with muddy sediments in the troughs. Shells found on some of the ridges are of a type indicating that the sea was lower during deposition.

Depths within the area are quite shallow, less than 60 meters except for the somewhat deeper Hudson Channel. In general, most of the area within 50 miles of the

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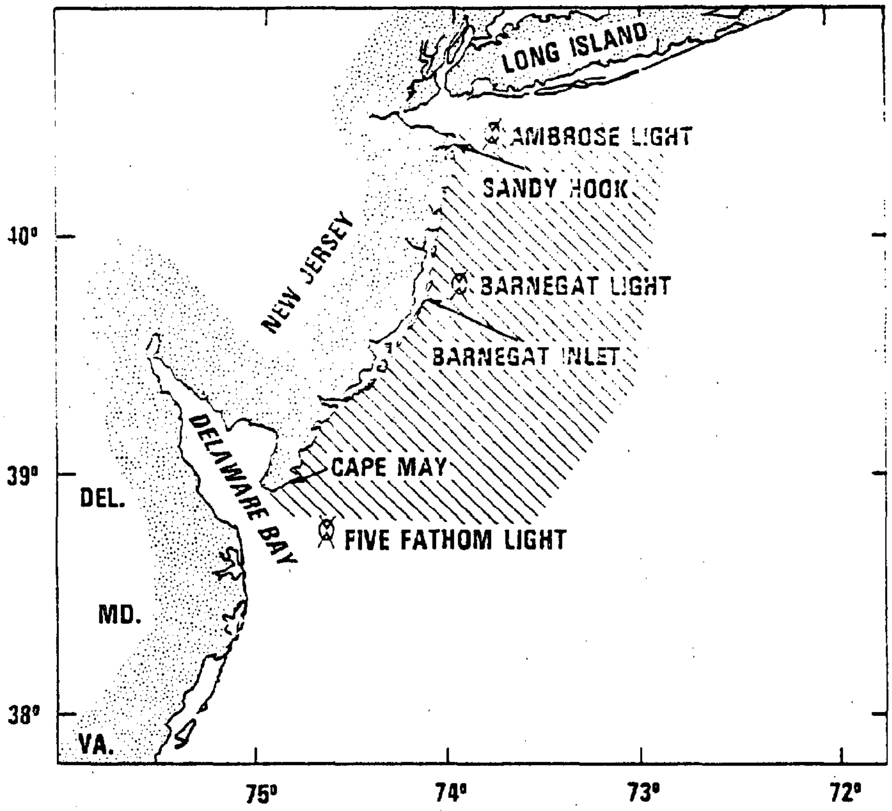
Figure 42.--Area 2 (shaded): Sandy Hook to Atlantic City, N.J.



Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

coast is less than 40 meters deep.[274]

Lateral gradations of offshore-to-inshore coastal plain sediments indicate that the present outcrop pattern is not everywhere parallel to the present shoreline. This divergence is believed to have been caused by an uplift in the Pliocene that 1) led to the erosion of Miocene sediments landward of the present coast of New Jersey, 2) created the present east-west trending shoreline, and 3) produced the southward dip of the coastal plain strata east of Long Island. A vast amount of sediment produced by the erosion was transported southward to add sediment to the continental shelf and slope.[275]

A striking feature of the shelf in the area is the shallow Hudson Shelf channel extending from the entrance of New York Harbor almost to the shelf break. This channel differs from typical river valleys in its straightness and from submarine canyons in general in its low relief and in having many basins along its course. The channel is a large erosional feature that extends seaward some 170 kilometers and is 27 km wide at its mouth. It has an average gradient of 0°14'. The channel was cut by the Hudson River during the Pleistocene Epoch, when sea level was near the present shelf break. Throughout most of its length the channel consists of a series of basins displaying reliefs as great as 40 meters.[276]

Although the tectonics of the area are not well known, there appear to be no active faults.

2. Sediments. Terrigenous sand, gravel, and carbonate sediments of Tertiary and Cretaceous are present in the area, thickening seaward and becoming as much as 1,000 meters thick at 50 miles out. The basement complex consists of pre-Carboniferous igneous and metamorphic rocks. Some miles farther east (about 70 to 150) sediment thicknesses increase considerably -- believed to be as much as 13,000 meters. These include Tertiary and Cretaceous terrigenous sand and gravel in the upper part, and Mesozoic evaporite and carbonates, as well as terrigenous deposits, in the lower part. The lower limit of this thick sequence has not yet been precisely determined. It is possible that strata considered "crystalline basement" (indicated by marginal seismic velocities measured off New Jersey) may be evaporite sequences of late Jurassic or older age, making the sedimentary sequence even greater than now defined. There is an almost total lack of fine surface sediments, throughout this sector of the coast.[277]

3. Turbidity Currents. Turbidity currents have not been reported but have been inferred from Pleistocene Age sediments recovered from the Hudson Canyon. Two cores obtained in the Canyon contain gravel in a clayey sediment and probably represent a mud flow down the canyon wall of possibly glacial marine sediment.

OCEANOGRAPHY

1. General. The following discussions of tides, tidal currents, circulation, and water mass characteristics apply to both Area 2 (fig. 42) and Area 3 (fig. 43). Along this entire coastline there is a westward to southward flow of inshore waters (see Atlantic Coast Part 1), which is influenced locally by river outflow, tides, bathymetry, and winds. These coastal waters are measurably diluted by river outflow along the entire coast, and the surface temperature undergoes a marked seasonal variation. 278/ In winter, salinity is at a maximum and the whole column of water is nearly homogeneous in temperature and salinity from surface to bottom. A thermocline develops after late April and the salinity is reduced to its minimum by the voluminous discharge of river effluent in spring. During summer, temperatures are maximum, salinities are minimum, and the water column is highly stratified. Surface waters begin to cool in early autumn, weakening the thermocline and mixing surface water downward so that the whole area is nearly homogeneous vertically by mid-November. 279/

2. Tides. The tides along the New Jersey and Virginia coasts are semidiurnal, with two highs and two lows each lunar day (about 24 hours 50 minutes), the two highs being nearly equal and the two lows being nearly equal. Mean and spring ranges along the New Jersey coast are highest at the north and south ends of the coast, and lowest in the center. However, on the Virginia coast, ranges are greatest in the center, and lowest at the north and south ends. 280/

Offshore tidal measurements are insufficient to establish ranges, but they should be less than tide ranges at nearby shore stations. Table 16 lists examples of tide ranges for stations along the New Jersey and Virginia coasts. 281/

3. Tidal Currents. Tidal currents, the horizontal movements of water that accompany the rising and falling of the tide, are semidiurnal along the New Jersey and Virginia coasts, with two ebbs and two floods per lunar day. Nearshore, tidal currents are generally of moderate velocity, and farther offshore they are usually weak and rotary. Rotary tidal currents of moderate velocity occur near Sandy Hook (table 17).

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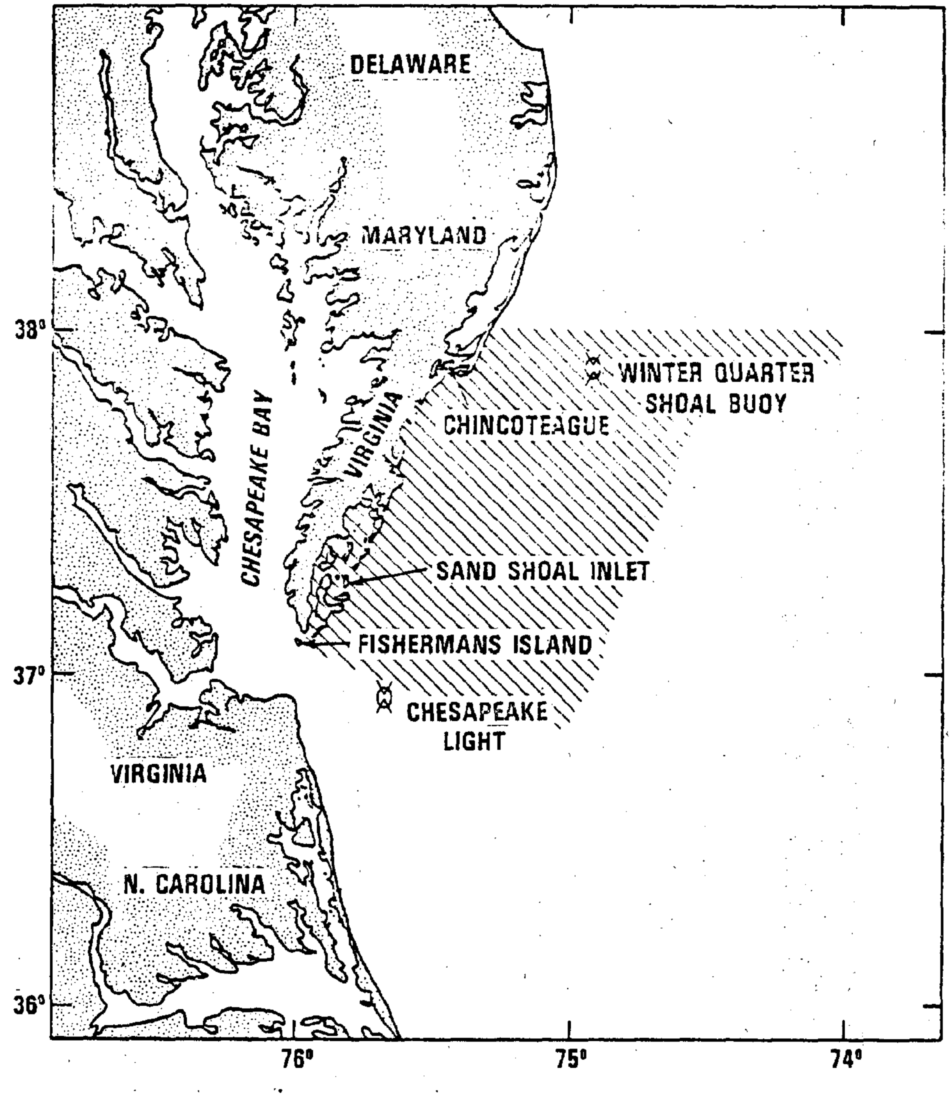
Figure 43.--Area 3 (shaded): Chincoteague Island to Cape Charles, Va.



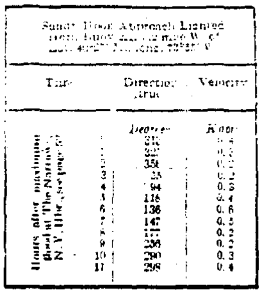
Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

Table 16.--Tidal ranges for New Jersey and Virginia coasts.

Station	Range (feet) Mean	Spring
Sandy Hook	4.6	5.6
Barnegat Inlet	3.1	3.8
Cape May	4.3	5.2
Chincoteague	2.6	3.1
Sand Shoal Inlet	4.1	4.9
Fishermans Island	3.0	3.6

Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1971: Tide Tables, High and Low Water Predictions, 1972, East Coast of North and South America, Including Greenland, Washington, D.C.

Table 17.--Rotary tidal currents.



Sandy Hook Approach Lighted [illegible]

Time		Direction (true)	Velocity
		Degrees	Knots
Hours after maximum flood at The Narrows, N.Y. Harbor	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	356	[illegible]
	3	25	[illegible]
	4	94	[illegible]
	5	116	0.4
	6	138	0.6
	7	147	[illegible]
	8	[illegible]	[illegible]
	9	236	[illegible]
	10	290	0.3
	11	[illegible]	0.4

Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1971: Tidal Current Tables 1972 — Atlantic Coast of North America, Rockville, Md.

At Barnegat Lightship (39° 46'N, 73° 56'W) off Barnegat Inlet, N.J., the tidal current is weak, averaging about 0.1 kt. At a point 72 miles east of Cape May, N.J., the tidal current is also weak, and again averages about 0.1 kt. At Five-Fathom Bank Lightship (38° 47'N, 74° 35'W) the weak tidal current averages about 0.2 kt. [282]

Tidal currents are similarly weak along the Virginia coast, being less than 0.1 kt at Winter-Quarter Shoal (37° 55'N, 74° 56'W), about .02 kt at a point 70 miles east of Cape Charles, and weak and variable at a point 4.4 miles northwest of the Chesapeake Light (36° 59'N, 75° 45'W). [283]

4. Circulation. The movement of shelf water in this region is controlled by several factors, the more important being fresh water outflow, winds, water structure, and tides. [284] Variations in any or all of the above factors will cause variations in the resultant current direction and speed.

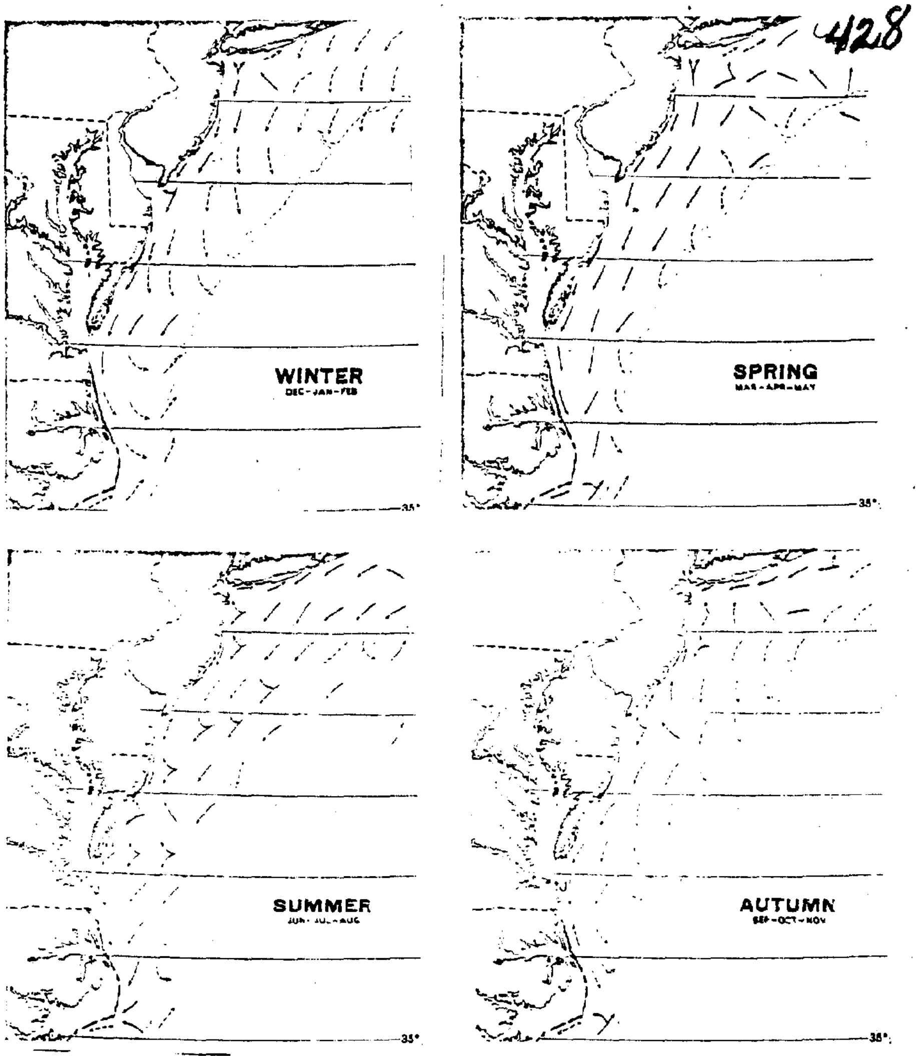
(a) Surface circulation. The prevailing surface flow is south to southwest, as shown in Figs. 44 and 45. Major departures from this general trend occur in summer, when there is a pronounced onshore flow, and autumn, when there is a northward flow along the New Jersey coast. The speed of this general flow is greatest in spring when river outflow is greatest. Average current speeds along New Jersey are between 0.4 and 0.6 kt during all months, and are slightly higher near-shore than offshore; maximum speeds of about 2.5 kt have been observed during autumn and winter. Near the Virginia coast, the mean speed is 0.6 to 0.7 kt throughout the year; maximum speeds of 2.5 to 3.0 kt occur in autumn and winter (NODC, surface current summary, H-1-9).

Weakening or reversal of the normal flow may occur with increased southerly winds and a highly stratified water column. A less than normal fresh water outflow of the Hudson and Delaware Rivers during March, April, and/or May can result in current reversals any time during April through September, when the wind is from the southern sector. [285]

The effect of the wind on current direction has been measured at several lightships along the coasts of New Jersey and Virginia, and is presented in table 18.

(b) Subsurface circulation. The movement of water below the surface is not as well known as at the surface. However, measurements of bottom drift indicate an onshore movement toward the New Jersey coast at about 38° 30'N. South of that

Figures 44 and 45.--Surface circulation, areas 2 and 3.



Source: Bumpus, D.F., and L.M. Lauzier, 1965: Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Serial Atlas of the Marine Environment, Folio 7, American Geographical Society.

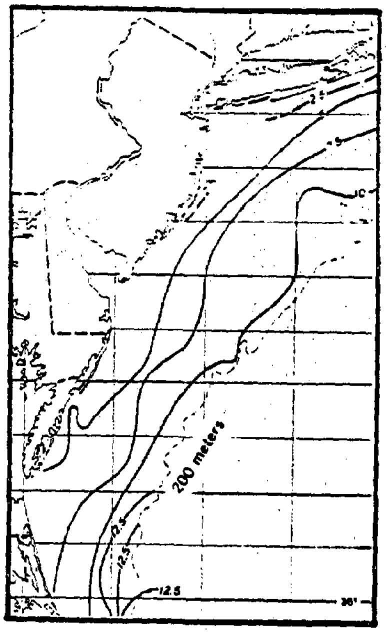
Table 18.—Average deviation of current to right of wind direction.

(A minus sign (-) indicates that the current sets to the left of the wind)

Wind from			N.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.
Old Lightship Stations	Lat. ° '	Long. ° '	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Ambrose Channel	40 27	73 49	36	40	21	11	18	72	27	112	82	70	63	46	37	22	23	21
Scotland	40 27	73 55	16	-12	-26	-36	-61	-36	-92	-150	90	33	77	44	15	30	27	13
Barnegat	39 46	73 56	6	5	-13	-9	-16	-7	33	54	55	30	14	8	0	-5	21	29
Northeast End	38 58	74 30	30	14	-3	-11	-20	-31	-42	-28	37	44	25	18	7	16	25	18
Overfalls	38 48	75 01	28	-6	-1	2	-40	-56	-78	-22	68	28	55	54	32	31	32	45
Winter-Quarter Shoal	37 55	74 56	18	-1	-5	-21	-27	-35	-19	31	23	20	4	14	9	8	28	27
Chesapeake	36 59	75 42	18	-2	-4	5	-6	23	73	71	57	38	27	26	22	18	15	22

Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1971: Tidal Current Tables 1972 — Atlantic Coast of North America, Rockville, Md.

Figure 46.—Bottom temperatures on the Continental Shelf (°C).



Source: Walford, L.A., and R.I. Wicklund, 1968: Monthly sea temperature structure from the Florida Keys to Cape Cod. Serial Atlas of the Marine Environment, Folio 15, American Geographical Society.

point, as far as the mouth of the Chesapeake Bay, bottom water moves southward and onshore. This onshore motion extends from approximately mid-shelf toward the coast at speeds on the order of tenths of a mile per day and eventually into the bordering estuaries (fig. 6, Part 1). 286/

5. Water Mass Characteristics.

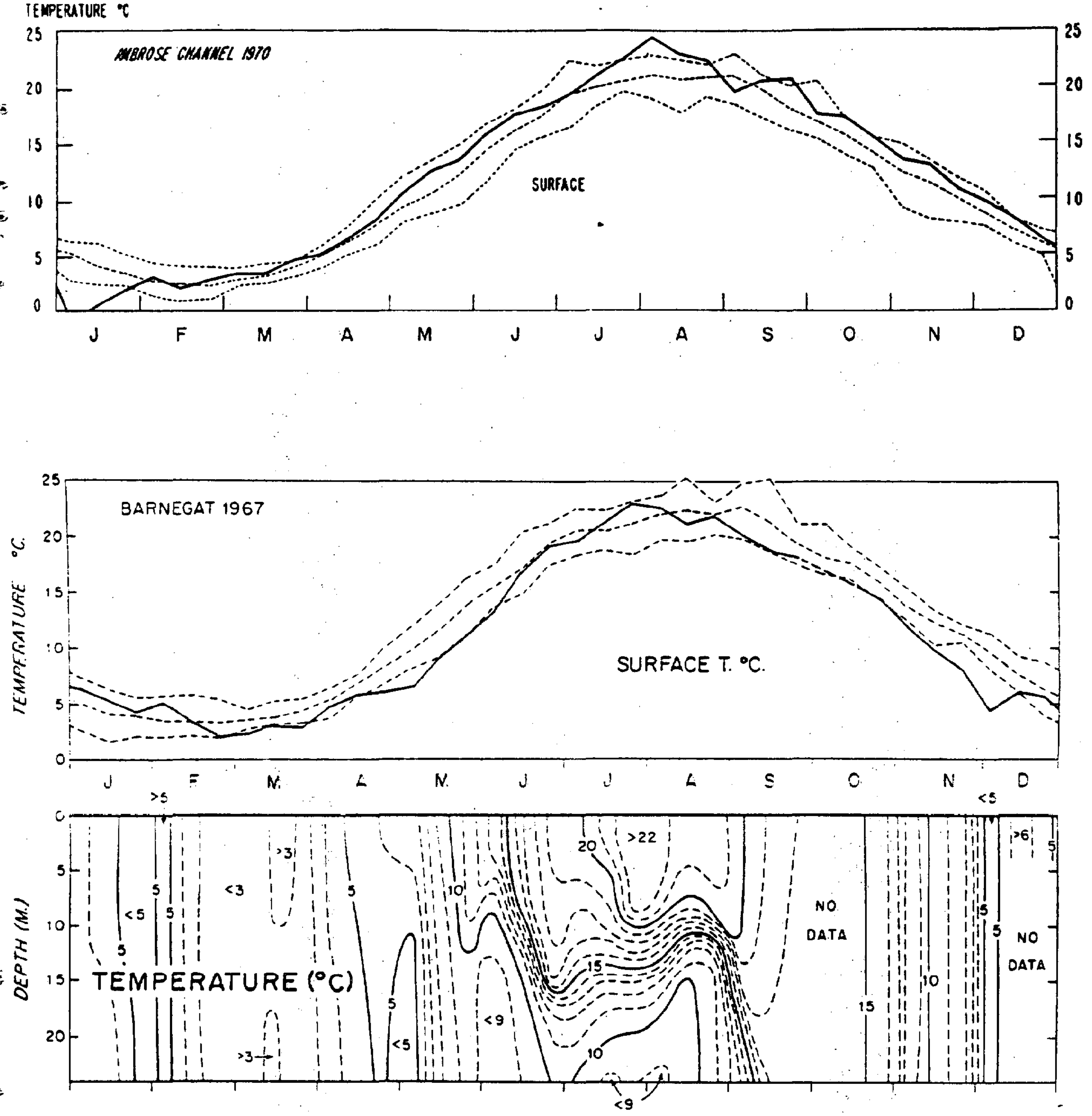
(a) Temperature. At Sandy Hook, N.J., surface temperatures show annual variations in mean temperature from 1.4°C to 23.5°C, in February and August, respectively. At Atlantic City, the range of mean temperature is from 2.3°C in February to 21.8°C in August; and at the Chesapeake Light, mean temperatures range from 4.7°C in February to 24.3°C in August.

Minimum surface temperatures along both coastal areas may reach -1.0°C at any time during December through February; maximum temperatures may be as high as 29.0°C along New Jersey and 32°C along Virginia during July and August. 287/ Even though average temperatures progress smoothly from month to month, the actual measured temperature at any location may differ significantly from the average value, as well as from the temperature measured at the same location in the previous month.

Subsurface and bottom temperatures follow similar seasonal progressions throughout both areas. A diagram representative of seasonal thermal structure along both coasts, is shown in fig. 10, part 1. Bottom temperatures shown in fig. 46 are colder inshore than offshore in winter, and warmer inshore than offshore in summer. Fig. 47 and 48 are presented to further illustrate the annual variation of minimum, mean, and maximum surface temperature, and of the representative monthly thermal structure at several light stations. Tables 19 and 20 illustrate the seasonal temperature ranges to depths of 300 meters for two bands across the continental shelf.

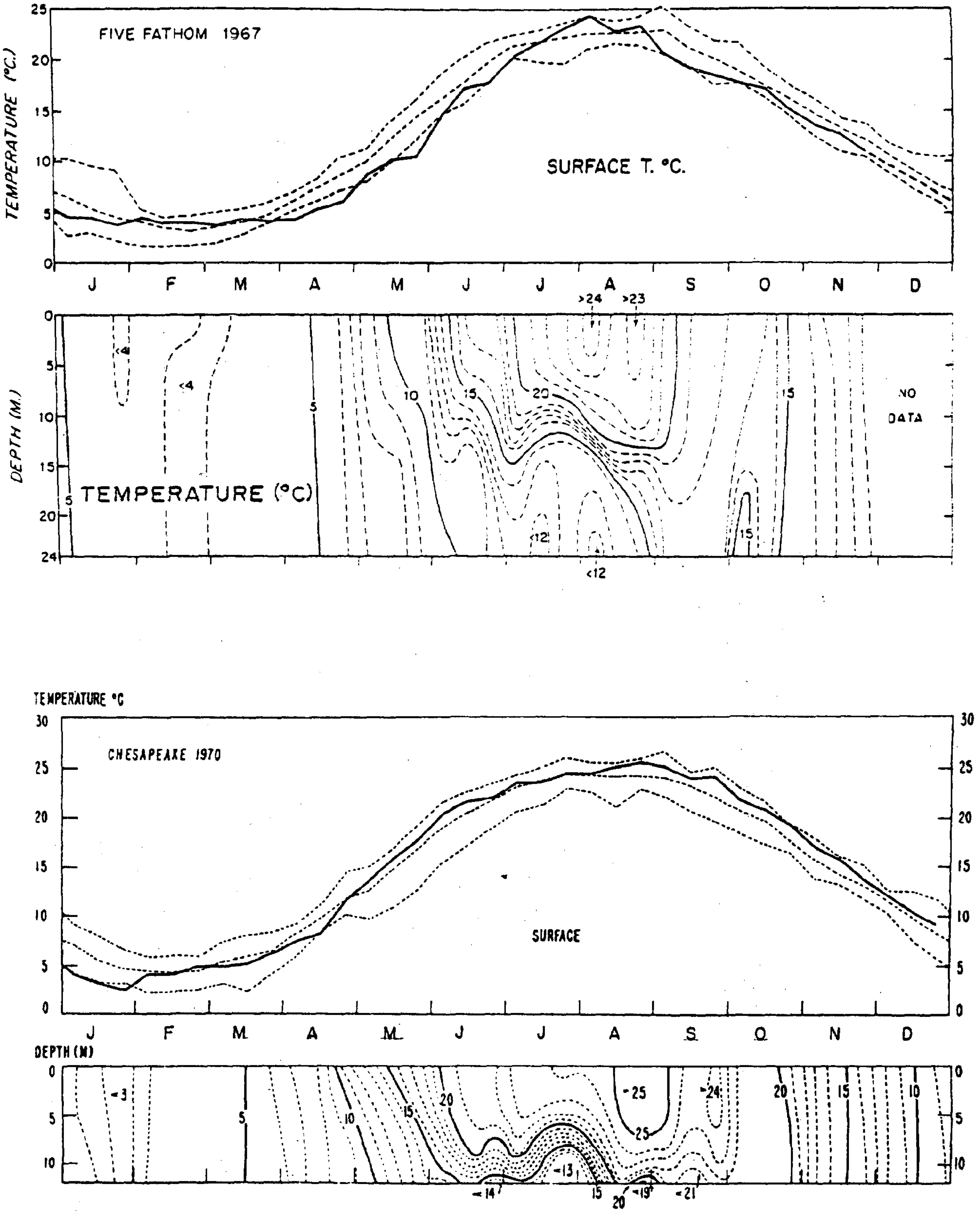
(b) Salinity. Salinity is at a maximum on the continental shelf in late February and early March, with values slightly less than 32‰ at the mouths of estuaries, 32‰ to 33‰ inshore, and about 33.5‰ seaward at mid-shelf. Vertical gradients are very small or non-existent, except near the mouths of rivers at times of recent outflow. 288/ Vertical sections representative of winter salinity structure are presented in fig. 12, Part 1.

Figure 47.--Annual variation of surface and subsurface temperatures at coastal light stations. Surface: solid lines indicate observed values in 1970 at Ambrose Channel and in 1967 at Barnegat: dashed lines show maxima, mean, and minima for 1956-69 at Ambrose and 1956-66 at Barnegat. Subsurface: no data available for Ambrose Channel; Barnegat, 1967 data.



Source: Chase, J., 1971 and 1972: Oceanographic observations along the east coast of the United States, January to December 1967 and 1970, Oceanographic Reports Nos. 38 and 53, U.S. Coast Guard.

Figure 48.--Annual variation of surface and subsurface temperature at coastal light stations. Surface: solid lines indicate observed values in 1967 at Five Fathom and in 1970 at Chesapeake; dashed lines indicate maxima, mean, and minima for 1956-66 at Five Fathom and 1956-69 at Chesapeake. Subsurface: Five Fathom, 1967; Chesapeake, 1970.



Source: Chase, J., 1971 and 1972: Oceanographic observations along the east coast of the United States. January to December 1967 and 1970

Table 19.--Seasonal water temperatures vs. depth, 38-40°N, 72-75°W.

MONTHS 1 - 3 NUMBER MONTHS PRESENT 2, 3

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	9.90	6.19	2.88	12	2.13
10	9.96	6.26	2.88	12	2.15
20	10.18	6.28	2.89	12	2.15
30	10.70	6.42	2.90	12	2.29
50	11.41	7.76	3.60	10	2.10
75	11.93	10.12	8.07	6	1.30
100	12.15	11.30	9.47	5	1.05
125	12.01	11.35	10.39	4	0.69
150	12.17	11.26	10.60	4	0.67
200	10.79	9.79	8.87	4	0.79
250	9.50	8.99	8.48	2	0.72
300	8.29	7.86	7.44	2	0.60

MONTHS 4 - 6 NUMBER MONTHS PRESENT 4, 5, 6

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	20.48	9.28	4.73	133	5.09
10	19.65	8.77	4.66	133	4.79
20	17.55	7.25	4.32	129	3.30
30	16.38	6.28	3.88	125	2.53
50	14.57	5.42	3.74	112	2.19
75	13.05	6.48	3.93	80	2.42
100	12.73	10.02	5.84	25	1.92
125	12.67	10.75	8.22	18	1.25
150	12.28	10.60	8.20	16	1.01
200	12.25	9.96	8.86	15	0.85
250	10.42	8.69	7.70	14	0.74
300	8.87	7.44	6.46	10	0.74

MONTHS 7 - 9 NUMBER MONTHS PRESENT 7, 8, 9

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	25.88	22.27	14.65	90	2.21
10	25.88	21.29	12.52	89	2.66
20	25.22	16.78	5.10	86	5.08
30	22.83	13.24	4.78	76	4.96
50	19.86	10.21	5.25	57	3.80
75	15.55	11.84	5.83	38	2.25
100	14.65	12.08	9.52	36	1.24
125	13.73	11.89	9.31	32	0.99
150	13.11	11.40	9.10	30	1.00
200	12.21	10.36	8.00	24	1.12
250	10.74	8.99	7.05	25	1.10
300	9.45	7.83	6.17	24	1.09

MONTHS 10 - 12 NUMBER MONTHS PRESENT 10, 11, 12

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	20.86	13.11	6.72	66	3.17
10	20.84	13.25	6.82	65	3.10
20	20.84	13.52	7.53	61	2.94
30	20.92	13.50	8.72	54	2.73
50	18.21	12.66	8.71	39	2.34
75	16.36	12.94	9.85	26	1.74
100	15.50	13.38	10.42	18	1.32
125	14.82	13.02	11.77	17	0.94
150	14.12	12.53	11.00	15	0.98
200	12.42	11.18	9.50	14	1.07
250	11.10	9.84	8.40	14	1.02
300	9.74	8.48	7.22	14	0.91

Table 20.--Seasonal water temperatures vs. depth, 36-38°N, 73-76°W.

MONTHS 1 - 3 NUMBER MONTHS PRESENT 1, 2, 3

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	19.32	8.91	2.48	41	4.17
10	19.30	8.94	2.61	41	4.03
20	19.06	10.20	2.75	31	3.62
30	18.46	10.63	5.96	27	3.18
50	18.14	11.55	6.75	20	2.74
75	16.76	11.76	6.92	19	2.58
100	15.48	12.57	8.80	15	1.87
125	14.79	12.76	9.57	14	1.35
150	14.15	12.55	10.20	14	1.05
200	12.58	11.48	9.45	10	0.98
250	11.43	10.56	9.44	8	0.83
300	11.40	9.38	8.05	8	1.13

MONTHS 4 - 6 NUMBER MONTHS PRESENT 4, 5, 6

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	26.28	15.52	5.90	69	4.72
10	26.27	15.31	6.05	60	4.38
20	26.24	14.59	8.29	48	4.87
30	25.44	14.27	6.99	43	4.82
50	22.59	13.53	5.32	39	4.01
75	20.40	13.06	7.63	37	2.80
100	19.87	12.69	8.20	36	2.16
125	18.81	12.30	9.25	35	1.68
150	17.45	11.91	9.24	34	1.39
200	14.55	10.74	8.06	33	1.13
250	13.08	9.45	6.31	32	1.14
300	10.50	8.28	5.55	32	1.05

MONTHS 7 - 9 NUMBER MONTHS PRESENT 7, 8, 9

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	29.20	23.25	16.22	69	2.93
10	29.20	21.43	9.50	69	3.98
20	29.20	19.11	8.80	59	4.58
30	29.08	17.06	8.48	47	5.15
50	28.10	14.32	8.13	36	5.23
75	26.46	13.86	7.89	33	3.99
100	24.96	13.45	9.25	32	3.27
125	23.38	12.89	9.50	32	2.93
150	21.70	12.29	9.73	32	2.71
200	18.43	10.97	8.10	31	2.37
250	17.49	9.55	6.95	29	2.33
300	15.78	8.29	5.77	30	2.19

MONTHS 10 - 12 NUMBER MONTHS PRESENT 10, 11, 12

DEPTH	MAX	AVG	MIN	OBS	SDEV
0	23.79	17.85	9.53	62	3.11
10	24.05	17.73	9.59	56	3.07
20	23.93	17.63	9.60	44	3.18
30	23.76	17.05	9.70	40	3.00
50	21.48	15.32	10.40	33	2.83
75	17.61	14.03	10.06	31	1.92
100	16.94	13.69	11.26	29	1.35
125	15.63	12.87	11.14	25	1.04
150	14.34	12.14	10.24	22	1.00
200	11.90	10.61	8.79	22	0.90
250	10.43	9.23	7.47	22	0.87
300	9.10	8.00	6.45	22	0.75

Source: Churgin, J., and S.J. Halminski, 1974: Temperature, Salinity, Oxygen, and Phosphate in Waters Off United States, Key to Oceanographic Records Documentation No. 2, Vol. I, Western North Atlantic. vironmental Data Service, National Oceanic and Atmospheric Administra-, U.S. Department of Commerce, Washington, D.C. In press.

Increased fresh-water outflow in spring lowers surface salinity and increases vertical gradients all along the coast from New Jersey through Virginia. Minimum values to be expected within 10 miles of the shore are < 26‰ near Sandy Hook, 30‰ off Atlantic City, 31‰ off the Coast of Virginia, and about 15‰ off the Chesapeake Bay entrance. The lower salinities at the surface, combined with occasional surges of higher salinity water along the bottom toward shore create large vertical gradients. Sharpest gradients develop in the upper 20 meters off New York City, off Delaware Bay, and especially off Chesapeake Bay, where a gradient of 8‰ in 20 meters has been recorded.

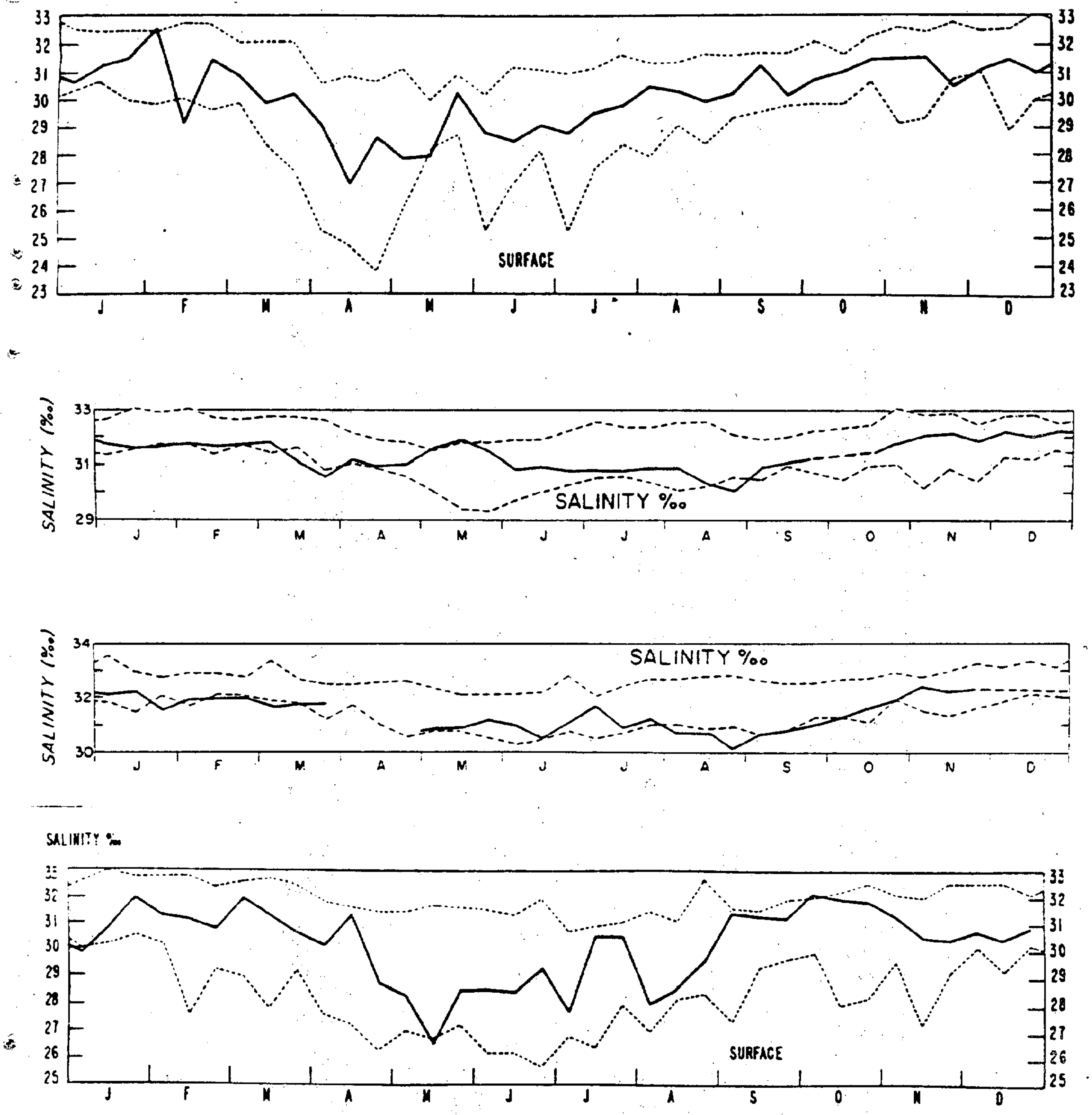
The low salinity water at the surface tends to remain in a belt along the coasts through the summer months, and vertical gradients of salinity remain large. At the bottom, at a depth of 40 meters, salinities vary from 32.5 to 33.1‰.[189] Vertical sections representative of summer salinity structure are presented in fig. 11, Part 1.

During autumn, increased cooling mixes the water column and increased surface salinity. This process continues until the column is nearly homogeneous by December or January. However, sharp gradients may occur sporadically near the mouths of estuaries, especially Chesapeake Bay, after recent increases in river outflow.

The annual variation and range of salinity at several lightships are presented in fig. 49.

(c) Oxygen. Dissolved oxygen is generally higher at the surface than at the bottom, and slightly higher off New Jersey than off Virginia. Particularly low values of oxygen (<3.0 ml/l) can be expected near the entrances to New York Harbor, Delaware Bay, and Chesapeake Bay. Historical data indicate mean surface values near New Jersey to vary from 4.5 ml/l in the south in summer to 7.5 ml/l in the north in winter. At a depth of 30 meters, average values range from 3.8 ml/l in summer to 7.5 ml/l in winter off Northern New Jersey. Off Virginia, mean values range from 4.6 ml/l at the surface in summer to 6.4 ml/l in winter and spring. At 30 meters, mean values vary from 5.0 ml/l in autumn to 6.8 ml/l in spring. These values are based on unpublished data summaries prepared by the National Oceanographic Data Center.

Figure 49.--Annual variation of surface salinity at coastal light stations. Solid lines indicate observed values in 1970 at Ambrose Channel and Chesapeake, in 1967 at Barnegat and Five Fathom. Dashed lines show maxima and minima for 1956-69 for Ambrose Channel and Chesapeake, 1956-66 for Barnegat and Five Fathom.



Source: Chase, J., 1971 and 1972: Oceanographic observations along the east coast of the United States, January to December 1967 and 1970, Oceanographic Reports Nos. 38 and 53, U.S. Coast Guard.

The horizontal and vertical distributions of oxygen along the shelf are shown in figs. 50 and 51. These figures are based on data obtained in September 1969, and are not, therefore, comprehensive; but they do illustrate the general distribution of oxygen. The annual variation of surface and bottom oxygen at two stations (40° 27'N, 73° 45'W; and 40° 10'N, 73° 14'W) off New Jersey, from data obtained during the period 1948 to 1950, is shown in fig. 52.

(d) Other characteristics.

(i) Phosphate. The distribution of inorganic phosphate along the shelf is shown in fig. 53. In the upper 10 meters phosphate values generally range between 0.3-0.5 ug-at/l with no distinct north-south gradient. Relatively high phosphates occur on the shelf in regions of low oxygen. 290/ Historical data show mean phosphate values vary from 0.15 µg-at/l in spring to 0.43 µg-at/l in summer and autumn off New Jersey (no data available during winter). Off Virginia, mean surface values range from 0.16 µg-at/l in spring to 0.36 µg-at/l in winter. Phosphate values are based on unpublished data summaries prepared by the National Oceanographic Data Center.

(ii). pH. Although little information is available, off New Jersey values of 7.0 to 8.4 should be expected (see table 22). Near Virginia, pH ranges from 7.0 to 8.6. 291/

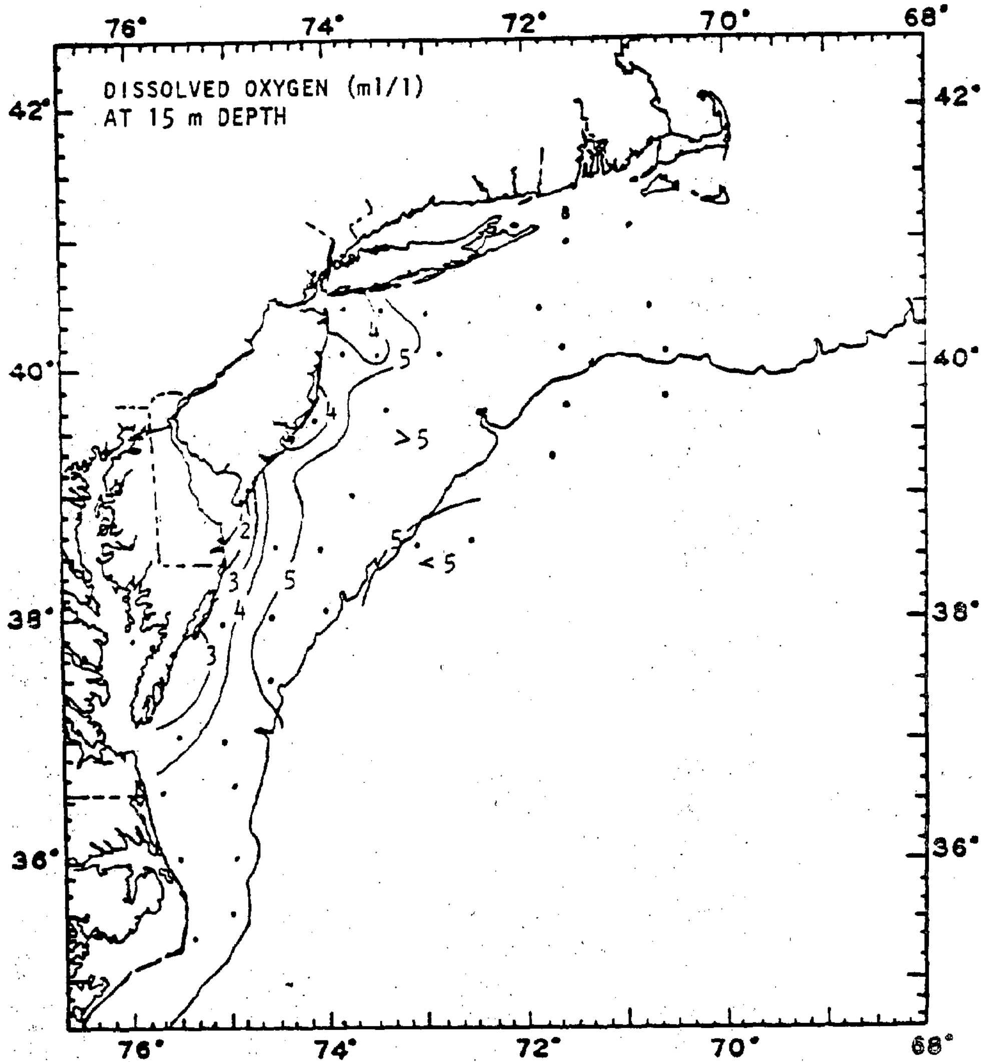
(iii) Miscellaneous. The primary features in the distribution of other biologically active components, such as nitrate, nitrite, ammonia, silicate, and others, follows the variations shown for oxygen and phosphate (figs. 51 and 53). The typical magnitudes of these other parameters are summarized in table 22. 292/

(iv) Pollutants. Information is not available for much of the shelf area, but recent surveys near the New York dumping grounds, shown in fig. 54, produced varying ranges of values for some heavy metals as well as some chemical constitutents (see table 22) in the waters surrounding dump sites.

CLIMATOLOGY

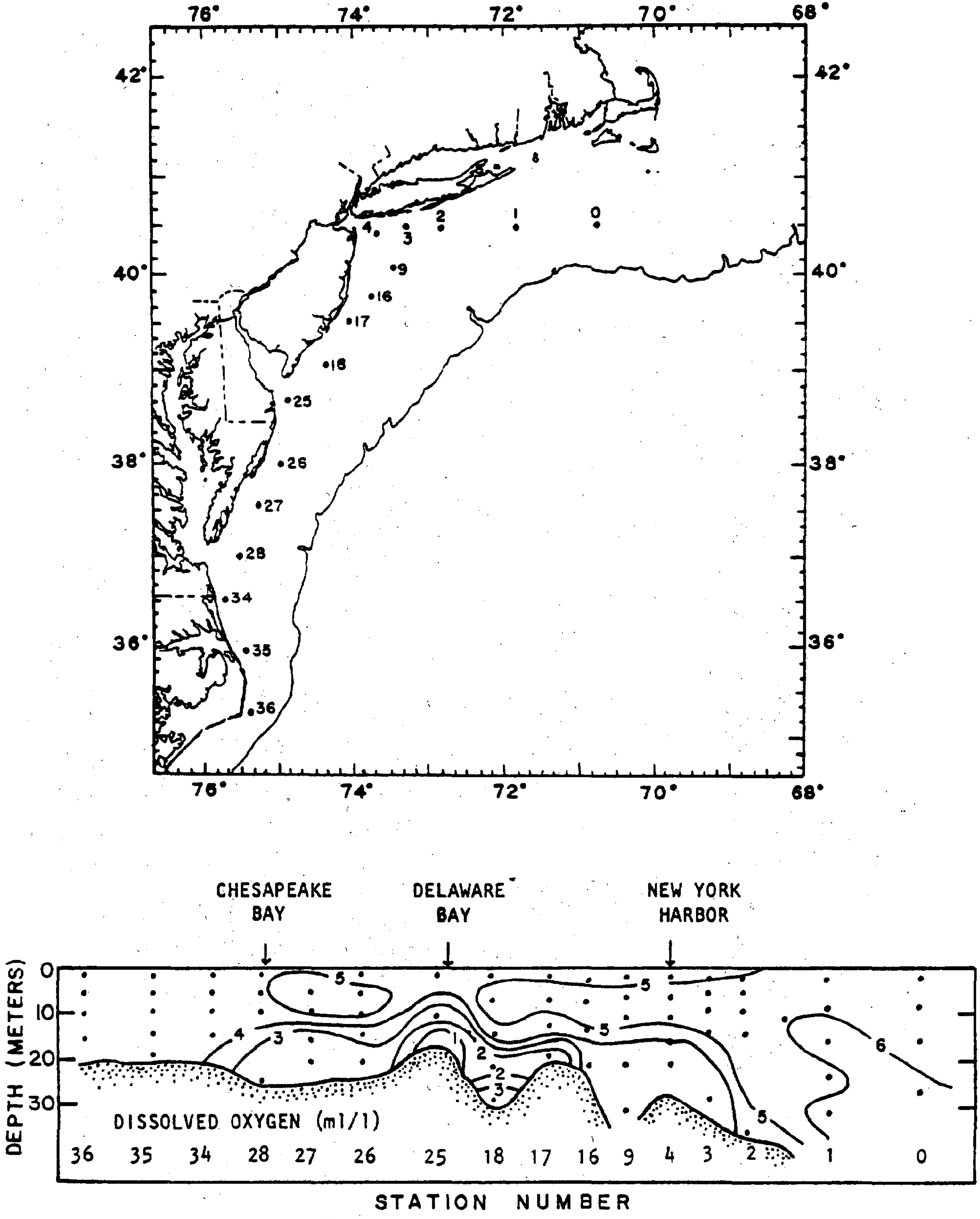
1. General. Area No. 2 lies in the prevailing westerly belt of the middle latitudes on the leeward side of the continent. The daily weather, which makes up the climatic pattern, moves generally from west to east; consequently, the region is influenced more by the land mass to the west than by the ocean to the east. However,

Figure 50.—Horizontal distribution of dissolved oxygen.



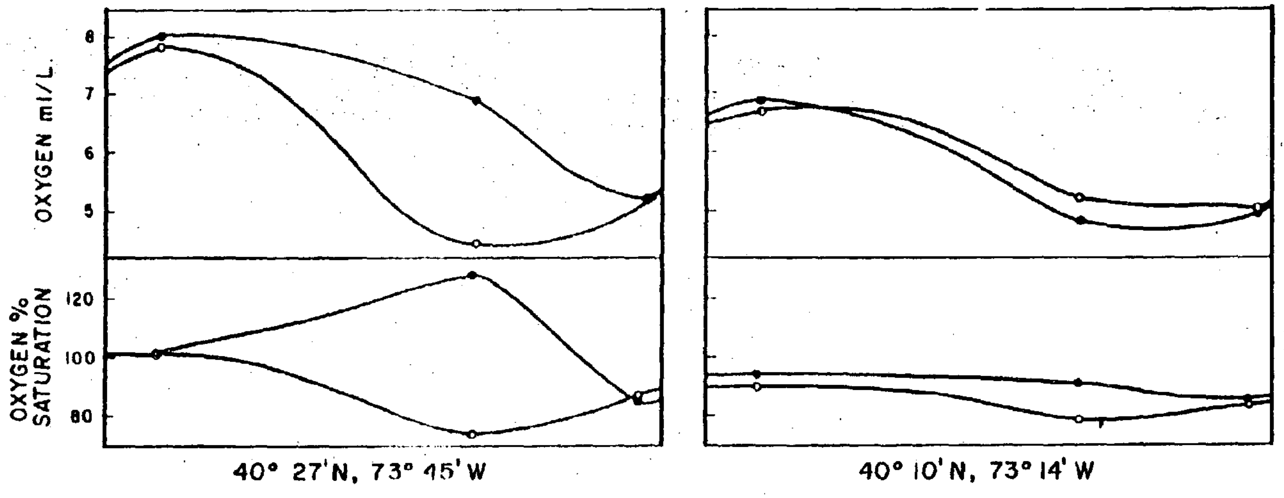
Source: Kester, D.R., and R.A. Courant, 1973: A summary of chemical oceanographic conditions: Cape Hatteras to Nantucket Shoals, Coastal and offshore environmental inventory. University of Rhode Island, Marine Publication Series No. 2.

Figure 51.—Vertical section of oxygen along the Continental Shelf about 10 to 20 miles from the coast.



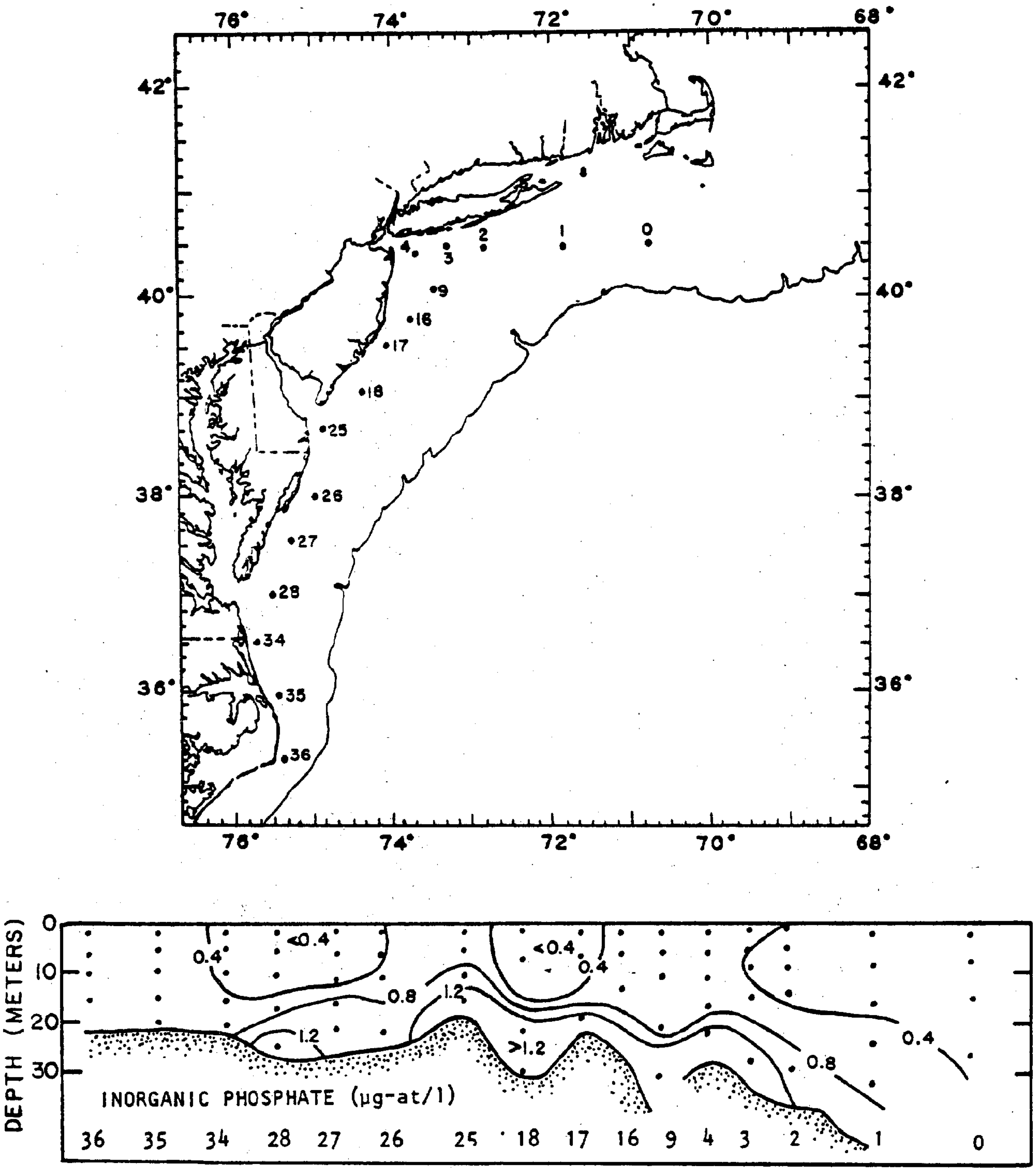
Source: Kester, D.R., and R.A. Courant, 1973: A summary of chemical oceanographic conditions: Cape Hatteras to Nantucket Shoals, Coastal and offshore environmental inventory. University of Rhode Island, Marine Publication Series No. 2

Figure 52.--Seasonal variation of surface and bottom oxygen at two stations off New Jersey.



Source: Pararas- Carayannis, G., 1974: Ocean dumping in the New York Bight: an assessment of environmental studies. U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Technical Memorandum No. 39.

Figure 53.--Vertical section of phosphate along the Continental Shelf about 10 to 20 miles from the coast.



Source: Kester, D.R., and R.A. Courant, 1973: A Summary of chemical oceanographic conditions: Cape Hatteras to Nantucket Shoals, Coastal and offshore environmental inventory. University of Rhode Island, Marine Publication Series No. 2.

Table 21.—Ranges of chemical data measure[illegible] grounds.

Chemical Variable	Range
Total iron	0 to 37.3 µg-at/1*
Chlorophyll-a	0.38 to 33.3 µg-at/1
Nitrate	0 to 3.28 µg-at/1
Orthophosphate	0.02 to 5.64 µg-at/1
Organic phosphate	0.04 to 2.28 µg-at/1
Metaphosphate	0.01 to 2.35 µg-at/1
Total phosphate	0.84 to 7.48 µg-at/1
Dissolved oxygen	2.0 to 15.2 ppm †
pH	7.10 to 8.40
Lead in sediment	0.55 to 249 ppm
Copper in sediment	0.013 to 338 ppm
Chromium in sediment	0.25 to 197 ppm

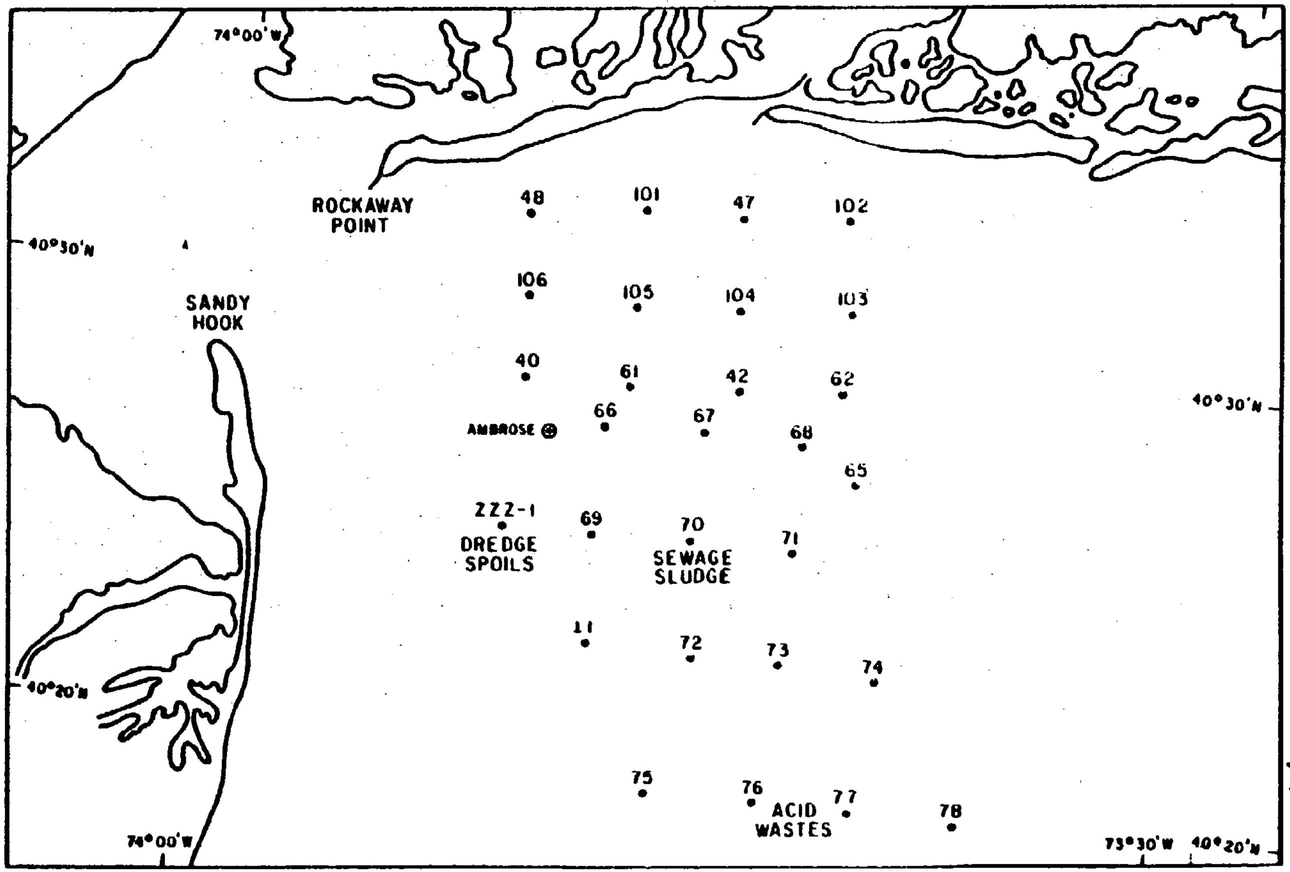
Source: Pararas - Carayannis, G., 1973: Ocean dumping in the New York Bight: an assessment of environmental studies. U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Technical Memorandum No. 39.

Table 22.—Magnitudes of various chemical parameters in continental shelf waters during August, 1969.

Parameter	Upper 10 m	Lower 10 m
Oxygen (ml/l)	5	2
Phosphate (µg at/l)	0.4	1.2
Nitrate (µg at/l)	0.1	2
Nitrite (µg at/l)	0.05	0.3
Ammonia (µg at/l)	0.5	4
Silicate (µg at/l)	1	12

Source: Kester, D.R., and R.A. Courant, 1973: A summary of chemical eanographic conditions: Cape Hatteras to Nantucket Shoals, Coastal offshore environmental inventory. University of Rhode Island, Publication Series No. 2.

Figure 54.--Stations occupied for chemical studies near New York dump sites.



Source: Pararas- Carayannis, G., 1973: Ocean dumping in the New York Bight: an assessment of environmental studies. U.S Army, Corps of Engineers, Coastal Engineering Research Center. Technical Memorandum the proximity of the cold coastal Labrador Current and the warm Gulf Stream farther to the east influences the winds, temperature, and precipitation enough to modify the typical continental regime. Therefore, the climate on all but the outlying islands can best be described as modified continental.

Superimposed on the general westerly circulation are the frequent wind shifts and changes in weather associated with extratropical cyclones. A principal area of storm formation is located off the Middle Atlantic Coast.

2. Tropical cyclones. Tropical cyclones occasionally move northward into the area in late summer or autumn. The storm centers generally move through the region on northeasterly courses toward Nova Scotia or over the adjacent ocean. Some severe hurricanes have moved northward across Long Island, with wind speeds of 70 to 80 kt. As a rule, these tropical storms are much more violent than the extratropical storms of the same season. Many of them take on some extratropical characteristics prior to reaching the area, and are less intense than in more southerly latitudes.

Since 1900, some 42 tropical cyclones have affected this area; 17 of them have been hurricanes. August and September are the main tropical cyclone months. [293/]

(a) Coast. Since 1900, a total of 16 tropical cyclones have come within 60 mi of the coast from Sandy Hook to Atlantic City; 4 have been of hurricane strength. In 1960, Hurricane Donna moved up the coast, bringing winds to 83 kt at Block Island and 5-to 9-ft surges along the southern coast of Long Island. In 1954, Carol and Edna were responsible for 40-to 50-kt winds and tides 5 ft above mean low water along the New Jersey coast. Two of the worst hurricanes ever to affect this coast were the storms of September 1938 and September 1944. Both caused tides in excess of 6 ft above mean low water, and both brought 70- to 80-kt winds to this area. [294/]

3. Extratropical cyclones. In winter, the core of the mean tracks followed by extratropical cyclones crosses this area. Consequently, there are frequent shifts from the prevailing westerlies and rapid weather changes. Usually, cyclones enter the area from the west, passing through the northeastern states, or they move from the southwest, with the center offshore.

The coastal storms which move northeastward (nor'easters) are likely to be of greater severity. Before the storm center passes, it may bring heavy rain or snow.

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Strong winds, sometimes of hurricane force, accompany it. The northwesterly winds in the western half of the storm, having come directly from the interior of the cold continent, will often be bitterly cold.

Table 23 shows that an average of nearly 24 extratropical cyclones affect this region each year. Few are dangerous, as indicated by the frequency of winds ≥ 48 kt, which never exceeds .4 of one percent. These frequencies do indicate, however, that the winter months are the most favorable for strong extratropical storms. Highest winter wind speeds at coastal locations run 45 to 50 kt, with gusts to 70 kt.

4. Winds. From November through March the prevailing winds blow from west through north at average speeds of 15 to 20 kt. Spring and autumn winds are variable. They blow at average speeds of 11 to 14 kt. These speeds are on the increase in fall and are slackening during spring. They continue to slacken until they reach a minimum average of 10.5 kt in June and July. South and southwest are the prevailing wind directions during these quiet summer months.

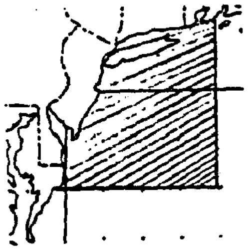
Summer gales are infrequent and usually accompany a thunderstorm, or squall line, or rarely, a tropical cyclone. Gales occur less than one percent of the time from May through August. The gale season runs from November through March, when they occur about 3 to 5 percent of the time. December, January, and February are the worst months. Due to tropical and extratropical activity, winds ≥ 48 kt may occur in any season, and the relative frequency of these storms is reflected in the frequency distribution of these winds in table 23.

(a) Coast. Along the shore, prevailing ocean winds are sometimes modified by local topography. Wind speeds are less because of increased surface friction. Average winter wind speeds of 10 to 12 kt are common. This is well below the open water averages. Gales are also a lot less frequent near the coast. During the summer, wind speed differences are less. If the area is not under the influence of a storm or a tight pressure gradient during the summer, there is a diurnal shift in winds. During the warmer part of the day, winds blow onshore (sea breeze), while at night an offshore breeze prevails. The sea breeze is the stronger of the two, and can reach 15 kt if conditions are right. The land-sea breeze phenomenon may occur in any season if temperature, wind, and pressure conditions are favorable.

Table 23.--Climatological summaries for area 2.

TROPICAL CYCLONE AND EXTRATROPICAL CYCLONE ACTIVITY

COASTAL AREA 38°N TO COAST, 71°W TO COAST



Area for which tropical and extratropical cyclone statistics appear below.

Tropical Cyclone Activity 1900-1972

	Feb.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tropical Storm Stage (34 to 63 kt)			2	2	6	5				15
Hurricane Stage (≥ 64 kt)				1	6	10				17
Extratropical Stage	1		2		2	6	4			15
Total	1		4	3	14	21	4			47

Extratropical Cyclones Affecting Area 1963-1972

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
25	31	34	16	19	15	12	8	10	13	24	32	239

Tropical Cyclones Striking within 60 Mi of Coast, Sandy Hook to Atlantic City (1900-1972)

	Feb.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tropical Storm Stage (34 to 63 kt)			1	1	3	2				7
Hurricane Stage (≥ 64 kt)					1	3				4
Extratropical Stage			1			2	2			5
Total			2	1	4	7	2			16

METEOROLOGICAL TABLES FOR AREA (2) 39° TO 40.5°N, 72°W TO COAST

Mean Recurrence Intervals

	5 yr	10 yr	25 yr	50 yr	100 yr
Maximum Sustained Wind (kt)	65	71	81	89	100
Maximum Significant Wave Height (ft)	37	42	49	55	62
Extreme Wave Height (ft)	67	75	85	99	112

Percentage Frequency of Wind Direction by Speed

January

DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.5	7.4	4.6	3.7	.1		17.3	16.1
NE	.8	3.0	1.9	1.6	.1		7.4	16.7
E	.7	2.4	1.3	.4	*		5.0	15.4
SE	.7	2.6	.7	.2	.0		4.2	12.7
S	1.6	3.9	1.8	.4	.0		7.8	13.3
SW	1.3	6.0	4.0	.8	.1		12.1	15.8
W	1.8	9.1	7.2	3.3	.5		21.9	18.3
NW	1.6	9.7	9.6	4.0	.3		25.3	18.9
AR	.0	.0	.0	.0	.0		.0	.0
LM	1.2						1.2	.0
OBS	239	918	648	259	23	2083		16.9
PCT	11.5	44.1	31.1	12.4	1.1		100.0	

February

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.9	6.2	3.7	1.2	.2		12.9	16.1
NE	1.1	3.8	2.4	.8	.2		8.4	16.3
E	1.0	4.2	2.4	.4	.1		8.0	15.3
SE	.9	3.0	1.3	.3	*		5.3	13.4
S	1.3	4.3	2.2	.7	.0		8.5	14.2
SW	1.1	5.5	3.6	.9	.1		11.1	15.9
W	1.3	7.6	7.1	2.6	.4		19.1	18.6
NW	1.4	8.8	10.1	3.5	.3		23.9	19.1
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	2.7						2.7	.0
TOT OBS	292	1014	749	242	31	2348		16.5
TOT PCT	12.4	43.2	31.8	10.3	1.3		100.0	

March

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.9	6.5	3.2	.9	.1		12.5	14.5
NE	1.9	5.7	2.9	1.3	.3		12.0	15.7
E	1.2	4.7	2.2	.7	.0		8.8	14.7
SE	1.1	2.8	1.2	.3	*		5.2	13.6
S	1.5	4.3	1.9	.3	*		8.0	13.1
SW	2.0	7.4	3.3	.3	.0		13.2	13.2
W	2.1	7.8	4.8	1.2	.1		16.1	15.3
NW	1.5	7.8	7.2	1.7	.1		18.2	17.2
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	6.2						6.2	.0
TOT OBS	566	1353	770	189	21	2897		14.0
TOT PCT	19.5	46.7	26.6	6.5	.7		100.0	

April

DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.8	4.7	2.2	.4	.2		9.4	14.1
NE	1.7	4.5	2.7	.5	.1		9.4	14.6
E	1.5	3.9	2.9	.5	*		8.7	14.5
SE	1.9	4.4	1.4	.2	.0		7.9	11.5
S	3.0	7.9	2.7	.2	*		13.8	12.1
[illegible]	1.9	11.7	3.5	.2	*		17.3	11.9
[illegible]	2.4	8.9	3.2	.7	.1		15.3	13.2
W	2.0	5.8	4.1	.7	.2		12.8	15.1
R	.0	.0	.0	.0	.0		.0	.0
N	5.6						5.6	.0
OBS	749	1684	742	109	20	3298		12.5
	22.5	51.1	22.5	3.3	.6		100.0	

May

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.6	4.8	1.2	.4	*		8.7	11.7
NE	2.0	5.3	2.6	.5	.1		10.5	11.4
E	2.4	5.3	1.5	.1	.0		9.3	11.0
SE	2.0	5.3	1.2	*	*		8.5	11.2
S	3.7	10.3	3.0	.1	.0		17.3	12.0
SW	3.7	13.6	3.2	.3	.0		20.8	11.8
W	2.3	7.1	2.0	*	.0		11.4	11.5
NW	1.9	5.1	1.4	.2	*		8.6	13.1
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	5.0						5.0	.0
TOT OBS	629	1420	394	48	4	2495		11.3
TOT PCT	25.2	56.9	15.8	1.9	.2		100.0	

June

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.6	3.4	.8	.1	*		5.9	11.0
NE	1.8	4.4	2.1	.4	.0		8.6	12.9
E	2.3	5.2	1.2	.1	.0		8.8	10.8
SE	2.7	4.4	.5	*	.0		7.6	9.2
S	5.4	15.5	3.1	.2	.0		24.3	10.9
SW	4.5	15.3	4.3	.1	.0		24.1	11.8
W	2.3	6.8	.9	.0	.0		10.2	10.2
NW	1.5	3.4	.7	.1	.0		5.8	10.8
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	4.8						4.8	.0
TOT OBS	641	1370	319	23	1	2362		10.5
TOT PCT	27.1	58.3	13.5	1.0	*		100.0	

Percentage Frequency of Wind Direction by Speed (Area 2 cont.)

July

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.1	3.9	.6	*	.0		6.6	9.6
NE	2.0	4.6	1.3	.2	.0		8.1	11.7
E	2.4	3.9	1.1	.1	.0		7.5	10.0
SE	2.1	4.3	.9	.1	.1		7.5	10.4
S	6.6	13.6	3.1	.1	.0		23.4	10.3
SW	4.3	15.4	4.1	.2	.0		24.0	11.9
W	3.2	7.1	1.1	.1	.0		11.5	10.6
NW	1.9	2.3	.8	.0	.0		5.0	10.1
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	3.9						3.9	.0
TOT OBS	557	1139	258	15	1	1990		10.3
TOT PCT	28.0	57.2	13.0	.8	.1		100.0	

August

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.3	4.3	1.6	.3	*		8.5	12.2
NE	2.7	5.4	2.3	.3	*		10.7	11.7
E	2.6	5.2	1.0	*	.0		8.8	10.3
SE	2.3	4.6	.8	*	.0		7.7	9.8
S	5.0	12.6	2.5	.2	.0		20.3	10.9
SW	4.3	15.4	3.3	.1	.0		23.1	11.3
W	3.3	6.2	1.0	.1	.0		10.6	10.0
NW	1.3	4.0	1.1	.1	.0		6.5	11.9
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	3.6						3.6	.0
TOT OBS	560	1186	276	28	2	2054		10.7
TOT PCT	27.3	57.7	13.4	1.3	.1		100.0	

September

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.7	6.7	2.9	.4	*		12.7	[illegible]
NE	2.2	7.1	3.7	1.5	*		14.6	[illegible]
E	2.5	7.0	2.0	.4	*		12.0	[illegible]
SE	2.4	4.6	.6	*	.0		7.6	9.6
S	4.0	8.0	1.1	.1	.0		13.1	10.6
SW	2.8	9.7	2.9	.2	.0		15.6	11.8
W	2.5	5.4	2.0	.4	.0		10.3	12.0
NW	1.5	5.6	1.9	.4	.1		9.6	13.6
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	2.6						2.6	.0
TOT OBS	467	1119	369	68	5	2028		12.1
TOT PCT	23.0	55.2	18.2	3.4	.2		100.0	

October

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.0	6.5	3.3	.8	*		12.6	14.5
NE	2.1	6.9	5.0	1.3	*		15.3	13.9
E	2.1	5.8	1.3	.3	*		10.3	12.9
SE	2.1	3.8	1.0	.1	.1		7.0	10.9
S	2.5	6.4	2.4	.1	.0		11.4	12.0
SW	2.2	7.8	3.1	.4	*		13.6	13.3
W	1.8	6.9	3.2	.8	.0		12.8	14.2
NW	1.4	6.8	5.1	1.1	*		14.3	16.2
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	2.4						2.4	.0
TOT OBS	390	1061	536	115	5	2105		13.7
TOT PCT	18.5	50.4	25.4	5.5	.2		100.0	

November

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.0	6.4	3.1	.9	.1		12.4	14.6
NE	1.4	4.2	2.3	.6	.3		8.8	15.9
E	1.2	2.8	1.6	.4	.1		6.1	14.6
SE	1.0	2.8	1.7	.2	*		5.7	13.8
S	1.1	6.3	3.1	.7	.1		11.4	13.4
SW	1.4	7.0	4.3	1.1	.1		13.8	15.7
W	1.3	8.7	7.1	1.9	.1		19.1	17.3
NW	1.1	8.3	8.7	2.8	.2		21.1	18.5
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	1.8						1.8	.0
TOT OBS	241	919	659	170	17	1990		16.0
TOT PCT	12.1	46.3	32.7	8.6	.9		100.0	

December

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.9	6.8	3.4	1.1	.1		13.2	15.0
NE	1.1	3.6	1.6	.3	.1		6.3	13.9
E	.7	2.9	1.6	.8	*		6.1	16.3
SE	.9	2.4	1.3	*	*		4.3	13.8
S	1.4	5.1	1.9	.3	.0		8.7	13.0
SW	1.4	6.5	3.6	.5	.1		12.2	14.9
W	2.0	9.6	7.5	3.1	.3		22.0	17.3
NW	1.9	10.0	9.7	3.2	.4		25.2	18.0
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	1.2						1.2	.0
TOT OBS	267	983	617	199	22	2092		15.9
TOT PCT	12.8	46.9	29.4	9.5	1.1		100.0	

Annual

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.0	5.6	2.5	.7	.1		10.9	13.2
NE	1.7	4.9	2.3	.8	.1		10.0	14.7
E	1.7	4.4	1.8	.4	*		8.3	13.2
SE	1.6	3.7	1.0	.1	*		6.6	11.6
S	3.1	8.4	2.5	.3	*		14.3	12.3
SW	2.7	10.2	3.6	.4	*		16.4	13.3
W	2.2	7.6	3.9	1.2	.1		15.0	14.1
NW	1.6	6.6	5.0	1.3	.1		14.7	15.1
VAR	.0	.0	.0	.0	.0		.0	.0
CALM	3.4						3.4	.0
TOT OBS	5579	14104	6355	1457	152	27870		13.4
TOT PCT	19.9	51.3	22.9	5.6	.5		100.0	

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Winds ≥34 kt	5.1	4.9	2.7	1.4	.3	.2	.5	.7	1.2	2.0	3.7	4.4	2.3
Winds ≥48 kt	.4	.3	.2	.3	.1	0	.1	.1	.1	0	.4	.2	.2

Percentage Frequency of Visibility (Nautical Miles) by Hour

January

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.0	.3	1.0	3.3	24.9	70.5	391
06&09	1.7	.6	.6	1.9	25.5	69.9	510
12&15	1.3	.3	1.0	5.9	30.8	60.8	390
18&21	1.2	1.2	1.4	6.0	28.7	61.4	415
TOT	19	9	17	71	468	1131	1718
PCT	1.1	.5	1.0	4.1	27.3	65.9	100.0

February

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	2.5	.5	2.9	8.2	31.3	54.0	461
06&09	2.5	1.1	1.5	6.6	25.3	63.0	530
12&15	2.2	2.6	2.2	7.3	37.1	48.6	463
18&21	2.9	.6	.8	7.7	33.7	54.3	461
TOT	46	25	35	142	607	1098	1915
PCT	2.5	1.3	1.8	7.4	31.7	57.3	100.0

March

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	2.7	.5	1.3	5.1	32.0	58.4	619
06&09	1.8	.0	1.1	6.1	27.2	63.8	557
12&15	2.4	1.7	2.0	9.6	33.3	51.0	586
18&21	3.0	1.8	2.1	9.3	28.3	56.3	623
TOT	62	19	48	204	744	1412	2405
PCT	2.5	.8	1.8	8.2	30.1	56.8	100.0

April

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	4.6	1.6	2.4	9.8	34.0	47.6	754
06&09	3.1	.9	2.0	9.3	30.6	54.1	784
12&15	4.5	.9	2.2	10.4	35.1	47.0	675
18&21	4.6	2.1	1.3	8.7	34.1	49.2	653
TOT	118	38	50	270	942	1400	2824
PCT	4.2	1.3	1.8	9.6	33.4	49.6	100.0

May

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	7.1	2.1	.9	9.7	31.9	48.4	580
06&09	5.6	1.2	1.7	4.9	26.8	59.8	633
12&15	5.6	1.9	1.4	9.6	33.3	48.0	428
18&21	5.7	1.7	1.5	7.8	36.7	48.6	472
TOT	131	36	29	160	684	1087	2133
PCT	6.1	1.7	1.4	7.8	32.1	51.0	100.0

June

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	4.2	.9	1.4	12.1	40.2	41.3	372
06&09	5.2	1.2	1.3	6.9	29.7	55.6	393
12&15	6.0	1.4	1.4	12.9	38.0	41.3	349
18&21	4.0	1.1	2.4	14.6	40.6	37.4	376
TOT	98	21	30	209	681	851	1890
PCT	5.2	1.1	1.6	11.1	36.0	45.0	100.0

July

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	1.0	.4	1.2	12.2	37.4	47.8	500
06&09	2.6	.0	1.1	4.6	33.3	58.9	504
12&15	4.7	.3	2.2	7.0	39.6	46.2	318
18&21	1.6	.3	.6	10.6	39.6	47.5	382
TOT	36	4	21	144	627	878	1702
PCT	2.1	.2	1.2	8.5	36.8	51.1	100.0

August

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.7	1.6	.7	9.3	32.8	55.0	481
06&09	.6	.6	.6	5.7	32.3	62.8	541
12&15	2.3	.9	1.1	8.9	34.5	52.3	348
18&21	1.8	.7	2.2	11.2	32.8	52.2	412
TOT	17	16	19	139	576	963	1782
PCT	1.0	.9	1.1	7.9	33.0	56.1	100.0

September

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.9	.7	.9	6.3	28.7	62.5	432
06&09	.7	.6	1.1	4.5	23.6	70.1	535
12&15	1.1	.5	1.9	5.8	24.3	68.2	368
18&21	1.0	.5	.5	5.8	27.7	64.5	394
TOT	16	7	18	89	449	1150	1729
PCT	.9	.4	1.0	5.1	26.0	66.5	100.0

October

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	1.0	.0	.2	4.1	22.8	71.8	412
06&09	2.2	1.0	.5	2.5	16.6	78.2	[illegible]
12&15	1.9	1.0	.7	6.6	24.3	65.5	411
18&21	.7	.2	.7	6.1	20.8	71.5	400
TOT	30	11	10	84	390	1304	1827
PCT	1.5	.6	.5	4.6	21.3	71.4	100.0

November

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	1.1	.5	.5	4.1	26.6	67.2	309
06&09	.7	.0	.7	3.8	20.8	74.8	534
12&15	.5	.2	1.2	4.1	27.6	66.5	412
18&21	.0	.3	1.8	3.0	26.9	67.3	364
TOT	13	4	17	60	420	1165	1679
PCT	.8	.2	1.0	3.6	25.0	69.4	100.0

December

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.6	.3	.3	4.9	31.0	63.2	345
06&09	.8	.4	.6	3.1	22.4	72.6	478
12&15	.5	.3	.5	5.1	31.1	62.7	389
18&21	2.5	.3	1.3	4.5	24.6	66.8	398
TOT	16	5	11	70	433	1075	1610
PCT	1.0	.3	.7	4.3	26.9	66.8	100.0

Annual

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	2.2	.8	1.1	7.7	31.2	57.1	5860
06&09	2.3	.6	1.1	4.8	26.4	65.0	6965
12&15	2.9	1.0	1.3	7.8	32.3	54.7	5133
18&21	2.4	.6	1.4	7.9	31.2	56.3	5296
TOT	602	199	303	1640	7038	13468	23262
PCT	2.6	.8	1.3	6.9	30.0	58.7	100.0

Percentage Frequency of Wave Height (Feet) vs. Wave Period (Seconds) for Area 2

January

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.5	15.6	19.7	8.0	1.8	.7	.3	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	833	3
6-7	.2	.7	4.3	8.2	4.8	2.2	1.7	.7	.3	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	388	6
8-9	.1	.3	.6	2.3	2.9	2.0	1.6	.5	1.5	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	201	8
10-11	.0	.2	.3	.4	.6	.7	.5	.7	.5	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	87	9
12-13	.0	.0	.2	.1	.0	.2	.2	.2	.2	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	22	10
>13	.0	.0	.0	.1	.1	.0	.2	.2	.2	.0	.0	.1	.2	.0	.0	.0	.0	.0	.0	17	14
INDET	3.7	1.3	1.4	1.1	.3	.0	.2	.1	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	136	2
TOTAL	126	300	444	336	172	97	81	41	53	4	4	2	4	0	0	0	0	0	0	1664	5
PCT	7.6	18.0	26.7	20.2	10.3	5.8	4.9	2.5	3.2	.2	.2	.1	.2	.0	.0	.0	.0	.0	.0	100.0	

February

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.1	12.2	16.6	8.1	3.4	1.5	.7	.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	894	4
6-7	.3	.9	4.7	7.3	4.7	1.9	2.3	.8	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	460	6
8-9	.1	.4	.8	2.1	2.1	1.9	.9	.7	.9	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	190	7
10-11	.0	.2	.1	.3	.6	.8	.7	.5	.3	.1	.0	.1	.2	.0	.0	.0	.0	.0	.0	72	10
12-13	.0	.0	.2	.2	.3	.0	.2	.2	.0	.1	.0	.2	.0	.0	.0	.0	.0	.0	.0	30	10
>13	.0	.0	.0	.1	.1	.1	.0	.1	.2	.0	.3	.4	.0	.0	.0	.0	.0	.0	.0	20	18
INDET	4.6	1.4	2.6	1.2	1.6	1.0	.7	.3	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	271	4
TOTAL	155	293	485	374	247	143	104	58	53	4	5	13	3	0	0	0	0	0	0	1937	5
PCT	8.0	15.1	25.0	19.3	12.8	7.4	5.4	3.0	2.7	.2	.3	.7	.2	.0	.0	.0	.0	.0	.0	100.0	

March

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.6	14.1	18.1	7.6	3.0	.9	.3	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1124	3
6-7	.2	1.2	4.6	5.5	4.2	1.9	.9	.4	.4	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	471	6
8-9	.1	.3	1.4	1.7	1.6	1.6	1.0	.7	.7	.0	*	.0	*	.0	.0	.0	.0	.0	.0	225	7
10-11	.0	.3	.1	.3	.6	.6	.1	.2	.5	.1	.2	*	.0	.0	.0	.0	.0	.0	.0	75	9
12-13	.0	.0	.1	.2	*	.3	.2	.1	.2	.1	.0	.0	*	.0	.0	.0	.0	.0	.0	31	10
>13	.0	.0	.0	*	.1	*	.1	*	.3	.0	.2	.1	.0	.0	.0	.0	.0	.0	.0	23	14
INDET	10.6	3.5	2.5	1.5	.9	.3	.2	.2	.2	.0	*	*	.0	.0	.0	.0	.0	.0	.0	484	2
TOTAL	351	471	606	412	254	138	75	42	62	5	11	4	2	0	0	0	0	0	0	2433	4
PCT	14.4	19.4	24.9	16.9	10.4	5.7	3.1	1.7	2.5	.2	.5	.2	.1	.0	.0	.0	.0	.0	.0	100.0	

April

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.4	17.3	15.7	7.6	2.2	.9	.4	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1300	3
6-7	.4	1.7	4.4	4.9	3.9	1.3	1.2	.4	.2	*	.0	.0	*	.0	.0	.0	.0	.0	.0	307	5
8-9	*	.6	.8	1.1	1.0	1.0	.5	.4	.4	.1	.0	*	*	.0	.0	.0	.0	.0	.0	162	7
10-11	.0	.1	.2	.3	.2	.1	.5	.1	.3	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	57	8
12-13	.0	.0	.1	.1	.1	.0	*	.1	*	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	14	8
>13	.0	.0	.0	*	.0	.0	.1	*	*	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	8	14
INDET	12.0	5.4	3.6	1.3	1.3	.3	.7	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	683	2
TOTAL	430	682	676	430	236	103	92	39	31	3	4	1	4	0	0	0	0	0	0	2731	4
PCT	15.7	25.0	24.8	15.7	8.6	3.8	3.4	1.4	1.1	.1	.1	*	.1	.0	.0	.0	.0	.0	.0	100.0	

May

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	5.9	22.3	19.5	7.1	1.5	.3	*	.0	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	1140	3
6-7	.2	2.2	5.5	5.5	2.0	1.1	.3	.0	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	344	5
8-9	*	.6	1.3	1.3	1.1	.7	.3	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	117	6
10-11	.0	.3	.3	.2	.3	.2	.2	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	36	6
12-13	.0	.0	*	.1	.1	.0	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	7	7
>13	.0	.0	.0	.1	*	.0	.1	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8	9
INDET	9.9	3.1	2.3	1.1	.3	.3	.1	.2	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	352	2
TOTAL	324	573	582	311	110	54	24	12	12	2	0	0	0	0	0	0	0	0	0	2004	3
PCT	16.2	28.6	29.0	15.5	5.5	2.7	1.2	.6	.6	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

June

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	8.5	24.3	20.1	6.2	.9	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1165	2
6-7	.5	3.2	6.2	5.3	2.4	.4	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	352	4
8-9	.2	.6	1.0	1.5	.7	.3	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	86	5
10-11	.0	.4	.3	.3	.2	.4	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	34	5
12-13	.0	.0	.3	.1	.2	.2	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	18	6
>13	.0	.0	.0	.1	.1	.1	.0	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	6	11
INDET	8.3	2.3	2.3	.5	.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	267	1
TOTAL	336	593	583	269	92	33	12	3	4	0	1	0	0	0	0	0	0	0	0	1926	3
PCT	17.4	30.8	30.3	14.0	4.8	1.7	.6	.2	.2	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

July

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	7.0	23.3	21.6	6.3	1.3	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	955	3
6-7	.1	2.6	7.4	6.2	2.7	.7	.1	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	319	4
8-9	.1	.9	1.3	.9	.2	.5	.1	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	66	5
10-11	.0	.4	.3	.1	.4	.0	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	23	5
12-13	.0	.0	.4	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8	4
>13	.0	.0	.0	.1	.0	.1	.0	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	4	12
INDET	6.7	3.5	2.3	.8	.0	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	215	1
TOTAL	220	490	532	228	74	27	6	5	6	1	1	0	0	0	0	0	0	0	0	1590	3
PCT	13.8	30.8	33.5	14.3	4.7	1.7	.4	.3	.4	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

August

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	5.7	23.4	20.0	7.2	1.7	.5	.1	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	978	3
6-7	.4	2.2	6.4	6.2	2.0	.5	.4	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	303	4
8-9	.1	.4	1.6	1.7	1.1	.5	.4	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	99	5
10-11	.0	.6	.1	.4	.4	.5	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	34	6
12-13	.0	.0	.3	.2	.1	.2	.1	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	16	7
>13	.0	.0	.0	.1	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	8
INDET	6.2	3.7	1.9	1.4	.1	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	229	2
TOTAL	205	503	504	287	91	46	16	4	5	2	1	0	0	0	0	0	0	0	0	1664	3
PCT	12.3	30.2	30.3	17.2	5.5	2.8	1.0	.2	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

September

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	4.7	21.3	19.9	6.8	1.7	.7	.2	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	901	3
6-7	.3	1.7	6.7	6.1	2.8	1.1	.6	.3	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	320	5
8-9	.1	.3	1.0	1.7	1.5	1.4	.2	.7	.4	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	119	7
10-11	.0	.8	.2	.2	.2	.6	.2	.2	.2	.0	.2	.1	.0	.0	.0	.0	.0	.0	.0	49	8
12-13	.0	.0	.3	.3	.1	.2	.2	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	22	8
>13	.0	.0	.0	.1	.0	.2	.0	.2	.1	.1	.0	.1	.1	.0	.0	.0	.0	.0	.0	13	13
INDET	5.3	2.6	2.2	.9	.6	.4	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	199	2
TOTAL	168	432	492	259	113	75	23	30	16	5	5	4	1	0	0	0	0	0	0	1623	4
PCT	10.4	26.6	30.3	16.0	7.0	4.6	1.4	1.8	1.0	.3	.3	.2	.1	.0	.0	.0	.0	.0	.0	100.0	

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Percentage Frequency of Wave Height (Feet) vs. Wave Period (Seconds) (Area 2 cont.)

October

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.9	10.8	18.6	7.8	2.9	1.0	.3	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	867	3
6-7	.3	1.5	6.2	7.4	4.3	1.8	1.0	.4	.6	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	397	5
8-9	.0	.5	1.2	2.5	2.0	1.4	.4	.5	.5	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	156	7
10-11	.0	.2	.1	.4	.5	.4	.5	.4	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	49	8
12-13	.0	.0	.1	.2	.2	.2	.0	.2	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	22	9
>13	.0	.0	.0	.1	.1	.1	.1	.1	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	10	11
INDET	5.4	1.5	1.7	.7	.7	.2	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	181	2
TOTAL	162	347	471	321	179	85	43	32	33	7	1	1	0	0	0	0	0	0	0	1682	4
PCT	9.6	20.6	28.0	19.1	10.6	5.1	2.6	1.9	2.0	.4	.1	.1	.0	.0	.0	.0	.0	.0	.0	100.0	

November

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.2	14.7	16.9	9.7	3.1	.7	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	781	3
6-7	.2	.9	4.9	7.8	3.7	2.9	1.2	.2	.2	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	389	6
8-9	.0	.3	.8	2.2	3.0	2.1	1.6	.9	.7	.3	.1	.1	.1	.0	.0	.0	.0	.0	.0	194	8
10-11	.0	.4	.4	.6	.7	1.2	.2	.1	.3	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	70	7
12-13	.0	.0	.3	.4	.1	.0	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	18	9
>13	.0	.0	.0	.2	.0	.1	.1	.2	.2	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	14	13
INDET	2.9	1.4	1.7	1.1	.3	.3	.2	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	130	3
TOTAL	103	285	405	352	210	117	59	26	27	7	4	5	2	0	0	0	0	0	0	1602	5
PCT	6.4	17.8	25.3	22.0	13.1	7.3	3.7	1.6	1.7	.4	.2	.3	.1	.0	.0	.0	.0	.0	.0	100.0	

December

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.1	13.7	19.0	6.9	2.0	1.6	.1	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	700	3
6-7	.2	1.0	6.1	10.5	6.0	2.7	.8	.3	.2	.1	.2	.1	.0	.0	.0	.0	.0	.0	.0	431	6
8-9	.1	.2	.9	1.5	1.9	2.0	1.0	.5	.7	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	139	8
10-11	.0	.4	.7	.5	.2	.4	.5	.3	.7	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	38	9
12-13	.0	.0	.4	.4	.4	.3	.1	.4	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	32	9
>13	.0	.0	.0	.1	.2	.1	.0	.1	.0	.1	.2	.0	.1	.0	.0	.0	.0	.0	.0	22	12
INDET	3.1	1.6	2.4	1.1	.3	.3	.2	.1	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	148	3
TOTAL	83	260	451	321	168	112	50	26	35	10	11	2	1	0	0	0	0	0	0	1530	5
PCT	5.4	17.0	29.5	21.0	11.0	7.3	3.3	1.7	2.3	.7	.7	.1	.1	.0	.0	.0	.0	.0	.0	100.0	

Annual

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	4.6	18.3	18.7	7.4	2.1	.8	.3	.1	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	11636	3
6-7	.3	1.7	5.6	6.7	3.8	1.8	.9	.3	.3	*	*	*	*	.0	.0	.0	.0	.0	.0	6481	5
8-9	.1	.4	1.1	1.7	1.6	1.3	.7	.4	.3	.1	*	*	*	.0	.0	.0	.0	.0	.0	1794	7
10-11	.0	.4	.3	.3	.4	.5	.3	.2	.3	.1	.1	*	*	.0	.0	.0	.0	.0	.0	526	8
12-13	.0	.0	.2	.2	.1	.2	.1	.1	.1	*	*	*	*	.0	.0	.0	.0	.0	.0	238	9
>13	.0	.0	.0	.1	.1	.1	.1	.1	.1	*	.1	.1	*	.0	.0	.0	.0	.0	.0	150	13
INDET	6.0	2.6	2.3	1.1	.6	.3	.2	.1	.1	*	*	*	.0	.0	.0	.0	.0	.0	.0	3301	2
TOTAL	2561	5229	6231	3900	1946	1030	585	318	337	50	48	18	17	0	0	0	0	0	0	22360	4
PCT	11.4	23.3	28.1	17.4	8.7	4.7	2.6	1.4	1.5	.2	.2	.1	.1	.0	.0	.0	.0	.0	.0	100.0	

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Waves ≥12 ft	6.4	7.1	5.2	2.9	1.3	.5	.9	.7	3.7	4.5	4.3	5.6	3.5
Waves ≥20 ft	.5	1.2	.9	.2	0	.1	.1	.1	.6	.2	.6	.9	.4
Maximum Seas	26-32	26-32	26-32	26-32	17-19	20-22	20-22	20-22	26-32	23-25	26-32	26-32	26-32

Consolidated Table of Meteorological Elements (Area 2)

WEATHER ELEMENTS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Visibility < 2 nautical mi (percentage frequency)	2.6	5.6	4.9	7.5	9.2	7.9	3.5	3.0	2.3	2.6	2.0	2.0
Precipitation (percentage frequency)	8.9	9.2	7.0	5.8	4.8	3.6	3.5	4.3	4.6	4.8	6.0	7.9
Temperature ≥ 85° F (percentage frequency)	0	0	0	0	0	0	.8	1.0	.1	0	0	0
Mean Temperature (° F)	38.9	37.7	41.5	46.4	54.6	66	73.1	73.7	68.6	60.8	52.0	43.7
Temperature ≤ 32° F (percentage frequency)	27.5	23.8	8.1	.3	0	0	0	0	0	0	1.4	11.5
Mean relative humidity (%)	79	78	78	81	83	85	85	83	79	78	76	77
Sky overcast or obscured (percentage frequency)	37.9	37.7	31.1	31.8	31.6	27.5	24.7	24.1	25.8	23.4	30.8	33.1
Mean cloud cover (eighths)	4.8	4.8	4.0	4.0	4.3	4.1	4.2	4.0	3.9	3.7	4.5	4.7
Mean sea level pressure (millibars)	1017	1017	1017	1015	1016	1016	1016	1016	1018	1018	1017	1018
Extreme maximum sea level pressure (millibars)	1036	1037	1037	1033	1031	1029	1027	1027	1031	1033	1035	1036
Extreme minimum sea level pressure (millibars)	975	971	976	985	988	999	997	984	985	993	979	986
Thunder and lightning (percentage frequency)	.2	*	*	.2	.9	1.0	1.5	1.4	.4	.2	.4	.1

* less than 0.5 percent

Potential Superstructure Icing (% Frequency)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Moderate (Air temp. < -2°C, wind ≥13 kt)	8.7	9.5	1.4	0	0	0	0	0	0	0	.1	3.2
Severe (Air temp. < -9°C, wind ≥30 kt)	0	.1	0	0	0	0	0	0	0	0	0	0

Area 2

PERCENT FREQUENCY OF OCCURRENCE OF SEA TEMP (DEG F) BY MONTH

SEA TMP DEG F	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	PCT
96+	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
95/96	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
93/94	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
91/92	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	1	*
89/90	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
87/88	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
85/86	.0	.0	.0	.0	.0	.0	.0	.1	.2	.0	.0	.0	6	*
83/84	.0	.0	.0	.0	*	.0	.4	.4	.2	.1	.0	.0	19	.1
81/82	.0	.0	.0	.0	.0	.0	.5	2.0	.9	.1	.0	.0	62	.2
79/80	.0	.0	.0	.0	.0	.2	2.5	5.3	1.8	.4	.0	.0	186	.7
77/78	.0	.0	.0	.0	.0	.4	8.0	13.6	5.1	.3	.1	.0	455	1.8
75/76	.1	.0	.0	*	.1	.8	12.8	21.8	8.8	1.0	.2	.1	815	3.2
73/74	.0	.0	*	*	.1	2.0	21.6	22.6	14.9	1.4	.1	.3	1138	4.5
71/72	.1	*	.0	*	*	3.8	20.9	17.6	15.2	3.2	.1	.1	1113	4.4
69/70	.0	*	*	.1	.4	8.9	17.4	9.5	17.0	6.3	.6	.0	1124	4.3
67/68	.2	*	.1	.0	.4	12.3	10.2	4.8	13.6	9.2	1.6	.2	999	4.0
65/66	.6	*	*	*	1.0	13.9	4.2	1.7	9.8	14.7	2.8	.4	951	3.8
63/64	.4	.1	.2	.3	2.0	16.6	1.6	.7	6.6	18.9	3.6	1.3	1030	4.1
61/62	.9	.1	.1	.2	3.0	14.6	1.0	.2	2.7	17.9	6.3	1.7	961	3.8
59/60	1.0	.1	.3	.6	4.7	11.6	.6	.1	1.9	14.9	12.0	3.5	1010	4.0
57/58	1.6	.7	.5	.7	7.5	8.0	.1	.0	.9	6.9	21.5	4.9	1060	4.2
55/56	3.5	1.2	1.1	1.2	11.0	3.0	.1	.0	.2	2.8	20.8	9.2	1086	4.3
53/54	5.1	1.8	1.6	2.1	13.1	2.3	.1	.0	.1	1.0	17.4	16.3	1224	4.9
51/52	5.7	2.8	1.8	2.8	13.2	.6	.0	.0	.0	.6	9.0	18.9	1136	4.5
49/50	7.9	6.0	3.1	5.5	12.1	.2	.0	.0	.1	.3	3.1	16.8	1187	4.7
47/48	12.8	9.7	5.0	10.2	9.4	.1	.0	.0	.1	.1	.7	12.0	1358	5.4
45/46	18.5	13.6	13.4	20.8	12.2	*	.0	.0	.0	.0	.1	8.1	2070	8.2
43/44	15.1	15.3	13.8	20.8	7.3	.0	.0	.0	.0	.0	.0	2.8	1895	7.5
41/42	9.7	18.7	20.8	20.2	2.0	.0	.0	.0	.0	.0	.1	2.2	1848	7.4
39/40	7.3	13.8	21.6	10.0	.4	.0	.0	.0	.0	.0	.1	1.0	1346	5.4
37/38	6.1	8.9	10.6	3.7	.0	.0	.0	.0	.0	.0	.0	.2	707	2.8
35/36	3.4	4.0	3.1	.6	.0	.0	.0	.0	.0	.0	.0	.1	290	1.0
33/34	.3	2.5	.6	.0	.1	.0	.0	.0	.0	.0	.0	.0	81	.3
31/32	.2	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	12	*
29/30	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1	*
27/28	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
<27	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
TOTAL	1890	2152	2650	3068	2286	2145	1772	1802	1807	1893	1785	1848	29116	100.0
MEAN	45.8	43.3	42.6	44.3	51.8	63.6	71.9	73.8	70.1	63.5	56.8	51.4	56.5	

LAND STATION DATA

STATION: J. F. KENNEDY INT'L. AIRPORT, NEW YORK
POSITION: 40.7N 73.8W
ELEVATION: 13 FEET

NORMALS, MEANS, AND EXTREMES

[illegible]

§ For the period June 1961 through the current year.

[illegible]

$ Greatest calendar day through March 1965.
# Greatest calendar day August 1966 through March 1969.

STATION: ATLANTIC CITY, NEW JRESEY
POSITION: 39.5N 74.6W
ELEVATION: 64 FEET

NORMALS, MEANS, AND EXTREMES

[illegible]

§ For period November 1966 through the current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Lowest temperature -9 in February 1934; maximum monthly precipitation 14.27 in August 1882; minimum monthly precipitation .01 in September 1941; maximum precipitation in 24 hours 9.21 in October 1903; maximum snowfall in 24 hours 18.0 in February 1902.

[illegible]

¶ Based on U.S. Naval Air Station and Weather Bureau Airport Station records.

‡ Beginning with August 1963.

-: U.S. Department of Commerce, National Oceanic and Atmospheric
-ration, Environmental Data Service.

5. Extreme winds. Extreme winds in this area have occurred most often during a hurricane. Hazel brought a 98-kt wind to New York City in 1954, while Donna, in 1960, brought 83-kt winds and 113-kt gusts to nearby Block Island. This island was also the recipient of 87-kt winds and 117-kt gusts during Hurricane Carol.[295] At Newark, extreme speeds have reached 71 kt. Gusts at Lakehurst Naval Air Station have been recorded at 75 kt, while Atlantic City clocked one at 70 kt.[296] Table 23 contains high wind speed frequencies and extreme wind recurrence intervals. You can expect a maximum sustained wind of 71 kt on an average of 10 years, and a 100-kt wind every 100 years.

6. Wave heights. The extreme waves of this area occur only in deep water, where they can be supported. High waves can be generated by extratropical or tropical cyclones. The frequency of these waves reflects the greater number of extratropical storms. From September through April, waves $\geq$ 12 ft occur from 3 to 7 percent of the time. During this period, seas of 3 to 4 ft are the most common. Even during the spring and summer, seas of 3 to 4 ft occur about 30 percent of the time. Waves of 20 ft or more have occurred in all months except May, but are most frequent in February (1.2 percent).[297]

Maximum significant observed seas (average of the highest 1/3 of the observed waves) in this area are 26 to 32 ft. These have been recorded in September and from November through April. Extreme conditions exist infrequently, and chances of being observed by a passing ship are small. Statistical formulas indicate that in Area 2 a significant wave height of 62 ft will occur once in every 100 years, on the average (in water depths of 80 feet or more) and an extreme wave height of 112 ft will occur during the same average period in deep water (see table 13).

7. Visibility. Visibility can be hampered by haze, rain, snow, and smoke, but fog is the worst restriction (table 23). In this area, advection fog in spring and summer is the major visibility problem. It occurs when warm south to southwest winds are cooled by the Labrador Current. In winter, steam fog may form during very cold weather, when the air temperature is much lower than the water temperature. However, it is usually short-lived and quite shallow. Visibilities less than 2 mi occur about 5 to 9 percent of the time from February to June; they are most frequent in May (9.2 percent). Poor visibilities are least frequent in November and December. Dense fog can drop visibilities to below 1/2 mi. In Area 2, this is most likely during April, May, and June, when it occurs from 4 to 6 percent of the time.

(a) Coast. Radiation fog, which forms on cold, clear, calm fall and winter mornings, can sometimes drift offshore and add to the frequency of poor visibilities along the coast. A good indication of the relative frequency of coastal fog is the average number of hours of operation of U.S. Coast Guard fog signals. These figures indicate that fog is most frequent in May, when signals are operating 70 to 100 hours, on the average. By late summer and fall, these figures fall off to 20 to 50 hours of operation per month. [298/]

8. Air temperatures. Average air temperatures in this area range from near 74°F in August down to about 38°F in February. Temperatures drop below freezing from November through April. Temperatures are $\leq$ 32°F a maximum of near 28 percent in January. Large temperature variations are common in winter. In summer, temperatures get above 85°F infrequently in July, August, and September (1 percent or less).

(a) Coast. Along the coast, air temperatures get colder in winter and warmer in summer. There is also a north-south gradient in winter. Average February temperatures range from about 32°F at New York City to 35°F at Atlantic City. Extremes range from -15°F in New York to -9°F in Atlantic City. Temperatures fall to freezing or below an average of 90 to 120 days per year. By June, the north-south gradient is gone, and temperatures along the coast average around 70°F. By July, a peak of 75° to 76°F is reached. Extremes of 106°F have been recorded. Temperatures of 90°F or more are reached on 10 to 20 days per year.

9. Storm tides. This phenomenon is coastal and results from a storm's wind and pressure effect on the waters (surge), plus the normal astronomical tide. When the surge peaks at the same time as a normal high tide, flooding can be severe. Along the coast, high storm tides have been generated by both tropical and extratropical storms. Record tides range from 7.5 feet to 10.5 feet above mean sea level. The New England hurricane of 1944 brought a record tide of 10.5 above mean sea level near Sandy Hook, as is passed northward, paralleling the coast.

10. Superstructure icing. See discussion in Area 1 (page 53). The potential for superstructure icing in Area 2 exists from November through March. It reaches a peak in January and February. During these months, conditions for potentially moderate superstructure icing occur just under 10 percent of the time. Conditions for potentially severe superstructure icing have only occurred in February (.1 percent).

LIVING MARINE RESOURCES

1. General. Based on recent proposals for siting of offshore floating nuclear power plants, [299/] the greatest impact is likely to impinge upon benthic infaunal invertebrates found in water depths of 40-90 feet and pelagic and demersal finfish which are indigenous to this zone or migrate seasonally through it. A few species of motil invertebrates such as the cancroid crabs, American lobster, moon snail, and seastars might also be affected by the siting and operation of nuclear power plants.

Many of the finfish are of commercial importance or have value as game fish. Several of the larger invertebrates, including the surf clam and American lobster, are commercially valuable species. Finally, almost all of the benthic and planktonic invertebrates are integral parts of complex food webs which support the more conspicuous species sought by man for food or recreation.

2. Estuarine and coastal wetlands. New Jersey is within the pine-barrens reach of the Atlantic coast. Vegetation types common to this area include cedar swamps, hardwoods, mixed stands of pines and hardwoods, pines marshes, and that of the barrier beaches. Coastal wetlands and open shoal water areas encompass about 940,000 acres. Of this area, about 215,000 acres are in coastal wetlands and about 375,000 acres in important open shoal water habitat. Coastal wetlands include about 61,000 acres dominated by freshwater plant species affected by tides, 135,000 acres of salt grass and saltmeadow cordgrass, and about 18,000 acres of salt marsh cordgrass. Estuarine and adjacent bay waters frequently support abundant stands of eel grass and widgeon grass. [300/]

New Jersey was one of the first states to set aside a portion of its hunting and fishing license funds for the specific purpose of acquiring hunting and fishing lands. This action has resulted in the purchase of several key coastal salt marsh areas. The Tuckahoe Hunting and Fishing Area is a prime example of this program on the Atlantic Coast.

In Delaware Bay, the Egg Island Waterfowl Area was one of the first purchases and has been used as a research area for mosquito control-wildlife relationships. In 1964, the Green Acres program, a 60-million dollar bond issue, was passed by referendum and has added to the state funds available to purchase salt marsh. The U.S. Fish and Wildlife Service maintains a waterfowl refuge, Brigantine National

Wildlife Refuge, which is about 19,500 acres in area. Barnegat Refuge, also maintained by the Service is about 3,300 acres in area.

The Island Beach and Sandy Hook State Parks and several state forests along the Mullica River also contain several thousand acres of essential wetland habitat.

3. Birds. Coastal marshlands and estuaries, including bays, are within the Atlantic flyway and are attractive to migrating waterfowl. Canada goose, American brant, blue-wing and green-wing teal, widgeon, redhead, gadwall, canvasback, greater scaup, and lesser scaup are some of the more abundant waterfowl utilizing the coastal zone. Some mallard and black ducks are also resident to the area. In addition to waterfowl, numerous species of shore birds, sea birds, song birds, and raptors are important to the region.

4. Land mammals. Wildlife associated with the coastal zone include squirrel, fox, beaver, and deer. The most sought game animals are the white-tail deer, bobwhite quail, and ruffed grouse. Muskrat and other small animals are common in open areas near water, and a few beaver occur in coastal marshes. Gray fox, mink, raccoon, and weasel are common to upland areas.

5. Indicator organisms, coliform bacteria. During an Ecosystems Investigations cruise conducted in late October and early November 1972, microbiologists from the U.S. Public Health Service analyzed waters and sediments for the presence of coliform bacteria at a series of stations along the New Jersey shoreline. Generally it was found that the bacterial populations were larger at stations off the various inlets along the northern part of the New Jersey shore, i.e., Shark River Inlet, Manasquan Inlet, and Absecon Inlet. Stations off sewer outfalls also had larger coliform counts.

Earlier studies of the distribution of coliform bacteria in the New York Bight [301] indicated that dense populations of coliform bacteria were associated with the sediments impinged upon by sewage sludge and contaminated dredge spoils.

A special study on the effects of metals on bacteria and the development of resistance to toxic effects of metals and antibiotics indicated that numerous taxa of bacteria existed in great densities in the sediments found in the New York Bight. [302]

The above findings are of great significance to proposals to site facilities which will produce and release large quantities of heated waters. It is known that heated water effects radically alter the population dynamics of microorganisms.303/ Temperature increases may result in greatly accelerated rates of growth and alter seasonal patterns of abundance. The New York Bight has been the site of extensive fish diseases 304/ in recent years and any increase in microbial activity could potentially aggravate this problem.

Heated water may also result in changes in phytoplankton populations. The New York Bight - Jersey shore has experienced numerous summer outbreaks of apparently toxic dinoflagellate blooms ("red tides") in recent years.

6. Plankton. Smayda and Jeffries and Johnson 305/ have reviewed the literature concerned with phytoplankton dynamics and the distribution and abundance of zooplankton, respectively, in coastal waters from Nantucket to Cape Hatteras. Standing crops in the New York Bight are not as great as observed off Montauk, Long Island, New York, but are approximately equal to those measured in Long Island Sound.

Murawski 306/ studied the ichthyoplankton associated with two inlets in central and southern New Jersey. He concludes that at least 41 species of developing finfish utilize tidal waters in New Jersey and that their well-being and survival are dependent upon quality estuarine environments.

The results of monthly sampling carried out in the New York Bight by Sandy Hook Laboratory 307/ from January through April 1970 at surface, midwater, and bottom depths indicate a general increase in the copepod population from January through late June, a decrease from July to October with an increase following. The average number of copepods per cubic meter of water filtered during the survey ranged from 41,000 to 700 individuals. This is within the range indicated by other studies in Middle Atlantic coastal waters.

Statistical analysis indicates surface samples contained the lowest numbers of individuals. Copepods are known to migrate vertically, descending in the water column during daylight hours and surfacing at night. The Sandy Hook samples were obtained during daylight hours.

The following is a list of the most common copepods found during the survey, ranked in order of abundance and indicating peaks in population:

(a) Oithona spp. The most abundant and most frequently occurring copepod. They were most abundant in midwater and bottom samples. Highest counts occurred in July and again in November.

(b) *Paracalanus* spp. The second in abundance and third in frequency of occurrence. The peak was reached one month earlier in surface samples with largest total abundance in October through early December.

(c) *Pseudocalanus minutus*. The third most abundant and second in frequency of occurrence. *P. minutus* is the most important copepod in the study area because of its size, which makes it a most valuable fishfood.

(d) *Centropages* spp. The fourth most abundant, with peaks occurring from June through January. This copepod is ranked second in importance as fishfood.

(e) *Temora* spp. Fifth in abundance with the most common species *T. longicornis* peaking from May through August.

(f) *Tortanus discaudatus*. Ranked sixth in abundance with peaks during spring and summer.

In addition to the copepods, several species of meroplankton were important because of their abundance; these included bivalve larvae, with peaks from January through April and August through November, 1969; polychaete larvae, peaking from January through early June and late August through December 1969; chaetognaths, which are most abundant near the bottom, peaking in May and June; and a gastropod, *Limnacia* sp. with highest numbers of individuals in October and August 1969 and January 1970.

Although the temporary planktonic larvae of benthic invertebrates (meroplankton) were well represented in samples taken in the Bight by Sandy Hook Laboratory[308], Jeffries and Johnson [309] report atypical distributions of meroplankton in Raritan Bay and suggest that this could be the result of inimical conditions arising directly from pollution.

According to Smayda [310] who has recently reviewed the phytoplankton research along the Atlantic Coast, there is a paucity of studies of phytoplankton along the New Jersey shoreline south of Sandy Hook.

Extensive studies, [311] however, have been made of the phytoplankton populations in Raritan and Lower Bays, adjunct to the New York Bight. During the course of their "red tide" investigations personnel at Sandy Hook Laboratory have intensively studied the blooms of dinoflagellates in the waters adjacent to Sandy Hook.

The above noted investigations indicated that the dominant diatoms in the area are the same as those important in New England and other coastal waters. Certain species, possibly indicative of polluted conditions [312], occurred in unusual numbers in Raritan

Bay. Possible effects of elevated temperatures and concomitant effects on population growth [313] and composition must be considered before additional heat producing facilities are sited in Raritan Bay.

Blooms of dinoflagellates resulting in so-called "red tides" have occurred with increasing frequency in Raritan Bay and New York Bight during recent years.[314] Smayda [315] reports a 1959 outbreak in Raritan Bay of a dinoflagellate, Massaritia rotundata, which produced a chlorophyll concentration at least twice those recorded during "red tides" in Long Island Sound and Delaware Bay.[316] Personnel assigned to Sandy Hook Laboratory have recently observed these dinoflagellate blooms to extend several miles south of Sandy Hook and seaward.

Eutrophication and consequent high standing crops of phytoplankton species may account for the large numbers of certain holoplanktonic animals in Raritan Bay.[317]

7. Invertebrates: benthos. Research by personnel assigned to Sandy Hook Laboratory on the benthic invertebrate fauna of the entire inshore area of New Jersey is now in progress. All samples have not been analyzed and data are therefore incomplete. Pratt [318] gives a general review of the inshore and offshore benthos from Cape Hatteras to Nantucket Shoals. A detailed study of the benthos was conducted in and around waste disposal areas of the New York Bight.[319] A computer-generated species list for a partial number of stations is available.

The surf clam densities at the proposed construction site off Long Beach Island (Public Service Electric and Gas Co. Site #7) are between .5 and 2 bushels per 4 min tow of a commercial clam jet dredge. Stations around Site #8 (off Little Egg Inlet) yielded densities of less than 0.5 bushels per 4 min tow, with the exception of station 141, at which a density of more than 2 bushels occurred. Mean length of surf clams at these sites range between 125 and 150+ mm. Few surf clams occur at the waste disposal sites in the New York Bight but ocean quahogs are abundant north of the sewage sludge grounds.

The small clam Nucula proxima is widely distributed along the New Jersey inshore waters and Hudson Canyon, often in high concentrations. Though it is known to withstand low dissolved oxygen concentrations, it is not generally present in the sludge disposal area. Its absence there is probably due to toxins.[320]

Telina agilis is another widely distributed bivalve, with the exception of the sewage sludge dump area where it is absent. Telina is known to be sensitive to copper.[321]

The blue mussel, *Mytilus edulis*, is common to hard substrates such as pilings, wrecks, jetties, and breakwaters. They may also cluster on large shell fragments. The proposed breakwaters that will enclose the nuclear generating stations will attract mussels and other fouling organisms. Such fauna are prime food sources for reef dwelling fishes such as tautog and cunner. *Balanus balanoides* is the most common barnacle inhabiting inshore oceanic areas, and will probably be a major component of encrusting or fouling communities at the construction site. *Balanus improvisus*, *B. eburneus* and *B. crenatus* may appear, but are usually limited to less saline waters.

Families of common polychaetes include Glyceridae, Nemphthyidae, Lumbrinereidae, Cirratulidae, Ampharetidae, and Capitellidae. The Polychaetes are common in high numbers around Site #8 during the summer. Polychaetes are important food items for many demersal fishes.

Common amphipods found in the vicinity of dumping grounds between estuarine and inshore oceanic waters in central New Jersey are especially important in the diet of demersal finfish, particularly juveniles, and are known to be sensitive to environmental change.[322]

Twenty-nine species of amphipods were identified by Sandy Hook Laboratory from the vicinity of Little Egg Inlet. The largest number of individuals were represented by *Ampelisca abdita* (530), *Ampelisca verrilli* (459), *Protohaustorius deichmannae* (78), *Amphiporeia virginiana* (61) and *Acanthohaustorius millsi* (42). These species were most abundant in estuaries and followed normal distribution patterns as described by Bousfield.[323] Both the families Ampeliscidae and Haustoriidae to which the above species belong have been found to be good indicator species for organic pollution. Blumer, et al.[324] found that *Ampelisca macrocephala* felt the effects of oil pollution before it could be detected by the most sophisticated scientific equipment. In the original study area of solid waste disposal[325] only relatively few specimens were found and very few were associated with the disposal area. However, in 1972 when the area of study was enlarged, *Ampelisca agassizi* was the dominant species in the Hudson Canyon (up to $294/0.1m^2$) and *Ampelisca macrocephala* was found in concentrations of $48/0.1m^2$ 3 miles off Sea Girt.

On Shrewsbury Rocks off Monmouth Beach, New Jersey, *Ampelisca vadorum* was obtained in counts over $2000/meter^2$. Only a few of the sibling species *Ampelisca abdita* were found in the Oyster Creek discharge canal of Jersey Central Power and Light Co.'s nuclear generating station. This species would normally be expected in large numbers.

Erichthonius brasiliensis has been found in concentrations of 36,000/0.2 meters^2 in Forked River, New Jersey.[326/]

No members of the family Haustoriidae were found in the sewage or dredging spoils disposal areas but haustorids were found in all surrounding areas and their population tended to increase at distances from the polluted areas.

Of the more important epibenthic organisms found near proposed Site #8, the crab, Cancer irroratus, a potentially commercial fishery resource with a high standing crop in coastal waters, is commonly fed upon by sea robins, sea ravins, long horned sculpins and other demersal elasmobrachs and teleosts. Polinces heros, the moon snail, is an important predator of surf clams and other bivalves. Asterias forbesii also feeds on bivalves. Crangon septemspinosa, the sand shrimp, ranges from the sublittoral zone to water well over 100 feet deep. It is another very important food item for demersal fishes. Recently, biologists at Sandy Hook Laboratory have found large numbers of diseased shrimp. The American lobster, Homarus americanus, usually inhabits areas characterized by rocks or rubble that offer shelter and nesting sites. Offshore breakwaters would probably be prime attractants and may be habituated by lobsters. Sand dollars, Echinarachinius parma, are limited to clean sandy substrates.

8. Finfish. The coastal zone from Sandy Hook to Atlantic City, New Jersey supports a wide variety and quantity of finfish species. Numerous investigations have been made of the standing stocks, population dynamics, and biology of these species. These endeavors were, in part, recently reviewed by Saila and Pratt [327/] in their paper concerned with the fisheries of the Middle Atlantic Bight.

Other sources of uniform, comprehensive, and current data available for assessment of the living marine resources in the 40-60 foot zone along the coast of the United States include 1) Statistics on the value and volume of commercial fishery landings in 1972, as assembled by the National Marine Fisheries Service (NMFS) (tabulations on file, but not yet published in full detail) and 2) Statistics on the marine sportfish catch in 1970, as collected by the U.S. Bureau of Census for the NMFS.[328/]

Of a total of about 300 species of fishes known from the Mid-Atlantic Bight (Cape Cod to Cape Hatteras) less than one half are consistently found from year to year. Of the latter, only about 30 are of significant commercial fishery value. In decreasing order of value, the most important species caught off the New Jersey coast are menhaden, summer flounder, scup, silver hake, black sea bass, bluefish, striped bass, and butterfish.

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Most of these same species are also caught by sport fishermen. In addition, several other species make up an important percentage of the sport catch; these include American mackerel, winter flounder, Atlantic croaker, red drum, black drum, cobia, tautog spadefish, puffers, sea robins and white perch.

Many of the species listed above are migratory. Their migrations are seasonal and for generations their movements have determined the character of the fisheries of the region. In the spring and summer, these fishes move into coastal waters, including bays and sounds, and sometimes river estuaries. They tend to be more concentrated at this season toward the northern part of their range. In the fall and early winter they migrate to offshore, more southerly wintering grounds.

9. Threatened species. Wildlife species threatened include bog turtle, American peregrine falcon, Arctic peregrine falcon, sperm whale, blue whale, finback whale, sei whale, humpback, right whale, and barehead whale.[329/]

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AREA 3: CHINCOTEAGUE ISLAND TO CAPE CHARLES, VA.

GEOLOGY AND TOPOGRAPHY

1. General. This unglaciated area (see fig. 43) is characterized by mainland coastal plains fringed by long sand barrier islands as well as deep embayments. Chesapeake Bay is one such embayment. The long narrow peninsula that forms the east margin of Chesapeake Bay and terminates at Cape Charles, because of the States involved, is called Delmarva Peninsula. The lower end of the peninsula is divided along a north-south line between Maryland and Virginia. To the east the area is largely marsh and lagoons with a barrier island along the seaward margin. To the north, Chincoteague Island is also a sand barrier island. Chesapeake Bay is a drowned river valley (the longest in the United States) about 180 miles in length, extending from the mouth of the Susquehanna River to Cape Charles.[330/]

The surface of the Continental Shelf in the area between Chincoteague and Cape Charles is relatively smooth, with numerous minor ridges and troughs. At the northern end of the area the depth at the outer limit is about 60 meters; farther south at Cape Charles the depth is only 40 meters at 50 miles from the shore. The entire shelf is some 60-70 miles wide and is little more than 100 meters deep at the shelf break. Two canyons appear very near the shelf break, the Washington and Norfolk Canyons, with no evidence that there is any landward expression of these features.[331/]

Linear sand bodies occur in the area. It has been suggested[332/] that such bodies north of Norfolk, Virginia, are drowned barrier beaches. One such beach to the south of the area was found to be composed of coarse brown sand along the crest and fine gray sand along the flanks. Sanders[333/] suggested that the ridges were a coastal-dune complex formed during a Pleistocene standstill of sea level. If these conjectures are correct there has been a recent substantial change in shoreline direction. Storm produced oscillatory currents could develop sufficient velocity to move the sediments present on the shelf.[334/]

Detailed contour charts of the Continental Shelf in this area reveal the presence of four terraces backed by slopes extending as much as 15 meters above the terraces. Two such terraces between Chincoteague and Cape Charles are called the Nicholls and Block Island Shores, and are interpreted as ancient shorelines. They have been recognized in continuous seismic reflection profiles and by echo sounding.

The Nicholls Shore has been Carbon-14 dated as 35,000 years old.

No faults have been reported in this region. 335/

2. Sediments. Sediments are characterized by their patchiness in distribution, with gravel occurring sporadically at all distances from the land. In the northern portion of the area there is a general decrease in grain size seawards. Further south, in crossing the shelf, the sediments become alternately finer and coarser.

The sediments on the shelf beneath the Holocene and Pleistocene are upper Miocene, middle Eocene, and upper Cretaceous. The underlying rocks are Triassic igneous and metamorphic rocks.

Sediment thickness is considerable, as much as 1000 meters in places. The sediments vay in grain size, with some occurrences of gravel and boulders, but are predominantly in the sand class. Silt and clay accumulations are very rare. Turbidity currents have not been reported. 336/

OCEANOGRAPHY

See Area 2.

CLIMATOLOGY

1. General. The Appalachian Mountains, although some distance from the ocean, exert an important influence on the winter climatic pattern in this coastal area. They partly block the cold continental air from the interior, and this factor combines with the moderating effect of the ocean to produce a more equable climate than is found in many continental locations in the same latitude. The major low-pressure storm systems which develop over the interior, the Gulf of Mexico, and off the southeastern coast, may sweep through the Middle Atlantic States.

2. Tropical cyclones. Tropical cyclones are infrequent in comparison with extratropical cyclones, but they have a record of destruction far exceeding that of any other type of storm.

As a tropical cyclone moves out of the tropics to the Delaware latitudes, it normally loses energy slowly, expanding in area until it gradually dissipates or acquires the characteristics of an extratropical cyclone. At any stage, a tropical cyclone loses energy at a much faster rate if it moves over land. 337/

From 1900 to 1972, a total of 89 tropical cyclones have affected this area. Of these, 35 were hurricanes.

(a) Coast. A total of 24 tropical cyclones have struck within 60 miles of the coast between Chincoteague Island and Cape Charles, Virginia since 1900. Only three have been hurricanes; all occurred in September. September is the most likely month for a tropical cyclone strike.

In 1960, Hurricane Donna brought 60- to 70-kt winds to the Virginia coastal area. Tides ran 3 to 4 feet above mean sea level. Back in 1954, Hurricane Hazel was responsible for 68-kt winds at Norfolk—an all time record. Cape Henry suffered winds of 116-kt during the hurricane of September 1944, which also pushed tides up to 7 feet above mean low water in southern Virginia. Back in August of 1933, a hurricane generated 7- to 9-foot tides (above mean sea level) and 50- to 60-kt winds along the Virginia coast. 338/

3. Extratropical cyclones. The winter extratropical cyclones traversing this area produce frequent wind shifts from the prevailing westerlies and rapid changes in the weather. The cyclones may be of continental or marine character, with the latter (nor'easters) usually being of greater severity. Strong winds, sometimes of hurricane force, accompany the storms. The northwesterly winds in the western half of the storm, having come directly from the interior of the cold continent, are often very cold. An average of 28.3 extratropical storms affect this area each year. 339/ Most of these are weak lows and pose little threat of damage. They are most frequent from November through April.

Within this area, a significant number of extratropical cyclones develop each year. This major area of cyclogenesis often spawns storms known as "Cape Hatteras Lows," which sometimes become the intense northeasters that plague the mid-Atlantic and New England coast.

4. Winds. From November through March, prevailing winds are from the northwest through north at 15 to 20 kt. Spring and autumn winds are lighter and more variable. Average wind speeds range from 12 to 14 kt. In fall, they are increasing; in spring, they are slackening toward a summer minimum. This minimum occurs in July, when the wind speed average falls to 10.7 kt. Summer winds blow from the south and southwest nearly one-half of the time. Northeasterlies are also common. 340/

Gales (winds $\geq$ 34kt) are uncommon in summer. If they occur, it is usually with a squall line, isolated thunderstorm, or in a rare tropical cyclone. Gales occur less than 1 percent of the time from May through August. They become more frequent by October, and November through March is the heart of the gale season. During these months, gales occur 3 to 4 percent of the time. Winds in the area do not often reach 48 kt or above, but this does happen about 0.4 percent of the time in January, February, and March.

(a) Coast. Coastal winds are similar to open-water winds, except they are modified to some extent by local topography. At Norfolk, for example, southwest winds are the most frequent in every season. Due to surface friction and coast production, wind speeds are lighter on and near the coast. Even at an exposed location like Cape Hatteras, average winter wind speeds are about 12 kt. During the summer, wind speed difference are less, as coastal average run about 7 to 10 kt. If pressure gradients are slack, then a land-sea breeze effect controls coastal winds. During the summer, wind speed differences are less, as coastal averages run about 7 to 10 kt. If pressure gradients are less, as coastal averages run about 7 to 10 kt. If pressure gradients are slack, then a land-sea breeze effect controls coastal winds. During the summer day, the land heats up faster than the water, creating a wind off the water (sea breeze). Wind speeds can reach 15 kt, if conditions are right. At night, the land cools quicker, and the wind reverses (land breeze).[341]

5. Extreme winds. In this region, extreme winds are the most likely during a hurricane. Norfolk recorded a 68-kt wind, with 87-kit gusts, during Hurricane Hazel.[342] Langley Air Force Base has recorded an 83-kt gust. South of the area, Helene generated 76-kt winds, with gusts to 117-kt at Wilmington, N.C., and a gust of 110-kt at Frying Pan Shoals Lightship. Cape Henry recorded a wind of 116-kt in the hurricane of September 1944. On the average, a maximum sustained wind of 76-kt can be expected every 10 years, and a 120-kt wind every 100 years.[343]

6. Wave heights. Extreme waves are only generated in deep water, where they can be supported. At shallow depths, they break before they are able to build to any great height. The breakers that pound coastal areas, however, can be destructive. Rough seas and high waves occur most often from September through April. During this season, waves are most often at 3 to 4 feet. While waves ≥ 12 feet occur 2 to 6 percent of the time, they are most frequent in January (6.4 percent). Waves of 20 feet or more have occurred in all months but July, but they are infrequent; January is the peak month (1.5 percent).

Maximum seas in this area have been reported at 49 to 60 feet during February. A water depth of about 77 feet or more would be needed to support 60-foot waves. These are significant waves, which means an average of the highest one-third observed. Extreme waves are rare, and their chances of being encountered by a passing ship are slim. Statistical formulas indicate that a significant wave height of 53 feet will be encountered on an average of 10 years, and 79 feet in 100 years; an extreme wave of 96 feet breaks once in every 10 years, while an extreme 143-foot wave could be encountered once in 100 years, on the average.

7. Visibility. Although generally good over this area, visibility can be hampered at any time by smoke, haze, fog, and precipitation. The frequency of occurrences of visibility less than 2 miles is greatest from February through June, when visibilities drop below this value 3 to 5 percent of the time.

Advection sea fog occasionally drifts onshore in the warmer months, burning off from the surface and usually lifting by afternoon. This process is reversed over water, where fog usually dissipates from the top downward. In dense fog, visibilities will drop below one-half mile. This occurs more than 1 percent of the time, from January through June, and is most frequent in April and May, when it occurs about 3 percent of the time.

(a) Coast. Along the coast, the most valuable source of relative fog frequencies is the number of hours of operation of fog signals. These indicate that fog frequencies, in general, decrease southward. Maximum fog frequencies occur during the winter, particularly in February, when fog signals operate on an average of 40 to 70 hours. Frequencies fall off in spring and reach a minimum in July and August, when fog signals operate on an average of 5 to 20 hours. [344/]

8. Air temperature. Mean air temperatures in Area 3 range from about 78°F in August down to 46°F in February. Temperatures drop to freezing or below from November through April; this occurs most frequently in January (6.9 percent). Large temperature variations can occur in winter. This is not so in summer. In July and August, temperatures $\geq$ 85°F occur 4 to 5 percent of the time, even though this is just 7°F above normal for these months.

(a) Coast. Along the coast, there is a greater daily and seasonal temperature range. At Norfolk, means range from 79°F in July down to 41°F in January. This compares to a 78"F average in July and a 47°F average in January at Cape Hatteras. There is little north-south temperature gradient in summer, and little difference in summer mean temperatures between the coast and open ocean. However, on the coast, daily temperature ranges are greater. For example, the mean maximum is above 85°F in July and August at Norfolk. At exposed coastal locations, such as Cape Hatteras, there is little difference between the coast and the sea. Temperature extremes at coastal stations are 97° to 105°F for a high, and 2° and 8°F for a low. Cape Hatteras has the lower maximum and higher minimum.345/

9. Storm tides. Storm tides result from the impact of the storm's winds and pressure (surge) on the normal astronomical tide. If the maximum storm surge coincides with a normal astronomical high tide, record-breaking, damage-wrecking tides can occur. Record high tides along this section of the coast have been generated by both extra-tropical and tropical cyclones. They range, in general, from 6 to 10 feet above man sea level. Since this portion of the coast is mostly lowland, tides of this magnitude are disastrous. Along the Outer Banks of North Carolina, they can change the topography, and from time to time carve new inlets from the ocean to the sounds. They also cause severe flooding along the Maryland-Virginia shores.

Table 24 summarizes climatological data for Area 3.

LIVING RESOURCES

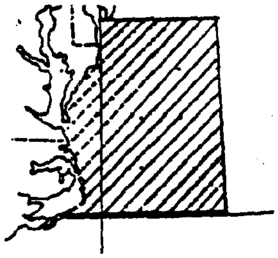
1. General. The coastal zone of Virginia is divided by Chesapeake Bay into two significantly different parts. The Eastern Shore is a sparsely populated, agricultural-and-commercial-fishery-oriented section that has changed little since Colonial times. The Tidewater section on the western side of Chesapeake Bay is dominated by the growing metropolis of Norfolk and its satellite cities, by Richmond, the State Capitol, and by Washington, D.C. As is to be expected, the losses of coastal salt marsh in Virginia are concentrated in the vicinity of Norfolk. The Eastern Shore and the coastline between the York and Potomac Rivers are still largely untouched.

State and Federal developments for wildlife and recreation are restricted to the Eastern Shore and to the Back Bay area. On the Eastern Shore the U.S. Bureau of Sport Fisheries and Wildlife owns the Chincoteague National Wildlife Refuge on the southern part of Assateague Island. Though most of the area is composed of sand dunes and barrier beach, it contains important marine resource habitats on the bay side. The Back Bay National Wildlife Refuge consists of both barrier beach and coastal freshwater marsh. The Virginia Commission of Game and Inland Fisheries owns the Saxis Island and Mockhorn Island Waterfowl Management Areas on the Eastern Shore and Trojan and Pocahontas Waterfowl Management Areas in Currituck Sound.346/ Seaside marshes and flats

le 24.--Climatological summaries for area 3.

TROPICAL CYCLONE AND EXTRATROPICAL CYCLONE ACTIVITY

COASTAL AREA 35°-39°N, 72°W TO COAST



Area for which tropical and extratropical cyclone statistics appear below.

Tropical Cyclone Activity 1900-1972

	Feb.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
Tropical Storm Stage (34 to 63 kt)		1	5	4	8	8	2	3	31
Hurricane Stage (≥ 64 kt)		1		4	10	16	3	1	35
Extratropical Stage	1		2		1	10	8	1	23
Total	1	2	7	8	19	34	13	5	89

Extratropical Cyclones Affecting Area 1963-1972

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
39	35	43	26	18	16	18	15	15	13	20	25	283

Tropical Cyclones Striking within 60 Mi of the Coast, Chincoteague Island, Va. to Cape Charles, Va., 1900-72

	Feb.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tropical Storm Stage (34 to 63 kt)				2	4	3	1		1	11
Hurricane Stage (≥ 64 kt)						3				3
Extratropical Stage			1		1	3	5			10
Total			1	2	5	9	6		1	24

METEOROLOGICAL TABLES FOR AREA 3 -- 36°-38°N, 73°W TO COAST.

Mean Recurrence Intervals

	5 yr	10 yr	25 yr	50 yr	100 yr
Maximum Sustained Wind (kt)	68	76	90	104	120
Maximum Significant Wave Height (ft)	47	52	63	70	79
Extreme Wave Height (ft)	85	96	113	127	142

Percentage Frequency of Wind Direction by Speed

January

WND DIR	WIND SPEED (KNOTS)					TOTAL OBS	PCT FREQ	MEAN SPD
	0-6	7-16	17-27	28-40	41+			
N	1.9	8.8	6.4	1.5	.2	1906	18.9	19.5
NE	1.3	4.6	2.1	.7	.1	846	8.6	14.0
E	1.0	2.5	.8	.1	*	421	4.3	11.6
SE	.9	1.9	.9	.2	*	376	3.8	12.9
S	1.7	5.4	3.4	.3	*	1101	11.3	14.2
SW	1.2	7.1	4.7	1.2	.1	1398	14.3	16.2
W	1.6	6.3	4.2	1.6	.2	1450	14.8	16.7
NW	1.8	8.6	9.2	3.3	.3	2216	22.7	19.0
VAR	*	.0	.0	.0	.0	1	*	3.0
CALM	1.3					127	1.3	.0
TOT	1107	4493	3111	880	101	9784	100.0	16.1
PCT	11.3	45.9	31.8	9.0	1.0	100.0		

February

WND DIR	WIND SPEED (KNOTS)					TOTAL OBS	PCT FREQ	MEAN SPD
	0-6	7-16	17-27	28-40	41+			
N	2.1	9.6	6.2	1.3	.2	1899	19.2	15.6
NE	1.3	5.1	2.6	.6	.1	848	9.3	13.9
E	1.3	2.9	1.2	.2	.1	497	5.6	13.0
SE	1.0	2.7	1.3	.2	.0	451	5.1	12.9
S	1.6	5.9	3.7	.9	.1	1049	11.9	15.3
SW	1.4	6.0	4.4	.9	.1	1073	12.4	15.7
W	1.2	6.8	5.0	1.6	.2	1232	14.0	17.3
NW	1.6	8.1	7.9	2.8	.2	1817	20.6	18.2
VAR	*	.0	.0	.0	.0	1	*	3.0
CALM	1.6					143	1.6	.0
TOT	1196	4046	2784	711	87	8826	100.0	15.7
PCT	13.6	45.9	31.5	8.1	1.0	100.0		

March

WND DIR	WIND SPEED (KNOTS)					TOTAL OBS	PCT FREQ	MEAN SPD
	0-6	7-16	17-27	28-40	41+			
N	1.9	8.8	5.1	1.1	.2	1604	17.0	15.5
NE	1.4	5.7	2.2	.3	.1	907	9.6	13.4
E	1.6	4.0	1.3	.2	*	661	7.0	12.3
SE	1.1	3.6	1.4	.3	*	613	6.5	13.4
S	1.6	7.1	4.6	1.2	.1	1369	14.5	15.8
SW	1.5	6.1	4.5	.8	*	1246	13.2	15.3
W	1.2	5.4	3.9	1.3	.1	1121	11.9	16.9
NW	1.2	7.4	7.8	2.3	.4	1727	18.4	18.3
VAR	*	.0	.0	.0	.0	2	*	3.5
CALM	1.6					153	1.6	.0
TOT	1181	4505	2849	723	82	9410	100.0	15.4
PCT	12.5	47.9	30.3	7.7	.9	100.0		

April

WND DIR	WIND SPEED (KNOTS)					TOTAL OBS	PCT FREQ	MEAN SPD
	0-6	7-16	17-27	28-40	41+			
N	2.2	7.3	4.6	.8	.1	1383	15.4	14.9
NE	1.8	5.7	2.1	.4	*	1032	10.0	13.0
E	2.0	4.3	1.0	.1	*	803	7.8	10.9
SE	1.5	4.3	1.7	.1	*	808	7.8	12.4
S	2.1	10.6	6.2	1.0	.0	1989	19.3	14.0
SW	2.0	7.3	3.8	.6	*	1386	13.1	14.7
W	1.8	5.3	2.3	.3	*	1062	10.3	13.3
NW	1.4	6.1	3.4	.9	*	1242	12.2	15.4
VAR	*	.0	.0	.0	.0	3	*	6.0
CALM	2.8					288	2.8	.0
TOT	1739	5364	2784	458	24	10306	100.0	13.6
PCT	16.9	52.0	27.0	4.4	.2	100.0		

May

WND DIR	WIND SPEED (KNOTS)					TOTAL OBS	PCT FREQ	MEAN SPD
	0-6	7-16	17-27	28-40	41+			
N	2.3	8.0	3.7	.3	.0	1512	14.7	13.3
NE	2.6	8.8	2.1	.2	*	1389	13.5	11.7
E	2.5	5.8	.9	*	*	972	9.5	10.3
SE	2.3	6.1	1.1	.1	.0	988	9.6	10.8
S	3.0	11.3	4.4	.5	.0	1973	19.2	12.9
SW	2.2	9.1	3.7	.2	*	1556	15.1	13.0
W	1.6	3.2	1.2	.1	*	631	6.1	12.3
NW	1.3	4.0	1.4	.2	.0	740	7.2	13.3
VAR	*	.0	.0	.0	.0	2	*	2.7
CALM	3.1					320	3.1	.0
TOT	2202	5995	1919	159	5	10282	100.0	11.8
PCT	21.4	58.3	18.7	1.5	*	100.0		

June

WND DIR	WIND SPEED (KNOTS)					TOTAL OBS	PCT FREQ	MEAN SPD
	0-6	7-16	17-27	28-40	41+			
N	3.0	5.6	2.1	.4	.1	1132	11.1	12.1
NE	2.3	7.3	2.6	.2	*	1325	13.1	12.3
E	2.0	5.4	1.0	.1	*	950	9.5	10.1
SE	2.7	5.9	.9	*	.0	971	9.6	10.1
S	4.4	14.3	4.1	.1	.0	2313	22.9	11.8
SW	3.2	9.4	2.7	.2	.0	1565	15.5	11.6
W	2.6	4.7	.8	*	.0	806	8.0	9.5
NW	1.6	3.2	1.0	.1	*	593	5.9	11.2
VAR	*	.0	.0	.0	.0	2	*	3.0
CALM	4.3					432	4.3	.0
TOT	2779	5646	1352	117	11	10186	100.0	10.9
PCT	27.3	55.4	13.4	1.2	.1	100.0		

Percentage Frequency of Wind Direction by Speed (Area 3 cont.)

July

WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)							
N	2.2	6.3	1.5	.1	.0	758	8.0	11.3
NE	2.0	7.3	1.9	.2	.0	1078	11.4	11.8
E	1.4	5.0	.5	*	.0	746	7.9	9.5
SE	3.9	5.1	.6	*	.0	809	8.6	9.4
S	5.6	10.3	4.5	.2	*	1951	20.7	11.6
SW	3.7	13.0	4.2	.1	.0	2072	22.0	12.0
W	1.5	4.8	.6	*	*	730	7.8	9.5
NW	1.4	2.6	.4	*	.0	412	4.4	9.6
VAR	*	.0	.3	.0	.0	1	*	2.0
CALM	3.1					294	3.1	.0
TOT	2430	5590	1335	67	2	9426	100.0	10.7
PCT	25.8	59.3	14.2	.7	*	100.0		

August

WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)							
N	2.7	7.7	2.3	.1	.0	1202	12.8	11.6
NE	3.2	8.9	2.6	.1	*	1394	14.8	11.7
E	3.2	5.7	.9	.2	*	939	10.0	10.0
SE	2.4	5.5	.4	.2	.1	857	9.1	10.5
S	4.3	12.7	3.3	.2	*	1943	20.6	11.5
SW	3.1	10.4	2.9	.1	*	1574	16.7	11.7
W	2.0	4.3	.6	.1	.1	660	7.0	10.3
NW	1.6	3.6	.6	.1	.0	576	6.1	11.3
VAR	.1	.0	.0	.0	.0	6	.1	1.0
CALM	2.7					255	2.7	.0
TOT	2424	5344	1323	101	19	9411	100.0	10.9
PCT	25.8	56.9	14.1	1.1	.2	100.0		

September

WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)							
N	2.5	8.9	3.6	1.2	.1	1730	18.3	13.0
NE	3.1	10.7	5.1	.8	*	1862	19.8	13.7
E	3.6	7.3	1.4	.4	*	1189	12.5	11.6
SE	2.4	5.0	.8	.1	*	798	8.4	10.3
S	3.5	8.5	2.1	.2	*	1352	14.3	11.3
SW	2.3	6.3	1.7	*	.0	987	10.4	11.3
W	1.5	3.6	.9	.2	.1	397	4.3	12.0
NW	1.3	4.1	1.4	.2	*	687	7.2	12.7
VAR	*	.0	.0	.0	.0	1	*	2.0
CALM	2.9					280	2.9	.0
TOT	2139	5191	1842	305	25	9522	100.0	12.2
PCT	22.7	54.5	19.3	3.2	.3	100.0		

October

WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)							
N	2.9	9.8	6.9	1.3	.1	2037	20.8	13.8
NE	2.1	8.6	5.1	1.1	.1	1689	17.2	13.1
E	2.3	5.8	1.3	.3	*	976	10.0	11.8
SE	1.8	3.5	.9	.1	*	626	6.4	10.9
S	2.1	6.1	2.0	.3	*	1025	10.5	12.4
SW	1.7	6.1	2.2	.3	*	1003	10.2	13.1
W	1.7	5.1	1.9	.4	*	899	9.2	13.2
NW	1.5	6.1	4.6	1.6	.1	1335	13.6	16.5
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	2.1					201	2.1	.0
TOT	1717	5031	2455	543	42	9788	100.0	13.0
PCT	17.5	51.4	25.1	5.5	.4	100.0		

November

WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)							
N	2.4	9.4	5.9	1.0	.1	1763	18.8	15.1
NE	1.4	5.0	3.1	.4	.1	882	9.4	13.6
E	1.5	3.6	.8	.2	*	571	6.1	11.4
SE	1.3	3.7	1.1	.4	*	616	6.6	13.1
S	1.9	6.4	3.7	.6	*	1189	12.7	14.1
SW	1.8	6.9	3.6	.8	*	1227	13.1	14.6
W	1.5	6.2	4.1	1.0	.1	1209	12.9	13.8
NW	1.8	7.6	7.3	2.3	.1	1773	18.9	17.6
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	1.5					144	1.5	.0
TOT	1459	4512	2691	629	41	9372	100.0	14.7
PCT	15.6	48.0	28.7	6.7	.4	100.0		

December

WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)							
N	2.0	8.2	5.9	1.4	.1	1375	17.5	15.6
NE	1.5	4.2	1.6	.4	*	605	7.7	13.2
E	1.2	2.3	.9	.1	.0	343	4.6	11.6
SE	1.0	2.4	1.2	.3	.1	382	4.8	14.0
S	1.5	5.6	2.7	.5	.1	817	10.4	14.0
SW	2.1	7.7	4.0	1.0	.1	1178	15.0	14.7
W	2.0	8.3	4.9	1.4	.2	1339	17.0	15.4
NW	1.8	9.3	7.7	2.6	.2	1703	21.7	17.5
VAR	*	.0	.3	.0	.0	1	*	5.0
CALM	1.2					98	1.2	.0
TOT	1124	3803	2268	604	62	7863	100.0	15.2
PCT	14.3	48.4	28.8	7.7	.8	100.0		

Annual

WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)							
N	2.3	8.0	4.7	.9	.1	18243	16.0	14.7
NE	2.1	6.9	2.7	.4	*	13869	12.2	13.2
E	2.1	4.7	1.0	.2	*	9098	8.0	11.1
SE	1.8	4.2	1.1	.2	*	8293	7.3	11.3
S	2.8	9.3	3.8	.5	*	18649	16.3	13.1
SW	2.2	8.1	3.6	.5	*	16491	14.4	13.6
W	1.8	5.4	2.5	.7	.1	11945	10.5	14.2
NW	1.5	5.4	4.5	1.3	.1	14868	13.0	16.5
VAR	*	.0	.0	.0	.0	13	*	5.8
CALM	2.3					2678	2.3	.0
TOT	21840	59730	26913	5293	302	114098	100.0	13.6
PCT	19.0	52.3	23.6	4.6	.3	100.0		

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Winds ≥34 kt	4.1	3.4	3.2	1.3	.2	.3	.2	.5	1.1	1.9	2.6	3.3	1.3
Winds ≥48 kt	.4	.4	.4	.1	*	*	0	.1	.1	.2	.2	.2	.2

Percentage Frequency of Visibility (Nautical Miles) by Hour

January

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.2	.1	.1	1.2	7.4	13.2	1732
06&09	.3	.1	.2	.8	6.7	14.1	1736
12&15	.2	.2	.3	1.5	7.8	14.8	1985
18&21	.3	.3	.3	1.9	9.4	18.3	2396
TOT	88	44	76	423	2436	4715	7789
PCT	1.1	.6	1.0	5.4	31.3	60.5	100.0

February

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.4	.2	.2	1.0	7.9	12.3	1356
06&09	.6	.2	.2	.8	7.5	14.2	1667
12&15	.7	.2	.3	1.6	8.0	13.4	1887
18&21	.8	.2	.4	1.7	10.2	17.0	2130
TOT	173	66	78	351	2366	4006	7040
PCT	2.5	.9	1.1	5.0	33.6	56.9	100.0

March

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.3	.1	.3	1.3	7.6	11.2	1551
06&09	.3	.2	.3	.8	7.7	13.4	1713
12&15	.5	.2	.4	1.6	8.3	13.0	1953
18&21	.7	.1	.5	1.8	10.3	17.3	2312
TOT	133	64	105	391	2546	4290	7529
PCT	1.8	.9	1.4	5.2	33.8	57.0	100.0

April

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.4	.1	.2	1.4	9.6	10.7	1821
06&09	.5	.1	.3	.8	8.3	12.6	1784
12&15	1.0	.2	.3	1.5	9.2	12.5	2004
18&21	.9	.4	.6	2.0	11.8	15.0	2524
TOT	231	59	109	457	3155	4126	8133
PCT	2.8	.7	1.3	5.6	38.8	50.7	100.0

May

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.6	.2	.2	1.3	9.1	10.5	1769
06&09	.6	.1	.2	1.0	8.9	12.7	1922
12&15	1.0	.3	.3	1.6	9.8	13.4	2062
18&21	.9	.1	.2	1.8	12.0	14.2	2370
TOT	247	56	80	452	3250	4058	8143
PCT	3.0	.7	1.0	5.6	39.9	49.8	100.0

June

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.6	.1	.1	1.6	9.6	10.4	1765
06&09	.3	.1	.1	1.1	9.1	11.4	1786
12&15	.7	.1	.2	1.8	10.6	12.4	2082
18&21	.5	.1	.5	1.8	12.6	14.6	2421
TOT	130	36	79	494	3366	3925	8052
PCT	1.9	.5	1.0	6.1	41.8	48.7	100.0

July

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	*	.1	1.0	8.8	11.2	1848
06&09	.1	*	.1	.6	8.7	13.5	1790
12&15	.1	*	.2	1.2	9.7	14.8	2024
18&21	.1	*	.2	1.1	11.9	16.7	2131
TOT	21	10	37	299	3044	4373	7793
PCT	.3	.1	.5	3.8	39.1	56.2	100.0

August

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	*	.2	1.1	9.7	10.9	1867
06&09	*	.1	.1	.6	8.4	12.3	1676
12&15	.1	.1	.2	1.4	9.6	14.0	1925
18&21	.1	.1	.2	1.6	12.0	16.6	2321
TOT	16	21	43	347	3051	4113	7591
PCT	.2	.3	.6	4.6	40.2	54.2	100.0

September

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.1	.1	.1	.9	8.7	11.8	1590
06&09	.1	.1	.1	.6	8.4	13.4	1739
12&15	.2	.1	.2	1.2	8.8	13.3	1930
18&21	.2	.1	.2	1.3	10.3	17.9	2285
TOT	47	21	56	318	2789	4398	7550
PCT	.6	.3	.7	4.2	36.1	58.1	100.0

October

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.1	*	.1	.8	7.8	13.1	1867
06&09	.2	*	.1	.6	7.3	13.8	1875
12&15	.2	.1	.4	1.1	7.8	13.9	1968
18&21	.1	.1	.3	1.3	9.6	18.4	2297
TOT	46	18	59	293	2525	4966	7907
PCT	.6	.2	.7	3.7	31.9	62.8	100.0

November

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.1	.1	.1	.7	7.1	13.3	1831
06&09	.2	.1	.2	.6	6.7	13.1	1754
12&15	.2	.1	.3	1.0	7.5	10.6	1924
18&21	.2	.1	.3	1.2	7.9	20.6	2310
TOT	31	30	66	286	2190	4996	7819
PCT	.4	.4	.8	3.6	28.0	63.9	100.0

December

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.1	*	.1	.5	5.4	14.0	1220
06&09	.1	.1	*	.5	5.8	17.1	1490
12&15	.2	.1	.2	.9	6.1	17.6	1941
18&21	.3	.1	.6	1.1	8.1	20.7	1830
TOT	46	16	48	188	1982	4200	6481
PCT	.6	.3	.8	3.1	25.8	64.8	100.0

Annual

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.2	.1	.2	1.6	8.2	11.8	19661
06&09	.3	.1	.2	.8	7.9	13.7	20874
12&15	.4	.1	.3	1.3	8.6	14.5	23039
18&21	.6	.2	.3	1.6	10.6	17.2	27821
TOT	1269	446	836	4296	32227	52201	91395
PCT	1.4	.5	.9	4.7	35.3	57.2	100.0

Percentage Frequency of Wave Height (Feet) vs. Wave Period (Seconds) for (Area 3 cont.)

January

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.3	16.9	22.8	8.0	3.8	1.2	1.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	986	3
6-7	.1	1.1	5.2	5.3	3.6	2.3	1.1	.5	.5	-.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	349	5
8-9	.0	.3	.9	1.5	2.0	1.5	1.6	.6	.9	.3	.3	.0	.1	.0	.0	.0	.0	.0	.0	179	8
10-11	.0	.1	.4	.2	.5	.4	.5	.5	.6	.1	.0	.1	.1	.0	.0	.0	.0	.0	.0	60	9
12-13	.0	.3	.2	.1	.1	.2	.2	.2	.3	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	32	9
>13	.1	.1	.0	.0	.1	.1	.1	.1	.1	.1	.2	.0	.2	.0	.0	.0	.0	.0	.0	17	14
INDET	5.8	.5	.6	.2	.1	.1	.1	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	135	1
TOTAL	145	342	531	270	179	101	79	35	43	9	16	2	8	0	0	0	0	0	0	1760	4
PCT	8.2	19.4	30.2	15.3	10.2	5.7	4.5	2.0	2.4	.5	.9	.1	.5	.0	.0	.0	.0	.0	.0	100.0	

February

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	1.2	10.4	23.3	8.6	3.3	1.0	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1047	3
6-7	.0	1.6	4.2	5.9	4.1	1.3	1.1	.6	.4	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	366	5
8-9	.1	.2	1.2	2.0	2.3	1.4	.9	1.1	.9	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	187	7
10-11	.0	.2	.1	.2	.4	.9	.8	.2	.4	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	68	10
12-13	.0	.2	.3	.1	.3	.2	.2	.2	.1	.0	.1	.0	-.0	.0	.0	.1	.0	.0	.0	31	9
>13	.0	.0	.1	.2	.1	.1	.1	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	13	7
INDET	5.6	.8	.7	.6	.1	.1	.1	.1	.1	.0	.0	.0	-.0	.0	.0	.0	.0	.0	.0	144	1
TOTAL	127	395	552	323	195	93	71	43	36	7	6	2	0	0	0	1	0	0	0	1851	4
PCT	6.9	21.3	29.8	17.5	10.5	5.0	3.8	2.3	1.9	.4	.3	.1	.0	.0	.0	.1	.0	.0	.0	100.0	

March

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	1.1	24.9	23.6	6.0	3.2	.7	.4	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1205	3
6-7	.0	1.9	4.6	4.3	3.5	2.5	.6	.5	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	372	5
8-9	.0	.8	1.1	1.7	2.0	1.0	.8	.3	.3	*	*	.0	.0	.0	.0	.0	.0	.0	.0	169	6
10-11	*	.1	.3	.5	.5	.0	.6	.3	.3	.0	.1	.0	*	*	.0	.0	.0	.0	.0	76	8
12-13	.0	*	.1	*	.2	.1	.2	*	.4	.1	.0	.0	*	*	.0	.0	.0	.0	.0	31	11
>13	.0	*	*	*	.1	.1	.0	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11	7
INDET	5.3	1.0	.0	.3	*	.0	*	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	139	0
TOTAL	131	582	602	262	196	106	56	28	29	3	3	0	4	2	0	0	0	0	0	2002	4
PCT	6.5	29.1	30.1	13.0	9.8	5.3	2.8	1.4	1.4	.1	.1	.0	.2	.1	.0	.0	.0	.0	.0	100.0	

April

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.5	25.1	21.2	6.8	2.3	1.3	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1159	2
6-7	.0	2.7	6.6	5.3	4.1	1.5	.4	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	409	4
8-9	.1	.6	1.9	1.2	1.2	1.3	.3	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	137	5
10-11	.0	.3	.5	.3	.4	.7	.3	.2	.2	.0	.1	.1	.1	.0	.0	.0	.0	.0	.0	95	7
12-13	.0	.0	.2	.1	.0	.1	.2	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	14	7
>13	.0	.0	.2	.2	.1	.1	.0	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13	7
INDET	6.4	1.0	.5	.2	.3	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	164	0
TOTAL	175	577	606	272	162	99	26	20	10	1	1	1	1	0	0	0	0	0	0	1951	3
PCT	9.0	29.6	31.1	13.9	8.3	5.1	1.3	1.0	.5	.1	.1	.1	.1	.0	.0	.0	.0	.0	.0	100.0	

May

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.0	27.5	24.1	5.7	2.5	.7	.6	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1226	2
6-7	.1	2.9	3.5	3.5	2.1	1.0	.4	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	301	4
8-9	.0	1.1	1.0	1.3	1.5	.5	.4	.3	.2	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	122	5
10-11	.1	.0	.6	.3	.3	.4	.2	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	40	6
12-13	.0	.4	.4	.1	.1	.1	.1	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	23	5
>13	.0	.1	.2	.0	.1	.1	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13	7
INDET	8.1	1.0	.3	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	186	0
TOTAL	216	631	618	206	126	55	29	14	12	0	2	2	0	0	0	0	0	0	0	1911	3
PCT	11.3	33.0	32.3	10.8	6.6	2.9	1.5	.7	.6	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	100.0	

June

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.6	31.6	21.1	4.2	1.2	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1203	2
6-7	.0	3.7	6.2	4.1	1.9	.8	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	326	4
8-9	.0	1.3	1.6	.7	.8	.4	.2	.2	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	99	6
10-11	.0	.4	.2	.1	.4	.1	.1	.2	.1	.0	.1	.0	.0	.1	.0	.0	.0	.0	.0	34	8
12-13	.0	.2	.3	.1	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13	3
>13	.0	.1	.1	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10	4
INDET	10.0	2.5	.6	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	257	0
TOTAL	265	768	584	186	84	29	10	7	6	1	1	0	0	1	0	0	0	0	0	1942	2
PCT	13.6	39.5	30.1	9.6	4.3	1.5	.5	.4	.3	.1	.1	.0	.0	.1	.0	.0	.0	.0	.0	100.0	

July

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.4	30.1	24.7	5.7	1.2	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1204	2
6-7	.3	3.2	5.5	4.5	2.2	.6	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	308	4
8-9	.1	.5	1.7	1.5	.8	.4	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	98	4
10-11	.0	.2	.4	.4	.2	.2	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	28	4
12-13	.0	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4	3
>13	.0	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3	3
INDET	9.6	1.9	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	224	0
TOTAL	235	673	613	230	84	25	7	2	0	0	0	0	0	0	0	0	0	0	0	1869	2
PCT	12.6	36.0	32.8	12.3	4.5	1.3	.4	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

August

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.3	29.0	21.8	4.7	.7	.3	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1100	2
6-7	.1	4.1	6.9	5.3	1.9	.3	.2	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	348	4
8-9	.1	.8	1.7	1.7	1.1	.3	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	113	4
10-11	.0	.3	.7	.3	.7	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	41	5
12-13	.0	.1	.1	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8	5
>13	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1	2
INDET	8.9	2.3	.7	.4	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	226	0
TOTAL	227	674	584	232	82	26	6	4	1	0	0	1	0	0	0	0	0	0	0	1837	2
PCT	12.4	36.7	31.8	12.6	4.5	1.4	.3	.2	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	100.0	

September

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.5	22.5	20.6	6.4	2.1	.4	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1005	2
6-7	.1	2.1	3.6	4.8	3.5	1.6	.9	.4	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	312	5
8-9	.1	.8	1.5	1.4	1.8	1.2	.5	.7	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	160	6
10-11	.0	.3	.5	.6	.7	1.0	.7	.6	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	81	7
12-13	.0	.0	.1	.3	.1	.8	.2	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	27	8
>13	.0	.0	.1	.2	.1	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8	7
INDET	9.3	1.2	.9	.3	.4	.3	.2	.1	.1	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0	233	1
TOTAL	218	490	498	252	157	90	52	36	29	0	1	2	1	0	0	0	0	0	0	1826	3
PCT	11.9	26.8	27.3	13.8	8.6	4.9	2.8	2.0	1.6	.0	.1	.1	.1	.0	.0	.0	.0	.0	.0	100.0	

Percentage Frequency of Wave Height (Feet) vs. Wave Period (Seconds) (Area 3 cont.)

October

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	1.1	24.7	22.3	7.7	2.9	.6	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1299	3
6-7	*	.7	4.7	5.8	3.9	1.6	1.0	.3	.3	.0	.0	*	.0	.0	.0	.0	.0	.0	.0	398	5
8-9	.0	.5	1.0	1.6	2.3	1.4	.8	.6	.6	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	186	7
10-11	.0	.1	.6	.5	.5	.4	.6	.3	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	62	7
12-13	.0	.0	.2	.3	.1	.1	.2	.1	*	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	23	7
>13	.0	.0	*	.2	.1	*	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10	7
INDET	6.9	1.1	.6	.2	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	200	0
TOTAL	175	589	640	351	216	91	61	31	20	1	2	1	0	0	0	0	0	0	0	2174	3
PCT	8.0	27.0	29.4	16.1	9.9	4.2	2.8	1.4	.9	*	.1	*	.0	.0	.0	.0	.0	.0	.0	100.0	

November

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.0	23.9	25.3	7.8	2.7	.6	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1292	3
6-7	.1	1.3	5.3	5.2	4.0	1.3	1.1	.4	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	393	5
8-9	.0	.3	.3	1.7	2.4	1.1	.3	.3	.2	.0	.2	.0	*	.0	.0	.0	.0	.0	.0	146	7
10-11	.0	*	.3	.4	.3	.4	.2	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	44	7
12-13	.0	.0	.1	.2	*	.1	.1	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	20	8
>13	.0	*	*	.0	.1	.0	.0	.2	.2	.0	.0	.0	*	.0	.0	.0	.0	.0	.0	13	11
INDET	5.6	1.2	.3	.1	.2	*	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	159	1
TOTAL	159	553	655	321	202	76	44	27	23	1	4	0	2	0	0	0	0	0	0	2067	3
PCT	7.7	26.8	31.7	15.5	9.8	3.7	2.1	1.3	1.1	*	.2	.0	.1	.0	.0	.0	.0	.0	.0	100.0	

December

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	1.1	19.9	22.1	8.3	3.5	.8	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	744	3
6-7	.0	1.3	6.0	7.7	5.1	1.3	.8	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	304	5
8-9	.0	.2	.7	1.3	2.7	1.8	1.1	.3	.3	.0	.1	.2	.0	.0	.0	.0	.0	.0	.0	120	7
10-11	.0	.3	.1	.2	.7	.9	.3	.2	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	40	7
12-13	.0	.1	.2	.1	.2	.1	.2	.4	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	17	8
>13	.1	.0	.0	.1	.0	.0	.1	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8	9
INDET	5.7	.9	.4	.2	.2	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100	0
TOTAL	92	301	391	241	165	68	34	17	20	0	1	3	0	0	0	0	0	0	0	1333	4
PCT	6.9	22.6	29.3	18.1	12.4	5.1	2.6	1.3	1.5	.0	.1	.2	.0	.0	.0	.0	.0	.0	.0	100.0	

Annual

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.2	24.7	22.8	6.6	2.4	.7	.3	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13474	2
6-7	.1	2.2	5.3	5.1	3.3	1.4	.7	.3	.2	*	*	*	*	.0	.0	.0	.0	.0	.0	4186	5
8-9	*	.6	1.2	1.5	1.7	1.0	.6	.4	.4	*	.1	*	*	.0	.0	.0	.0	.0	.0	1716	6
10-11	*	.2	.4	.3	.5	.5	.3	.2	.2	*	*	*	*	*	.0	.0	.0	.0	.0	524	7
12-13	.0	.1	.2	.1	.1	.1	.1	.1	.1	*	*	*	*	*	.0	*	.0	.0	.0	243	8
>13	*	*	.1	.1	.1	*	*	*	.1	*	*	.0	*	.0	.0	.0	.0	.0	.0	118	8
INDET	7.3	1.3	.5	.2	.1	.1	*	*	*	.0	*	.0	*	.0	.0	.0	.0	.0	.0	2167	3
TOTAL	2165	6575	6874	3145	1848	839	475	264	229	23	37	14	16	3	0	1	0	0	0	22528	3
PCT	9.6	29.2	30.5	14.0	8.2	3.7	2.1	1.2	1.0	.1	.2	.1	.1	*	.0	*	.0	.0	.0	100.0	

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Waves ≥12 ft	6.4	5.1	3.3	1.9	1.5	1.0	.1	.4	3.9	2.4	2.7	3.1	3.7
Waves ≥20 ft	1.5	.5	.4	.3	.2	.2	0	.1	.3	.1	.3	.3	.4
Maximum Seas	26-32	49-60	33-40	26-32	23-35	33-40	12	23-25	26-32	23-25	26-32	23-25	49-60

Consolidated Table of Meteorological Elements (Area 3)

	Weather Elements	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Percentage freq.	Visibility < 2 naut. mi.	2.7	4.5	4.1	4.8	4.7	3.4	0.9	1.1	1.6	1.5	2.0	1.9
	Precipitation	9.3	9.2	7.1	6.5	5.3	4.4	5.0	4.8	5.7	6.1	6.5	7.5
	Sky overcast or obscured	36.7	35.4	33.1	29.2	26.1	22.6	20.5	21.3	22.2	23.6	25.8	32.2
	Thunder and lightning	0.4	0.4	0.5	0.7	1.5	1.7	2.4	3.0	1.2	0.8	0.4	0.4
	Temperature ≥ 85°F	0.0	0.0	0.0	*	0.1	1.5	5.1	4.4	1.5	0.1	0.0	0.0
	Temperature ≤ 32°F	6.9	6.4	1.4	*	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.1
	Mean temperature (°F)	46.6	46.3	49.2	55.3	62.7	71.8	77.5	77.7	73.4	65.5	57.5	49.9
	Mean relative humidity (%)	75	74	76	78	79	81	82	80	78	76	73	74
	Mean cloud cover (eighths)	4.9	4.8	4.5	4.2	4.3	4.2	4.3	4.4	4.1	3.9	4.3	4.8
Millibars	Mean sea-level pressure	1019	1017	1016	1016	1017	1016	1017	1017	1018	1018	1018	1019
	Extreme maximum sea-level pressure	1046	1044	1044	1039	1037	1033	1034	1034	1040	1040	1041	1041
	Extreme minimum sea-level pressure	983	975	983	974	994	991	981	990	991	992	981	983

*0.0-0.05%

These data are based upon observations made by ships in passage. Such ships tend to avoid bad weather when possible, thus biasing the data toward good weather samples.

Area 3

PERCENT FREQUENCY OF OCCURRENCE OF SEA TEMP (DEG F) BY MONTH

SEA TMP DEG F	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	PCT
97+	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
95/96	.0	.0	.0	.0	.0	.0	.0	.0	*	.0	.0	.0	3	*
93/94	.0	.0	.0	.0	.1	.1	.0	.0	*	.0	.0	.0	16	*
91/92	.0	.0	.0	.0	.1	*	.0	*	*	.0	.0	.0	12	*
89/90	.0	.0	.0	.0	*	*	*	.1	*	*	.0	.0	19	*
87/88	.0	.0	.0	*	*	*	.2	.4	.1	*	*	.0	75	.1
85/86	.0	.0	.0	.0	*	.2	1.5	2.9	1.0	.2	.0	.0	498	.5
83/84	*	*	*	.0	.1	1.1	5.1	7.6	2.9	.6	.1	*	1528	1.6
81/82	*	*	*	.1	.3	3.6	9.1	12.3	4.9	2.0	.3	*	2883	2.7
79/80	*	*	*	.2	1.4	5.4	13.6	17.7	9.1	3.5	1.4	.3	4629	4.6
77/78	.3	.2	.3	.8	2.2	5.3	17.0	21.1	11.6	3.0	2.9	1.0	5750	5.4
75/76	1.4	1.0	.7	2.8	2.3	7.3	20.5	19.2	19.2	3.7	2.7	2.0	7182	6.8
73/74	2.1	1.8	1.6	1.6	2.5	8.8	15.3	11.2	19.2	5.8	2.1	2.5	6578	6.2
71/72	2.0	1.8	1.4	1.2	2.4	10.1	9.8	4.8	13.6	8.6	2.1	2.0	5305	5.0
69/70	2.1	1.8	1.8	1.5	3.8	12.0	4.6	1.9	9.3	13.6	3.3	2.4	5232	4.9
67/68	2.0	2.2	1.7	1.8	5.0	11.8	1.5	.7	4.0	16.4	5.6	2.6	4993	4.7
65/66	2.2	1.6	2.1	2.1	5.7	10.6	.6	.2	2.7	17.8	8.8	3.4	5183	4.9
63/64	1.9	1.8	2.5	2.0	7.7	9.1	.3	.1	1.2	13.8	11.0	4.7	5024	4.7
61/62	2.1	1.6	2.2	2.6	8.4	5.5	.2	.1	.4	6.7	12.3	6.1	4275	4.0
59/60	4.2	2.3	2.4	4.5	10.3	4.0	*	*	.2	3.3	16.5	9.1	5006	4.7
57/58	6.4	3.9	2.9	5.0	10.0	2.4	*	*	*	.8	13.6	10.8	4874	4.6
55/56	8.9	6.3	4.6	7.9	10.9	1.4	.0	*	.1	.2	10.5	13.1	5574	5.3
53/54	10.1	7.8	6.6	10.5	9.8	.7	*	.0	*	*	3.8	12.7	5436	5.1
51/52	9.2	8.1	6.8	11.2	6.9	.4	.0	.0	*	.1	1.8	9.5	4745	4.5
49/50	11.3	9.5	9.3	13.0	5.0	.2	.0	.0	*	.1	1.1	7.6	5123	4.8
47/48	8.4	9.5	11.0	11.5	2.8	.1	.0	.0	.0	*	.2	3.8	4175	3.9
45/46	8.7	10.5	13.4	10.5	1.8	.1	.0	.0	.0	*	.1	2.7	4233	4.0
43/44	5.7	9.1	12.1	5.7	.4	.0	.0	.0	.0	.0	.1	1.7	3033	2.9
41/42	4.1	7.9	9.8	3.0	.1	.0	.0	.0	.0	.0	*	1.0	2256	2.1
39/40	3.5	5.1	4.7	.9	.1	.0	.0	.0	.0	.0	.0	.6	1290	1.2
37/38	1.6	3.5	1.6	.1	*	.0	.0	.0	.0	.0	.0	.3	600	.6
35/36	1.1	1.9	.3	*	*	.0	.0	.0	.0	.0	.0	.1	302	.3
33/34	.4	.5	.1	*	.0	.0	.0	.0	.0	.0	.0	*	89	.1
31/32	.1	.2	*	.1	.0	.0	.0	.0	.0	.0	.0	*	41	*
29/30	*	*	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	17	*
27/28	.0	.0	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	1	*
<27	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
TOTAL	9270	8182	8735	9682	9833	9344	8715	8591	8737	9074	8589	7226	105998	100.0
MEAN	52.8	50.6	50.3	53.2	60.1	69.5	76.4	77.8	74.5	68.3	62.2	57.3	62.4	

LAND STATION DATA

NORMALS, MEANS, AND EXTREMES

Station: NORFOLK, VIRGINIA NORFOLK REGIONAL AIRPORT Standard time used: EASTERN Latitude: 36° 54' N Longitude: 76° 12' W Elevation (ground): 26 feet

	Temperature	Precipitation	Relative humidity	Wind	Mean number of days
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 105 in August 1932; lowest temperature 2 in February 1895; maximum monthly precipitation 15.61 in August 1942; minimum monthly precipitation 0.04 in October 1874; maximum monthly snowfall 18.6 in December 1892; maximum snowfall in 24 hours 17.7 in December 1892; fastest mile wind 80 W in June 1923.

[illegible]

‡ To 8 compass points only.

NORMALS, MEANS, AND EXTREMES

Station: CAPE HATTERAS, NORTH CAROLINA WEATHER SERVICE BUILDING Standard time used: EASTERN Latitude 35° 16' N Longitude 75° 33' W Elevation (ground): 7 feet

	Temperature	Precipitation	Relative humidity	Wind	Mean number of days
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 97 in June 1952; lowest temperature 8 in December 1880; maximum monthly precipitation 20.95 in June 1949; minimum monthly precipitation T in November 1890; maximum precipitation in 24 hours 14.71 in June 1949; maximum monthly snowfall 12.0 in December 1917; maximum snowfall in 24 hours 12.0 in December 1917; fastest mile wind 110 W in September 1944.

[illegible]

** The National Weather Service considers the accuracy of solar radiation data questionable; therefore, publication is suspended pending determination of corrected values.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

are dependent on protection by the barrier islands. The latter are probably Virginia's most valuable non-urban real estate. The demand for public access to beaches, the need for erosion control, and the value of these islands as natural areas will concern us in the immediate future, as exemplified by Assateague Island.

Erosion affects not only the barrier islands but also the shores of Chesapeake Bay and the banks of rivers unprotected by marshes. No survey of land lost by erosion has been made for the total coastal shoreline of Virginia but it could be as high as 40,000 acres since Colonial times. Loss of "fast land" would be countered partially by the general filling of creeks at their heads by soil erosion, although this has degraded the creeks. Erosion studies have been made on the Potomac and Rappahannock Rivers.

As in Area 2, the greatest impact of recent proposals for siting offshore floating nuclear powerplants would likely be upon benthic infaunal invertebrates found in water depths of 40-90 feet and pelagic and demersal finfish indigenous to this zone or which migrate seasonally through it. Again, a few species of motile invertebrates such as the cancroid crabs, American lobster, moon snail, and seastars might also be affected by the siting and subsequent operation of nuclear powerplants.

2. Estuarine and Coastal Wetlands. The estuarine zone, both coastal wetlands and shoal water habitat, encompasses an area of about 1,797,000 acres. Shoal water comprises an area of about 1,600,000 acres, of which about 426,000 acres are considered important open shoal water habitat for fish, shellfish and wildlife. There are about 197,000 acres of coastal wetlands in this region, of which about 74,000 acres are dominated by freshwater plant species affected by tides, and about 16,000 acres are dominated by salt grass and saltmeadow cordgrass. Salt marsh cordgrass and needle rush dominate the remaining 107,000 acres.[347]

Coastal wetlands represent only about one percent of the total area of the State, and marshes about one-half of one percent. Yet, 95 percent of Virginia's annual harvest of fish (commercial and sport) from tidal waters is dependent to some degree on wetlands. Also, ducks, rails, snipe, and many other kinds of birds could not survive without the wetlands, which also shelter muskrat, otter, beaver, and mink.

Most of the fish of the area spend part of their lives in brackish wetland waters. Dependency on these areas varies from total for the white perch and catfish to dependency only during the juvenile period for several species of sport and commercial finfish. Despite the brevity of the latter's stay, however, survival of the species is dependent upon suitable conditions in the marsh-bordered spawning and nursery grounds.

The waters bordered by wetlands provide essential food and habitats for most Bay sport fish during a critical period of their life history. Several of the most valuable species, including the menhaden, several species of sciaenids (croaker, spot, and sea trout), four species of shad and river herring, the American eel and the sturgeon, spend their early lives in wetland nursery grounds, where part of their food is derived from marches.

3. Birds. Coastal marshlands and estuaries, including bays, are within the Atlantic flyway and are attractive to migrating waterfowl. Canadian goose, American brant, blue wing and green wing teal, widgeon, redhead, gadwall, canvasback, greater scaup and lesser scaup are some of the more abundant waterfowl utilizing the coastal zone. Some mallard and black ducks are residents of the area. In addition to waterfowl, numerous species of shore birds, sea birds, song birds, and raptors are important inhabitants of the region.

4. Land Mammals. Wildlife associated with the coastal zone include squirrel, fox, beaver, and deer. The most sought-after game animals are the white-tail deer, bobwhite quail, and ruffed grouse. Muskrat and other small mammals are common in open areas near water and a few beaver occur in coastal marshes. Gray fox, mink raccoon, and weasel are common to upland areas.

5. Plankton. Smayda and Jeffries and Johnson[348/] have reviewed the literature concerned with phytoplankton dynamics and the distribution and abundance of zooplankton, respectively, in coastal waters from Nantucket to Cape Hatteras. Personnel at Sandy Hook Laboratory have studied coastal and oceanic ichthyoplankton since 1965. Recent papers on the distribution and development of individual species of finfish eggs and larvae in the Middle Atlantic Bight include those by Smith and Smith and Fahay[349/] concerned with the summer flounder, Paralichthys dentatus; Kendall[350/] concerned with black sea bass, Centropristes striata; and Richards and Kendall[351/] with sand lance, Ammodytes sp.

6. Invertebrates: benthos. Pratt[352/] made a general review of the inshore and offshore benthos from Cape Hatteras to Nantucket Shoals. Offshore distributions of the commercially important sea scallop, surf clam, ocean quahog, and hard clams are similar to those discussed in the Sandy Hook to Atlantic City area, although the abundance of these species and the commercial fisheries harvest is lower off the Virginia coast

than off the New Jersey coast.[353/]

The oyster seed beds in the James River in Virginia are considered to be one of the most important shellfish areas in the world. This area is famous for producing seed oysters which are the basis of the valuable oyster industry in Virginia, which normally leads the Nation in oyster production. Oyster seed areas are also found in the small tidal rivers on the Eastern Shore.

The blue crab is the other major commercial shellfish species in Virginia and the State has set aside an area of refuge for this species. The soft clam is abundant in some sections of Virginia, but it is not harvested as intensely as it is in Maryland. Diamond-backed terrapins and snapping turtles are of local commercial importance throughout Chesapeake Bay.

The blue mussel, *Mytilus edulis*, is common to hard substrates such as pilings, wrecks, jetties, and breakwaters and may also cluster on large shell fragments. The proposed breakwaters to enclose the nuclear powerplants will attact mussels and other fouling organisms. Such fauna are prime food sources for reef dwelling fishes such as tautog and cunner. *Balanus balanoides* is the most common barnacle inhabiting inshore oceanic areas, and will probably be a major component of encrusting or fouling communities at the construction site. *Balanus improvisus*, *B. eburneus*, and *B. crenatus* may appear, but are usually limited to less saline waters.

The importance of polychaetes and amphipods has been discussed adequately in the preceding section on Area 2.

The crab, *Cancer irroratus*, a potentially commercial fishery resource, is commonly fed upon by sea robins, sea ravins, long horned sculpins and other demersal elasmobranchs and teleosts. Both the size of the crab and its high standing crop in coastal waters account for its large biomass. *Polinces heros*, the moon snail, is an important predator of surf clams and other vivalves. *Asterias forbesii* also feeds on bivalves. *Crangon septemspinsoa*, the sand shrimp, ranges from the sublittoral zone to water well over 100 feet deep, and is another very important food item for demersal fishes. The American lobster, *Homarus americanus*, usually inhabits areas characterized by rocks or rubble that offer shelter and nesting sites. The proposed breakwaters will probably be prime attractants and my be habituated by lobsters. Sand dollars, *Echinarachinius parma*, are limited to clean sandy substrates.

7. *Finfish*. The coastal zone from Chincoteague to Cape Charles supports a wide variety and quantity of finfish species. Numerous investigations have been made

concerned with the standing stocks, population dynamics and biology of these species. These endeavors were, in part, recently reviewed by Saila and Pratt[354/] in their paper concerning fisheries of the Middle Atlantic Bight.

Other sources of current data available for assessment of the living marine resources in the 40-60 foot zone along the coast of the United States are (1) statistics on the value and volume of commercial fishery landings in 1972, as assembled by the National Marine Fisheries Service (NMFS) (tabulations on file, but not yet published in full detail) and (2) statistics on the marine sportfish catch in 1970, as collected by the U.S. Bureau of Census for the NMFS.[355/]

Off the Virginia coast and in Chesapeake Bay, the important commercial species, in decreasing order of value, are menhaden, summer flounder, alewife, striped bass, black sea bass, scup, shad, catfish, and bullheads, American eel, spot, weakfish, and butterfish.

Most of these same species are also caught by sport fishermen. In addition, several other species make up an important percentage of the sport catch; these include American mackerel, winter flounder, Atlantic croaker, red drum, black drum, cobia, tautog, spadefish, puffers, sea robins, and white perch. Many of the species listed above are migratory. Their migrations are seasonal and for generations their movements have determined the character of the fisheries of the region. In the spring and summer, these fishes move into coastal waters, including bays and sounds, and sometimes river estuaries. They tend to be more concentrated at this season toward the northern part of their range. In the fall and early winter they migrate to offshore, more southerly wintering grounds.

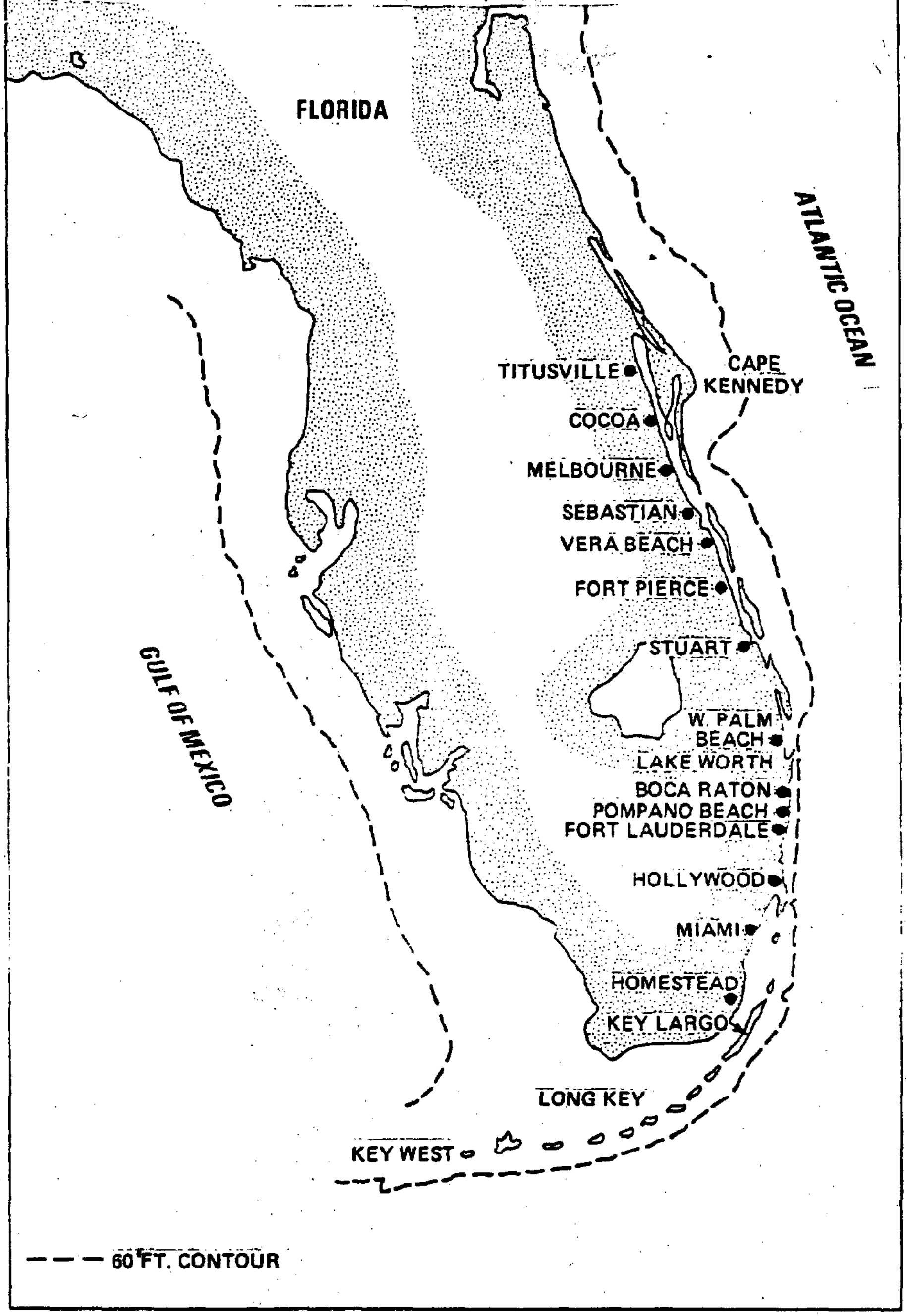
8. Threatened species. Wildlife species threatened include bog turtle, American peregrine falcon, Arctic peregrine falcon, sperm whale, blue whale, finback whale, sei whale, humpback whale, right whale, and barehead whale.[356/]

AREA 4: CAPE KENNEDY TO KEY WEST, FLORIDA

GEOLOGY AND TOPOGRAPHY

1. General. This area (fig. 55) includes the narrowing Continental Shelf between Cape Kennedy and Palm Beach, the Florida-Hatteras Slope, and the western portion of the Blake Plateau. From Palm Beach south almost to Miami the shelf all but disappears; seaward of the Florida-Hatteras Continental Shelf are the Straits of

Figure 55.--Area 4: Cape Kennedy to Key West, Fla.



Source: Bruun, P., T. Chiu, F. Gerritsen, and W. Morgan, 1962: Storm Tides in Florida as related to Coastal Topography, Florida Engineering and Industrial Experiment Station, Bulletin Series No. 109.

Florida, which separate the Bahama Banks from the United States. The Florida Keys veer abruptly to the west at the southern tip of Florida.[357/]

At Cape Kennedy, the shelf area is some 25 miles wide and is generally smooth except for numerous linear sand swells oriented at an angle with the shoreline. The shelf deepens evenly to the break at about 100 meters. At Palm Beach the width has decreased to about 1 kilometer. A fairly smooth slope, designated the Florida-Hatteras Slope by Uchupi,[358/] extends from the shelf break to the Blake Plateau. At Cape Kennedy the relief of this slope is more than 700 meters. The Blake Plateau extends from Cape Lookout, Virginia, to the northern limit of the Bahamas Platform. Depths along the western margin range from 60 to 750 meters. In this area, the Blake Plateau consists of a series of broad benches separated by slopes of 0°15'. The bench surfaces are slightly warped and contain many boxlike depressions with steep-sided slopes. The Plateau contains many conical hills which may be coral mounds.[359/]

The Straits of Florida separate the East Coast Shelf from the Bahama Banks. The U-shaped trough ranges in depth from 2,200 meters to 785 meters in the general area of Little Bahama Bank. Its width ranges from 90 to 160 km. The Miami Terrace extends from latitude 26°30' to 25°21', has a maximum width of 22 km and its depth varies from 245 to 350 meters. Its surface consists of a smooth inner area separated from an outer rough zone by a narrow channel. The Pourtales Terrace which borders the Florida Keys, extends from a depth of 180-280 meters and is 10-20 km wide. Its surface contains numerous depressions and isolated rises. The shelf in this area is neither traversed by shelf channels nor incised by heads of submarine canyons.[360/]

Reefs are common, some within a few kilometers of the shore where they consist of an outcrop of lower Miocene marl overlain by a great variety of calcareous organisms dominated by pelecypods, tubiform gastropods, annelid worms, and encrusting algae. More spectacular than the shelf reefs are the ancient algal reefs that border the shelf break. Sounding profiles show that the reef extends more or less unborken from Cape Hatteras to Miami. A general suthward shoaling of the reef is not the result of tectonic tilting but probably of more active growth of calcareous reef-building organisms in the warm southern waters.[361/]

The Florida Keys serve as a transition between the physiographic provinces in the Atlantic Ocean and those in the Gulf of Mexico. The Keys are outcrops of the Pleistocene Key Largo Limestone and the Miami Oolite. On the seaward (southern) side is a shelf whose width averages about 7 km to the shelf break at about 10 m depth. The surface of the shelf is quite irregular, having abundant living coral reefs that are mainly concentrated at the shelf break. These are shallowest at the southwestern end of the Keys, where they consist dominantly of coral. Further northeast the reefs are deeper, and they probably form a continuous transition into the algal reefs north of Miami.

Dominating shelf morphology from Key West to Palm Beach are three reefs paralleling the shoreline (fig. 56). Between the reefs lie sediment-filled pockets or "flats." The reefs are built up from three platforms which are relict shorelines formed during rises of sea level following the most recent glacial period.[362] The same fundamental three-reef configuration found south of Palm Beach is discernible to the north of Palm Beach but in greatly attenuated form (fig. 57). Two zones predominate on this widening shelf: a coastal zone from shore to about 60 feet and an open-shelf zone from about 60 feet to the shelf break at about 90 feet. Gently-sloping sand swells surrounded by flat bottom typify the coastal zone; in the open-shelf zone, patches of live shells, dead shell-rubble, and reefs punctuate the flats.

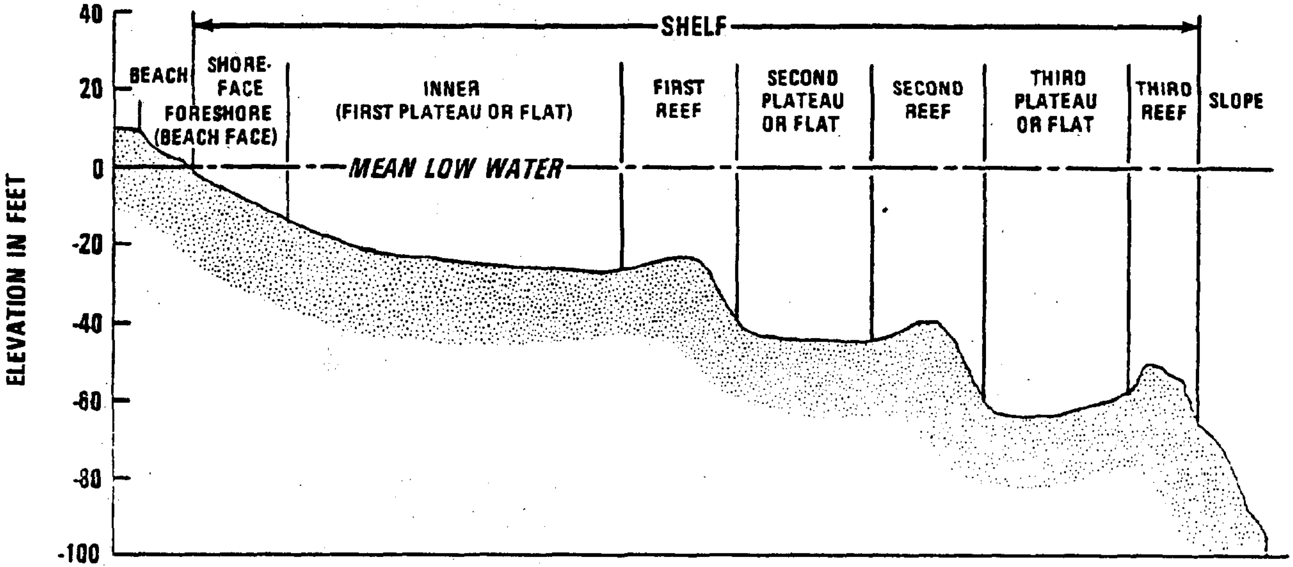
Because the 40- to 100-foot contours lie astride the shelf break from Key West to slightly north of Palm Beach, they enclose an extremely narrow strip varying in width from about 100 to 1,500 yards. North of Palm Beach this zone increases up to about 17 statute miles.

NOTE: Engineering geology information is unavailable for these areas.

2. Sediments. The sediments on the shelf are almost entirely of sand size, of which almost 18 percent are calcium carbonate. The sediments that cap the Blake Plateau are almost entirely calcareous except for deposits of phosphorite and manganese oxide. The calcareous sediments are of two types; coral debris in areas of irregular topography and foraminiferal sand in smooth, flat areas. The Straits of Florida display a variety of carbonate types. The Miami Terrace and Pourtales Terrace are capped by foraminiferal sand that locally is rich in quartz and phosphorite grains. Bedrock ledges of phosphatic limestone capped by manganese oxide are relatively common both terraces and on their seaward slopes. Thicknesses of the sediments on the Plateau are great.[363]

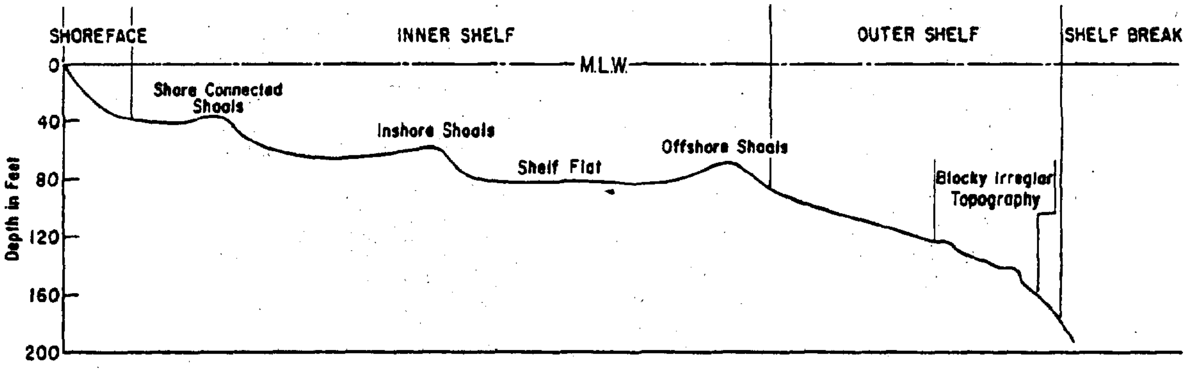
The fundamental character of sediments changes from 100 percent biogenous south of Palm Beach to a mixture of nearly 50-50 percent terrigenous-biogenous to the north.

Figure 56.--Profile of southeastern Florida shore and shelf morphology.



Source: Duane, D.B., and E.P. Meisburger, 1969: Geomorphology and sediments of the nearshore continental shelf, Miami to Palm Beach, Florida. U.S. Corp of Engineers, Coastal Engineering Research Center. Technical Memorandum No. 29.

Figure 57.--Profile of east central Florida shore and shelf morphology, Palm Beach to Cape Kennedy.



Source: Meisburger, Edward P., and David B. Duane, 1971: Geomorphology and sediments of the inner continental shelf, Palm Beach to Cape Kennedy, Florida. U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Technical Memorandum No. 34.

Along the narrow shelf south of Palm Beach, sand and gravel-size material collect on the flats between reefs. They are the skeletal remains of resident biota. Calcareous algae (especially Halimeda), molluscs, foraminiferans, bryozoans, and corals are the major contributors.[364] On the broadening shelf north of Palm Beach, sediments consist of sand, silty sand, and shell gravel, over 50 percent being carbonate skeletal fragments from molluscs, barnacles, and foraminiferans. The remainder is quartz sand.[365] Fines are more prevalent in the coastal zone, which extends to a depth of about 60 feet, than in the open-shelf zone. Characteristic of the latter are numerous patches of rock, dead coral, ridges, ledges, cliffs, and depressions.[366]

Pollution may also influence the character of sediments in the vicinity of offshore outfalls. Seven of eight such outfalls between Miami and Palm Beach discharge untreated domestic sewage at 60- to 90-foot depths, and water movements frequently carry their effluents landward over the shelf (fig. 58).[367]

3. Turbidity currents and faults. Recent data on turbidity currents and structural features such as faults in the bedrock are not available for this area.

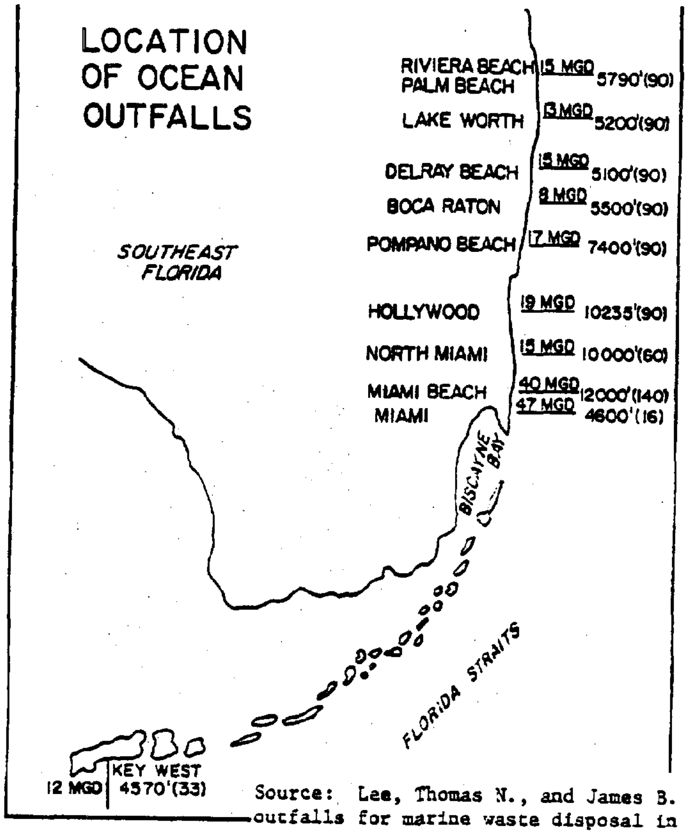
OCEANOGRAPHY

1. General. The circulation along southeastern Florida is dominated by the northward flowing Florida Current. The surface flow is generally northward with speeds increasing from the shoreline seaward to the axis of the Florida Current. However, the shelf waters display very sudden current reversals (southerly flow) which is believed to be caused by counterclockwise eddies spinning off the western edge of the Florida Current. The water mass characteristics of the shelf are in a constant state of flux, being influenced by freshwater runoff, the east/west migrating nature of the Florida Current, and the flushing action produced by the counterclockwise eddies. Tidal ranges are low, and the tides are of the mixed type in the Keys and semidiurnal on the mainland proper.

2. Tides. Tides along the Atlantic coast of southern Florida are semidiurnal in nature with mean tidal ranges increasing northward from 1.3 feet at Key West to 2.5 feet at Miami Beach and 3.5 feet at Cape Kennedy. In the coastal region of the Florida Straits tides exhibit characteristics of both diurnal and semidiurnal tidal cycles.

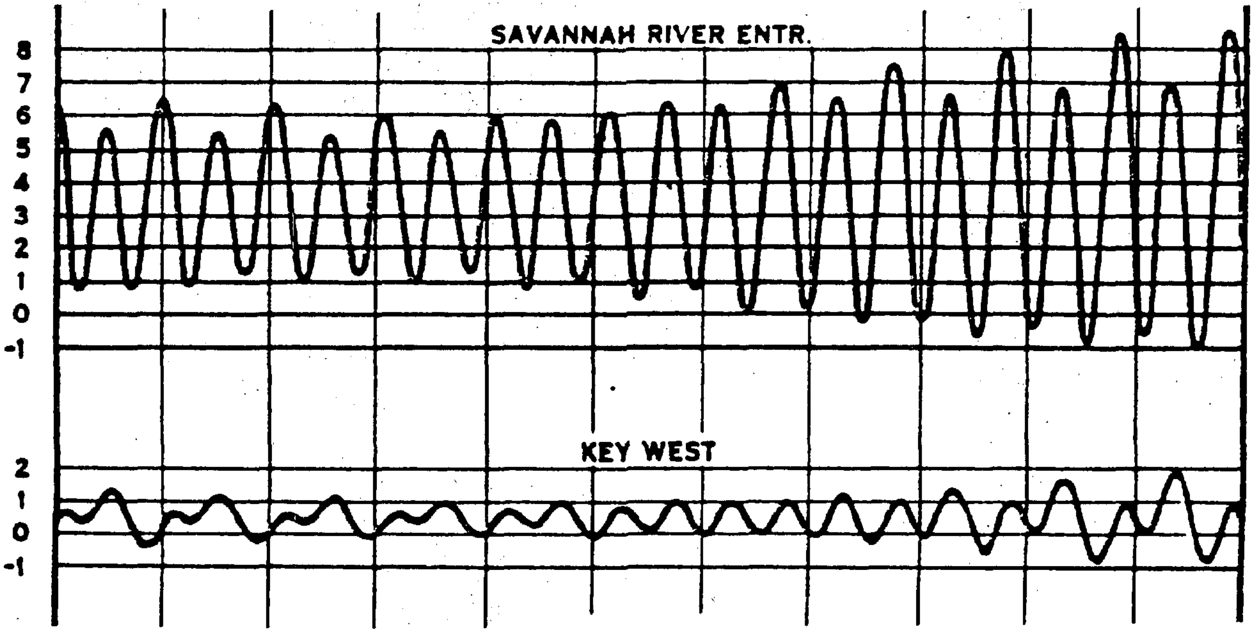
Figure 59 illustrates the typical tide curves for observations made at the Savannah River Entrance and Key West. The Savannah River location exhibits a semidiurnal tidal cycle with two nearly equal highs and lows over a lunar day which is

Figure 58.—Ocean outfalls discharging domestic sewage. All are primary treatment effluents except that of Miami, which is secondary. Number following MGD (million gallons/day) is length of discharge pipe in feet. Number in parentheses is depth of discharge in feet.



Source: Lee, Thomas N., and James B. McGuire, 1973a: The use of ocean outfalls for marine waste disposal in southeast Florida's coastal waters. Univ. Miami, Sea Grant Coastal Zone Management Bull.

Figure 59.—Typical tide cuves for the Savannah River Entrance and Key West, Fla.



Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1972: Tide Tables, High and Low Water Predictions 1972 — East Coast of North and Douth America Including Greenland typical for the Miami area. At the Key West location there is considerable inequality in the heights of high and low waters. By reference to the curves, it can be seen that where the inequality is large there are times when there is but a few tenths of a foot difference between high and low water.[368]

Tropical cyclones which move across the Florida peninsula at frequent intervals can produce water levels as much as 15 feet above normal. Figure 60 shows the resulting maximum tides caused by hurricanes from 1950 to 1955.[369]

3. Tidal currents. Tidal currents in the offshore region of southern Florida are generally weak (average values ≤ 0.2 kt) and rotary in nature. The direction of flow changes continuously with no period of slack water. Table 25 illustrates the rotary nature and velocities of these currents for a position east of Miami.

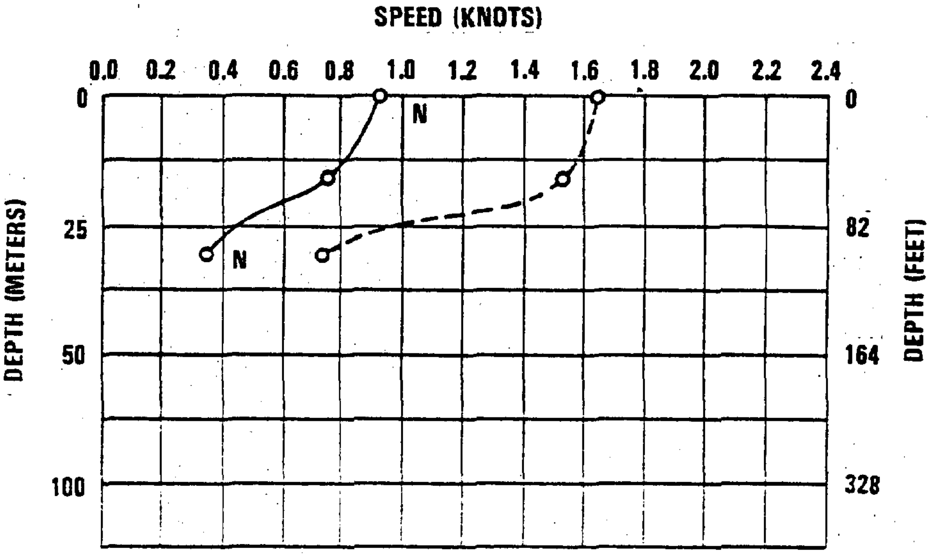
Tidal currents at coastal and estuarine locations display the typical ebb and flood of reversing tidal currents with definite periods of slack water. Velocities of flow are controlled by the coastal topography and seabed configuration. In confined locations maximum speeds will exceed 3 kt, with most locations along the coast showing average speeds between 1 and 2 kt.[370]

4. Circulation.

(a) Gulf Stream. The northward flowing Florida Current of the Gulf Stream System dominates and influences the circulation along the entire Florida Coast. Restricted to the natural channel created by the land masses of Florida, Cuba, and the Bahama Islands, the Florida Current can reach speeds in excess of 3-1/2 kt in the axis of flow. The velocity of the predominantly northward flowing current is subject to fluctuations brought about by variations in winds and barometric pressure.[371]

The western edge of the Florida Current can be determined from horizontal changes in temperature, salinity, current speed, and water color. Based on measurements of these parameters over a three-year period at locations off Boca Raton and Pompano, the western edge of the current meanders in an east-west direction with a horizontal displacement of 2-3 n mile and at times extends into the shelf region. The period of these lateral meanders ranges from 2 to 8 days.[372] From Fowey Rocks (approximately 5 miles S.S.E. of Key Biscayne) to Jupiter Inlet (approximately 5 miles N. of West Palm Beach), the western edge of the Florida Current lies very close to the shoreline. The axis of the flow lies approximately 10 miles east of Fowey Rocks and increases to 20 miles off Jupiter Inlet. Off Cape Kennedy the axis of flow

Figure 60.--Vertical current profile at 26°02' 15"N, 80°05' 02"W. Solid line represents annual mean velocities, dashed line maximum observed speeds. Current direction is north (N). Based on data for 1964-65.



Source: U.S. Naval Oceanographic Office, 1973: Unpublished current profiles (profiles numbers: 1-081-604A, 1-081-60-4B, 1-081-60-4C), Suitland, Md.

Table 25.--Rotary tidal currents.

Miami Outer Bay Cut Entrance Lat. 25°46' N., long. 80°06' W.			
Time		Direction (true)	Velocity
		Degrees	*Knots*
Hours after maximum flood at Miami Harbor Entrance, see page 108	0	338	0.1
	1	319	0.1
	2	352	0.1
	3	18	0.1
	4	36	0.1
	5	30	0.2
	6	25	0.1
	7	32	0.1
	8	25	0.1
	9	26	0.1
	10	6	0.3
	11	355	0.1

Source: U.S. Department of Commerce, NOAA, National Ocean Survey, 1972: Tidal Current Tables — Atlantic Coast of North America, Rockville, Md.

is located 45 miles offshore, with the western edge positioned approximately 10 miles offshore.[373]

(b) Surface circulation. The surface circulation southwest of Key West inside the 90 mile contour is quite variable with a mean velocity of 0.1 kt setting westerly. Seaward of the 90 mile contour the surface currents tend to be variable; however, the dominant component is northerly, with a mean speed of 0.6 kt and a secondary component to the west with a mean speed of 0.2 kt. From Key West northward along the coast, between the 90 and 180 mile contour, the current sets to the north with speeds increasing from 1.3 kt off Key West to 2.5 kt off Cape Kennedy. Immediately seaward of the 180 mile contour speeds increase rapidly until the axis of the Florida Current is reached.[374]

Winds and eddies from the Florida Current produce variability in the northward flow at inshore positions. The southern winds which prevail during July and August produce an offshore component to the drift in the area just south of Cape Kennedy.[375] Observations made at Fowey Rock show sudden reversals in the northerly flow with speeds equal to the northern component.[376]

Near-surface current meters placed near the sewage outfalls at Boca Raton and Pompano (90 feet of water) and off Miami revealed that the coastal currents were predominantly alined with the coast in a north-south direction but exhibit a great deal of variability (current reversals). The flow is in a northerly direction approximately 65 percent of the time with speeds ranging from 0.0 to 1.5 kt and to the south 35 percent of the time with similar speeds. The current meter records consistently show a westerly component with durations of several days which could be produced in part by the predominant onshore winds.

The most striking feature revealed by the current meter observations is the large number of current reversals. These reversals are believed to be produced by counterclockwise eddies which spin off the western edge of the Florida Current and are transported northward through the coastal waters. Width of the eddies ranges from 1 to 6 miles, with north-south dimensions 2 to 3 times greater. The counterclockwise nature of the eddies transports water from the Florida Current into the shelf region at the north end of an eddy and transports coastal water offshore at the southern end. The frequency of occurrences of eddies large enough to flush the coastal waters suggests that the residence time of the coastal waters is on the order of one week.[377]

(c) Subsurface circulation. The bottom drift is northerly over the outer shelf and slope with speeds of 1 n mile/day. There is a convergence toward Cape Kennedy from offshore and frequently a southerly drift inshore south of the Cape.[378]

Current meter arrays located off Fort Lauderdale in water depths of 31, 62, and 93 meters show subsurface currents setting to the north with speeds decreasing from the surface down. Annual mean speeds along the bottom at all three locations range about the 0.5 kt value. Figures 61 thru 63 show the vertical current profiles for the three locations with annual mean velocities and maximum observed speeds.[379]

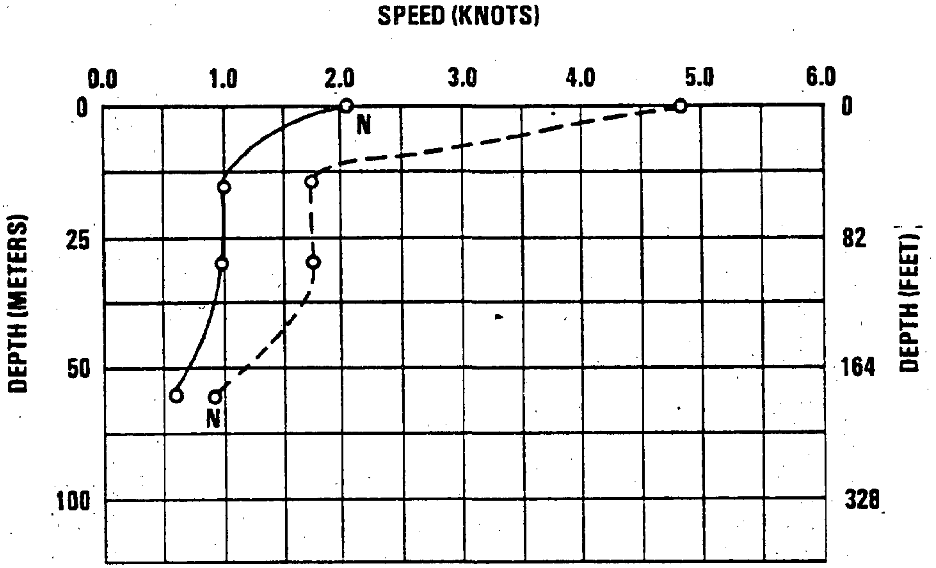
The configuration of ripple marks in the bottom sediments of the Florida Straits indicate a southward counter current.[380] Based on high resolution current profiles in the Florida Straits, the lower half of the water column (water depth 580 m) shows at times a southward flow, with speeds up to 30 centimeters per second.[381]

5. Water mass characteristics.

(a) General. The coastal waters off southeast Florida can be thought of as a narrow buffer zone for exchange between the estuaries to the west and the offshore Florida Current. The estuaries consist of interconnecting shallow embayments and lagoons with very weak land run-off, except during the wet seasons of early summer and fall.[382] Estuarine discharge, being less saline and warmer than the shelf waters and therefore less dense, floats above the shelf water as a shallow lens approximaterly 1.2 m deep. Estuarine discharge has been traced from 900 m to 1800 m offshore adjacent to Pompano, Florida.[383]

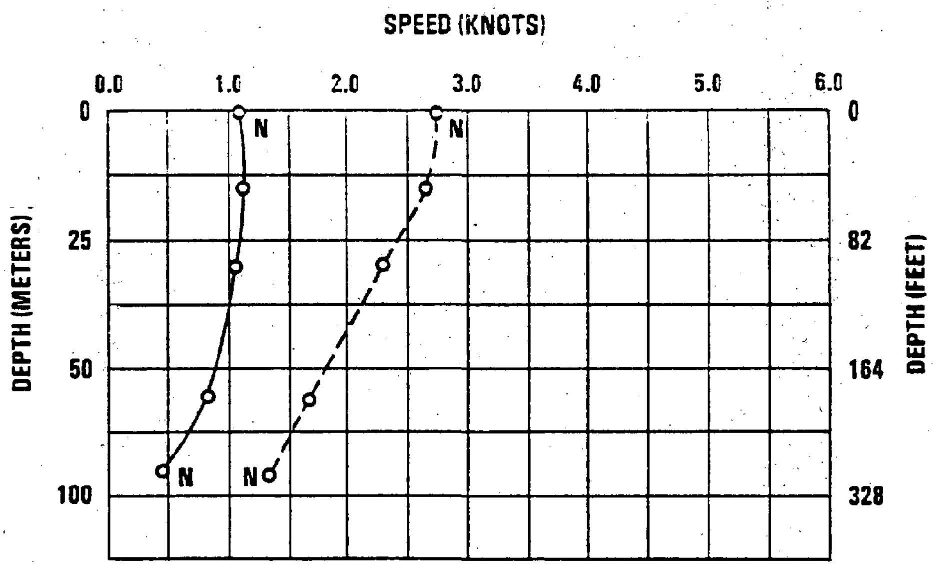
Characteristics of the Florida Current show temperatures at the surface in the axis of flow of approximately 24°C and maintaining temperatures of 20°C at depths of 200 meters. Surface temperatures decrease with increased distance from the axis and much more so toward the west. Where the Florida Current pushes up against the Continental Shelf of Florida a very sharp thermal gradient exists in water depths between 50 and 125 meters. Along the axis a core of high salinity water exists At about the 200 m level with values of 36.5 percent. A tongue from this high salinity core extends onto the Florida Shelf. Surface salinities in the axis are about 36.1 percent and increase with depth as the core is approached and decrease with depth beyond the core. Isohalines show a steep salinity gradient against the Continental Shelf of Florida between the 75 and 175 meter level.[384]

Figure 61.--Vertical current profile at 26°02', 80°04.5'W. Solid line represents annual mean velocities, dashed line maximum observed speeds. Current direction is north (N). Based on data for 1964-65.



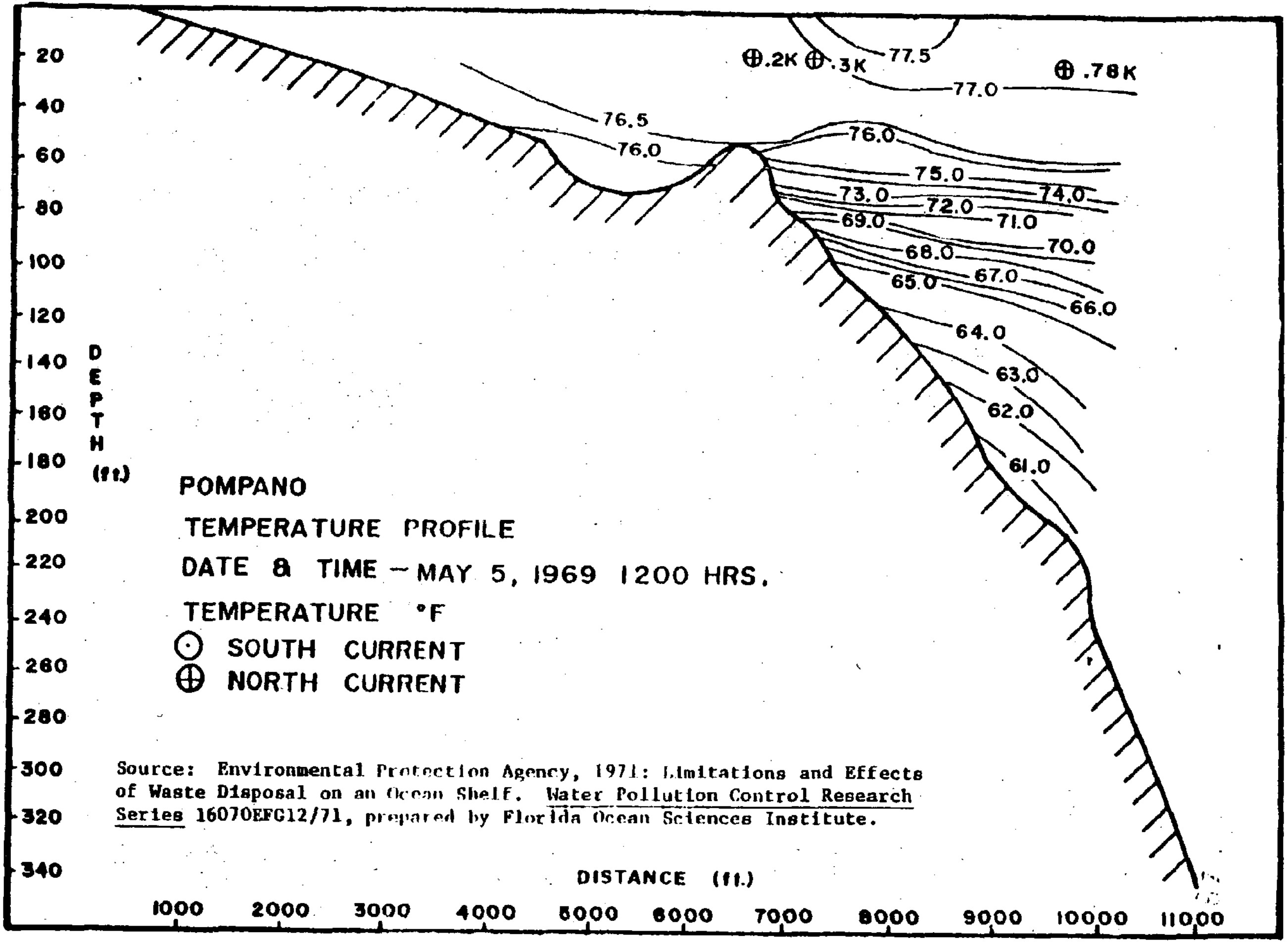
Source: U.S. Naval Oceanographic Office, 1973: Unpublished current profiles (profiles numbers: 1-081-60-4A, 1-081-60-4B, 1-081-60-4C), Suitland, Md.

Figure 62.—Vertical current profile at 26°03'N, 80°04'W. Solid line represents annual mean velocities, dashed line maximum observed speeds. Current direction is north (N). Based on data for 1961-65.



Source: U.S. Naval Oceanographic Office, 1973: Unpublished current profiles (profiles numbers: 1-081-60-4A, 1-081-60-4B, 1-081-60-4C), Suitland, Md.

Figure 63.--Vertical temperature distribution off Pompano Beach, Fla.



Source: Environmental Protection Agency, 1971: Limitations and Effects of Waste Disposal on an Ocean Shelf. Water Pollution Control Research Series 16070EFG12/71, prepared by Florida Ocean Sciences Institute.

The shelf waters reflect changes in water mass characteristics as a function of the direction of current flow, which is dominated by the Florida Current. The counterclockwise eddies which spin off the western side of the Florida Current function as major exchange mechanisms for mixing coastal waters with that of the Florida Current. When inshore coastal waters exhibit a southerly flow, resulting from the passage of an eddy, both temperature and salinity values are characteristic of the Florida Current.[385]

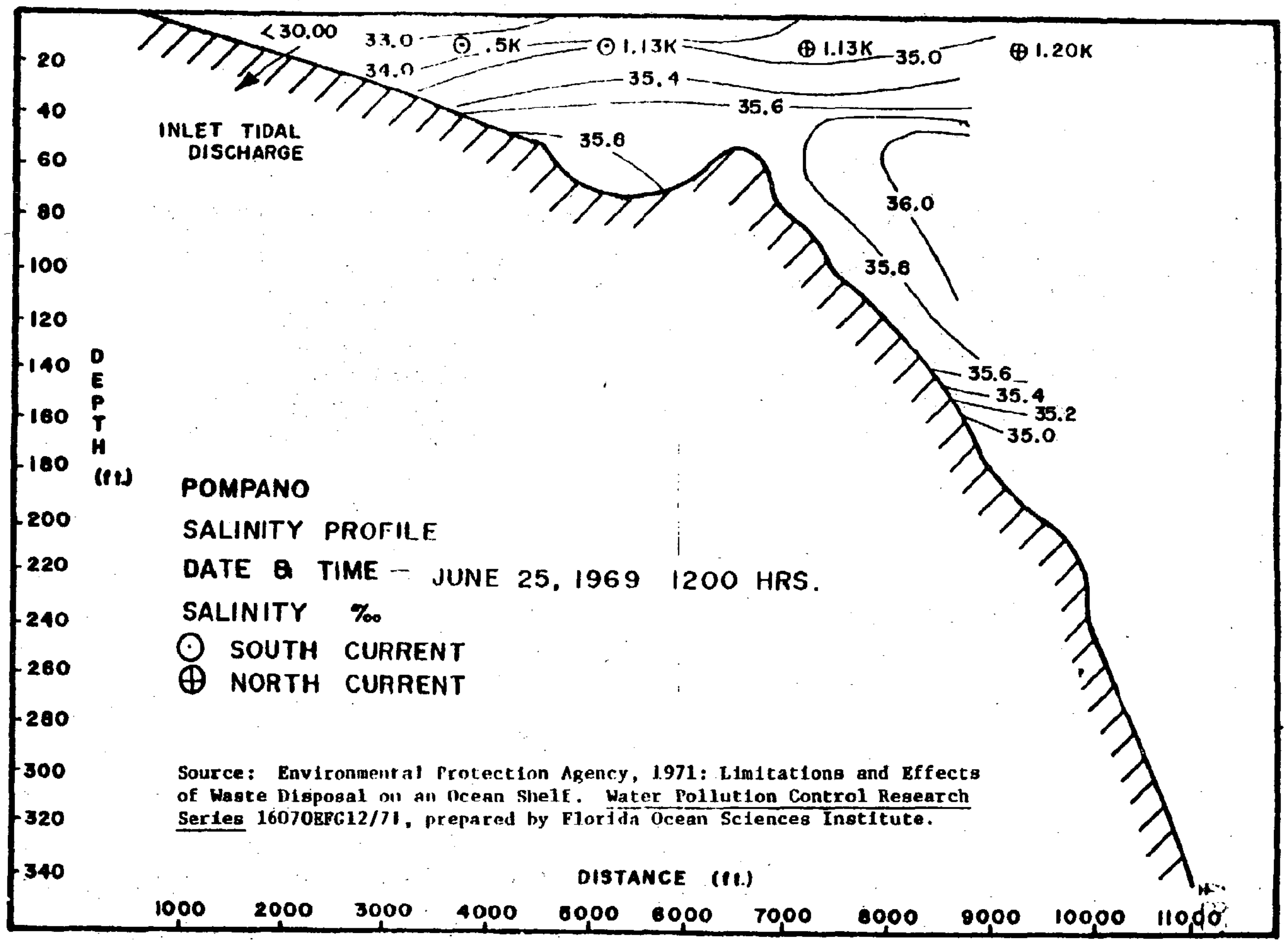
(b) Temperature. Temperature transects off Pompano and Boca Raton, starting inshore and proceeding east until the edge of the Florida Current is reached, reveal that a sea-surface temperature of about 21°C occurs in January and February and increases to a maximum of about 30°C in June and July. The vertical temperature structure of the nearshore waters is well mixed, with small vertical temperature gradients from mid-August to the latter part of April. Beginning in May and continuing to mid-August strong stratification appears at depths of 30 meters with vertical gradients as high as 6.5°C over a 10-meter change in depth. Figure 64 illustrates this sharp thermal gradient at approximately the 30 m level. Bottom temperatures at the 30-meter level show a range of temperatures between 20°C in May to 29°C in July.[386]

Surface temperature values recorded at shore positions at Conova Beach (just south of Cape Kennedy), Miami Beach, and Key West, show that maximum surface temperature values are quite consistent over all years, ranging between 32° and 33°C at Miami Beach and Key West, and between 29° and 31°C at Conova Beach. Minimum values show a slightly wider range over all years, with values ranging between 16° and 20°C at Key West, 14° to 20°C at Miami Beach, and a constant 14°C at Conova Beach. Mean annual temperature values at Key West range between 25.8° and 27°C, at Miami Beach between 25.5° and 26.7°C, and at Conova Beach between 23.2° and 23.4°C.[387]

Table 26 illustrates the seasonal variability of temperature at various depths for a band along the entire Florida Continental Shelf.

(c) Salinity. Salinity transects off Pompano and Boca Raton show a subsurface core of high salinity water encroaching on the shelf. The salinities in the core range from 36.2 to 36.6‰ and represent the high salinity core of the Florida Current. The position of this core, located between 10 to 20 m beneath the surface, migrates horizontally in an east-west direction, ranging from 1.3 km to 5.0 km

Figure 64.--Subsurface high-salinity core offshore at Pompano Beach, Fla.



Source: Environmental Protection Agency, 1971: Limitations and Effects of Waste Disposal on an Ocean Shelf. Water Pollution Control Research Series 16070EFG12/71, prepared by Florida Ocean Sciences Institute.

Table 26.--Seasonal water temperatures vs. depth, 25-29°N, 78-81°W.

MONTHS	1 - 3 NUMBER MONTHS PRESENT 1, 2, 3					MONTHS 4 - 6 NUMBER MONTHS PRESENT 4, 5, 6				
DEPTH	MAX	AVG	MIN	OBS	SDEV	MAX	AVG	MIN	OBS	SDEV
0	27.20	24.48	18.15	247	1.16	29.63	26.60	21.37	458	1.25
10	27.18	24.43	18.18	232	1.19	29.28	26.39	20.70	453	1.30
20	27.15	24.38	18.81	228	1.15	29.09	26.19	18.33	443	1.44
30	27.12	24.26	15.93	226	1.29	28.73	25.96	15.84	434	1.44
50	26.58	23.98	18.22	227	1.33	27.91	25.42	17.19	419	1.40
75	25.92	23.40	15.81	244	1.63	27.22	24.38	15.66	415	1.93
100	25.94	22.87	12.65	223	1.98	26.21	23.11	12.63	408	2.62
125	25.18	21.94	14.28	218	2.33	25.60	21.67	10.09	402	3.19
150	24.46	20.78	10.72	212	2.90	25.40	20.54	8.60	372	3.25
200	22.40	18.99	7.10	188	2.92	22.66	18.33	8.55	332	3.20
250	20.14	17.41	6.90	171	2.67	21.03	16.60	7.12	294	3.37
300	18.83	16.07	6.63	159	2.38	19.33	15.82	6.96	241	2.79

MONTHS	7 - 9 NUMBER MONTHS PRESENT 7, 8, 9					MONTHS 10 - 12 NUMBER MONTHS PRESENT 10, 11, 12				
DEPTH	MAX	AVG	MIN	OBS	SDEV	MAX	AVG	MIN	OBS	SDEV
0	30.97	29.20	27.28	150	0.70	29.07	26.70	21.79	177	1.19
10	30.32	28.98	25.60	149	0.69	29.04	26.70	21.78	179	1.23
20	30.13	28.71	22.12	144	0.96	29.07	26.74	21.77	177	1.17
30	29.60	29.35	21.02	140	0.96	29.02	26.72	21.15	176	1.17
50	29.31	27.35	19.60	139	1.34	28.94	26.54	23.20	173	1.04
75	23.41	25.67	12.41	139	2.27	28.30	25.86	21.12	174	1.17
100	27.03	24.05	13.86	135	2.77	27.28	24.59	17.80	173	1.95
125	25.78	22.09	11.09	132	3.42	26.06	22.59	12.69	172	2.70
150	24.58	20.60	8.66	124	3.39	24.59	20.63	10.50	170	3.14
200	21.64	18.20	8.24	109	3.01	22.88	17.97	8.45	151	3.14
250	19.62	16.29	7.86	98	3.42	20.47	16.04	7.11	130	3.37
300	18.74	15.93	7.69	80	2.82	18.69	15.18	7.91	115	3.23

Source: Churgin, J., and S.J. Halminski, 1974: Temperature, Salinity, Oxygen, and Phosphate in Waters Off United States. Key to Oceanographic Records Documentation No. 2, Vol. I, Western North Atlantic. Environmental Data Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C. In press.

offshore. Salinities inshore of the core can reach minimum values below 30‰ as a result of seasonal fresh water discharge during early summer and fall. Figure 65 illustrates the vertical salinity characteristics across the shelf when the core is in an offshore position. Figure 66 illustrates the salinity characteristics with the core at an inshore postion.[388]

(d) Oxygen. The Florida Current exhibits oxygen concentrations between 5.5 and 3.0 ml/l to a depth of 100 meters during all months. On the Florida Shelf between 25°N and 29°N oxygen values are quite low, ranging from about 4.0 to 5.0 ml/l during all months and at all depths. Oxygen concentration decreases slightly with depth to minimums of about 3.6 ml/l, except off the Florida coast to the south of Miami, where it increases slightly to the 50-m depth level, and then decreases with depth (National Oceanographic Data Center, unpublished data summaries).

(e) Other characteristics.

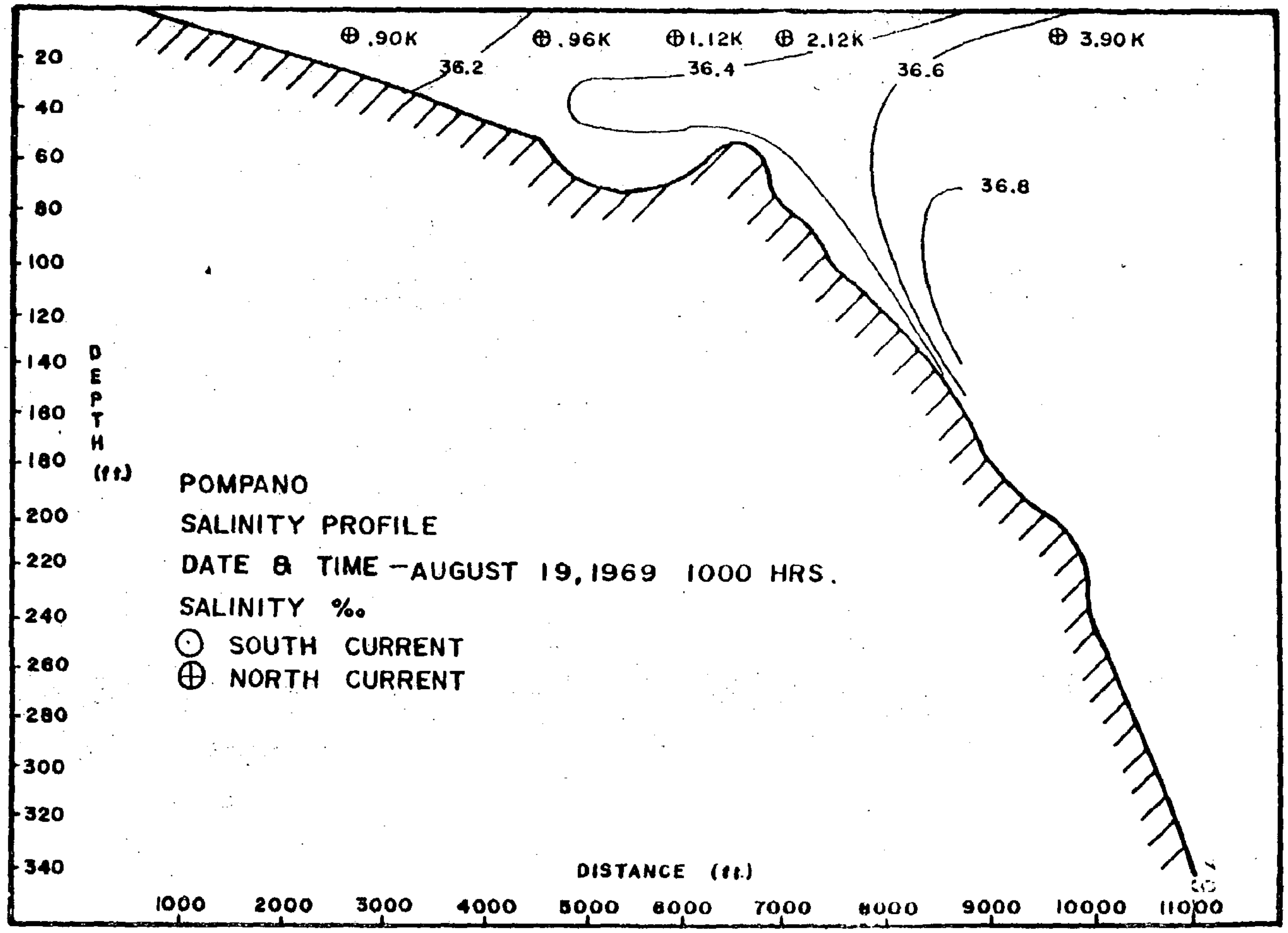
(i) Phosphate. For the Florida coastal waters (including the Florida Current) in general, phosphate values increase from trace levels at the surface to maximum values of about 2.0µg at/l at the 300-meter depth level. Phosphate levels of less than 1.0µ are found to a depth of 100 meters.[389]

(ii) Nutrients/contaminants. Along the Florida coast between Key West and Palm Beach there are 10 sewage outfalls located at various distances and depths on the Florida shelf. Discharge rates range from 50 million gallons/day (MGD) at Miami to 2 MGD at Delray Beach. Studies have shown that these outfalls do not discharge into the Florida Current, but move either north or south along the coast under the influence of the Florida Current or westerly to the beaches under the influence of onshore winds.[390] This would suggest that concentration of nutrients as well as contaminants associated with raw and semi-treated wastes would show higher than normal concentrations in this area.

CLIMATOLOGY

1. General. The chief factors in the climate along this coast are latitude and the Atlantic Ocean. Summers are long, warm, and humid. Winters, although punctuated with periodic invasions of cool to occasional cold air from the north, are mild. The Gulf Stream exerts a warming influence, particularly since prevailing winds are off the water.

Figure 65.—Subsurface high-salinity core inshore at Pompano Beach, Fla.



Source: Environmental Protection Agency, 1971: Limitations and Effects of Waste Disposal on an Ocean Shelf. Water Pollution Control Research Series 16070EFG12/71, prepared by Florida Ocean Sciences Institute.

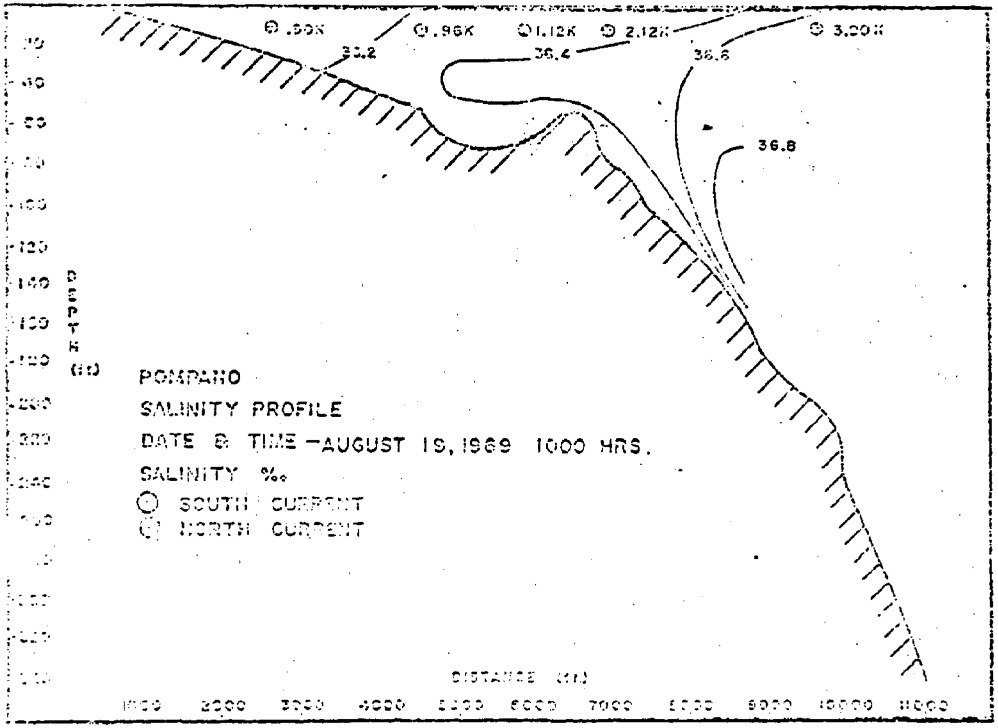


Figure 66.

Source: Environmental Protection Agency, 1971: Limitations and Effects of Waste Disposal on an Ocean Shelf, Water Pollution Control Research Series 16070EFG12/71, prepared by Florida Ocean Sciences Institute.

2. Tropical cyclones. Tropical cyclones can occur in any month, but a real threat exists from June through November. Area No. 4 lies within the hurricane belt. A total of 94 tropical cyclones have affected this area since 1900; one-half of these have been hurricanes. Nearly three-fourths of the tropical cyclones have occurred in August, September, and October.[391] In the southern part of the area tropical cyclones generally head toward the northwest, and in the northern part, toward the north-northeast. Tropical cyclones are more frequent in the southern waters.[392]

(a) Coast. A total of 51 tropical cyclones have struck within 60 miles of the coast from Cape Kennedy to the Florida Keys since 1900. More than one-half were hurricanes, and about 60 percent occurred during September and October. The concentration of coastal crossings lies south of Ft. Pierce: the area northward has been relatively hurricane-free. The annual chances of hurricane-force winds along this coast range from 1 in 30 at Daytona Beach to 1 in 7 at Miami and Key West.[393]

The most recent severe hurricane to affect this coast was Betsy in 1965. The storm brought 50- to 80-kt winds with gusts to 140 kt, and 4- to 8-foot tides to the area. A year earlier, Cleo had raked the coast with 80- to 115-kt gusts. Back in 1950, Hurricane King (female names for tropical cyclones were not introduced until 1953) brought 60- to 100-kt winds and 130-kt gusts to the area, and tides ran 4 to 5 feet above mean sea level. A year earlier, a severe August hurricane generated winds over 100-kt and tides over 10 feet along sections of this coast. Other devastating hurricanes occurred in September 1947, 1935, 1928, and 1926.[394]

3. Extratropical cyclones. This area is usually more affected by associated frontal activity than by the LOW itself, particularly off southeastern Florida. The northern part of the area provides a spawning ground, or area of cyclogenesis, for winter storms that often affect the east coast to the north. These developing storms usually remain weak until well north of the area. Sometimes a winter LOW from the Gulf of Mexico will cut across Florida and bring strong winds and rough seas to the area. When a "norther" does occur, seas are particularly rough in the Florida Straits. Jacksonville's winter windspeed maximum of 54-kt gives an indication of the peak intensity of these infrequent storms. About five or six extratropical cyclones pass through this area each year, and they are most likely from fall to spring, particularly in February and October.[395]

4. Winds. Prevailing winds blow from an easterly quarter (northeast through southeast) all year round. Easterly winds are most persistent (frequencies ≥ 20 percent) from April through September. Northeasterlies occur from 19 to 30 percent of the time from September through December. Southeasterlies are most frequent from March through August, when they occur from 15 to 20 percent of the time. Average wind speeds run 13 to 15-kt from October through April. They reach a low of 9-kt in July. During fall and winter, northwest winds are the strongest, averaging 14 to 17-kt.[396/]

Gales (winds ≥ 34-kt) are infrequent in this area; they occur less than 2 percent of the time in all months. They occur more than 1 percent of the time in October, December, January, and February. Winds ≥ 48-kt are rare, but have been recorded in every month.[397/]

(a) Coast. Wind directions along the coast are similar to those over open water, except where modified by local topography. Winds from an easterly quarter become more persistent toward the south. At Key West, the prevailing direction for every month has an easterly component. Winds tend to be weaker along the coast, particularly in winter. Average coast wind speeds run from about 9 to 12-kt and are strongest in the Keys. There is little difference in summer speeds, which average about 7 to 9-kt at coastal locations. The land-sea breeze is an important feature along the coast during most of the year. When the land heats up during the day, a windflow off the water is created. This sea breeze can reach 15-kt. At night, as the land cools rapidly, an offshore windflow is created—a land breeze.[398/]

5. Extreme winds. Extreme winds have been caused by hurricanes. The maximum winds of record are mostly estimates, since wind instruments usually fail at speeds over 130-kt. A one-minute wind speed of 135-kt was measured at Hillsboro Lighthouse in the September hurricane of 1947. In the Labor Day hurricane of 1935, winds were estimated at up to 200-kt. Miami Beach has a recorded extreme of 106-kt, as does Key West. West Palm Beach recorded a 104-kt wind back in 1949.[399/] The strongest winds tend to occur along the southern part of the coast.

A maximum sustained wind of 77-kt can be expected every 10 years, on the average, and a 128-kt wind, every 100 years.

6. Wave heights. Extreme waves occur only in deep water. In shallow water, waves break before reaching extreme height. These breakers in a hurricane can be powerful, particularly on top of a storm surge (see storm tides). The pounding

hurricane surf has been heard more than 5 miles inland.[400] Seas, in general, run 3 to 4 feet from September through April; 5 to 6 feet seas are common from October through March. From May through August, seas from 1 to 2 feet are most common, while 3 to 4-foot seas are alo frequent. Waves ≥ 12 feet occur more than 1 percent of the time from September through March and in May. They are most frequent in September, October, and February, when they occur between 3 and 4 percent of the time. Waves of 20 feet or more never occur more than 1 percent of the time, but are most likely in September and February. They have been observed in every month except June.[401]

Maximum seas in Area 4 have been observed at 33 to 40 feet in September. These are significant wave heights, which are the average of the one-third highest observed waves. Extreme waves are rare, as are their chances of being encountered. Statistical formulas indicate that over a period of 100 years, on an average, an extreme wave of 114 feet will occur, along with a significant height of 63 feet. A 63-foot wave would require a water depth of about 81 feet or more to sustain itself.

7. Visibility. Visibility in this area is generally good throughout the year. While it is briefly reduced in showers, fog is the main restriction. Visibilities less than 2 miles occur less than 0.5 percent of the time all year round. There is little seasonal variation; dense fog where visibilities drop below one-half mile occur 0.1 percent of the time in every month.

(a) Coast. Land stations indicate the presence of heavy fog on an average of 32 days annually at Daytona Beach, 8 days at West Palm Beach, and 1 day at Key West. The northern coast of this area experiences radiation fog, which can be particularly dense in the morning hours. Infrequently, a sea fog will move into the coastal regions, and may persist for 2 or 3 days. St. Johns Lightship, north of the area, indicates fog is most common in December and January, when the fog signal operates an average of 25 to 35 hours per month and least frequent from May through July, when it operates an average of 1 to 3 hours per month.[402]

8. Storm tides. Storm tides are the result of a storm's wind and pressure effect on the water (surge), plus the normal astronomical tide. When both reach a peak simultaneously, severe flooding occurs. Record high tides along this section of Florida coasta are the direct result of tropical cyclones. Many of the records along the southeast coast were set in the September hurricane of 1926, when tides 8 to 13 feet above normal occurred in the Miami area. An October 1944 storm caused

record 7- to 11-foot tides around Daytona Beach. The highest tides in this area occurred in the Florida Keys, when the Labor Day hurricane of 1935 pushed tides up to 18 feet above mean sea level. In 1960, Hurricane Donna caused 10- to 14-foot tides in this same area.[403/]

9. Air temperature. Mean air temperatures over Area 4 range from nearly 84°F in August to just less than 70°F in January. Temperatures have never been observed below freezing offshore. Temperatures at or above 85°F occur in every month. They are most common in July and August, when they occur 26 to 30 percent of the time. The daily temperature range is small compared to that at coastal stations, particularly in summer.

(a) Coast. Winter mean temperatures along the coast range from a low of 59°F in January at Daytona Beach to a mild 69°F at Key West. The daily range is about 10°F in the Keys to 20°F in the north. Winter extremes range from a 41°F reading at Key West down to an 18°F temperature at Daytona Beach. The north-south temperature gradient is reduced to about 3°F by August, when means run from about 80° to 83°F. The daily temperature range is about 15° to 18°F. Temperatures reach 90°F or above on about 45 to 55 days annually. Extremes range from 97° to 102°F, with the warmer temperatures occurring at the less-exposed stations to the north.[404/]

10. Thunderstorms. Portions of the Florida peninsula observe more seasonal thunderstorm activity than any other areas in the United States; it is one of the major thunderstorm-genesis areas in the world. Thunderstorms can be isolated occurrences or can form a squall line. Gusts in thunderstorms can reach hurricane force.

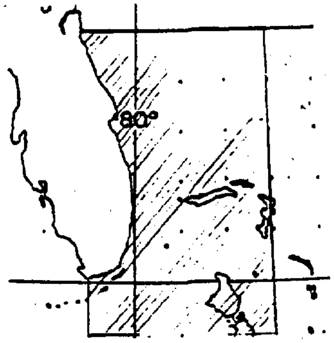
While thunderstorms can occur in every month, they are most frequent along the east Florida coast from June through September; during this season, they occur on about 30 percent of the days offshore from Cape Kennedy to Key West. During July and August, this figure jumps to 40 percent. At Cape Kennedy, thunderstorms occur on about 13 to 15 days during June, July, and August. These occurrences (on many days, multiple occurrences) add up to about 30 to 40 hours of thunderstorm activity per month. On the average, a summer thunderstorm at the Cape lasts from 1-1/2 to 2 hours. At sea, thunderstorms are also at a peak from June through September, when they have been observed about 3 to 5 percent of the time.[405/]

Table 27 summarizes climatological data for Area 4.

Table 27.--Climatological summaries for area 4.

TROPICAL CYCLONE AND EXTRATROPICAL CYCLONE ACTIVITY

COASTAL AREA 24° TO 30°N, 77°W TO COAST



Area for which tropical and extratropical cyclone statistics appear below.

Tropical Cyclone Activity 1900-1972

	Feb.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tropical Storm Stage (34 to 63 kt)	1	2	7	5	9	12	9	2		47
Hurricane Stage (≥ 64 kt)		1	1	4	8	15	16	1	1	47
Extratropical Stage										0
Total	1	3	8	9	17	27	25	3	1	94

Extratropical Cyclones Affecting Area 1963-1972

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
6	12	4	3	5	1	1	2	4	9	5	2	54

Tropical Cyclones Striking within 60 Mi of the Coast, Cape Kennedy to Florida Keys, 1900-72

	Feb.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tropical Storm Stage (34 to 63 kt)	1	1	3	2	5	5	5	2		24
Hurricane Stage (≥ 64 kt)			1	2	2	11	10	1		27
Extratropical Stage										0
Total	1	1	4	4	7	16	15	3		51

METEOROLOGICAL TABLES FOR AREA (4) 25° TO 29°N, 78° TO 81°W

Mean Recurrence Intervals

	5 yr	10 yr	25 yr	50 yr	100 yr
Maximum Sustained Wind (kt)	66	77	94	110	128
Maximum Significant Wave Height (ft)	38	43	50	56	63
Extreme Wave Height (ft)	68	77	90	101	114

Percentage Frequency of Wind Direction by Speed

January

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.7	6.7	3.7	.7	.1	1200	12.9	14.9
NE	1.4	8.1	3.8	.5	*	1323	14.3	14.3
E	2.9	11.4	3.3	.2	.0	1656	17.8	12.4
SE	1.4	6.7	1.9	.1	.0	969	10.4	12.1
S	1.9	5.9	2.6	.4	.0	977	10.5	13.3
SW	1.0	3.1	1.9	.4	*	589	6.3	14.7
W	1.1	5.3	3.2	.7	*	989	10.7	15.3
NW	1.4	7.3	3.3	1.1	*	1250	13.5	14.2
VAR	.1	.0	.0	.0	.0	6	.1	8.0
CALM	1.3					133	1.3	.0
TOT	1408	5066	2194	378	16	9282	100.0	13.7
PCT	15.2	54.6	23.6	4.1	.2	100.0		

February

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.3	6.3	3.3	.4	.0	1008	11.5	14.0
NE	1.7	7.6	2.7	.4	.0	1056	12.6	13.1
E	2.6	10.7	3.4	.2	*	1506	17.2	12.7
SE	2.1	8.6	2.6	.2	.0	1129	12.9	12.7
S	1.7	7.2	4.1	.4	*	1172	13.4	14.2
SW	1.1	3.9	1.8	.3	.0	619	7.1	13.9
W	1.2	5.3	3.4	.9	.1	947	10.8	15.3
NW	1.2	6.8	4.7	1.2	.1	1201	13.7	15.5
VAR	.1	.2	.0	.0	.0	3	.1	8.0
CALM	1.4					124	1.4	.0
TOT	1276	4877	2295	327	14	8767	100.0	13.9
PCT	14.6	55.6	26.2	3.7	.2	100.0		

March

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.8	6.7	3.0	.3	*	1148	11.8	13.7
NE	1.0	6.9	2.6	.2	.0	1079	10.8	13.1
E	2.6	11.2	3.1	.2	.0	1690	17.0	12.3
SE	2.3	10.0	2.9	.2	.0	1541	15.5	12.3
S	2.3	9.3	3.6	.3	*	1531	15.4	13.1
SW	1.2	3.9	1.4	.1	.0	660	6.3	12.6
W	1.2	4.9	2.5	.7	*	883	8.9	13.6
NW	1.0	8.1	4.3	.9	*	1363	13.7	13.8
VAR	*	.0	.0	.0	.0	2	*	1.5
CALM	1.7					170	1.7	.0
TOT	1381	5793	2314	366	9	9963	100.0	13.2
PCT	13.9	58.1	23.2	3.7	.1	100.0		

April

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.7	5.1	2.0	.3	*	882	9.1	13.0
NE	2.2	9.3	3.4	.2	.0	1362	15.1	13.1
E	3.4	18.3	5.0	.2	*	2206	24.8	12.1
SE	2.6	9.8	2.0	.1	.0	1322	14.9	12.2
S	2.3	7.4	2.0	.2	*	1123	12.0	12.6
SW	.7	3.3	1.3	.1	.0	499	5.6	13.0
W	1.2	3.6	1.7	.3	.0	633	7.1	13.7
NW	1.1	4.6	2.2	.3	*	733	8.3	13.9
VAR	*	*	.0	.0	.0	6	*	3.8
CALM	1.6					139	1.6	.0
TOT	1513	5290	1919	150	3	8843	100.0	12.6
PCT	17.0	59.7	21.6	1.7	.1	100.0		

May

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.1	4.7	1.6	.1	*	776	8.1	11.3
NE	3.0	10.4	3.6	.2	*	1587	17.0	12.1
E	4.4	18.6	3.2	.1	.0	2276	26.4	11.3
SE	3.7	11.9	1.5	*	*	1586	17.0	10.3
S	3.7	8.7	1.2	*	.0	1267	13.6	10.2
SW	1.8	4.3	.8	*	.0	647	6.9	10.3
W	1.3	3.1	.7	.1	.0	508	5.3	10.4
NW	1.1	2.7	.5	.1	*	405	4.3	10.8
VAR	*	.0	.0	.0	.0	3	*	3.0
CALM	2.0					238	2.0	.0
TOT	2283	5780	1187	59	9	9311	100.0	10.8
PCT	24.5	62.1	12.7	.6	.1	100.0		

June

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.3	2.9	.3	*	*	600	5.7	9.1
NE	3.3	8.1	1.3	*	.0	1345	12.8	10.6
E	6.6	14.7	1.9	.1	*	2451	23.1	10.1
SE	4.7	11.6	1.3	.1	*	1849	17.6	10.0
S	3.3	12.0	1.6	.1	.0	2006	19.0	10.2
SW	2.6	6.1	1.0	.1	*	1004	9.6	10.7
W	1.6	2.3	.4	*	.0	361	4.3	9.8
NW	1.2	2.2	.2	*	.0	381	3.6	9.6
VAR	.1	.0	.0	.0	.0	10	.1	3.3
CALM	3.7					385	3.7	.0
TOT	3333	6319	867	33	6	10508	100.0	9.7
PCT	31.8	60.2	8.3	.3	*	100.0		

Percentage Frequency of Wind Direction by Speed (Area 4 cont.)

July

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.7	1.1	.1	.0	.0	300	3.0	8.9
NE	3.2	3.3	.4	*	.0	643	6.6	8.0
E	8.3	18.3	1.5	*	.0	2776	27.8	9.3
SE	8.3	13.0	1.0	.1	.0	2098	21.0	9.3
S	5.4	12.9	1.2	.1	*	1957	19.6	9.9
SW	2.4	5.8	.9	*	.0	911	9.1	10.3
W	1.4	2.4	.4	*	.0	423	4.2	9.2
NW	1.1	1.2	.1	.0	.0	239	2.4	7.9
VAR	.1	.0	.0	.0	.0	11	.1	2.1
CALM	4.3					428	4.3	.0
TOT	3413	6069	500	24	1	10007	100.0	9.0
PCT	34.1	60.6	5.0	.2	*	100.0		

August

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.3	3.2	.7	*	.0	637	6.1	9.6
NE	4.1	8.3	1.3	*	.0	1409	13.7	9.9
E	7.3	15.9	1.2	.1	.0	2495	24.4	9.4
SE	5.1	9.5	.7	.1	.0	1390	13.7	9.2
S	5.1	9.4	1.0	.1	.0	1503	15.4	9.3
SW	3.3	6.1	.8	*	.0	957	9.4	10.0
W	2.0	3.5	.3	*	*	617	6.1	9.6
NW	1.2	2.2	.6	.1	.0	436	4.2	10.8
VAR	*	.0	.0	.0	.0	3	*	1.8
CALM	4.7					480	4.7	.0
TOT	3542	5972	686	42	1	10243	100.0	9.1
PCT	34.6	58.3	6.7	.4	*	100.0		

September

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.3	5.3	2.1	.3	*	1023	10.5	12.4
NE	4.0	13.3	4.6	.3	*	2197	22.5	12.7
E	6.3	17.1	3.1	.2	.1	2610	26.8	10.9
SE	4.0	8.1	.8	.3	*	1283	13.2	10.0
S	3.1	6.1	1.7	.2	*	1087	11.1	11.4
SW	1.4	3.2	.9	.1	*	542	5.6	11.8
W	1.1	2.1	.4	.1	*	361	3.7	10.4
NW	1.0	1.9	.8	.2	.0	367	3.8	12.9
VAR	.1	.0	.0	.0	.0	9	.1	4.4
CALM	2.8					270	2.8	.0
TOT	2551	5596	1397	191	18	9753	100.0	11.2
PCT	26.2	57.4	14.3	2.0	.2	100.0		

October

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.9	8.9	4.4	.6	.1	1509	16.8	13.6
NE	3.2	13.4	9.6	1.7	.1	2531	28.4	15.2
E	3.2	12.3	3.9	.3	.1	1902	19.8	12.7
SE	1.7	4.8	.9	.1	*	720	7.8	10.9
S	1.0	3.5	.8	.1	*	577	6.0	11.1
SW	.9	2.1	.7	.1	.0	399	4.1	11.9
W	1.4	3.4	1.6	.1	*	506	5.3	13.6
NW	1.5	5.0	2.4	.3	*	886	9.2	13.7
VAR	*	.0	.0	.0	.0	1	*	2.0
CALM	2.2					211	2.2	.0
TOT	1740	5305	2209	311	25	9030	100.0	13.1
PCT	19.1	58.6	22.9	3.3	.3	100.0		

November

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.3	9.0	5.6	.7	*	1694	17.4	14.7
NE	2.3	14.4	7.9	.9	*	2358	25.6	14.9
E	2.9	11.6	3.9	.3	.0	1730	18.7	13.0
SE	1.4	4.3	.9	*	.0	619	6.7	11.1
S	1.7	3.0	1.6	.1	.0	644	7.0	11.8
SW	1.1	2.9	.9	*	.0	460	5.0	11.0
W	1.3	3.5	1.8	.3	.0	633	6.9	13.6
NW	1.4	6.6	3.2	.3	.0	1040	11.3	14.6
VAR	.1	.0	.0	.0	.0	3	.1	3.6
CALM	1.4					129	1.4	.0
TOT	1451	5101	2393	270	2	9217	100.0	13.3
PCT	15.7	55.3	26.0	2.9	*	100.0		

December

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.0	7.3	4.7	.3	*	1366	15.1	14.6
NE	2.4	11.0	5.2	.6	*	1733	19.2	14.1
E	2.4	12.3	3.2	.8	*	1664	18.4	12.8
SE	1.7	6.6	1.6	.1	.0	886	9.8	11.0
S	1.4	4.6	2.1	.1	.0	736	8.2	13.2
SW	1.0	2.7	1.2	.1	.0	457	5.1	14.9
W	1.3	4.3	3.3	.3	*	779	8.6	14.0
NW	1.4	7.2	6.3	.8	*	1392	16.3	15.6
VAR	*	.0	.0	.0	.0	4	*	1.8
CALM	1.3					113	1.3	.0
TOT	1343	5067	2294	311	8	9023	100.0	13.7
PCT	14.9	56.2	25.4	3.4	.1	100.0		

Annual

	WIND SPEED (KNOTS)							
WND DIR	0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.1	5.6	2.6	.4	*	12133	10.6	13.2
NE	2.7	9.0	3.8	.4	*	19124	16.7	13.1
E	4.5	14.0	3.0	.2	*	24893	21.7	11.6
SE	3.2	8.8	1.6	.1	*	15595	13.6	10.8
S	3.0	7.6	2.0	.2	*	14654	12.8	11.4
SW	1.5	4.6	1.1	.1	*	7732	6.8	11.6
W	1.2	3.6	1.5	.2	*	7718	6.8	12.3
NW	1.3	4.4	2.3	.6	*	9673	8.4	14.4
VAR	.1	*	.0	.0	.0	61	.1	2.4
CALM	2.3					2642	2.3	.0
TOT	25370	66211	20463	2706	100	114497	100.0	11.9
PCT	22.1	57.8	17.9	2.3	.1	100.0		

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Winds ≥34 kt	1.1	1.4	.8	.4	.3	.1	*	.1	.8	1.2	.6	1.2	.6
Winds ≥48 kt	.1	*	*	*	.1	*	*	0	.1	.1	*	.1	*

Percentage Frequency of Visibility (Nautical Miles) by Hour

January

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.0	.0	*	.1	1.1	19.4	1866
06&09	*	.0	.0	.1	1.3	22.0	1934
12&15	*	*	.1	.2	1.7	21.9	1909
18&21	.1	.1	.1	.3	2.1	28.5	2403
TOT	8	5	13	53	529	7384	7992
PCT	.1	.1	.2	.7	6.6	92.4	100.0

February

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	.0	.0	.1	1.6	19.2	1669
06&09	.1	.0	*	.1	1.4	23.2	1912
12&15	*	.0	*	.2	2.0	21.3	1888
18&21	*	*	*	.2	2.3	27.4	2277
TOT	11	1	5	43	595	6945	7600
PCT	.1	*	.1	.6	7.8	91.4	100.0

March

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.0	.0	*	.1	2.1	19.6	1877
06&09	*	*	*	.1	1.4	23.6	2174
12&15	*	.0	*	.1	1.7	22.1	2057
18&21	*	.0	*	.1	2.6	28.1	2469
TOT	4	1	19	32	621	7720	8397
PCT	.1	*	.2	.4	7.4	91.9	100.0

April

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	*	.1	.1	2.0	19.9	1879
06&09	*	.0	*	.1	1.7	23.0	1932
12&15	*	*	.0	.1	1.8	21.8	1787
18&21	*	*	.1	.1	2.0	26.8	2361
TOT	6	4	8	31	586	6983	7599
PCT	.1	.1	.1	.4	7.5	91.9	100.0

May

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	.0	.0	.2	1.8	21.4	1804
06&09	*	*	*	.1	1.3	23.5	1994
12&15	*	*	*	.1	1.5	21.5	1876
18&21	.1	*	*	.2	2.0	27.2	2304
TOT	11	8	10	46	539	7446	8060
PCT	.1	.1	.1	.6	6.7	92.4	100.0

June

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	*	.1	.2	1.0	21.1	2265
06&09	*	*	*	.1	1.3	22.3	2212
12&15	*	*	.1	.2	1.3	21.8	2179
18&21	*	*	*	.2	2.1	28.1	2667
TOT	12	10	17	62	551	8669	9321
PCT	.1	.1	.2	.7	5.9	93.0	100.0

July

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	.0	.0	.1	.1	1.5	22.4	2121
06&09	*	.0	.1	*	.7	23.3	2163
12&15	*	*	*	.1	1.0	22.6	2129
18&21	*	*	*	.1	1.1	27.2	2568
TOT	10	3	15	18	359	8568	8981
PCT	.1	*	.2	.3	4.0	95.4	100.0

August

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	*	*	.1	1.1	22.1	2128
06&09	*	.0	*	*	.9	21.7	2149
12&15	*	*	.0	.1	.9	23.2	2282
18&21	*	.0	*	.3	1.5	27.0	2399
TOT	10	3	4	46	390	8623	9078
PCT	.1	*	.1	.5	4.3	95.0	100.0

September

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	*	*	.2	2.0	19.9	1912
06&09	*	.0	*	.2	1.9	21.8	2045
12&15	*	*	*	.2	2.1	22.7	2164
18&21	*	*	.1	.3	2.3	28.2	2511
TOT	5	7	15	80	711	7816	8632
PCT	.1	.1	.2	.9	8.2	90.5	100.0

October

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	.0	*	.1	1.2	19.6	1949
06&09	.0	*	*	.2	1.9	21.6	1987
12&15	*	*	.1	.2	1.8	22.7	2183
18&21	*	*	.1	.2	1.6	26.2	2449
TOT	8	4	23	60	720	7569	8384
PCT	.1	*	.3	.8	8.7	90.1	100.0

November

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	.0	*	.1	1.1	20.3	1796
06&09	*	*	*	.1	1.1	23.1	1968
12&15	*	.0	*	.2	1.1	23.5	1994
18&21	*	*	*	.1	1.3	28.0	2381
TOT	7	3	11	35	373	7643	8074
PCT	.1	.1	.1	.4	4.6	94.7	100.0

December

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	.0	.0	.1	1.0	20.3	1794
06&09	.0	.0	*	.1	1.1	23.8	1965
12&15	*	.0	.0	.1	1.4	22.1	1876
18&21	*	*	*	.2	1.3	28.0	2292
TOT	7	1	4	30	403	7474	7927
PCT	.1	*	.1	.4	5.1	94.3	100.0

Annual

HOUR (GMT)	<1/2	1/2<1	1<2	2<5	5<10	10+	TOTAL OBS
00&03	*	*	*	.1	1.6	20.3	22344
06&09	*	*	*	.1	1.4	22.9	24462
12&15	*	*	*	.1	1.8	22.3	24076
18&21	*	*	*	.2	1.9	27.1	29351
TOT	99	50	152	661	6422	92849	100233
PCT	.1	*	.1	.6	6.4	92.7	100.0

Percentage Frequency of Wave Height (Feet) vs. Wave Period (Seconds) for Area 4

January

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.4	16.6	24.4	12.0	3.4	.9	.4	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	959	[illegible]
6-7	.1	.9	6.5	9.5	4.6	1.4	.7	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	384	[illegible]
8-9	.0	.3	.8	1.9	1.6	1.7	.6	.6	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	120	[illegible]
10-11	.1	.1	.4	.4	.8	.3	.1	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	40	[illegible]
12-13	.0	.1	.3	.5	.3	.3	.0	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	25	[illegible]
>13	.0	.0	.0	.1	.3	.1	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	12	[illegible]
INDET	1.8	.2	.4	.0	.3	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	54	[illegible]
TOTAL	69	288	521	401	179	77	30	17	11	1	0	0	0	0	0	0	0	0	0	1594	[illegible]
PCT	4.3	18.1	32.7	25.2	11.2	4.8	1.9	1.1	.7	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

February

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.8	15.6	25.2	12.8	3.2	1.1	.5	.4	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	960	3
6-7	.0	.7	4.9	7.2	5.3	4.8	1.1	.7	.2	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	350	5
8-9	.0	.4	.5	1.6	1.8	2.0	1.1	.4	.2	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	124	7
10-11	.0	.1	.3	.5	.7	.3	.5	.1	.4	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	47	8
12-13	.0	.0	.0	.1	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	7	[illegible]
>13	.0	.0	.1	.1	.0	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6	7
INDET	1.8	.3	.4	.1	.2	.1	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	47	2
TOTAL	70	260	475	342	173	100	49	28	14	5	3	1	1	0	0	0	0	0	0	1521	4
PCT	4.6	17.1	31.2	22.5	11.4	6.6	3.2	1.8	.9	.3	.2	.1	.1	.0	.0	.0	.0	.0	.0	100.0	

March

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.5	18.8	25.2	10.6	2.5	1.7	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1085	3
6-7	.0	1.0	5.2	7.4	4.3	2.3	1.1	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	379	5
8-9	.0	.1	1.5	1.8	2.0	1.0	.6	.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	132	6
10-11	.0	.1	.1	.1	.9	.5	.2	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	35	7
12-13	.0	.0	.0	.1	.1	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	7
>13	.0	.1	.1	.1	.1	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10	7
INDET	3.8	1.3	.9	.2	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	114	1
TOTAL	112	373	579	356	175	102	43	11	9	0	0	0	0	0	0	0	0	0	0	1760	3
PCT	6.4	21.2	32.9	20.2	9.9	5.8	2.4	.6	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

April

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	4.7	24.8	24.4	8.5	2.3	.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	994	2
6-7	.1	1.9	4.9	7.6	3.4	1.7	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	305	[illegible]
8-9	.0	.4	.4	1.6	1.3	1.0	.3	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	87	5
10-11	.0	.1	.4	.5	.7	.3	.2	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	41	5
12-13	.0	.1	.3	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8	[illegible]
>13	.0	.1	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	[illegible]
INDET	3.1	.2	.4	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	60	[illegible]
TOTAL	119	414	470	281	137	50	16	5	5	0	1	0	0	0	0	0	0	0	0	1500	3
PCT	7.9	27.6	31.3	18.7	9.1	3.3	1.1	.3	.3	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

May

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	8.1	30.8	24.0	8.4	1.2	.4	.2	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1235	[illegible]
6-7	.2	1.6	6.1	5.1	3.3	.7	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	255	[illegible]
8-9	.1	.3	.5	.8	1.2	.5	.3	.1	.1	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	72	[illegible]
10-11	.0	.2	.0	.2	.1	.1	.2	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	25	[illegible]
12-13	.0	.1	.0	.1	.0	.1	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	5	[illegible]
>13	.0	.2	.1	.1	.0	.1	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11	[illegible]
INDET	3.3	.8	.4	.2	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	79	[illegible]
TOTAL	195	569	496	274	75	32	18	6	5	1	4	0	1	0	0	0	0	0	0	1677	[illegible]
PCT	11.6	33.9	29.6	16.3	4.5	1.9	1.1	.4	.3	.1	.2	.0	.1	.0	.0	.0	.0	.0	.0	100.0	

June

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	7.0	28.1	23.6	7.4	1.7	.6	.2	.0	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	1418	2
6-7	.2	1.7	3.6	5.4	2.5	1.2	.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	350	4
8-9	.0	.3	1.1	.9	.9	.9	.4	.0	*	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	93	5
10-11	.0	*	.2	.3	.3	.1	.1	.0	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	25	6
12-13	.0	.1	.3	.2	.1	.0	.0	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	19	5
>13	.0	*	.1	*	.1	*	*	.0	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	10	6
INDET	5.4	.8	.3	.1	.3	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	145	0
TOTAL	259	640	644	296	122	60	22	5	6	6	0	0	0	0	0	0	0	0	0	2060	3
PCT	12.6	31.1	31.3	14.4	5.9	2.9	1.1	.2	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

July

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	8.5	34.6	21.3	4.6	.9	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1234	2
6-7	.1	1.9	6.5	4.3	2.5	.5	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	281	4
8-9	.0	.6	.9	1.1	.4	.3	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	60	4
10-11	.0	.2	.3	.3	.2	.2	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	23	3
12-13	.0	.1	.0	.1	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	5
>13	.0	.2	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4	3
INDET	7.4	.6	.5	.2	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	155	0
TOTAL	281	670	524	185	71	20	6	3	2	0	0	0	0	0	0	0	0	0	0	1762	2
PCT	15.9	38.0	29.7	10.5	4.0	1.1	.3	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

August

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	9.6	38.2	21.2	3.5	.6	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1418	2
6-7	.2	1.9	5.1	3.1	1.5	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	237	4
8-9	.2	.7	.5	.9	.5	.4	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	63	4
10-11	.0	.1	.3	.3	.3	.2	.1	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	28	6
12-13	.0	.1	.0	.2	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	5	7
>13	.0	.0	.1	.0	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4	7
INDET	7.5	1.3	.4	.3	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	187	0
TOTAL	339	817	536	159	58	18	6	6	2	0	1	0	0	0	0	0	0	0	0	1942	2
PCT	17.5	42.1	27.6	8.2	3.0	.9	.3	.3	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

September

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	5.6	22.1	21.7	5.1	1.4	.2	.1	.0	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	1015	[illegible]
6-7	.2	1.7	5.9	7.7	3.4	1.8	.6	.3	.2	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	395	[illegible]
8-9	.0	.3	1.0	1.6	2.4	1.4	.8	.6	.3	.0	.1	.1	.1	.0	.0	.0	.0	.0	.0	157	[illegible]
10-11	.1	.1	.7	.3	.7	.4	.3	.3	.2	.1	.1	.0	.1	.1	.0	.0	.0	.0	.0	99	[illegible]
12-13	.0	.0	.1	.2	.3	.3	.5	.1	.4	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	35	[illegible]
>13	.0	.1	.2	.1	.1	.3	.2	.1	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	71	[illegible]
INDET	5.1	.6	.3	.4	.1	.0	.1	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	118	[illegible]
TOTAL	196	447	537	275	151	82	46	23	28	3	4	3	4	1	0	0	0	0	0	1800	[illegible]
PCT	10.9	24.8	29.8	15.3	8.4	4.6	2.6	1.3	1.6	.2	.2	.2	.2	.1	.0	.0	.0	.0	.0	100.0	

Percentage Frequency of Wave Height (Feet) vs. Wave Period (Seconds) (Area 4 cont.)

October

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.4	14.7	20.4	9.2	2.4	.5	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	880	3
6-7	.2	.9	5.6	11.2	6.9	2.4	.9	.3	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	484	3
8-9	.0	.3	.9	2.4	2.6	2.5	1.8	.6	.7	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	197	7
10-11	.1	.0	.1	.4	.5	.5	.5	.4	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	48	8
12-13	.0	.0	.1	.3	.1	.0	.2	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	17	9
>13	.0	.0	.0	.1	.0	.1	.1	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	9	10
INDET	2.4	.9	.5	.1	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	76	1
TOTAL	103	296	466	398	212	104	65	23	30	2	1	0	1	0	0	0	0	0	0	1691	4
PCT	6.1	16.9	27.6	23.5	12.5	6.2	3.8	1.4	1.8	.1	.1	.0	.1	.0	.0	.0	.0	.0	.0	100.0	

November

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.8	14.6	22.4	9.0	2.2	.4	.3	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	834	3
6-7	.1	.8	7.6	10.9	6.4	3.0	.9	.5	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	481	3
8-9	.0	.1	.8	1.7	3.0	2.7	.8	.4	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	155	7
10-11	.0	.1	.4	.4	.6	.4	.3	.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	45	7
12-13	.0	.0	.1	.0	.0	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6	8
>13	.0	.0	.1	.1	.0	.1	.1	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	6	9
INDET	2.5	.5	.2	.1	.2	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	60	1
TOTAL	98	254	499	352	198	108	40	26	11	0	1	0	0	0	0	0	0	0	0	1587	4
PCT	6.2	16.0	31.4	22.2	12.5	6.8	2.5	1.6	.7	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

December

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	3.9	16.4	27.4	9.5	2.3	.8	.3	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	881	3
6-7	.0	1.0	4.7	10.0	5.3	1.2	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	393	3
8-9	.0	.6	.9	1.8	3.5	1.2	.6	.3	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	131	6
10-11	.0	.2	.2	.1	.5	.8	.6	.2	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	42	8
12-13	.0	.0	.1	.1	.2	.1	.0	.1	.2	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	12	8
>13	.0	.1	.1	.1	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	8
INDET	1.7	.6	.6	.2	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	49	1
TOTAL	82	273	494	317	174	60	32	11	6	2	2	0	0	0	0	0	0	0	0	1453	4
PCT	5.6	18.8	34.0	21.8	12.0	4.1	2.2	.8	.4	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

Annual

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	5.3	23.4	23.3	8.3	2.0	.6	.2	*	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	12873	2
6-7	.1	1.4	5.6	7.4	3.9	1.6	.5	.2	.1	*	*	*	*	.0	.0	.0	.0	.0	.0	4234	5
8-9	*	.4	.9	1.5	1.7	1.3	.6	.3	.2	*	*	*	*	.0	.0	.0	.0	.0	.0	1391	6
10-11	*	.1	.3	.3	.5	.3	.3	.2	.2	*	*	.0	*	*	.0	.0	.0	.0	.0	653	7
12-13	.0	*	.1	.2	.1	.1	.1	.1	.1	*	*	.0	*	.0	.0	.0	.0	.0	.0	149	7
>13	.0	.1	.1	.1	.1	.1	*	*	.1	*	*	.0	.0	.0	.0	.0	.0	.0	.0	103	7
INDET	4.0	.7	.5	.2	.1	.1	*	*	*	.0	.0	*	.0	.0	.0	.0	.0	.0	.0	1144	1
TOTAL	1923	5291	6241	3636	1726	813	373	165	130	20	27	4	7	1	0	0	0	0	0	20547	3
PCT	9.5	26.0	30.7	17.9	8.5	4.0	1.8	.8	.6	.1	.1	*	*	*	.0	.0	.0	.0	.0	100.0	

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Waves ≥12 ft	1.9	3.4	1.1	.9	1.1	.8	.3	.5	3.8	3.5	2.4	1.4	1.6
Waves ≥20 ft	0	.4	0	.1	.3	0	0	.1	.7	.2	.1	.1	.1
Maximum Seas	17-19	26-32	13-16	20-22	26-32	17-19	13-16	20-22	33-40	26-32	20-22	20-22	33-40

Consolidated Table of Meteorological Elements (Area 5)

	Weather Elements	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
% freq	Visibility < 2 naut. mi.	0.4	0.2	0.2	0.3	0.3	0.4	0.3	0.2	0.4	0.4	0.3	.2
	Precipitation	2.9	2.6	2.0	1.8	2.7	3.7	2.3	2.8	4.4	4.3	2.6	2.5
	Sky overcast or obscured	15.7	13.9	14.7	11.6	11.2	14.2	8.0	8.7	14.5	15.5	10.8	13.8
	Thunder and lightning	0.3	0.6	0.8	1.3	1.9	3.0	3.8	4.4	3.7	2.1	0.8	0.4
	Temperature ≥ 85°F	0.2	0.4	0.8	1.1	4.4	13.4	26.4	30.2	18.8	5.8	1.1	0.5
	Temperature ≤ 32°F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mean temperature (°F)	68.5	68.9	71.8	74.5	78.1	81.1	83.1	83.5	82.3	79.0	74.8	71.1
	Mean relative humidity (%)	74	75	75	74	77	79	78	78	79	76	74	73
	Mean cloud cover (eighths)	4.2	4.1	4.0	3.8	3.7	4.3	3.9	4.1	4.5	4.4	3.9	4.2
millibars	Mean sea-level pressure	1019	1018	1018	1016	1016	1016	1017	1016	1014	1014	1017	1019
	Extreme max. sea-level pressure	1034	1034	1034	1033	1031	1031	1030	1035	1028	1030	1033	1033
	Extreme min. sea-level pressure	999	995	993	1000	998	995	1002	1000	987	975	981	976

AREA 4

PERCENT FREQUENCY OF OCCURRENCE OF SEA TEMP (DEG F) BY MONTH

SEA TMP DEG F	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	PCT
97+	.0	.0	.0	.0	.0	.0	*	.0	.0	.0	.0	.0	1	*
95/96	.0	.0	.0	.0	.0	*	*	.0	*	.0	.0	.0	4	*
93/94	.0	.0	.0	.0	.0	*	*	.0	*	.0	.0	.0	9	*
91/92	.0	.0	.0	.3	*	.1	.1	.2	.1	.1	*	.0	59	.1
89/90	.0	*	.0	*	.1	.2	.6	2.4	.7	.3	*	*	416	.4
87/88	*	*	.1	.1	.1	1.1	5.9	13.0	6.9	1.3	.2	.1	2752	2.5
85/86	.1	.1	.1	.1	1.1	9.0	30.1	43.2	32.8	10.2	1.0	.2	12406	11.2
83/84	.3	.2	.3	.8	6.7	30.7	43.5	30.6	41.3	33.7	7.6	1.0	18959	17.1
81/82	2.0	1.1	1.6	6.0	17.8	30.0	15.7	7.9	13.9	34.4	25.9	4.5	16801	15.1
79/80	10.6	8.9	12.7	25.0	33.6	10.5	3.7	1.9	3.7	14.9	35.4	23.9	17324	15.6
77/78	26.9	23.2	27.4	31.6	17.7	4.7	.3	.3	.4	3.8	20.1	30.6	16780	15.1
75/76	28.5	28.2	26.2	19.1	8.9	1.3	.2	.2	.1	.9	7.7	22.1	12806	11.5
73/74	18.0	19.1	16.5	10.8	3.0	.3	.1	*	.1	.3	2.2	18.5	7205	6.5
71/72	8.7	11.3	8.8	4.3	.7	.1	*	*	.0	.1	.6	3.3	3392	3.1
69/70	3.6	4.9	3.7	1.5	.2	*	*	.0	.0	*	.2	.9	1299	1.2
67/68	.9	1.6	1.1	.5	*	*	*	.0	.0	*	.1	.4	626	.6
65/66	.3	.7	.5	.1	*	.0	*	.0	.0	*	*	.3	174	.2
63/64	.2	.6	.3	.1	.0	.0	.0	.0	.0	.0	*	.1	91	.1
61/62	*	.2	.1	*	.0	.0	.0	.0	.0	.0	.0	*	31	*
59/60	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	*	26	*
57/58	*	*	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	9	*
55/56	*	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	*
53/54	.0	*	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	7	*
51/52	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
49/50	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1	*
47/48	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
45/46	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
43/44	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
41/42	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
39/40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
37/38	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
35/36	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
33/34	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
31/32	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
29/30	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
27/28	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
<27	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0		
TOTAL	8966	8469	9621	8600	9066	10219	9695	9833	9483	9349	8988	8738	111021	100.0
MEAN	75.7	75.1	75.7	77.1	79.5	82.0	84.8	84.9	84.1	82.2	79.6	77.2	79.9	

LAND STATION DATA

NORMALS, MEANS, AND EXTREMES

[illegible]

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Lowest temperature 18 in January 1940; maximum monthly precipitation [illegible] in October 1924; maximum precipitation in 24 hours [illegible] in October 1924.

[illegible]

NORMALS, MEANS, AND EXTREMES

[illegible]

‡ For period February 1966 through the current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Highest temperature 101° in July 1942.

[illegible]

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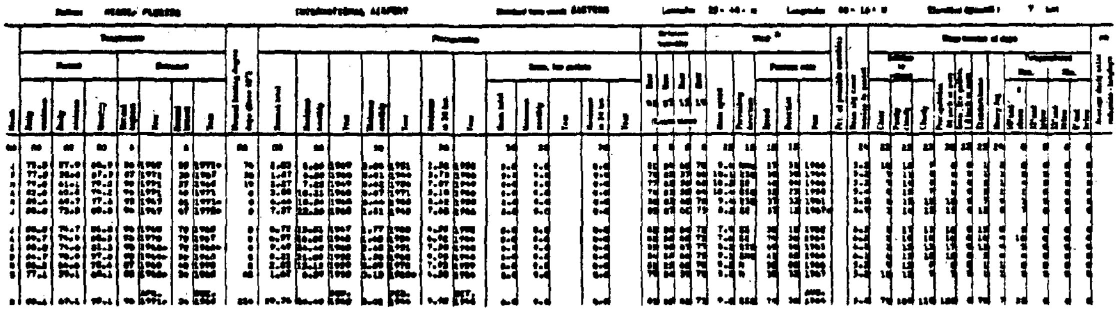
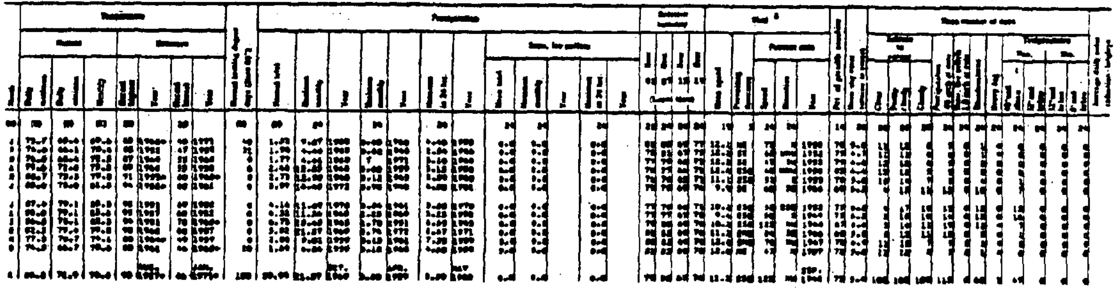
NORMALS, MEANS, AND EXTREMES



Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Airport locations: highest temperature 100 in July 1942; lowest temperature 28 in January 1940; maximum precipitation in 24 hours 12.58 in April 1942. City locations: lowest temperature 27 in February 1917; maximum precipitation in 24 hours 15.10 in November 1925; fastest mile of wind 132 from the East in August 1926.

** The National Weather Service considers the accuracy of solar radiation data questionable; therefore, publication is suspended pending determination of corrected values.

NORMALS, MEANS, AND EXTREMES – BASED ON RECORDS FROM AIRPORT LOCATIONS FOR 1-1-49 TO 6-30-58 AND 7-1-57 TO DATE.



Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 97 in August 1956; lowest temperature 41 in January 1886; maximum monthly precipitation 23.56 in October 1953; maximum precipitation in 24 hours 19.88 in November 1956.

To 8 compass points only.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

LIVING RESOURCES

1. General. Southeastern Florida is a broad, flat extension of the coastal plain which terminates abruptly at the steep continental slope a few miles offshore. The warm coastal waters, a major asset, are confined to a 1- to 6-mile-wide band except northward of Palm Beach where the band widens to about 30 miles just south of Cape Kennedy. Especially noteworthy is the living tropical reef chain extending from Key West to a few miles south of Miami, the only such reefs adjacent to American shores. Patches of tropical reefs and of hardier species of tropical plants and animals are found northward to about Palm Beach, but the organisms inhabiting the broad shelf south to Cape Kennedy are distinctly temperate. These faunal and floral changes reflect, of course, the distribution of minimum water temperatures, which in summer near Cape Kennedy drop very close to the winter minima at Key West and Miami Beach, and which in winter drop considerably below those at Key West and Miami.

Periodically in summer, upwelling of cold water occurs along the northeastern half of the Florida peninsula.[406/] The 10°C water seems to spill over the shelf when the Gulf Stream meanders close inshore and when winds are offshore.[407/] Evidence is accumulating that the cold upwellings effectively bar tropical marine life from occupying waters of the northern half of the coast.[408/] Detailed observations are lacking.

Uplands in this region are low-lying and flat. Vegetation indigenous to the area include that associated with coastal sand dunes, coastal hardwood hammock forests, and palmettos. Coastal wetland areas are common, as are numerous small, low-lying offshore islands.

Several of the Florida Keys contain unique ecosystems. On some (Key Largo and Lignum Vitae Key) tropical hammocks comprising a West Indies flora and fauna can be found. The ecological communities of the hammocks are as rare and as endangered as any other biotic system of the United States.

The highest human population density in Florida is along the southeast coast and particularly in the Palm Beach-to-Miami coastal strip, a corridor of almost continuous urbanization. The population of this area, their technological demands, and their wastes have made demands upon the land that are intolerable to many forms of fish and wildlife. Destruction has been widespread. Along the lower coast and in the Keys, coastal hardwood hammock forest has also been severely depleted. The high-and-dry coastal and near-coastal areas vegetated by these types are regarded by developers a prime building sites. In the Florida Keys, and notably in the upper Keys, clearing of hammock forest still continues at a steady pace as upland sites are prepared for residential development.

Another vegetative habitat in the region that has been severely depleted by development are the scrub forest community dominanted by _Pinus clousa_, the scrub pine. Continuous large tracks of unoccupied land within miles of the coast are scarce and costly.

Revegetation of the altered land surface by native plants is difficult. Over the past 40 to 50 years, lower peninsular Florida has become a stronghold of several aggressive exotic plant species (Brazilian peppers, Australian pine, melakuca). These species prefer disturbed land areas. They rapidly establish on the available area and prevent the re-establishment of native forms. Revegetation of terrestrial sites by indigenous plants, altered along much of the lower peninsular shoreline and outlying barrier islands, is not expected to occur.

Along the State's Atlantic coast, only a few areas have been set aside specifically for conservation purposes. One of these, the Pelican Island National Wildlife Refuge, was set up in 1908 as the first Federal refuge. This was the start of the successful effort to control the plume hunters. The Merritt Island National Wildlife Refuge was purchased as part of the NASA complex at Cape Kennedy, and was turned over the U.S. Bureau of Sport Fisheries and Wildlife for management. There are no State-owned wildlife conservation areas along the Atlantic coast of Florida. There are two State parks that contain extensive areas of marine habitat: Tomoka near Ormand Beach and Jonathan Dickinson near Jupiter.[409/]

2. _Estuarine and coastal wetlands_. Coastal wetlands and open shoal water areas encompass about 433,000 acres. Of this area, about 160,000 acres are in coastal wetlands and about 180,000 acres in important, open-shoal water habitat. Coastal wetlands include about 3,000 acres dominated by freshwater plant species affected by tides, 26,000 acres of salt grass and saltmeadow cordgrass, and about 59,000 acres of salt marsh cordgrass and needle rush. About 80,000 acres are included in mangroves.[410/] Estuarine and adjacent bay waters frequently support abundant stands of Thlassia and other sea grasses.

3. Land mammals. Mammals inhabiting the coastal zone and in large measure dependent on wetland areas include bobcat, deer, gray fox, mink, muskrat, nutria, opposum, river otter. eastern and swamp cottontail rabbits, raccoon, and the striped skunk.

4. Birds. Coastal marshlands and estuaries provide important habitat for many of the wading birds, as well as birds of the sea and shore. Brown pelicans, water turkeys, cormorants, gulls, egrets, and herons are numerous. The many scattered mangrove islands provide the required seclusion for rookeries and resting.

5. Plankton. Comprehensive studies of the plankton of the Continental Shelf are lacking. Only the study of Reeve[411/] at Bear Cut (Miami) provides some indications as to the composition and seasonal dynamics of the zooplankton. Reeve found four major peaks of animal production in the year, with their mid-points approximately in January, April/May, July, and October, the latter period being perhaps the time of greatest abundance. Copepods accounted for a fairly constant 65-85 percent of the total plankton.

In descending order of abundance, the major species were Acartia spinata or A. bermudensis, Paracalanus parvus, Temora turbinata, and Calanopia americana. The chaetognath Sagitta hispida occurred consistently, peaking in abundance from May through August. Fish eggs constituted 21 percent of the total plankton in July but the methods of capture precluded conclusions as to their seasonal abundance in shelf waters. Other groups of importance included barnacle larvae, annelid larvae, decapod larvae, medusae, and larvaceans.

6. Benthic habitats. Because of the multiplicity of nooks and crannies within, under, and around living corals, sponges, and other sessile invertebrates of living coral reefs, the reef chain from Key West to Miami, plus scattered patch reefs northward to Cape Kennedy, support a great abundance and diversity of life. Starck[412/] found 517 different fishes on Alligator Reef alone, a considerable proportion of the total of 1,120 species of fishes in all Florida.[413/] Proceeding northward, the number of species of fishes in benthic habitats diminishes sharply. Courtenay et al[414/] found 299 species in the Pompano Beach to Lauderdale-by-the-Sea area (about 23-30 miles north of Miami), and Miller,[415/] who combined all previous records of bottom-dwelling fishes with his own, reported about 78 species in benthic habitats of the shelf near Cape Kennedy.

Courtenay et al provide detailed descriptions of the shelf habitats and their biota a few miles north of Miami. The reefs, containing coral heads and gorgonids, are the major attractants of fishes, but the flats betwen reefs are also productive.

Quoting the report[416] (p. 12-13), "Fishes are found in abundance in all...areas (of the shelf). The sand flats are characterized by the porgies, goatfish, and rays—fishes which feed to a large extent on the molluscs and burrowing crustaceans in this area. At the edge of the flats, where rubble has fallen from the reef to afford suitable substrate, jawfish and other burrowing fishes are found. Although appearing devoid of life to the daytime observer, the sand flats are both productive and necessary to the adjacent reef inhabitants, many of which forage over this area at night.[417]

"The reef edge has the largest assemblage of fishes. This assemblage is particularly striking if there is sufficient relief to provide cover for the numerous cryptic species. Cardinalfishes, drums, gobies, and sweepers can be observed in the crevices within the ledge, as well as the larger squirrelfish and groupers. This is also the haunt of the moray eel. In close association with the reef edge, and generally in the open, are the colorful angelfish and butterflyfish, damselfish, hamlets, wrasses, and parrotfish. Large schools of grunts can be observed swimming at the edge, and with surgeonfish, parrotfish, and wrasses are the dominant fishes. This is also where the commercially-important snappers are found. Often in transit through the area are the jacks, tunas, mackerels, and billfish—important to the local sport fisheries—and the wide-ranging sharks."

Miller[418] divided benthic habitats in the Cape Kennedy area into two zones: coastal to 60 feet and open shelf to about 180 feet. The primary habitat and bottom type in the coastal zone is sandy mud, supporting primarily a sciaenid fish fauna (drums, croakers, seatrouts, weakfish, and southern kingfish). The open shelf zone he divided into three habitats: live shell-rubble, dead shell-rubble, and reef.

Live shell-rubble habitat off the Cape Kennedy area is inhabited by the calico scallop. The animals spawn in late February or early Mary until June. The young settle in live shell-rubble but later move out to form new beds adjacent to the old ones. Their maximum life-span is two years.[419]

The dead shell-rubble habitat is formed when an incoming group of scallops dies from various causes or when the young move away from a bed and no recruitment of new individuals occurs. This habitat supports few fish because the rapidly-disintegrating scallop shells are not elevated sufficiently off the bottom to support organisms requiring a hard substrate.

The reef habitat covers large areas of the bottom. Reefs are formed when corals, sponges, or other encrusting marine organisms attach and grow on hard substrates. They constitute an important habitat for recreational and commercial fisheries.

7. *Commercial fisheries*. The annual State publication of landings statistics produced in cooperation with NMFS is the basic source of information.[420/] In 1971, the counties bordering the area of concern landed 31,289,149 pounds worth $9,241,536. Although nearly all commercial species visit shelf areas during some phase of their life histories—commonly for spawning—some species are actually fished offshore whereas others are caught primarily in lagoons and estuaries. The landings of those caught on the shelf in the area of concern totaled 12,821,375 pounds in 1971 worth $5,689,828. Heald[421/] compiled an atlas picturing the areas of coast where important commercial species are landed. In the order of decreasing value, the species that are caught on the shelf are the spiny lobster (*Panulirus argus*), king mackerel (*Scomberomorus cavalla*), shrimp (*Penaeus setiferus* and *P. aztecus*), calico scallop (*Pecten gibbus*), red snapper (*Lutjanus aya*), Spanish mackerel (*Scomberomorus maculatus*), bluefish (*Pomatomus saltatrix*), groupers (*Epinephelus spp*. and *Mycteroperca spp*.), yellowtail snapper (*Ocyurus chrysurus*), southern kingfish (*Menticirrhus americanus*), and fluke or summer founder (*Paralichthys dentatus*). These species and others that are important in sport fisheries are listed in Tables 23, 24, and 25.

8. *Sport fisheries*. As mentioned above, the offshore reefs are important habitat for species caught by sport fishermen. The estimated total weight of fish caught by sport fishermen from Cape Hatteras to Key West in 1970 was 403,913,000 pounds,[422/] of which the southeastern Florida catch was perhaps 192,000,000 pounds. The weight of the catch clearly exceeded greatly that of the commercial catch, and its value was probably many times that of the commercial catch because of the money spent by sport fishermen in pursuit of their sport.

9. *Migrations and spawning*. The shelf is an important avenue for migrations and is the major site for spawning of the important fishes and invertebrates.

Spawning of the spiny lobster takes place in south Florida coastal waters primarily in spring and summer, but recruitment from Caribbean waters probably also occurs because most larval and postlarval stages have been found in the Yucatan Strait and the western Straits of Florida year-round.[423]

Vast schools of Spanish and king mackerel are found offshore of the Palm Beach area in winter and spring. These fish apparently move northward along the coast to spawn off Cape Kennedy and northward in late summer. The schools reappear offshore of St. Lucie County, about 40 miles north of Palm Beach in the late fall, evidently waiting to join the winter assemblage farther south. Because some individuals of both species are caught year-round in south Florida, many do not migrate with the major populations.[424]

White shrimp (<u>Penaeus setiferus</u>) migrate from inshore to offshore waters, moving southward in the fall and early winter and northward in late winter and early spring.[425] Spawning is offshore mainly from late March or early April to the end of September.

October to November is the spawning time of calico scallops.[426]

Red snapper movements seem to be related to food supply, but little known of their migrations and spawnings.[427]

The winter-visiting bluefish move northward from south Florida in spring and summer, probably to spawn in waters north of Florida in early summer.[428]

Small groupers are essentially non-migratory, remaining on 10- to 60-foot-deep reefs for extended periods. Large groupers, however, apparently undertake considerable offshore migrations to reefs more than 120 feet deep coincident with first maturity. Large groupers in depths of 90 to 300 feet may also undergo extensive seasonal migrations.[429]

The yellowtail snapper seems to be a semi-pelagic wanderer over reef habitats, but little is known of its biology and behavior.[430]

The sciaenids (drums, croakers, seatrouts, weakfish, and southern kingfish) are predominantly inshore fishes which do not move far parallel with the shore. Most species do, however, undertake strong offshore deepwater spawning migrations.[431]

The mullets, important commercial and forage fish, perform an annual fall spawning migration to offshore waters. Striped mullet (<u>Mugil cephalus</u>), spawn from October to February from lower Florida to North Carolina from about the 20-fathom line into the Gulf Stream. Peak spawning occurs in December.[432]

The commonest reef fishes—grunts and parrotfishes—are essentially residential, some species remaining on or near the same reef for years. Whereas some species of grunts make nocturnal feeding migrations of up to a mile, other species remain on the reef night and day. Parrotfishes move over rather broad areas to feed by day, traveling in small schools; they are quiescent at night. Neither grunts nor parrotfishes move far to spawn.[433/]

Much additional information is available, although site-specific details are usually non-existent. Special studies on migrations and spawning of marine life at a particular site seem to be amply justified.

10. Threatened species. Threatened species include the Florida great white heron, eastern brown pelican, Florida Everglades kite, American peregrine falcon, Arctic peregrine falcon, southern bald eagle, Cape Sable sparrow, Florida manatee (sea cow), Caribbean monk seal, green turtle, bog turtle, Key deer, Key Largo woodrat, Key Largo deer mouse, American crocodile and alligator, sperm whale, blue whale, finback whale, sei whale, humpback whale, right whale, and barehead whale. Marginally endangered species include the roseate spoonbill, and the eastern reddish egret.

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APPENDIX D. ENVIRONMENTAL EFFECTS OF ALTERNATIVES TO THE FNP

The direct environmental effects of a powerplant depend mainly on how the energy is generated and on where the plant is located. The primary methods of generation are hydroelectric, fossil, and nuclear. Present fossil and nuclear plant sitings are mainly inland and on the shores of seas, lakes, and rivers. Alternatives to the FNP include inland and shore locations of fossil and nuclear plants as well as other sites-- underground, seabed, and artificial and natural island.

Great research efforts are being devoted to electric power generation, both to improving operating efficiency and to finding new sources of power with less impact on the natural environment. One emerging method that may be important is the high temperature gas cooled nuclear reactor (HTGR). Another system in advanced development is the fast breeder reactor; it is not expected to be ready for commericial operation much before the end of the century. The alternatives discussed here are based on the light water reactor and fossil plants. Geothermal energy sources, which are generally located inland, are not included.

Environmental Effects of Fossil and Nuclear Powerplants

The environmental effects of fossil plants differ significantly from those of nuclear plants in the amount and in the nature of the pollutants discharged. The differences arise from the energy sources. The environmental challenges are most evident at the plants, but processing, transport, and use must all be considered. Coal, oil, gas, and nuclear powerplants are compared in Tables D-1 through D-3.

The Coal Electric System

Surface mining disturbs large amounts of land and often leads to acid mine drainage and silt runoff, both of which pollute water. It is commonly believed that environmental damage results from surface mining, but underground mining also results in acid drainage and may cause land subsidence over mined-out areas. Underground coal mining is dangerous, leading to facilities, injuries, and disease. Without reclamation the ecological and aesthetic damage from surface mining is severe.

Table D-1. Potential Environmental Effects of Fossil and Nuclear Fuel Production and Utilization for Electricity

		COAL	OIL	GAS	NUCLEAR
Extraction	Water	Acid mine drainage. Leaching of waste piles. Erosion and silting of streams	Disposal of brine	----------	Leaching of waste banks. Uranium mine water
	Air	Mine fires Waste pile fires	----------	----------	----------
	Land	Strip mining damage	----------	----------	Strip mining damage
	Solid Waste	Waste from underground mining	----------	----------	Waste from underground mining
	Radiation	----------	----------	----------	Exposure of miners
Processing	Water	Preparation plant effluent streams. Leaching of waste piles	Thermal pollution Sulphuic acid. Spent caustic	----------	Leaching of waste banks
	Air	Particulates from fine coal drying. Nitrogen oxides. Waste bank fires	Sulfur oxides. Hydrocarbons. Nitrogen oxides	----------	Particulate emission and waste banks
	Land	----------	----------	----------	
	Solid Waste	Waste from coal cleaning	Spent phosphoric acid catalyst. Spent clay	----------	Wastes from ore processing
	Radiation	----------	----------	----------	Exposure of plant workers

Table D-1. (continued)

		COAL	OIL	GAS	NUCLEAR
Transport	Water	-----------	Tanker accidents	-----------	-----------
	Air	-----------	-----------	Nitrogen oxides at compressor stations	-----------
	Land	-----------	Alaska pipeline	-----------	-----------
	Solid Waste	-----------	-----------	-----------	-----------
	Radiation	-----------	-----------	-----------	Possibility of accidents
Conversion	Water	Thermal pollution	Thermal pollution	Thermal pollution	Thermal pollution
	Air	Sulfur oxides Nitrogen oxides	Sulfur oxides Nitrogen oxides	Nitrogen oxides	-----------
	Land	-----------	-----------	-----------	-----------
	Solid Waste	Disposal of fly ash and slag	-----------	-----------	Waste disposal from fuel processing plant:
	Radiation	Some radiation emitted from stacks	Some radiation emitted from stacks	-----------	During generation and disposal of waste

e: Adapted from H. Perry and H. Barkson, "Must Fossil Fuels Pollute," Technology Review, December 1971, pp. 34-43.

able D-3. Annual Discharges from Typical 1,000-MWe Fossil and Nuclear Powerplants with a 0.75 Load Factor and with Environmental Controls

	Coal[1,2]	Oil[1,3]	Gas[1]	Nuclear[5]
Fuel consumption	2.5 x 10^6 tons	9.39 x 10^6 bbl.	56.8 x 10^9 cf.	1.14 tons of U-235
Emissions to air tons curies	 [4]45,200 2.0 (radium and thorium)	 38,360 .0005 (radium and thorium)	 12,870 0.0	 0.0 [6]1,400 (mostly xenon and krypton)
Water discharges tons curies	 55 0.0	 55 0.0	 55 0.0	 55 332 (mostly tritium)
Solid waste produced tons curies	 1.94 x 10^6 0.0	 0.0 0.0	 0.0 0.0	 58 tons uranium 31,500
Heat rejected (MWt) to stack to condenser total	 271 1,360 1,631	 271 1,360 1,631	 271 1,360 1,631	 0 2,100 2,226
Water consumed, cf/sec if heated 10° F. if evaporated	 2,000 26	 2,000 26	 2,000 26	 3,300 42

. Plant efficiency is assumed at .38.

. Ash content assumed at .10, sulfur content at .026.

. Assumes wet limestone scrubber system for SO_x and particulate control. Removal efficiencies used are .85 for SO_x and .99 for particulates.

. Based on use of .006 sulfur residual fuel.

. Plant efficiency is assumed at .31.

. This is a reduction of .99 over uncontrolled case. It is estimated to cost $4 million.

ources: Council on Environmental Quality, 1973, Energy and the Environment, Electric Power; W. W. Lowe, "Creating Power Plants: The Costs of Controlling Energy," Technology Review, January 1972, p.24.

Table D-2. Annual Environmental Effects of Fuel Extraction, Processing, Transport, and Conversion of 1,000-MWe Powerplants with a 0.75 Load Factor and with Environmental Controls

	Coal		Oil[1]	Gas	Nuclear
Land[2]	Deep	Surface			
acres	29,637	21,451	20,752	20,859	18,314
Emissions to air					
tons	71,504	71,504	43,079	24,057	6,192
curies	n.a.	n.a.	n.a.	0	3.50×10^5
Water discharges[3]					
tons	282	3,084	3,664	55	20,498
curies	0	0	0	0	2,682
BTU's	0	0	0	0	0
Solid or stored waste					
tons	1.558×10^6	4.219×10^6	213	0	2.62×10^6
curies	n.a.	n.a.	0	0	1.4×10^8

n.a. = Not available.

1. Onshore wells are assumed. Offshore sources required somewhat less land but result in more discharges to the water.

2. Includes land used for fuel extraction, processing, transport, conversion and transmission right-of-way.

3. Use of wet natural draft cooling towers is assumed because they create no thermal pollution.

Source: Council on Environmental Quality, 1973, Energy and the Environment: Electric Power, Tables A-3, A-6, A-9, and A-12.

For better pollution control, the coal is cleaned to reduce the inorganic sulfur and ash content. Processing waste water often pollutes streams with suspended solids. The solid wastes are piled onto waste banks. Most coal is shipped to powerplants by rail for which rights-of-way use considerable amounts of land.

Electricity is produced by burning the coal. A coal-fired plant emits large quantitites of sulfur oxides, nitorgen oxides, carbon monoxide, and particulates. During the past few years when powerplants had few emission controls, fossil-fueled plants (including oil and gas) are estimated to have contributed 12.5 percent of emissions from all conventional air-pollution sources, including most of the SO_x.[1/]

SO_2 can injure human and animal health, and vegetation and damage painted surfaces, metals, building materials, and fibers. Most of the sulfur in sulfurous smog (a mixture of sulfur dioxide, sulfur trioxide, sulfuric acid, aerosols, and organic sulfur compounds) comes from coal and oil.[2/] The severe responses of human beings from exposure to sulfurous smog is well summarized by Williamson:[3/]

> SO_2 interacts synergistically with aerosols in affecting the lower respiratory system. The details of how sulfur dioxide or sulfuric acid affect the pulmonary membranes are not known, but epidemologic studies indicate that prolonged exposure to sulfurous smog may cause chronic bronchitis. There is strong statistical evidence that it increases the incidence of acute lower respiratory disease, at least among children, and there is suggestive evidence that it may cause other chronic lung diseases and increase mortality from respiratory and heart disease.

The amount of SO_2 emitted by a coal-fired plant depends first on the sulfur content of the coal, which ranges from 0.2 to 7 percent for U.S. sources,[4/] and on the emission controls. The most prevalent device is the wet scrubbing limestone process, which can remove over 80 percent of the SO_2 particulate matter from the stack gases.[5/]

Large quantities of NO_x are also emitted by fossil-fueled plants. They form in the hot combustion air. Once in the atmosphere and under the influence of sunlight, NO_x form photochemical smog and ozone,[6] both highly irritating to the eyes and damaging to vegetation. In fog, NO_x may combine with water to form nitric acid, which can corrode plants and materials and irritate the lungs.[7] Nitrogen oxide controls are not as advanced as those for sulfur oxide.

Coal, and to a lesser extent residual fuel oil, contain incombustible materials that are converted to slag, dry bottom ash, or fly ash. Particulates emitted during coal combustion consist primarily of carbon, silica, alumina, calcium, and iron oxide. The two main variables affecting fly ash formation and emission are ash content of the fuel and the manner of firing.

Coal used in powerplants normally contains from 5 to 20 percent ash, averaging about 10 to 11 percent for the Nation.[8] Combustion air carries some of the ash out of the furnace in the form of fly ash. Most fly ash can be collected in mechanical and electrostatic percipitators which today are about 99 percent efficient.

Fossil plants contribute CO to the atmosphere. The increase of this substance may be a long-range problem due to modification of the heat balance of the atmosphere, resulting in possible changes in global climate.[9]

Other problems which may arise in fossil plants under certain conditions involve the fog or spray produced by moisture from large evaporative cooling systems. In local areas the fog may reduce visibility and may cause icing problems in cold weather. The interaction of merging cooling tower plumes may encourage development of photochemical smog.

Studies done during the 1960's concluded that the stacks of coal- and oil-fired plants release small amounts of radioactivity. Other studies considered of their health significance and compared them with the routine releases of nuclear plants. A 1972 National Academy of Engineering report summarizes the conclusions of these studies as follows:

> Trace quantities of uranium and thorium and their products of radioactive decay are released in fly ash from large, fossil-fuel steam electric stations, raising the question of the significance of these releases compared with those from nuclear power plants. A study to evaluate the radioactivity discharge from fossil-fuel plants compared to nuclear plants was conducted in 1967-1968 by the Eastern Environmental Radiation Laboratory of the Environmental Protection Agency (formerly the Bureau of Radiological Health's Southeastern Radiological Health Laboratory). This study showed that the radioactive material discharged to the environment from a fossil-fuel plant is not a form that is readily transferable to man. However, the radioactive material discharged from a nuclear power plant is in a form that can result in an external exposure and is transferable to man via the food chain. Comparisons were also made between coal-fired and nuclear power plants of current design to show the effects modern technology has on the relative radiological significance of each. The long-range effects of power plant fuel use are considered relative to the buildup of Kr in the atmosphere and the release of carbon (except C) from fossil-fuel plants. It was concluded that nuclear power reactors over the long term represent a greater overall radiological burden on the environment than fossil-fuel plants, although all are well below radiation protection guides established by the Federal Radiation Council.[9]

This conclusion - that radioactive emissions from fossil plants create less environmental damage than those from nuclear plants - contrasts with the statement that "when the physical and biological properties of the various radionuclides are taken into consideration, the conventional fossil-fueled plants discharge relatively greater quantities of radioactive materials into the atmosphere than nuclear-powered plants of comparable size."[10]

The Residual Fuel Oil Electric System[11]

Petroleum is consumed in the form of a variety of liquid and solid products. Residual fuel oil, as the name imples, is a residual refinery product that normally competes directly with natural gas and coal for heavy-fuel uses, such as the generation of steam at electric powerplants. Almost 80 percent of the residual fuel oil burned in powerplants is imported[12]

Because residual fuel oil is generally quite viscous and cannot be economically moved by pipeline over long distances, its competitive position is best in areas with cheap water transport facilities or with adjacent petroleum refineries. Some low-sulfur residual oil, however, is less viscous and can be moved economically by pipeline over greater distances.

Petroleum extraction involves drilling through overburden to the oil-bearing strata and removing the oil. Environmental effects depend on the location. Onshore production requires land for oil rigs and related equipment. There is a problem of oil spillage and the large quantities of brine pumped up with the oil. Offshore production may result in oil pollution from spills and blowouts.

Up to 85 percent of the total water discharges of the oil system occurs at the refineries,[13] mostly in the form of chemical oxygen demand and dissolved solids. Only about 7 percent of the total air pollution occurs at the refinery. Essentially all the production of soild waste by the oil system takes place at the refineries. The air emissions are primarily sulfur and nitrogen oxides, so that the environmental effects are of the same nature as those of the coal-fired plants.

The residual fuel oil system is generally less damaging to the environment than the coal system. It causes much less air pollution than coal (see

Table D-2), causes about the same amount of water pollution as the surface-mined coal system, and creates only a small amount of solid wastes. If once-through cooling systems are used, coal, oil, and gas create the same amount of thermal pollution.

The Gas Electric System

Natural gas extraction is in many ways similar to oil production. Indeed, both are often taken from the same well. Gas extraction requires some land for drilling rigs and associated equipment, and it produces considerable amounts of brine, posing a disposal problem. Pipelines, having extensive rights-of-way, then transport the gas to processing facilities where impurities are removed. In the process, some air pollution may result.

After processing, the gas is piped to the powerplant. Its combustion causes minor amounts of air pollution from carbon and nitrogen oxides.

Natural gas is by far the least environmentally damaging of the fossil fuels. There is essentially no water pollution other than thermal discharges, and total air pollution is about one-third of the coal system. There are almost no solid wastes.

The Nuclear Electric System

Because fuel cycle for light water nuclear power systems is more complex than that for other electric generation systems, it is discussed in somewhat more detail. Present light water reactors use a uranium-based fuel. Uranium ore is extracted from both surface and underground mines. Thorium, which is used in conjunction with uranium as a fuel for gas-cooled reactors, is similarly mined. A series of physical and chemical processes called milling separates the uranium from the excess rock and other material in the ore and usually concentrates the uranium as the compound U_3O_8. Because of the high potential energy content of nuclear fuels, relatively little land is affected in supplying the annual needs of a 1,000-megawatt powerplant, and few occupational injuries result. Milling releases some radiation to the air and leads to a very small amount of radioactive liquid and solid wastes.

The U_3O_8 is chemically converted to another uranium compound, UF_6, which can be easily gasified. In nature, uranium is primarily composed of the fertile isotope, U-238 (99.3 percent), and the fissile isotope, U-235 (0.7 percent). The UF_6 is transported to a gaseous diffusion plant where the uranium is enriched to a higher concentration (between 2 and 3 percent for light water reactors) of its fissionable, or fissile, isotope, U-235. Very little radioactivity is released in the enrichment process.

The UF_6 is then shipped to a fuel fabrication plant where it is converted to uranium dioxide, UO_2, and formed into metal-clad fuel elements which are then shipped to the nuclear powerplant as original or replacement fuel.

At the light water reactor powerplant, fission energy released in the form of heat is transferred to a conventional steam cycle which generates electricity. Because of collant temperature limitations in LWRs, their thermal efficiency is lower than modern fossil-fueled plants. This lower efficiency, as well as the absence of hot gaseous combustion products released through a stack, mean that a LWR powerplant discharges over 60 percent more heat to receiving waters than its fossil fuel counterpart. Very small quantities of radionuclides are also routinely released to the water and to the atmosphere. Because most components of nuclear system require relatively little land, the transmission line rights-of-way are the primary users of land for the system.

Spent fuel - fuel that has been used in the reactor to generate power - contains highly radioactive fission products and is stored at the reactor for several months while the radioactivity dies down. It is then transported to a reprocessing plant where the fuel is chemically treated to recover the remaining uranium and some plutonium that is produced during the fission process. Other fission products are also removed and concentrated.

In the entire fuel cycle, radioactive emissions to air, measured in units of curies, are greatest from the reprocessing plant.

The concentrated fission products cannot be discharged to the environment but must be monitored and stored indefinitely because of their biological hazards and long half-lives. AEC regulations require the liquid wastes must be converted into solids within 5 years, and shipment to a Federal repository must take place within 10 years. The plutonium separated from the spent fuel may eventually be used to power either LWRs or advanced reactors now under development. Because of its extreme toxicity and long half-life, the plutonium must be carefully handled and stored, and constantly monitored. Similarly, plutonium-containing scrap requires careful handling and permanent storage.

About 88 percent of the radioactivity discharged to water and better than 99 percent of the radioactive air emissions and solid radwaste from the nuclear system takes place during fuel processing, the rest essentially takes place during generation.[14/] . As seen in Table D-3 the largest amount of radioactivity is in solid form, which is not released to the environment. Gaseous emissions, which are the next important form of release, are mainly krypton-85 and xenon-133,[15/] but only the former is important because its 10.7-year half-life[16/] means that it can accumulate in the general atmosphere. However, the average population dose from this radioactive gas should not exceed 1 to 2 mrems per year by the year 2000, so that there is adequate time to develop practical means to remove it from waste gas streams.[17/] Essentially all the radioactive releases to water are tritium, which because of its 12-year half-life can also accumulate in the environment, but the average population dose by the year 2000 is expected to be much less than 1 mrem per year.[18]

In addition to release of low levels of radioactivity at several steps within the fuel cycle, radioactive releases, although highly unlikely, could theoretically occur from accidents in powerplant operations or during transport of radioactive materials.

The nuclear system is unique in producing radioactive and extremely long-lived solid wastes. In particular, the wastes from fuel reprocessing must be stored and monitored indefinitely. In addition, thermal discharges to surrounding waters are considerably higher for a nuclear plant than for a fossil fuel equivalent. Finally, the potential accident from nuclear powerplants and processing facilities ranges from the very small, intermittent release of radioactive materials to major reactor malfunction. Should the most serious reactor failure occur (which is exceedingly improbable and which nuclear plants are designed both to avoid and to contain), the potential for large-scale damage to human health and the environment is vastly greater than for fossil fuel systems.

Description of the Main Environmental Challenges of Alternative Sitings of Fossil and Nuclear Plants

All nuclear siting concepts which will be described are based on a single-unit LWR plant of 1,000-MWe similar to that being considered for the FNP. The main parts of the plant are the reactor containment turbine-generator building, the fuel storage building, auxiliary building, and the switchyard.

The systems for handling cooling water depend on whether the plant uses once-through cooling, cooling reservoirs, spray ponds, or cooling towers.

The main differences between a fossil powerplant and a nuclear plant is that a boiler replaces the reactor. The safety systems of fossil plants are much less extensive than the nuclear plants. Although fossil plants do not require radioactive waste and radiation protection systems, they have ash and flue gas cleanup systems. The quantities of fuel consumed by fossil plants (see Table D-3) necessitate large storage areas and extensive fuel handling equipment. The amounts of land for the two types of plants are given in Table D-4. A coal plant requires about six times the area of a gas plant; an inland nuclear plant may occupy a larger area than either a gas or oil plant because of the exclusion zone required.

Aboveground Concepts

In this category are both shore (seaside, lakeside, and riverside) and inland nuclear and fossil plants. The main difference between the shore and inland plants is that the former use once-through cooling systems and the latter recirculate cooling water. A few Europena plants are underground, but in the United States all are aboveground.

Shore Nuclear and Fossil Plants. Plants are sited near water in order to use it for cooling. Once-through cooling is usually cheaper and more efficient than other systems. After passing through the plant condenser(s), the cooling water is returned to the natural water body, and the heat is dissipated by evaporation, radiation, and conduction. The cooling water is pumped and discharged through underground ducts.

Many environmental challenges of plant construction and operation are similar for both nuclear and fossil, although their magnitudes may differ. Construction requires a labor force of about 1,500,[19/] which, together with materials and equipment, will affect the environment in a number of ways. Construction activity imposes an additional load on highway traffic by

Table D-4. Typical Land Requirements of 1,000-MWe Fossil and Nuclear Powerplants Using Cooling Towers[1]

Source	Acres
Coal	941[2]
Oil	260[3]
Gas	160[4]
Nuclear	314[5]

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[1] Cooling towers are estimated to require 10 acres, except for nuclear plants, which may require 14 acres.

[2] Includes 13 acres for coal storage and 15 acres for ash and limestone solid waste.

[3] Includes storage.

[4] Includes backup oil storage

[5] Includes exclusion area.

Source: Council on Environmental Quality, 1973, Energy and the Environment: Electric Power. Washington, D.C.

increasing the number of vehicles interfering with normal flow. Because the added flow will subside considerably at the end of construction, this disturbance is largely temporary. New access roads may be required, resulting in permanent change. Construction noise, tree clearing, and excavation will displace local fauna and disturb habitats. Unless the plant site is very secluded, construction will be visible from nearby highways for a number of years. Noise also may have an adverse effect on nearby communities, recreation areas, and highways.

All plants that take cooling water from a nearby body of water tend to pull in aquatic or marine life. Depending upon their size and swimming ability, some fish will be trapped in the intake structure. Smaller fish, larvae, and other organisms will be destroyed as they pass through the screens and condenser. Another mechanical effect of the cooling water system is the turbulence of the jet discharges, which may cause disorientation in organisms and affect predator-prey relationships. The water discharge may also cause upwelling of the seabottom and increased turbidity, thus reducing light availability and photosynthetic activity. Turbidity may also increase as a result of periodic condenser cleaning. The temperature of the cooling water may rise from 10 to 20° F. as it passes through the condenser. The warmer surrounding waters may then kill some species of fish, block spawning migrations, introduce new species of fish, and proliferate certain species and algal growth. Increased effects may also be expected from the rapid temperature changes upon plant shutdown.

<u>Shore nuclear plants</u>. A coastal nuclear powerplant may require about 150 acres of land when the water provides a part of the exclusion area and 200 acres if located farther inland.[20/]

The environmental effects of effluents from a shore plant, quite similar to those from an FNP, are detailed later. Besides the thermal effects described above, the nuclear plant onshore or offshore discharges small amounts of radioactive gaseous and liquid substances. The small amount of radioactivity released to the cooling water during normal operation has not yet been found to damage biological systems. The same is true of gaseous emissions.[21/]

Besides possible internal and external accidents, the aboveground shore concept must be capable of withstanding adverse conditions such as high winds and waves, tsunamis, storm and floods, and landslides and earthquakes.

Shore fossil plants. The coal plant occupies a larger area than the nuclear plant similarly situated and the oil plant about the same as the nuclear plant.

Fuel may be shipped to a fossil plant by rail or water. Disposal of solid waste is usually by rail, requiring rail and possibly docking facilities at the facility. Docking facilities are most likely for an oil-fired plant because much of the residual oil is imported.

In view of the large number of fuel and solid waste handling and storing facilities required by fossil plants, their construction and physical plant have a greater effect on the environment than nuclear plants. If docking facilities are required, the dredging and excavation would also disturb the shore ecology.

As discussed earlier, the largest effect of coal and oil plants is the air pollution caused by stack emissions. Thermal water pollution from a fossil plant is somewhat lower than from a nuclear plant. Fossil plants discharge hot gases to the atmosphere, which may cause weather changes.

Environmentally dangerous accidents in oil plants are mainly the oil spills. Such an accident at a shore plant may damage marine life and the birds using the land/sea habitat. Although the consequences of a nuclear accident may be much greater than those of a fossil plant, the frequency of occurrence of nuclear accidents is expected to be substantially lower than that of fossil plants.

Inland Nuclear and Fossil Plants. With siting inland a closed-cycle cooling system is often required. It is assumed for inland power plants in this section. Large evaporative cooling reservoirs, spray ponds, and wet or dry cooling towers using mechanical or natural draft systems are the closed-cycle cooling systems considered feasible. This concept requires a supply of fresh water. Water requirements are estimated in Table D-3. When hyperbolic natural draft wet cooling towers are used, they dominate the plant. They can be as high as 430 feet and have a base diameter of 325 feet and a top diameter of 200 feet.[22/]

Construction of an inland plant creates essentially the same environmental disturbances as a shore plant, although land use conflicts may be less serious inland than at the shores. The creation of large reservoirs may displace some animal life, but they may become the habitat of aquatic life.

Underground Nuclear Plant

Siting nuclear plants underground has been proposed as a safety measure which might make it more acceptable to locate nuclear units near urban areas. Because of cooling water requirements, such a plant would still have to be connected to surface systems. Since the consequences of a major accident at a fossil fuel plant are much less severe, the impetus for underground locations for these plants is much less.

Two underground designs have been proposed, both based on existing LWR designs but differing on location of components. One locates the plant in hilly terrain in six large caverns connected by tunnels, all at above the same level.[23] The second locates the reactor(s) and fuel storage areas as deep as 450 feet and the turbine-generator structure just below ground level[24]. The two structures would be connected by five large shafts for ventilation, personnel access, steam and feed water, and equipment replacement. Shore locations require water intake and discharge pipes, and inland locations require surface ponds or cooling towers. In both cases the visual impact of the facility is considerably lower than the aboveground concept.

The large amount of excavated material (some 1,400,000 cubic yards for a 1,000-MWe plant [25]) creates considerable disposal problems. Traffic, construction activity, and noise are also considerable.

Operations would have the same impacts as aboveground plants because discharges are the same. The facility could blend much better with the surroundings than one that is aboveground.

Existing reactor containment designs are considered safe under any credible accident so that no worthwhile improvement could be achieved by placing the plant underground [26]. In addition, it is felt that radioactive gases could still escape through the support tunnels.

Offshore Concepts

Several offshore alternatives to the FNP have been proposed: floating fossil plants, fossil or nuclear plants on artificial and natural islands, and nuclear plants on the seabed.

Offshore sites make available large amounts of cooling water relatively near major load centers. Thermal effects on shorelines and estuaries may be reduced and land use and aesthetics improved. The floating powerplant may be less affected by certain types of earthquake stresses than those which are rigidly fixed to foundations.

Floating Fossil Plants. A modification of the FNP concept is that of floating a fossil plant (FFP) within a protective breakwater.

The fuel and soil waste handling and storage facilities would need a larger barge for a fossil plant than an FNP. Because collision of a vessel with a floating fossil plant would probably have less adverse consequences than a collision with a nuclear plant, a less massive (though larger) breakwater would likely be required for the fossil concept. Required landside facilities would be approximately the same kind and size. Transports of coal may necessitate transshipment from rail cars onto barges at the shore and then from the barges into the plant. Oil may possibly be supplied directly from ocean tankers so that less extensive landside docks may be required. This concept is probably not economically feasible due to the large amount of storage area required for fuel and solid wastes.

Construction of the breakwater and landside facilities for the FFP and FNP would create the same kinds of disturbances. They would be greater for the fossil plant due to the larger shore facilities that would probably be required.

Operation of a FFP would create the same kind of environmental disturbances as a shoreside fossil plant. An offshore location may have an air pollution advantage when prevailing winds are in the direction of the ocean. But under certain conditions atmospheric mixing tends to be less efficient over water, and air pollution concentrations may be higher at a given distance from an offshore plant than from a land-based plant. This would be of concern where the wind patterns blow toward land.

Oil spills from FFP are a serious threat to larval forms of marine life, waterfowl, and marine mammals.

Accidental dumping of fuel from a coal-fired FFP is not so serious a threat as that from an oil-fired plant because coal would rapidly sink, thus localizing any effects.

Nuclear and Fossil Plants on Artificial Islands. A powerplant could also be located on an artificial island. Two designs have been suggested, an island made of fill materials and one similar to platforms used for drilling operations.[27/] A platform large enough for a powerplant is expected to be much costlier than the island, which would be feasible in waters no deeper than about 100 feet. The plant would be connected to a land-based switchyard by underground cables. Shore facilities are similar to those of the FNP.

Because constructing an artificial island is similar to constructing a breakwater, similar shore facilities will be required. The amount of fill material is considerably larger for an artificial island than for a breakwater. One major cost disadvantage of the artificial island concept contrasted to the floating concept is that the powerplant cannot be assembled at a remote facility. After completion of the artificial island, erection of the plant would be like on land. A fossil facility would require greater area due to fuel handling and storage.

Environmental effects of an artificial island are expected to be similar to those of a floating plant, except that construction effects may be greater due to the larger quantity of materials required.

The possibility of accidents from adverse meterological conditions is reduced by placing the plant on a solid stable mass. This plant is susceptible to ship collision, however.

Nuclear and Fossil Plants on Natural Islands. A suitably located natural island would have some of the advantages of a floating plant without the costly construction of a breakwater or artificial island and associated detrimental environmental effects. The most suitable islands are uninhabited or with low population density. This concept also requires onshore support facilities during construction and operation.

Nuclear Plant on the Seabed. Recent studies[28] envisioned a nuclear plant build and outfitted - as are large oceangoing vessels - in a shipyard. It would be towed to a predetermined seabed area and then lowered into place by compartment flooding or ballasting. The plant is completely submerged and is connected to a support surface platform by several large tunnels. It is contained in a reinforced concrete vessel to reduce corrosion. The surface platform would be about 50 feet above the mean water line and thus protected from maximum storm waves. Surface facilities include laydown area, shops, heliport and docking capability, and cranes. Transmission to land is by underground cables. Shore facilities would be required.

A plant on the seabed would require less effort than the other offshore concepts because little site preparation is required. Emissions to the atmosphere and water are the same as those of a floating plant.

The seabed plant poses two special risks: one is involved in towing the long, narrow plant in open seas and lowering it into place while subject to possible unfavorable sea conditions; the second is the vulnerability of the surface platform to ship collisions.[29]

High Temperature Gas Cooled Nuclear Reactors

The high temperature gas cooled reactor (HTGR) will be the next design used commercially.[30] It differs from the LWR in that helium, rather than water, is the heat transport medium. The first HTGR built in the United States is a 40-MWe unit that has been in operation since 1967. A second HTGR of 330-MWe may begin operations in 1974; it uses the uranium/thorium fuel cycle, thereby expanding the usable reserves of nuclear fuel.

Because the HTGR has a higher thermal efficiency than the LWR, HTGR requires a lower flow of cooling water, creating less thermal pollution. It also produces substantially less radioactive solid, liquid, and gaseous wastes. An HTGR would have lower environmental disturbances than a LWR or fossil plant.[31]

Summary

Table D-5 and D-6 compare environmental effects of construction and operations of plants and sites.

Disturbance to biota is likely to be highest from construction of a fossil plant located on a natural island because it is the most confined environment. A corresponding nuclear plant would occupy less space, so that it is expected to have lower effects. Shore plants have slighly higher effects than island plants because the shore habitat is more delicate. The other offshore plants have lower disturbances.

Construction effects on traffic are likely to be highest for the artificial island and floating plants due to transportation of material. The effects on aesthetics and noise are high for land-based facilities because of their proximity to population centers.

Table D-6 lists the environmental effects of operation on human population through air pollution, biota intake of cooling system, marine life due to thermal effects, terrestrial life due to thermal effects, biology due to plant interference, and water pollution.

Fossil plants have higher effects on air pollution. An inland site is expected to pose the highest environmental challenges because of its potential for reaching urban centers. If prevailing winds disperse the smoke plume toward the sea away from population concentrations, the shore concepts would generally have lower pollution effects on population. Assuming normal operation, nuclear plants would contribute almost nothing to air pollution.

Assuming that inland plants use closed cycle cooling, the effect of drawing water through an intake system would cause the greatest damage at shore plants both because of the higher density of biota near the shore and because many species spend their most vulnerable, larval stages of life in these areas. Because nuclear powerplants require more cooling water than fossil fuel plants of the same capacity, the damages associated with volume of water would be higher.

Interference by plant presence is high for the natural island because of the confined environment and for the seabed concept because of the marine environment. The island and shore concepts have medium disturbance. The underground concept has the lowest biological interference.

The impact on health of the population from release of radioactive materials from offshore nuclear powerplants is expected to be of negligible consequence for routine operations, independent of the particular configuration (floating, submerged, etc.). The acute health effects resulting from accidental release are expected to be of greatest consequence for those above surface facilities located in close proximity to shore. Submerged facilities and/or those above surface facilities located at large distances from population centers will necessarily result in lower health impact.

Table D-5. Environmental Effects of Plant Construction

CONCEPT	Biota	Highway Traffic Nearby	Asethetics	Noise
Aboveground shore fossil plant	Significant effects due to delicate nature of shore habitat	Significant effects while preparing site and erecting plant	Highest disturbance due to high stacks and large boiler houses	Some disturbance due to open-air activities
Aboveground shore nuclear plant	Significant effects but less than fossil	Significant effects but less than fossil	Less disturbance than fossil alternative	Some disturbance due to open-air activities
Aboveground inland fossil plant	Significant effects but less than shore concept	Effects somewhat less than shore concept	Significant disturbance	Some magnitude of disturbance as shore concept
Aboveground inland nuclear plant	Less effects than fossil design	Effects somewhat less than shore location	Significant disturbance	Some potential disburbance as shore alternative
Underground nuclear plant	Some effect due to excavation	High effects due to extensive excavation	Significant disturbance due to excavation	Low disturbance since most activity is underground
Fossil plant floating within breakwater	Low disturbance	Some effect due to transport of breakwater materials	Some disturbance	Some disturbance due to collection and transport of materials
Nuclear plant on seabed	Minimal effects	Low effects since little site preparation is required	Low effects	Minimal disturbance
Fossil plant on artificial island	Low effects	Considerable disturbance due to construction of island	Greater disturbance than FFP	Same as FFP
Nuclear plant on artificial island	Low effects	Significant disturbance	Slightly more disturbance than FNP	About as much disturbance as construction of FNP
Fossil plant on natural island	Effects expected to be high in view of essentially confined wilderness	Low effects	Some disturbance while erecting plant	Minimal disturbance
Nuclear plant on natural island	Effects expected to be high but less than fossil	Low effects	Some disturbance while erecting plant	Minimal disturbance, only to island population

Table D-6. Environmental Effects of Plant Operations

CONCEPT	Air Pollution	Biota Intake Of Colling System	Thermal Effects on Marine Life
Aboveground shore fossil plant	Effects expected to be high but less than inland alternative	Less effect than nuclear plant	Some effect but not as high as high as deep-water seabed concept
Aboveground shore nuclear plant	Nil effects	Highest effect due to location of water intake in shallow water	Somewhat higher effect than fossil alternative
Aboveground inland fossil plant	Highest potential effects to urban centers	Nil effects (closed cycle cooling)	Nil
Aboveground inland nuclear plant	Nil effects	Nil effects (closed cycle cooling)	Nil
Underground nuclear plant	Nil effects	Effect can be high if plant located at shore	Stress can be of some magnitude if plant located on shore
Fossil plant floating within breakwater	Significant effects expected but less than inland or shore	Significant effects but less than FNP	Same magnitude of disturbance as shore alternative
Nuclear plant on seabed	Nil effects	Somewhat less disturbance than FNP due to deeper water	Medium disturbance
Fossil plant on artificial island	Significant effects expected	Somewhat less effects than FNP	Medium disturbance
Nuclear plant on artificial island	Nil effects	About as great an effect as FNP	Medium disturbance
Fossil plant on natural island	Same magnitude of effect as other offshore alternatives	Same as shore alternative	Medium disturbance
Nuclear plant on natural island	Nil effects	Effects expected to be same as shore concept	Medium disturbance

Table D-6. (Continued)

CONCEPT	Accident Considerations	Effects on Land Use
Aboveground shore fossil	Consequence of spills more localized than offshore alternative	High effects on recreation; some effects on residential and commercial use
Above ground shore nuclear plant	Nuclear accident may affect population	High effects on recreation; some effects on residential and commercial use
Above ground inland fossil plant	Consequences of oil spills not as serious as shore alternative	Possible high effects on agricultural land; some effect on residential and commerical use
Aboveground inland nuclear plant	Concept with highest possible consequence due to nuclear accident	Same effects as fossil
Underground nuclear plant	Escapes of radioactivity may reach atmosphere and human population	Some effects on recreational or agricultural land use
Fossil plant floating within breakwater	Possibility of oil spills with serious consequences to aquatic birds and mammals	Slight effects on recreation
Nuclear plant on seabed	Radioactivy reaches population through seawater	Slight effects on recreation
Fossil plant on artificial island	Consequences of oil spills serious	Some effects on recreation
Nuclear plant on artificial island	Possibility of ship collision with resulting escape of radioactivity	Some effects on recreation; less than fossil
Fossil plant on natural island	Consequences of oil spills serious	Low effect on recreation
Nuclear plant on natural island	Radioactivity may reach poputión through air transport	Low effects on recreation

1/
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2/
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11/
Discussion based mainly on Federal Power Commission, *op. cit*., pp. 1-4-17 and Council on Environmental Quality, *op. cit*., pp. 15-16.

12/ Council on Environmental Quality, *op.cit.*

13/
Loc.cit.

14/
Council on Environmental Quality, *op.cit.* Table A-12. Processing is herein defined to include UF_6 production, enrichment, fabrication, reprocessing, and waste mangement.

15/
Appendix A (Releases of gaseous radionuclides from FNP).

16/
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17/
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25/
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26/
Loc.cit.

27/
Holmes and Narver, Inc., op.cit.

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See Holmes and Narver, Inc., op. cit. and General Dynamics, Potential Environmental Effects of an Offshore Submerged Nuclear Power Plant, E.P.A. Program 16130-GFI. June 1971.

29/ General Dynamics, op. cit.

30/ Federal Power Commission, op. cit.

31/ Council on Environmental Quality op. cit.

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APPENDIX E - EFFECTS OF TEMPERATURE ON MARINE ECOSYSTEMS

Although it is possible to measure the temperatures that kill fish, it should not be assumed that temperatures which do not reach lethal levels are harmless. The impacts of sublethal temperatures are subtle and difficult to measure. In some cases, although no individual fish die from exposure to high temperatures, changes to the ecosystem in terms of altered population and species distribution are significant.

This appendix summarizes what is known about indirect effects, as well as a presentation of the variations caused by regional differences.

Indirect Effects

Activity

Numerous papers discuss the relationship between activity and temperature in poikilothermic marine species, including Fry[1] and Brett[2]. As Fry[3] points out, temperature can affect spontaneous movement of marine fishes, thereby acting as a directive factor in addition to affecting activity levels at specific temperatures. However, there exist major differences in responsiveness to temperature by benthic (resident) and pelagic (nonresident/transient) species which may ultimately affect survival potential at the FNP site.

The kinds and types of activity patterns exhibited by different species categories may influence to a high degree their ability to respond to and/or escape from potentially lethal temperatures. Pelagic species such as bluefish, Pomatomus saltatric, and Atlantic mackerel, Scomber scombrus, although possessing clearly defined activity rhythms, are continually in motion-only at a lower level of activity at night than during the day.[4] Increasing temperatures apparently have a directive effect on these animals, with activity increasing as temperature departs from preferred levels. In recent studies on bluefish,[5] as temperatures increased or decreased from acclimation levels of 19° to 20° C (within presumed preferred limits for this species), swimming speed increased. As temperatures reached stress levels of 11.9° and 29.8° C, significant increases in average speed and disruption of daily rhythmic activity patterns occurred.

Although activity remained significantly high, the amount of food ingested decreased by 40 to 50%. Normal feeding behavior was not resumed even as temperatures returned to preference levels. The increased responsiveness as temperature departs from preferred levels may move bluefish from areas of adverse temperatures.

Current studies on Atlantic mackerel[6] indicate that different categories of response depend upon the range of temperature change. In the first category, increases and decreases in temperature occurring within preferred limits (approximately 7.3° to 12.8° C) result in only minimal changes in activity and feeding. In the second category, temperature departs from preferred limits to the extent that there are significant increases in the activity of the mackerel. Swimming speeds continue to increase for days after the temperature rise, but eventually they stabilize at the original level or slightly higher, depending on absolute temperatures. A third type of response occurs when temperatures are just beyond levels at which acclimation can occur. Although the fish may appear to be able to live at a given temperature for extended periods, they never achieve complete acclimation. For example, when mackerel were held for 55 days at 23° C, night swimming speeds increased and decreased several times as the fish attempted to achieve stability in activity. Amounts of food ingested decreased although activity levels were well above those recorded at preferred temperatures, incurring what was assumed to be a severe metabolic debt. Irritability increased, and 6 of 19 test fish died by jumping out of the tank or swimming into the tank wall. In the last category of response, the animals were under continued severe stress as temperatures rose to lethal levels (92% mortality by 28.7° C).

Seasonal changes in responsiveness were also noted for Atlantic mackerel. Differential responses to two identical 3° C increases in temperature at different seasons were apparently due to physiological changes in the fish at a time of year when migration and gonadal development were occurring.

Although there were essential differences in the responses of the bluefish and Atlantic mackerel to changes in temperature, both pelagic species increased their overall activity as temperature rose. An increase in their so-called kinetic level would relate to an increase in search area, allowing them to seek more optimal temperature situations. Adding to the increase in search area, some directionality from the area of stress could enhance the value of an activity increase -- not improbable at least during certain periods of the year for marine migratory species.

A variety of these pelagic species may be expected to take up residence around this manmade habitat much as has been indicated for many subsurface structures. Although it is generally assumed and has often been stated in the literature that many fish species may avoid thermal regimens that are potentially lethal, this is not a generality that may be applied to the benthic species that are expected to reside in the breakwater area.

A number of benthic species which are abundant in the candidate areas and will be attracted to the breakwater (e.g., cunner, Tautogolabrus adspersus; tautog, Tautoga onitis; and winter flounder, Pseudopleuronectes americanus) typically enter an inactive night phase characterized by decreased responsiveness to altering stimuli.[7] The probability that the fish would be able to respond and escape a potentially lethal change in temperature (e.g., initial plant operation and any possible shutdown) during this inactive night phase would be less than if the same stress were applied during the day. Recent laboratory evidence has shown that young tautog reduce activity at 25° C and may not attempt to escape lethal temperatures even during the day but may remain in close proximity to the habitat until death occurs.[8] It was shown that winter flounder reduced activity at 22° C, well below the estimated upper incipient lethal levels of 26.5° C[9] and 28° C[10] It has also been shown that sudden drops in temperature effected significant reductions in activity in summer flounder, Paralichthys dentatus.[11] Besides death from chronic exposure, if the inactivity induced by sublethal temperature changes continued over prolonged time intervals, the susceptibility of the fish to predation would increase. Further, these species might experience a metabolic deficit which would lower the chance for survival when activity was resumed and could interfere with spawning success of the population if the deficit occurred at a time of gonadal maturation.

Benthic species such as cunner and young tautog normally become torpid during the winter months.[12] This condition persists at temperatures 5° to 6° C and below. Potentially higher temperatures resulting from thermal discharge would keep these fish abnormally active during the winter months, with unknown adverse effects. Massengill[13] observed that the bullheads, Ictalurus nebulosus, which are normally inactive during the winter, became active and began feeding when exposed to a heated discharge. He also observed that the active fish were in considerably poorer condition than the inactive fish even though they had actively fed.

A potential sublethal temperature effect on reef-dependent species is the destruction of important invertebrate food sources. Olla and co-workers[14] found tautog to be highly dependent on a single food item, 1 to 2-year old mussels, Mytilus edulis, with no potential alternate sustenance. The upper limit for mussels appears to range from 26.7° to 28.9° C.[15] Therefore, temperatures that are not directly harmful to the tautog would directly affect the mussel population and would then lead to a high probability of stress in the mussel-dependent tautog population. This effect would be especially true for young fish because they seem especially dependent upon their home site.[16] This dependence raises the question of whether it is within their capability to move out and seek new feeding areas and, if so, how successful they would be.

Metabolism and Feeding

Numerous reviews are available on the effects of high temperature on fish physiology and metabolism.[17] In essence, as temperature increases toward upper lethal limits, the standard metabolic rate increases continuously if no other stresses are imposed and if there is time available for adjustment. Active metabolism, however, may stabilize or decrease well below upper lethal levels.[18] Increased heart rate, increased oxygen consumption, changed levels in biochemical processes, as well as inactivation of digestive enzymes are some of the myriad metabolic and physiological factors affected by increased temperature.

Up to a point, feeding rate increases as temperature increases.[19] Bluefish ingested 30% more during feedings as temperature increased from 19° to 22.2° C;[20] similar results were obtained for Atlantic mackerel.[21] However, at least for some species, there is an upper thermal limit (below established lethal tolerance limits) at which ingestion decreases. It may be due to changes in motivational and/or physical states resulting from elevated temperatures. Laboratory studies on mackerel indicated a significant change in feeding motivation following exposures to sublethal temperatures ranging from 21.6° to 23.6° C.[22] These changes were reflected in lowered responsiveness to prey, capture rates, satiation levels, and approach speeds. Bluefish, another predatory type, subjected to water temperatures of 28.4° to 30.4° C exhibited a 40 to 50% decrease in amount of food ingested, with no resumption of normal feeding behavior even as the temperature was returned to acclimation levels.[23] Similar levels have also been observed by Olla and co-workers[24] on winter flounder; Brown[25] on brown trout, Salmo trutta; Brett and Higgs[26] on fingerling sockeye salmon, Oncorhynchus nerka; and Peters and Boyd[27] on hogchoker, Trinectes maculatus. Reduced motivation to feed may result from sublethal stress conditions.[28] Cairns[29] points out that lowered predatory capacities of fish at sublethal temperatures may be caused by loss of equilibrium or impaired swimming due to excessive mucus extrusions from the fishes' bodies.

Another effect of temperature may be to alter a prey's ability to avoid natural predation. Results of Sylvester[30] suggested that sockeye salmon fry exposed briefly to sublethal heat stress of 30° C have an increased vulnerability to predators both day and night. Additional work by Coutant[31] indicated that the major effects of brief exposures to these elevated temperatures was to lower the escape performance of the prey, dur to equilibrium loss and/or lowered swimming efficiency.

Changes in population structure and diversity of prolonged residency may also affect normal predator-prey relationships. For example, the normal time of appearance during migration of Atlantic mackerel and bluefish in New Jersey waters is generally staggered.[32] This timing may ultimately benefit the

the mackerel, one of whose natural predators is the bluefish. Mackerel, normally following a temperature regime ranging from approximately 8° to 12° C in both its northern and southern routes,[33] may be attracted to the breakwater structure because of favorable temperature and an abundant food source. The appearance of bluefish at the same site at the same time may result in a precipitous drop in the current mackerel population and may ultimately affect future year-class structures.

Another effect of heat stresses on predatory animals may be imposed alterations in the established diet, either by eliminating natural prey through overcompetition or by establishing replacement fauna in the area of thermal discharge. Brown bullheads collected in the discharge canal of the Connecticut Yankee Atomic Power Co. plant exhibited a major shift in diet from invertebrates to small fish and were in considerably poorer condition than control fish residing in a nearby unaffected pond.[34] Another critical alteration was the maintenance of feeding activity in the winter months, a period in which this species is relatively inactive or is burrowed in the sediment. Shifts in diet and normal feeding cycles may be a result of high population densities and increased competition for food, as suggested by Marcy.[35]

Because many fish species primarily use vision in feeding,[36] any deterioration of the visual sensory component would also impair successful feeding and predatory behavior. High sublethal temperatures may be a source of visual stress. Yonezawa and Tamura[37] suggested that at temperatures of 23° to 25° C the eye function of rainbow trout, _Salmo gairdneri_, deteriorated. Exposure to low temperatures may also affect visual metabolism. Visual nerve signals of goldfish, _Carassuis auratus_, nearly disappeared within 14 days at 6° C.[38] The rate of the fast component of protein transport in the optic axons of goldfish was reduced from about 60 mm per day at 20.5° C to about 20 per day at 9° C.[39]

Migration

Many fish species ordinarily respond to the stimulus of a temperature gradient by congregating about temperature levels characteristic of the species concerned.[40] The terms "preferred temperature" or "temperature preferendum" have been used to define this phenomenon. Knowledge of temperature preferenda for adult fishes and the influence of temperature upon abundance, migrations, and particular locale appearance has been utilized for many years by both commercial and sports fishermen.

The dependence on temperature as one of the directing factors in the distribution and migration times and pathways of fish has been cited for bonito, _Sarda sarda_;[41] eel fry, _Anguilla japonica_;[42] sockeye salmon, _Oncorhynchus nerka_;[43] cod, _Gadus morbua_;[44] and herring, _Clupea harangua_.[45]

The primary role of temperature in triggering migrations is known for Atlantic mackerel, which appear in spring as temperatures begin to rise from 7° C,[46] and bluefish, which begin their fall migration as the temperature drops below 15° C.[47] From catch statistics on shad, _Alosa sapidissima_, it is known that the species is abundant from 8° to 15° C and that the catches increase as the higher temperature is reached. However, an abrupt decline in catches occurred above this temperature.[48] Winter flounder move into the ocean when bay waters reach 15° to 20° C,[49] although Olla and co-workers[50] found flounders active and feeding at temperatures up to 22° C.

One effect of thermal discharges may be the attraction, prolonged maintenance, and hence the disruption of normal migratory mechanisms in many pelagic fish. From studies on Atlantic mackerel[51] and bluefish[52] it is known that as temperatures increased above preferred, significant speed increases resulted which potentially enable these species to move out of water affected by thermal discharges and to continue their seasonal migrations. However, the additional stimulus of abundant food resources at an FNP site may encourage prolonged residency and hence delay or inhibit normal seasonal movements.

Some phases of migrations among pelagic fish are integrally involved with the onset and development of the sexual cycles,[53] the culmination of which is spawning and fertilization of gametes. The implications of the effects of temperature changes on altered reproduction is discussed below.

Temperature preferenda may be related to the attraction or avoidance mechanisms described in experimental studies.[54] However, the variables (food resources, species and habitat diversity, population densities, and seasonal fluctuations) possible at the FNP site may pose more far-reaching problems than anticipated for the scope of present experimental research.

Reproduction

In many species of fish, spawning, the culmination of the reproductive process, is limited to a relatively brief time span and usually occurs at a particular locale where conditions for release, fertilization, and survival of eggs and larvae are best.[55] However, the reproductive behavior of fish cannot be viewed as a single event, but rather as a series of continually transforming, physiological processes, defined in terms of seasonal cycles and ultimately subject to synchronization by external factors.[56]

As fishes migrate along coastal waters, they may be in a state of reproductive development, moving in waters in which temperatures are optimal. It would seem likely that temperature optima of prespawning animals are similar to those required for successful reproduction.[57]

Passage through water in which the fish might encounter deterrents to reaching their natural spawning grounds might result in desynchronization of gonadal growth and development, disruption of spawning and fertilization at the proper locale, or abnormal development and growth of eggs and larvae.

One potential effect on fish subjected to warmer waters is an "out-of-season" or desynchronized reproductive development. For example, high temperatures promoted the early phases of spermatogenesis in the cyprinid, Phoxinus laevis, regardless of exposure to winter (short) or summer (long) photoperiods.[58] Similarly, in adult female mosquito fish, Gambusia affinis,[59] and males of bitterling, Rhodeus anarus,[60] sexual maturity could be induced in midwinter by exposure to high temperatures.

Another related aspect of the desynchronization is additional or multiple spawning cycles. The mud pickerel, Esox vermiculatus,[61] normally has one brief spawning period in the spring, but it was found to spawn again in mid-November following abnormally warm October weather. Another possibility is premature maturation of gonads in immature fish. In the immature green sunfish, Lepomis cyanellus, it was found that gonadal maturation proceeding at high temperatures regardless of changing day length.[62] The total effect of desynchronization might ultimately affect established population densities at a particular site.

Conversely, the effect of high temperatures on reproductive development may cause postponement or even inhibition of normal sexual cycles. Species may successfully grow at temperatures higher than those at which they could successfully reproduce. For example, it has been shown that exposure of the gobid fish, Gillichthys mirabilis, to temperatures above 24° C for only 7.5 hours per day was sufficient to induce gonadal regression.[63] Brook sticklebacks, Eucalia inconstans, subjected to prolonged exposures to temperatures above 20° to 22° C, showed a cessation of spawning and atresia of mature oocytes.[64]

Although many authors point to the fact that there is a strong interaction between photoperiod and temperature in the regulation of gonadal development,[65] there is also evidence that in many species, temperature may be a more critical stimulus than photoperiod.[66] Reproductive development proceeding in Atlantic mackerel maintained at a constant winter (short-day) photoperiod and within preferred temperatures.[67] Similar reproductive development has been reported for sunfish, Lepomis gibbosus, which are insensitive to photoperiod changes after mid-November.[68]

Development and Morphology

The fate of fertilized eggs and larvae in the area of an FNP depends on temperature.[69] Development of fertilized eggs is strictly controlled by temperature. The literature substantiating the fact that eggs develop more rapidly with increasing water temperature (and in some cases results in developmental arrest) is extensive.[70] One important principle was established by Kinne,[71] who found that young Cyprinodon macularius exposed to temperatures ranging from 15° to 30° C grew faster from hatching to maturity at the higher temperatures. However, the high growth rates were not maintained later in the lives of the fish. The effect of accelerated initial growth rates could be a precocious maturity in fish, decreased adult sizes, and perhaps a shortening of life cycles.[72] Even with abundant food resources, growth rates exhibit a marked thermal optimum: growth rates are low at low temperatures, and weight is lost as temperatures approach lethal levels.[73]

The relationship between high temperatures and aberrant morphological changes is another factor to be considered. Some of the most extensively studied anomalies of eggs and larvae related to temperature increases are deviations in mean number and formation of vertebrae and spinous and soft ray counts.[74]

For eggs and larvae maintained at relatively constant temperatures and then subjected to sudden temperature decreases (e.g., if the plant were temporarily shut off), their morphological development could perhaps be even more impaired. For example, Stockard,[75] after exposing embryos of mummichogs, Fundulus heteroclitus, and trout (presumably Salvelinus fontinalis) to sudden, drastic temperature reductions, found abnormalities of the eye ranging from anophthalmia to cyclopia, bilateral asymmetry of the brain, dysplastic development of mandibles and branchial arches, reduction of abdominal and peduncular regions, and twinned forms with shared yolk sacs.

Although a morphological change need not necessarily be lethal, the potential for reducing the survival rate of fish, in terms of altering normal motor and nervous functions, is greatly increased.

Elevated temperatures also affect the energy utilization in embryos and prolarvae. Laurence,[76] incubating prolarval tautog at 16°, 19°, and 22° C, found that at 22° C yolk absorption occurred at a greater rate, with the result that energy deficits were present on the day of feeding capability. Survival of the larvae would be in question if food were in limited supply. In marine fishes, prefeeding energy deficits which could result in 100% mortality are possible at sublethal temperatures.

Effects of Size and Age

Potential for escape from lethal thermal conditions is generally greater for adults than for larval and juvenile forms.[77] In addition to possessing more effective mechanisms for escape, adults of a number of species found in the proposed site (e.g., cod, sculpin, flounder, herring) are found to have higher thermal tolerance limits than younger forms.[78] Brett[79] also states that the range of temperature tolerances is generally less for larval and embryonic stages than for adults.

Regional Temperature Toleration Differences

Regional temperature ceilings for FNP thermal discharges are demarcated by geographic provinces. Marine species composition and, most important, responses to elevated temperature are generally similar within a region. Boundaries of a biotic province are characterized by significant thermal discontinuities. Boundary areas are maintained during summer and winter by the combined forces of current, wind, and coastal geomorphology. On the East coast, Cape Canaveral, Fla., Cape Hatteras, N.C., and Cape Cod, Mass. mark the three provinces. On the West coast, Pt. Conception marks the warm and cold temperate zones.

Thermal criteria guidelines published by EPA[80] are based on best available data. Selected representative data are given below by biotic region. The data document limitations on thermal addition during the summer. Unless otherwise noted, cited studies deal only with summer temperatures or warm-acclimated organisms. Results of sublethal effects studies are cited. Twenty-four-hour TLm (median tolerance limit) data have been adjusted by subtracting 2.2° C to estimate the upper thermal protection limit (50% of optimal survival) for the life history stage in question.[81] Recognized biological variables such as recent environmental history, nutritional state, size, sex and age are considered for all thermal effects investigations. Likewise, contrasting methods of study are considered.

Thermal effects data derived in one biotic region should generally not be applied to another. Latitudinally separated populations of widely distributed species may exhibit significant generic variability and usually have experienced different recent environmental histories.

Atlantic Boreal Zone

This region extends from Cape Cod, Mass., to the Gulf of Maine. Insufficient data are available for setting regional temperature limits. Upper discharge limits should be determined on a case-by-case basis using best available data for the site and its environs.

In the boreal region, maintenance of a general temperature regime resembling natural conditions is particularly important during winter months. Some boreal species require periods of uninterrupted low water temperatures for successful maturation of sexual products, spawning, and subsequent egg and larval survival. Winter flounder, Pseudopleuronectes americanus, have an upper limit of 5.5° C[82] for spawning. Spawning occurs during the winter.

Ten °C is the upper thermal limit for Atlantic salmon, Salmo salar, smolt migration to the sea, which normally occurs in June. Twelve °C inhibits maturation of sex products.[83] Development of winter flounder, Pseudopleuronectes americanus, eggs to hatching is reduced 50% at 13° C.[84] Blood worm, Glycera americana, spawning is induced when temperatures reach 13° C.[85] Fifteen °C is the upper limit for spawning of Atlantic herring, Clupea harangus,[86] and of an amphipod, Psammonx nobilis.[87] In Atlantic herring, there is above normal incidence of a protozoan disease at 15° C,[88] and at 16° C there is a prevalence of erythrocyte degeneration.[89] Field mortality of yellowtail flounder larvae, Limanda ferruginea, was observed at 17.8° C.[90] The protection limit for yearling Atlantic herring (48-hr TLm - 2.2° C) is 19.0° C.[91] At 21° C, embryonic development ceases in the amphipod, Gammarus deuben.[92] Above 21.1° C, spores are killed and growth is reduced in the macroalga, Chondrus crispus, which is commercially harvested as Irish moss.[93]

Atlantic Cold Temperate Zone

Temperature ceilings are particularly critical in the southern portion of this region (the south shore of Long Island to Cape Hatteras, N.C.) where enclosed sounds and large coastal plain bays and rivers are prevalent. Maximum temperatures should not exceed 30° C (86° F). The true daily mean should not exceed 27.8° C (82° F). Were 30° C to persist for over 4 to 6 hours, appreciable stress or direct mortality would occur among juvenile winter flounder, striped mullet larvae, Atlantic silverside eggs, larvae, and adults, adult northern puffer, adult blue mussel, and adult soft shell clam (*Mya arenaria*). Specific critical temperatures for these species are detailed in Table 1. The adult protection limit (TLm 0 2.2° C) is 28.8° C for sand shrimp, *Crangon septemspinosa*, and 30.8° C for opossum shrimp, *Neomysis americanus*. Both are important food organisms for fish.[94] Respiration rate is depressed above 30° C in the mole crab, *Emerita talpoida*.[95] At 31.5° C, there is 67% mortality in the coot clam, *Mulinia lateralis*, when exposed for 6 hours.[96]

A limit of 27.8° C approximates the upper limit for larval growth of the coot clam (27.5° C),[97] the upper tolerance limit for soft shell clam adults is 28.0° C.[98] Between 28° and 30° C juvenile amphipods, *Corophium insidiosum*, leave their tubes and thereby lose natural protection from predation.[99] Such elevated temperatures may also have subtle sublethal effects, such as reducing feeding and growth. In the quahaug, *Mercenaria mercenaria*, growth is optimum at 20° C.[100] Growth is inhibited above 24° C in the rock week, *Ascophyllum nodosum*.[101] Prolonged locomation is markedly reduced at 22° C in the rock crab, *Cancer borealis*; at 28° C in *C. irroratus*.[102] An oyster pathogen, *Dermocystidium marinum*, proliferates readily only above 25° C.[103]

High temperature will usually elicit avoidance response in fishes. Avoidance is triggered at 29° C in Atlantic menhaden, *Brevoortia tyrannus*, and at 26.5° C in sea trout, *Cynoscion regalis*.[104] Breakdown of the avoidance response in striped bass occurs at 30° C.[105] The maximum reported temperature for capture of spotted hake, *Urophycis regis*, is 24.8° C in Chesapeake Bay.[106]

North of Long Island, a 1.1° C rise above summer ambient temperature would provide reasonable protection. For example, maximum short-term temperatures in Narragansett Bay, R.I., would usually not exceed 23.4° C in August (judging from 15-year mean temperature data for Fox Island). Larval Atlantic silverside, juvenile winter flounder, and blue mussel should be protected by that thermal limitation. Thermal protection limit (TLm - 2.2° C) for juvenile winter flounder, *Pseudopleuronextes americanus*, is 26.9° C.[107] Everich and Neves[108] found that exposure to 24.6° C for 15 days caused 50% mortality of

Atlantic silverside larvae, *Menidia menidia*. Repeated exposures to 25° C would stress the blue mussel, *Mytilus edulis*, causing cessation of feeding[109] and arrest of embryonic development and larval growth.[110] Diurnal summer maxima exceeding 22° C can alter normal metabolic rates in embryonic tautog, *Tautoga onitis*[111] and cause feeding problems for adult winter flounder[112] and the sand-collar snail, *Polinices duplicata*.[113]

Optimum for summer development of the rock crab larva, *Cancer irroratus*, is 20° C; at 25° C, mortality precludes completion of larval development. Optimum for the northern crab, *C. borealis*, is 15° C, with development blocked at 20° C.[114] Between 15° and 20° C, activity of the amphipod, *Gammarus oceanicus*, is much reduced.[115] Initiation of spawning is often cued by temperature. Blue mussel spawning occurs when spring temperatures reach 12° C.[116] A minimum of 10° C is required for their embryonic development.[117] Migration occurs among striped bass, blue fish, and Atlantic silverside[118] at 15° C. Peak spawning runs of American shad, *Alosa sapidissima*, into rivers occurs at 19.5° C (15-year average, Connecticut River); downstream migration of juveniles occurs as temperature falls below 15.5° C.[119] Menhaden migrate at 10° C;[120] striped bass, *Morone saxitallis*, migrate into or leave rivers at 6° to 7.5° C.[121] In the fall and winter, fishes congregate in discharge plumes above these temperatures; the fishes exhibit increased incidence of disease and a general loss of physiological condition.[122]

Atlantic and Gulf Warm Temperate Zone

This region extends from Cape Hatteras, N.C., to Cape Canaveral, Fla., and on the Gulf coast from Tampa to Mexico. A maximum of 32.2° C is recommended by EPA. The upper incipient lethal temperature for two dominant estuarine fishes, mullet and pinfish, is 33° C.[123] At 33° C, bay anchovy, *Anchoa mitchilli*, embryonic development is reduced to 50% of optimum.[124] The upper tolerance limit for coot clam embryos, *Mulinia lateralis*, and for embryos and larvae of American oyster and quahaug is 32.5° C.[125] The upper limit for growth of juvenile white shrimp, *Panaeus setiferus*, is 32.5° C.[126] A decline in field abundance of brown shrimp, *P. aztecus*, at temperatures above 30° C was reported by Chin.[127]

Protection limits of two sardines, Harengula jaguana and H. pensacolae, for development of the yolk sac larval stage are 31.4° C and 32.2° C, respectively.[128] The critical thermal maximum (CTM) is exceeded for striped bass at 30° C.[129] Larval pinfish, Lagodon rhompoides, and spot, Leistomus xanthurus, have CTM of 31.0° C and 31.1° C, respectively.[130] Protection limit (TLm - 2.2° C) for young-of-the-year Atlantic menhaden is 30.8° C.[131] Upper limit for adult growth of the quahaug, Mercenaria mercenaria, is 31° C.[132]

Mean temperatures exceeding 29° C would result in mortality of striped mullet, Mugil cephalus, eggs. Their 96-hr. TLm is 26.4° C.[133] Egg and yolk sac larval survival of sea bream, Archosargus rhomboidalis, is reduced to 50% of optimal at 29.1° C. For yellowfin menhaden, Brevoortia smithi, exposure to 29.8° C reduced survival of egg and yolk sac larvae to 50% of optimal.[134] Sublethal but potentially damaging effects could occur at levels well below 29° C. For example, the upper limit for optimal growth of post larval brown shrimp, Penaeus aztecus, is 27.5° C;[135] in the American oyster, Crassostrea virginica, it is 25° C.[136] Developing embryos and fry of striped bass cannot tolerate 26.7° C in fresh water.[137] This report may also apply to fry in waters at the head of estuaries. Elevation of winter temperatures above 20° C in St. Johns River, Fla., could interfere with upstream migration of American shad, Alosa sapidissima.[138]

Tropical Regions

Tropical regions such as south Florida (Cape Canaveral and Tampa southward), Puerto Rico, and tropical zone Pacific Islands should not exceed an instantaneous temperature maximum 32.3° C and a true daily mean not exceeding 30° C. A review by Zieman and Wood[139] suggests that the thermal optimum is 26 to 28° C for tropical marine systems, with chronic exposure to temperatures between 28° and 30° C causing heat stress. Death of the biota is readily discernible between 30° C and 32° C. Myer[140] recognized that nearshore tropical marine biota normally live at temperatures only a few degrees below their upper lethal limit. A study of elevated temperature effects on the benthic community in Biscayne Bay resulted in the following data:[141]

Phylum	Temperature for High Species Diversity (°C)	Temperature for 50% Species Exclusion (°C)
Molluscs	26.7	31.4
Echinoderms	27.2	31.8
Coelenterates	25.9	29.5
Porifera	24.0	31.2

Other thermal data for tropical biota include a 25.4° to 27.8° C optimum for fouling community larval settlement;[142] 25° C optimum for larval development of Polyonyx gibbesi, a commensal crab;[143] 27° to 28° C optimum for larval development of pink shrimp (Penaeus duorarum);[144] and 30° C optimum for tutle grass, Thalassia testidinum, productivity.[145] Kuthalingham[146] studied thermal tolerance of newly hatched larvae of 10 tropical marine fishes in the laboratory.

Pacific Cold Temperate Zone

Winter and spring spawning temperature ranges are 3° to 6° C for Pacific herring, Clupea pullasi;[147] 7° to 8° C for English sole, Parophyrs retulus;[148] and 13° C for May and June spawning of razor clams, Siliqua patula,[149] and 12° to 14° C for native little neck clams, Protothaca staminea.[150] Opimal growth occurs at 10° C in the small filamentous red algae, Antithamnion spp.[151] and 12° to 16° C is optimal for growth and reproduction of various red and brown algae, including kelp, Macrocystis pyrifera.[152] Twelve to 16° C favors sea grasses, Zostera marina and Plyllospudix scouleri.[153] Spawning migration of striped bass, Morone saxitilis, occurs at 15° to 18° C;[154] in American shad, Alosa sapidissima, spawning runs occur at 16.0° to 19.5° C.[155]

Dungeness crab, Cancer magister, larval development is optimal at 10° and 13.9° C; survival is reduced at 17.8° C, with no survival to megalop at 21.7° C.[156] The upper thermal limit for razor clam embryonic and larval development is 17° C.[157] The upper growth limit for small filamentous red algae (e.g., Antithamnion spp. is 18° C.[158] King salmon migration into the San Jouquin River may be delayed by an estuarine temperature in excess of 17.8° C.[159]

The sea grass, Phyllospadix scouleri, begins to die off at 20° C,[160] and the pea pod borer, Botula fulcata, ceases to develop.[161] Twenty °C is also the upper limit for embryonic and larval development of the summer-spawning horse clam, Tresus nuttalli, and native little neck clam, Protothaca staminea.[162] The upper incipient lethal temperature for the mysid shrimp, Neomysis intermedia, is 21.7° C.[163] This value is corroborated by reports of a drop in field populations of this important fish food organism above 22.2° C in the San Joaquin estuary.[164] Twenty-two °C is the upper tolerance limit for embryological development of the wooly sculpin, Clinocttus analis.[165] A 4-hour exposure to 23° C results in significant mortality of the adult razor clam, Siliqua patula,[166] and the sockeye salmon, Oncorhynchus nerka.[167] Striped bass, Morone saxatilis, are believed stressed at temperatures above 23.9° C.[168] Sexual maturation in a gobiid fish, Gillichys mirabilis, is blocked at high temperatures. Gonadal regression begins at 22° C in females, at 24° C in males; gonadal recrudescence will not occur at 24° C or above, regardless of photoperiod.[169] The 36-hour TLm for red abalone adults is 23° C when acclimated to 15°; for the embryos, 26° C when exposed for 30 hours.[170] The sea urchin, Strongylocentrotos purpuratus, upper tolerance limit is 23.5° C for adults;[171] 25° C is lethal to embryos and renders adults limp and unresponsive after 4 hours.[172]

Pacific Warm Temperate Zone

The thermal threshold for spawning in the Pacific sardine, Sardinous caerulea, is 13°[173] Temperature optima for spawning includes 15° C in a ctenophore, Pleurobranchia bachei;[174] 16° in the spring spawning wooly sculpin, Clinocottus analis;[175] 17.5° for northern anchovy, Engravlis mordax; and 19° C for opaleye fish, Girella nigricians.[176] Larval survival is best at 16° to 18° C in white abalone, Haliotis sorenseni.[177]

Limiting effects of temperature include scarcity of the kelp isopod in beds above 17.8° C.[178] The upper limit for growth in P. bachei is 17° C; 20° C is the upper tolerance limit for the adult ctemophore.[179] Twenty °C also causes limited survival in recently settled juvenile white abalone.[180]

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Effects for the wooly sculpin the upper limit of optimal growth is 21° C; at 22° C, there is a 50° reduction in development of eggs; at 240°, the upper limit for embryonic development is reached.[181] Sea urchins, Strongylocentrotus spp. are weakened or killed at 24° to 25° C.[182] At 25° C, partial osmoregulatory failure occurs in staghorn sculpin, Leptocottus armatus at 37.6%.[183] A maximum temperature of occurence of 25° C is reported for topsmelt, Atherinops affinis, by Doudoroff[184] and northern anchovy, Engraulis mordax.[185] For topsmelt, the upper limit at which larvae hatch is 26.8° C.[186]

Natural summer temperatures are stressful to beds of giant kelp Macrosystis in southern California, precluding any thermal discharge in the vicinity. Deterioration of surface blades is evident from late June onward, due in part to reduced photosynthesis.[187]

Several weeks' temperatures over 20° C result in pronounced loss of kelp.[188] Temperatures above 20° C are limiting for the giant kelp, Macrocystis pyrifera. Brandt[189] reported some 60% reduction of kelp harvest when the temperature was 20.65° C and a bacterial disease, black rot, that thrives on kelp at 18° to 20° C. One-day exposure to 22° C is quite harmful to cultured gametophytes.[190]

TABLE 1. SELECTED THERMAL REQUIREMENTS & LIMITING TEMPERATURE DATA

Atlantic cold temperate biotic province: South of Long Island, New York, to Cape Hatteras, North Carolina

Temperature °C	°F	Effect	Species	Seasonal Occurrence
30	86.0	Avoidance response breakdown (CTM)	striped bass *Morone saxatilis*	April-November
29.8	85.6	Behavior-reduced feeding and behavior altered	bluefish *Pomatomus saltatrix*	May-October
29.4	84.9	Survival-eggs (50% optimal survival)	Atlantic silverside *Menidia menidia*	May-June
29.1	84.3	Survival-larvae (TLm)	striped mullet *Mugil cephalus*	January-April (coastal waters)
29.0	84.2	Survival-adult protection limit (TLm - 2.2° C)	Northern puffer *Sphaeroides maculatus*	January-December
29.0	84.2	Avoidance response	Atlantic menhaden *Brevoortia tyrannus*	April-October
28.2	82.7	Survival-adult protection limit (TLm - 2.2° C)	Atlantic silverside *Menidia menidia*	April-November
28.0	82.4	Survival-adult limit	soft shell clam *Mya arenaria*	January-December
27.5	81.5	Development-upper limit larval development	coot clam *Mulinia lateralis*	March-October
26.9	80.4	Survival-juvenile protection limit (TLm - 2.2° C)	winter flounder *Pseudopleuronectes americanus*	April-December
26.5	79.7	Avoidance response	sea trout *Cynoscian regalis*	May-October
26.0	78.8	Survival-adult	blue mussel *Mytilus edulis*	January-December
25.5	77.9	Avoidance response	spot *Leiostomus xanthrus*	January-December
24.8	76.7	Occurrence-maximum temperature for occurrence in Chesapeake Bay	spotted hake *Urophycis regulis*	January-December
24.6	76.2	Survival-larvae (TLm)	Atlantic silverside *Menidia menidia*	May-June
20	68.0	Growth-optimum	Northern quahaug *Mercenaria mercenaria*	January-December

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APPENDIX F: IMPACTS OF A REDUCTION IN RESORT-RELATED ECONOMIC ACTIVITIES IN ATLANTIC AND CAPE MAY COUNTIES, NEW JERSEY[1]

Atlantic and Cape May Counties, located in southeastern New Jersey and bordering the Atlantic Ocean, are major summer resort areas. The following exercise illustrates the possible economic impact of a disruption of seashore resort activities. The principal measure of economic activity in a local area is personal income. For use in gauging the growth or decline of a specific industry, wages and salaries, supplementary labor income, and self-employment income are combined and called earnings. Personal income and its components are shown in Table F-1 for Atlantic and Cape May Counties.

The impact measurement approach used here is based on the export-base theory of regional economic growth. According to the export-base theory, each area of the Nation specializes in the production of certain goods and services in which it has a comparative advantage. These goods and services make up the export base of an area and are termed export industries. The export industries of the two counties are also shown in Table F-1.

The remaining industries of an area are termed residentiary industries. They produce the goods and services required by local business as intermediate products and by the household sector for personal consumption. Each economic area attains or approaches self-sufficiency with respect to its residentiary industries. Residentiary industries are shown in the table as "In local production."

Some industries are both export and residentiary, the trade and service industries for example. They are engaged in wholesale and retail trade, bookkeeping, restaurants, hotels, etc. Usually, the entire output of the trade and service industries is consumed locally.

In a resort area, however, a portion of trade and service is consumed by, or exported to, visitors. This portion is classified as an export industry. Some transportation, finance, and contract construction may be produced for nonresidents.

Export-base theory assumes that the primary factor in an area's growth or decline is a change in one or more export industries. Increased production of an export industry has two effects. First, more workers are required, thereby directly increasing employment, earnings, income, and population. In turn, the increased production stimulates production in industries that supply its raw and semiprocessed materials, causing these residentiary industries to expand. This growth also increases employment, earnings, income, and population. Second, the increased earnings of workers in the export industries and in the residentiary industries supplying them increase the demand for residentiary goods and services by the household secotor, or local consumer. The increased income of employees causes successive expansions in residentiary industry, thus creating further growth. The sequence of events in response to reduction in an export industry is just the opposite.

The total impact of an export industry is measured by the amount of change in that industry and by the size of its multiplier. Data are not available for the calculation of separate multipliers for each basic industry in our example. Instead, an aggregate multiplier has been calculated for all basic industries combined. These are shown in Table F-1. The multiplier measures the effect on total income caused by a reduction or expansion in earnings of basic industry. As shown in the table, earnings in export industries in the two-county area account for approximately $300 million, or one-third of total income in 1971. A little more than one-half of this, or $153 million, comes from industries based on the seashore location of these two counties. These industries are contract construction, trade, services, out commuters, and transfer payments.

About one-fourth of contract construction is assumed to be resort-oriented -- that is, $17 million originates in construction and maintenance of homes, roads, and buildings required by visitors to the shore. Export of earnings in trade and service are the earnings of persons employed in these industries to meet the demands of tourists and vacationers. That is, were there no summer resort attraction in this area, a trade and service industry disbursing earnings of $219 million ($114 million plus $105 million) instead of $282 million would be sufficient to meet the demands of tourists and other visitors assumed to be attracted to the resort activities.

Out-commuters are persons who live in one place and work in another; hence, they are exporting their labor. It is assumed that the seashore attracts these residents who commute to work. Finally, of a total of $151 million of transfer payments, $60 million is classified in the export base on the grounds that it is received by persons who spent their working lives elsewhere and are now living in retirement in the area.

As indicated in the table, the multiplier for these two counties is 3.06. That is, for every dollar reduction or increase in basic earnings, there will be a $2.06 reduction or increase in supporting income flows, for a total change of $3.06 in personal income. Accordingly, if construction of an offshore nuclear facility were to kill seashore tourist and resort activities, force all commuters to work and live elsewhere, and cause all retirees to leave the area, total earnings would be reduced directly by over $153 million and indirectly by $316 million ($153,338,000 x 2.06 = $315,876,28) for a total income decline of over $469 million, a reduction that would probably cause a population decrease of some 125,000.

On the other hand, to the extent that the FNP does not distress residents and potential visitors, it will not diminish economic activity. Rather, it would stimulate economic activity: construction and operation require personnel located in the area, and their earnings would carry a multiplier of approximately 3. Further, the FNP would signal the availability of additional electrical power, which might well attract new export industries to the area, thereby causing further economic expansion. Because the multiplier as calculated here is a linear function of the basic industries and total income, various assumptions regarding the reduction in basic earnings can be made and the multiplier of 3.06 used to calculate total impact.

It must be emphasized that the foregoing is not a prediction. It is simply a method of calculating the total income impact on an area resulting from an *assumed* initial effect of an offshore nuclear installation.

A further caution may be noted. The multiplier shown reflects the effect on residentiary income of an increase or decrease in export-based income, not the indirect effect on other export industries. Other measurements would be required for that. However, it is probable that a reduction in economic activities relating to seashore resort activities would have little or no interindustry effects among export industries. If the manufacturing industry were involved, such effects would likely be present, and the multiplier would be understated.

The table shows separate calculations for Cape May and Atlantic Counties. Because export industries related to seashore activities bulk somewhat larger in the Atlantic economy than in Cape May's, elimination of resort activity would have a larger effect, both absolutely and relatively in Atlantic County.

No evidence has been presented to show that a seashore area will lose its attractiveness as a result of emplacement of a FNP. However, if in fact a nuclear powerplant off New Jersey eliminated or significantly reduced seashore resort activities in Atlantic and Cape May Counties, the economic effects on that area could be large. The ultimate effect can be determined using this methodology and adding in the psychological factors.

For comparison it is useful to consider the other FNP candidate areas. One variable in the analysis is the income multiplier. It ranges from 2.16 for the sparsely developed region from Chincoteaque to Cape Charles to 3.05 for Portsmouth, N.H., north. Because of tourist activity and retirement communities from Cape Kennedy to the Keys, the multiplier calculations are more difficult, but preliminary analysis suggests that the multiplier is at the high end of the above range.

REFERENCES

1/ Data in this Appendix was prepared by the Bureau of Economic Analysis, U.S. Department of Commerce, from unpublished materials available in the Regional Economic Information System.

Table P-1

Personal Income in Atlantic and Cape May Counties, N.J.

1971

(in thousands of dollars)

Income Source	Atlantic and Cape May*			Atlantic			Cape May		
	Total+	In export production	In local production	Total	In export production	In local production	Total	In export production	In local production
arnings									
Farm	$ 6,257	$ 6,257	$ --	$ 5,685	$ 5,685	$ --	$ 572	$ 572	$ --
Federal civilian	37,134	37,134	--	35,179	35,179	--	1,955	1,955	--
Federal military	17,341	17,341	--	3,679	3,679	--	13,662	13,662	--
State and local	97,119	22,980	74,139	70,752	14,614	56,138	26,367	8,374	17,993
Manufacturing	80,123	80,123	--	70,572	70,572	--	9,551	9,551	--
Mining	5,054	--	5,054	3,250	--	3,250	1,804	--	1,804
Contract construction	59,676	17,047	42,629	42,471	*10,173	32,298	17,205	* 6,868	10,337
Transportation, communication, & public utilities	49,913	--	49,913	39,177	* 1,807	37,370	10,736	--	10,736
Wholesale and retail trade	149,302	35,799	113,503	112,072	*26,078	85,994	37,230	* 9,681	27,549
Finance, insurance, and real estate	40,106	--	40,106	33,820	* 6,094	27,726	6,286	--	6,286
Services	132,792	*28,162	104,630	104,819	*25,613	79,206	27,973	* 2,582	25,391
otal earnings (place of work)	674,817	244,843	429,974	521,476	199,494	321,982	153,341	53,245	100,096
arnings of									
Out commuters	12,149	*12,149	--	--	--	--	12,149	*12,149	--
In commuters	- 5,077	- 1,939	- 3,138	- 5,077	- 1,939	- 3,138	--	--	--
otal earnings (place of residence)	681,889	255,053	426,836	516,399	197,555	318,844	165,490	65,394	100,096
ther income									
Property income	119,100	--	119,100	91,697	--	91,697	27,403	--	27,403
Transfer payments	160,870	*60,181	100,689	119,216	*42,035	77,181	41,654	*18,146	23,508
Personal contributions for soc. insurance	33,059	12,000	21,059	25,912	9,924	15,988	7,147	2,480	4,667
Total personal income	928,800	303,234	625,566	701,400	229,666	471,734	227,400	81,060	146,340

ltiplier 3.06

Total

igures may not add because of intercounty transactions.