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Department of Energy

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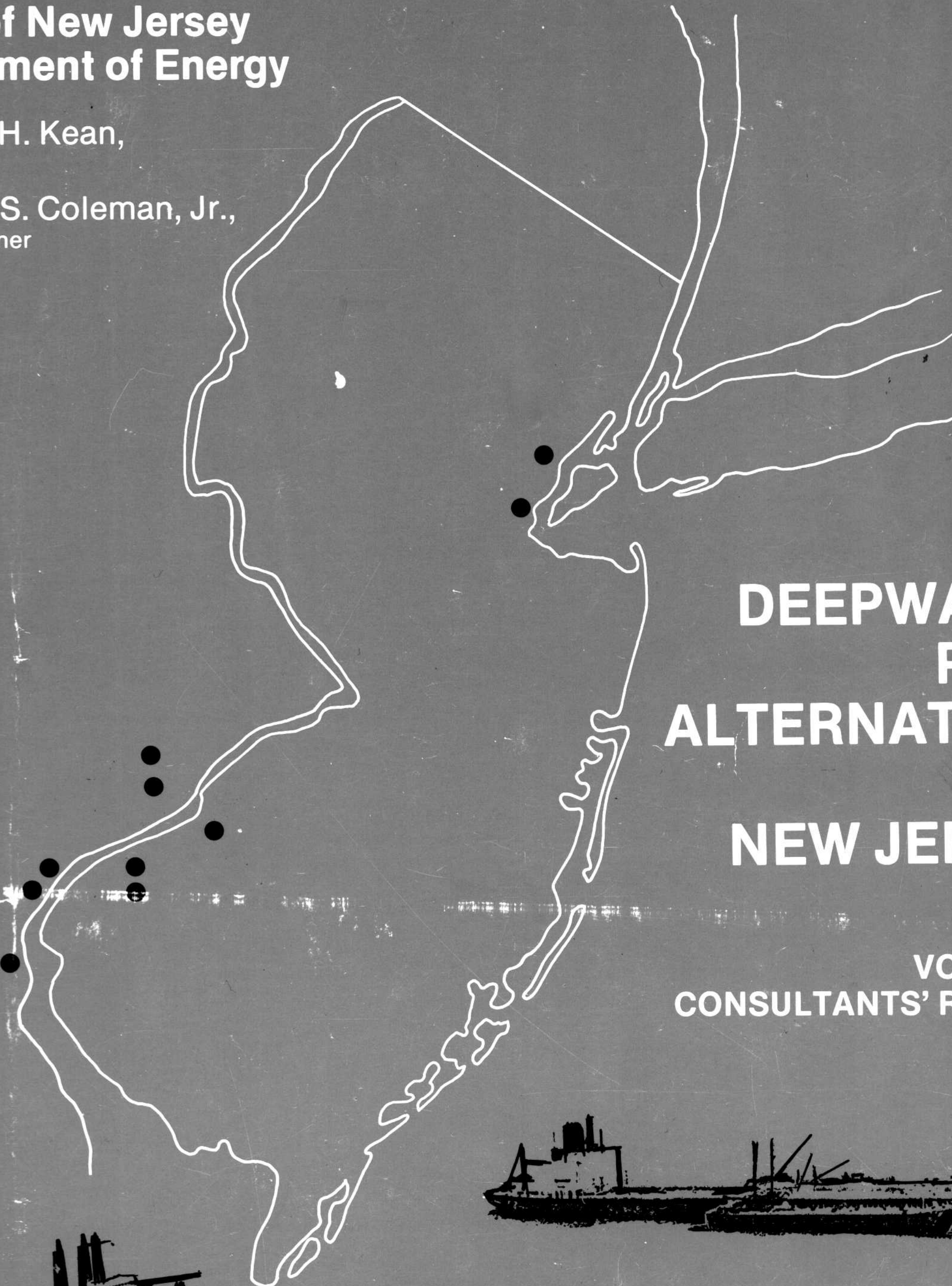
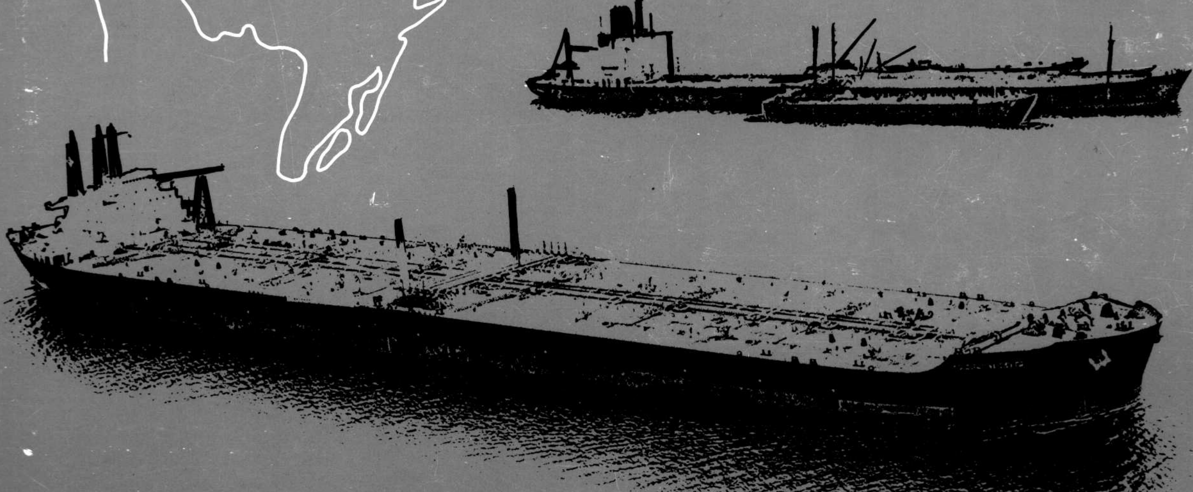


DEEPWATER PORT ALTERNATIVES FOR NEW JERSEY

VOLUME II: CONSULTANTS' REPORTS



THE PORT AUTHORITY OF NY & NJ

INTRODUCTION TO DEEPWATER PORT ALTERNATIVES

FOR NEW JERSEY - VOLUME II

This volume contains complete reports prepared by several consultants who participated in the Deepwater Port Alternatives For New Jersey study under subcontract to The Port Authority of New York and New Jersey. A general summary of conclusions from each of their investigations is found in Chapter 10. It is worth noting that these reports do not constitute an exhaustive analysis of environmental impacts associated with deepwater oil terminals in Delaware Bay and New York Harbor. The consultants' studies were directed toward basic water and air quality issues involved with the construction and operation of in-harbor terminals. The intent of each of the consultants' reports was to diagnose and frame issues correctly for further investigation in a project-oriented environmental impact statement.

Noticeably absent is a study on dredging and dredge spoil disposal. There are significant environmental issues related to dredging but scholarly examination of them was beyond the time and financial resources committed to this study. The dredging requirements and their environmental impacts vary widely among the potential sites considered here. The dredging of federally maintained waterways traditionally has been the responsibility of the U.S. Army Corps of Engineers. Therefore, it was determined that the dredging issue should be left to a specialized study either by an applicant for such a facility or the appropriate federal agency responsible for dredging permits.

The several consultants who prepared these reports are recognized experts principally from the region's academic community. From years of *in situ* research, they have acquired specific knowledge of the two water bodies which are under investigation as sites for the in-harbor terminal. The conclusions of the respective studies are those of the individuals involved and do not necessarily reflect the views of the State of New Jersey or The Port Authority of New York and New Jersey.

This acknowledges the financial assistance provided by the Coastal Zone Management Act of 1972, as amended, with funds administered by the National Oceanic and Atmospheric Administration, Office of Coastal Zone Management. This study was prepared under the supervision of the New Jersey Coastal Energy Impact Program of the New Jersey Department of Energy. However, any opinions, findings, conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the New Jersey Coastal Energy Impact Program.

BIOGRAPHIES

Dr. Richard Bartha: **Research Professor, Department of Biochemistry and Microbiology, Rutgers - The State University of New Jersey**

Dr. Bartha is a recognized expert in the biodegradation of hydrocarbons in the marine environment. In the past ten years, he has published more than twenty papers on this subject as a result of extensive studies which he has conducted in the Raritan Bay/Sandy Hook/New Jersey Shore regions. Funding for these studies came from governmental and private sources. Dr. Bartha also provides consultative services to major petroleum refiners with regard to facilities which they operate in the region. Currently, he is a member of a distinguished panel which is updating and revising a 1976 National Academy of Sciences report on the impact of oil spills in the marine environment.

Center for Coastal Environmental Studies: **Dr. Norbert P. Psuty, Director, Rutgers The State University of New Jersey**

The Center for Coastal and Environmental Studies, a research and academic resource division of Rutgers - The State University of New Jersey, has broad experience in the performance of studies of potential environmental impacts associated with the construction and operation of energy facilities. The Center has published reports on coastal dune management, dredge spoil disposal siting, ecological research on the Pine Barrens and environmental effects of Outer Continental Shelf oil and gas exploration, among many other subjects. Some past clients include the National Park Service and New Jersey's Department of Environmental Protection and Department of Energy. Staff members of the Center for Coastal and Environmental Studies contributed to the multi-volume report entitled "The Delaware Estuary System; Environmental Impacts and Socioeconomic Effects of a Deepwater Oil Terminal."

Dr. Harold H. Haskin: **Chairman, Oyster Culture Department, New Jersey Agricultural Experiment Station, Rutgers - The State University of New Jersey**

Dr. Harold H. Haskin is presently Professor of Zoology, and Chairman of the Department of Oyster Culture at the N.J. Agricultural Experiment Station, Rutgers -The State University of New Jersey. His work with oysters in Delaware Bay started during his undergraduate years at Rutgers. After receiving his Ph.D. from Harvard University, in 1941, he served for five years in the United States Army. Before coming to Rutgers University he worked in the coastal oceanography program at the Woods Hole Oceanographic Institution. He teaches graduate courses in estuarine ecology, malacology and coastal oceanography. His research interests are in these same fields and are centered about shellfish of commercial importance, particularly oysters, hard clams and surf clams. He directs the work at two Rutgers laboratories in the Delaware Bay area - a year-round facility at Bivalve and a field station in Cape May County.

Dr. Richard I. Hires: **Associate Professor, Ocean Engineering Department, Stevens Institute of Technology**

Dr. Hires and his associates, Drs. George L. Mellor and Lie-Yauw Oey, both of Princeton University, are eminently qualified to perform trajectory projections for New York Harbor. Together they developed and tested a two-dimensional numerical model of circulation in the New York Harbor region. Its output has been checked against actual trajectories of dye spills in the region of interest with a resultant high degree of accuracy. Presently, they are engaged in the development of a fully three-dimensional, time dependent numerical model of this circulaton. This three-dimensional model may prove to be the most advanced numerical model ever applied to an estuarine region.

Dr. Allahverdi Farmanfarmaian: Professor, Department of Physiology, Rutgers - The State University of New Jersey

Dr. Farmanfarmaian is widely recognized for his work in the biochemistry and physiology of marine animals. He has published more than seventy papers, reports, presentations and reviews on the physiology, biochemistry, nutrition and aquaculture of, as well as environmental hazards to, marine animals. These papers and reports have included works on the effects of petroleum on aquatic animals, specifically in the Raritan Bay and other United States Atlantic coastal waters. He has acted as a consultant to the petroleum industry on the effects of oil transshipment on the marine environment. Currently, he is directing a National Oceanic and Atmospheric Administration research project on the sublethal effects of heavy metals on nutrient absorptions in fish from the New York Bight.

Enviro Sciences, Inc.: Denville, New Jersey

The staff of Enviro Sciences, Inc. possesses the requisite expertise to perform air quality evaluations in New York Harbor and Delaware Bay. Individually and collectively, members have been involved in federal and state permitting processes for proposed marine petroleum facilities in the Port of New York and in the Port of Philadelphia. Enviro Sciences, Inc. performed the air emissions studies leading to air quality permits for the construction of a refinery in Maine which would have had a marine crude oil receiving facility capable of handling Very Large Crude Carriers (VLCC's). The company has a good record of success in obtaining permits for petroleum facilities.

Dr. Kenneth N. Derucher: Professor, Civil Engineering Department, Stevens Institute of Technology

Dr. Derucher has earned high regard for his expertise in the area of analysis and design of bridge and pier protective fendering systems. He has developed a specialized dynamics oriented computer program which is capable of analyzing and designing bridge and pier protective systems rapidly and at relatively low cost. Among his previous clients are: the U.S. Coast Guard, Port Everglades, the Ports of New Orleans and San Francisco and the governments of Australia and Saudi Arabia.

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REPORT

TO THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY

Deepwater Port Study:

Biodegradation of Accidental Petroleum Spills in New York Harbor and Delaware Bay Now and After Completion of Bulk Oil Receiving Facilities

By

Dr. Richard Bartha

Department of Biochemistry and Microbiology

Rutgers University

New Brunswick, New Jersey 08903

INTRODUCTION

This report compares the biodegradation rates of accidentally spilled petroleum at locations and in volumes specified by the Port Authority under the present status (Status A) and after the projected construction of Bulk Oil Receiving Facilities in New York Harbor and Delaware Bay (Status B).

My report and calculations are based on an extensive literature review and on personal research experience in the oil biodegradation field. My report takes into consideration factors such as petroleum types and volumes, temperature, dissolved mineral nutrients, dissolved oxygen and populations of degrading bacteria. I believe it represents an assessment as realistic as possible short of performing an extensive experimental study. The primary aim of the report is *comparison* of two situations. Since the same set of assumptions is used in the assessment of Status A and B, the comparison is valid even if the absolute value of one of the parameters (e.g., the specific biodegradation rate of a petroleum) needs to be revised on the basis of direct measurements.

STATE OF KNOWLEDGE

The biodegradation of petroleum in the marine and estuarine environment was the subject of hundreds of scientific articles and reports. Major recent reviews summarizing this information were published by Atlas and Bartha (1973a), Crow et al. (1974), Hughes and McKenzie (1975), Bartha and Atlas (1977), Atlas (1977), Colwell and Walker (1977), Gutnick and Rosenberg (1977), Jordan and Payne (1980) and Atlas (1981). The National Academy of Sciences published a comprehensive report on "Petroleum in the Marine Environment" (NAS, 1975) and in connection with a current effort to update this report, I contributed a Background Paper "Fate of Petroleum in the Marine Environment: Microbial Metabolism" (Bartha, 1981, in press). This report is based primarily on the conclusions and generalizations about marine and estuarine petroleum biodegradation published in the above reviews.

Petroleums are extremely complex mixtures of aliphatic, alicyclic and aromatic hydrocarbons and of some non-hydrocarbon compounds such as naphthoic acids, phenols, thiols, heterocyclic nitrogen, sulfur and oxygen (NSO) compounds, as well as some metalloporphyrins (Atlas and Bartha, 1973a). The NSO compounds constitute the "resins"; the highly condensed and insoluble residue constitutes the ill-defined "asphaltene" fraction of the crude oils. Even when the most advanced techniques, such as computerized GC-MS analysis, are applied to petroleum (Pancirov, 1974), hundreds of its components remain unresolved and unidentified. According to their origin, crude oils vary greatly in composition and biodegradability. No crude oil is completely biodegradable, even under the most favorable conditions. The proportion of non-volatile components removable by biodegradation may vary, according to the nature of the petroleum, from as little as 11% to as much as 90% (Collwell and Walker, 1977). The "rate" of petroleum removal by biodegradation reflects the simultaneous or sequential removal of various components at various rates. Compared to measuring the biodegradation of a single chemically defined

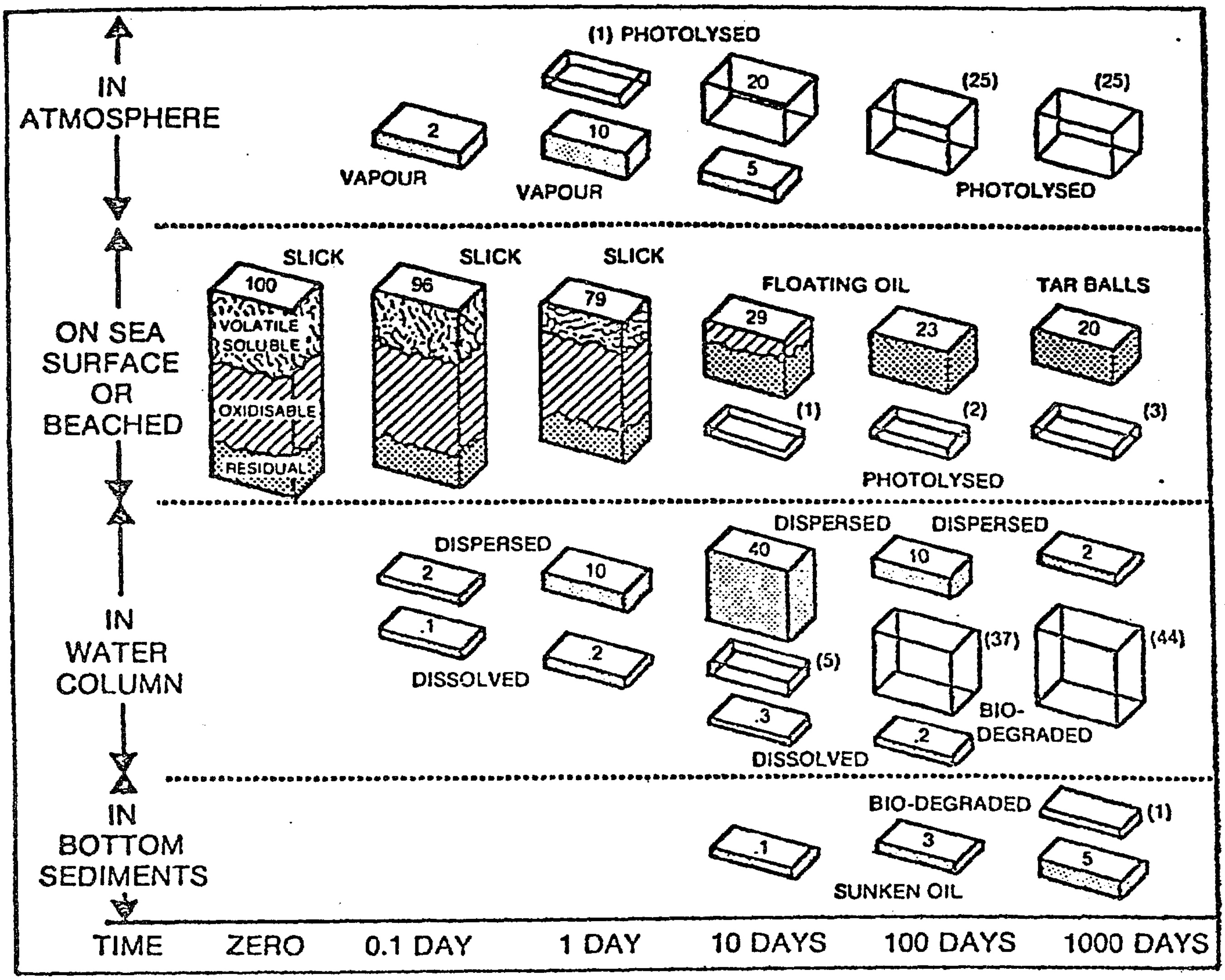

Figure 1. Speculative mass balance illustrating the distribution and conversion of an initial 100 volumes of oil at various times after spilling. Empty unshaded boxes represent oil converted to another chemical form. (Based on a similar diagram by J. N. Butler, Harvard University). From Mackay (1981).

organic substrate, the monitoring of petroleum biodegradation is a complex, demanding and relatively inaccurate procedure. It becomes necessary either to use relatively non-specific monitoring techniques such as CO_2-evolution, O_2-consumption, weight loss, etc. or, conversely, to follow the fate of individual hydrocarbons attempting to extrapolate from these results to the overall fate of the complex petroleum. Both approaches have obvious limitations. Nevertheless, all recent reviews agree that the non-volatile components of most crude oils are removed from the marine environment predominantly by the biodegradation mechanism. The mass balance of spilled oil (Mackay, 1981), for a speculative but representative case, illustrates the importance of biodegradation as one of the principal self-purification mechanisms of the marine environment (Fig. 1).

PETROLEUMS HANDLED

Under favorable environmental conditions, it is the composition of a crude oil that determines its biodegradability and the amount of tar residue. The data most commonly available for characterization of a petroleum (API gravity, pour point, sulfur content) are not very helpful for predicting biodegradability. The data sheets made available to me through the courtesy of Crude Assay Services, Analytical and Information Division, EXXON R&E, Florham Park, New Jersey, for each of the four major petroleum types handled in the Port of New York and in Delaware Bay, provide much more detailed information. Based on these data sheets (see Appendix), I have calculated and extrapolated the parameters of the four petroleums that are most critical in terms of their fate in the marine environment. These are summarized in Table I.

Some petroleums contain volatile bacteriostatic components that, at low water temperatures, may substantially delay the onset of biodegradation (Atlas and Bartha, 1972; Atlas, 1975). Saudi Arabian light petroleum has no such bacteriostatic components (Atlas, personal communication). For the other three petroleums this information is not presently available.

Table I. Critical parameters of the major petroleums handled in New York Harbor and Delaware Bay

Petroleum	Volatile or photodegraded (%)	Biodegradable (%)	Residual tar (%)
Saudi Arabian Light	25	55	20
Saudi Arabian Heavy	20	50	30
Nigerian Bonny Medium	15	55	30
Algerian Zarzatine	30	50	20

ENVIRONMENTAL CONDITIONS

Maximum and minimum average water temperatures (August and February, respectively) were set on basis of our own measurements (Atlas and Bartha, 1973b), supplemented by information from the New York City Division of Water Resources. Water temperatures in Delaware Bay were assumed to be similar on basis of geographic proximity and similar water exchange patterns. Abundance of oil-degrading microorganisms in New York Bay and Raritan Bay was measured by our research group (Atlas and Bartha, 1973b; Dibble and Bartha, 1976). Hydrographic conditions at the potential spill sites were determined from nautical maps. Existing pollution patterns including tar and oil deposits were personally observed in New York Harbor and Delaware Bay on previous sampling and field trips.

GENERAL ASSUMPTIONS

1) All crude oil spills are assumed to be Saudi Arabian Light. This is the predominant crude in New York Harbor, and a significant one in Delaware Bay. The best degradation data are available for this crude from the Amoco Cadiz spill (Amoco Cadiz Proceedings of the International Symposium, 1981, Ward et al., 1980). The other three oils (Arabian Heavy, Nigerian Bonny Medium and Algerian Zarzatine), as judged by their composition, will behave very similarly in terms of spreading, evaporation and biodegradation. The estimated differences, summarized in Table I, are within $\pm$ 10%. Since other factors introduce substantially larger uncertainties into the calculations, the very small differences that may occur in the behavior of the four major oil types were intentionally ignored.

2) One ml of a fresh crude spreads over 1 to 10 m^2 of water surface (Berridge et al., 1968). Since evaporation rapidly increases the viscosity of the spreading crude, the lower limit (1 ml/m^2) was assumed in my calculations. Biodegradation rates may be calculated from surface slick area (m^2), per water volume (ℓ) for suspended oil, or per sediment surface area (m^2) for beached oil. Initially, biodegradation will be calculated per m^2 surface area. The corresponding water volume based on a 1 mm layer is 1 ℓ (100 x 100 x 0.1 cm). The biodegradation rates of oil in oxidized sediments are generally higher as compared to rates for floating or suspended oil.

3) Perhaps the most crucial point of this study is to set the rate of crude oil biodegradation at a realistic level. Biodegradation rates are influenced by the nature of the crude oil, and by the prevailing environmental conditions such as temperature, mineral nutrients, dissolved oxygen, etc. In addition, the previous oil pollution history of an environment is also critical, especially for the early biodegradation phase of a slick. Based on an extensive literature review (Bartha, 1981, in press), I set the rate of Saudi Arabian light crude oil biodegradation at the highest expected water temperature (30°C) at 20 $\mu l/m^2$ slick/day or at a corresponding 20 $\mu l/\ell$/day in the water column. In comparable situations, the literature reports values between 0.5 and 60 $\mu l/\ell$/day. Given the relatively favorable biodegradation characteristics of Saudi Arabian light crude oil and the high environmental temperature, the assumed

20 $\mu l/\ell$/day seems to be a realistic figure, slightly on the conservative side. The 20 $\mu l/\ell$/day figure is referred to hereafter as the "base rate".

4) Temperature effects on biological processes are expressed by Q_{10} values. These express the acceleration of a process with a 10°C rise in temperature. For petroleum biodegradation, an average Q_{10} value of 2.7 was determined between 6 and 26°C (Gibbs et al., 1975; Gibbs and Davis, 1976). This means that petroleum would degrade 2.7-times faster at 20°C than at 10°C. The reverse is true when temperatures drop.

5) It is assumed that the spilled oil will exist as a floating slick until 10% of the total spill is biodegraded. At or around this time, the oil will be emulsified and dispersed in the water column. Biodegradation of the suspended oil continues in the water column at rates comparable to the surface slick biodegradation rates, until the "Biodegradable" portion is largely exhausted. In the early (slick) stage, biodegradation is favored by the availability of the most easily degraded hydrocarbons (*n*-alkanes) and by the direct contact with atmospheric oxygen, but limited by a low microbial population and low surface to volume ratio. In the later, (dispersed) stage, biodegradation is favored by a higher microbial population, and a higher surface to volume ratio, but is limited by the gradual exhaustion of the most easily degradable hydrocarbons and by the low amounts of dissolved oxygen in seawater. The shifting advantages and disadvantages largely compensate for each other and bring about a more or less steady rate of biodegradation. In narrow waterways subject to tidal fluctuations, a large portion of the oil is likely to "beach" during the floating slick stage. The beached oil will continue to biodegrade on aerobic sediment surfaces and at rates that are higher than in the water. Higher microbial numbers and greater availability of mineral nutrients cause the elevated biodegradation rates in aerobic sediments. Dispersed oil loses its tendency to beach in significant amounts.

UNITS

The specific weights of petroleums vary and tend to increase during biodegradation. Therefore, petroleum is always quantified in terms of volume.

$$1 \text{ gal} = 3.785\ \ell^{*} = 3{,}785 \text{ ml} = 3{,}785{,}000\ \mu l$$

Petroleum concentration is expressed per surface area.

m^2 = 1.196 sq. yards

ha = 10,000 m^2 = 2.47 acres

km^2 = 100 ha = 10^6 m^2 = 0.386 sq. miles.

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*ℓ is used as symbol for liter in order to avoid confusion with the number 1.

CALCULATIONS

New York Harbor, Refinery Piers, Arthur Kill, Saudi Arabian light crude, 336 gallon spills. Applies to Status A and B.

Covered water surface: 336 gal (3,785 ml x 336) = 1,271,760 ml; will cover at 1 ml/m^2 1,271,760 m^2 = 127.2 ha

Biodegradation at summer temperature, 30°C
Base rate: 20 μl/m^2/day at 30°C

Slick disappears: (100:20) in 5 days

Biodegradation complete: (550:20) in 27.5 days

Biodegradation at winter temperature, 3°C
Base rate: 20 μl/m^2/day at 30°C
Rate at 3°C: (30-3 = 27 x 0.27 = 7.29;
20:7.29) = 2.75 μl/m^2/day

Slick disappears: (100:2.75) in 36 days*

Biodegradation complete: in ∿ 100 days**

Expected tar residue: 67.2 gal (254.2 ℓ) per spill
Status A (5x) 336 gal/year Status B (2x) 134.4 gal/year

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* During the long slick stage, most of the oil is expected to beach in the narrow waterway.

**Because of the warming weather trend, biodegradation will accelerate with time. Biodegradation at a steady 3°C is calculated to be (550:2.75) 200 days.

New York Harbor, Stapleton Anchorage, Saudi Arabian light crude, 42 gallon spills. Applies to Status A and B.

Covered water surface: 42 gal (3,785 ml x 42 = 158,970 ml) will cover at 1 ml/m^2 158,970 m^2 = 15.9 ha

Biodegradation at summer temperature, 26°C
Base rate: 20 µl/m^2/day at 30°C
Rate at 26°C: (30-26 = 4 x 0.27 = 1.08;
20:1.08) = 18.5 µl/m^2/day

Slick disappears: (100:18.5) in 5.4 days

Biodegradation complete: (550:18.5) in 29.7 days

Biodegradation at winter temperature, 5°C
Base rate:20 µl/m^2/day at 30°C
Rate at 5°C: (30-5 = 25 x 0.27 = 6.75;
20:6.75) = 2.96 µl/m^2/day

Slick disappears: (100:2.96) in 33.8 days*

Biodegradation complete: in ~100 days**

Expected tar residue: 8.4 gal (31.8 ℓ) per spill

Status A (4x) 33.6 gal/year   Status B (2x) 16.8 gal/year

---

* Flushing by currents and beaching will remove visible slick before biodegradation could do so.

** Because of the warming weather trend, biodegradation will accelerate with time. Biodegradation at a steady 5°C is calculated to be (550:2.96) 186 days.

New York Harbor, Stapleton or Port Jersey Bulk Facility, Saudi Arabian light crude, 504 gallon spill. Applies to Status B.

Covered water surface: 504 gal (3,785 x 504 = 1,907,640 ml) will cover at 1 ml/m^2 1,907,640 m^2 = 1.9 ha

Biodegradation at summer temperature, 26°C
Base rate: 20 $\mu l/m^2$/day at 30°C
Rate at 26°C: (30-26 = 4 x 0.27 = 1.08;
20:1.08) = 18.5 $\mu l/m^2$/day

Slick disappears: (100:18.5) in 5.4 days

Biodegradation complete: (550:18.5) in 29.7 days

Biodegradation at winter temperature, 5°C:
Base rate: 20 $\mu l/m^2$/day at 30°C
Rate at 5°C: (30-5 = 25 x 0.27 = 6.75;
20:6.75) = 2.96 $\mu l/m^2$/day

Slick disappears: (100:2.96) in 33.8 days*

Biodegradation complete: in ~100 days**

Expected tar residue: 100.8 gal (381.0 ℓ) per spill (1X) 100.8 gal per year

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* Flushing by currents and beaching will remove visible slick before biodegradation could do so.

**Because of the warming weather trend, biodegradation will accelerate with time. Biodegradation at a steady 5°C is calculated to be (550:2.96) 186 days.

New York Harbor, Bergen Point, catastrophic underway spill, Saudi Arabian light crude, 1,680,000 gallons. Applies to Status A.

Covered water surface: (1,680,000 x 3,785) 6,358,800,000 ml, will cover at 1 ml/m^2 6,358,800,000 m^2 = 635,880 ha = 6,359 km^2

The physical confines of the waterway will not allow the slick to spread out to the 1 ml/m^2 distribution. The slick will form a bank-to-bank slug, too thick for effective biodegradation activity.

Biodegradation at summer temperatures, 26°C:

Dissolved oxygen in the shallow waters of Newark Bay, Arthur Kill and Kill Van Kull will be rapidly exhausted. The biodegradation of 1 gallon of oil would exhaust dissolved oxygen in about 400,000 gallons of Newark Bay water. The thickness of the surface slick and the anoxic conditions in the water column will render biodegradation essentially insignificant as an oil removal mechanism until well over 90% of the oil is beached and/or flushed out from the shallow water area. I have no way to calculate in this case the actual biodegradation rates. Slick removal will occur primarily by non-biodegradative mechanisms (evaporation, photodegradation, beaching and incorporation into bottom sediments). The biodegradation of the oil associated with oxygenated sediments and water will be near complete at the end of the summer season of the year following the spill (∿ 14 months). Localized oil accumulations (mousse and clumps) may persist considerably longer.

Biodegradation at winter temperatures, 5°C:

Biodegradation will be a negligible removal mechanism during the first 2-3 months following the spill. Anoxic conditions in the water column will develop in late March - early April, as water temperatures start to rise. Non-biodegradation mechanisms of oil removal will predominate until more than 90% of the oil is beached and/or flushed to deeper waters. Biodegradation of the oil in oxygenated sediments and water will be near completion by mid-summer of the year following the spill (∿ 18 months). Localized oil accumulations (mousse and clumps) may persist considerably longer.

Expected tar residue: 336,000 gallons (1,270,080 ℓ)

New York Harbor, Ambrose Channel Dogleg, catastrophic underway spill, Saudi Arabian light crude, 2,814,000 gallons. Applies to Status B.

Covered water surface: (2,814,000 x 3,785) 10,650,990,000 ml, will cover at 1 ml/m^2 10,650,990,000 m^2 = 1,065,099 ha = 10,650 km^2

Confinement of the oil slick by land is much less severe than in case of Status A. Completely anoxic conditions in the water column are less likely to develop. If the wind direction allows the seaward movement of the slick, biodegradation will substantially contribute to oil removal, but the actual biodegradation rate is very difficult to predict for the following reason:

The small spills (up to a few hundred gallons) were assumed to spread out ideally, forming an even, thin layer of 1 ml/m^2. With the low pour point oil in question this seems to be a valid assumption. The spreading process of a few hundred gallons of crude is complete within a few hours, a time period too short to cause drastic viscosity changes by evaporation. This is not the case if the spill size is increased to the million gallon range. The spreading process will take days, and during this period evaporation will drastically change viscosity properties. As a result, the oil will cover a much smaller than the ideally calculated area (over 10,000 km^2) but in much thicker layer. The reduced surface area of the oil slows the biodegradation process. I assume that the slowing effect is approximately five-fold. Unfortunately, the literature is of little help in this respect, and the above figure is little more than a guess.

Biodegradation at summer temperatures, 26°C:
Base rate: 20 $\mu l/m^2/day$ at 30°C
Rate at 26°C:(30-26 = 4 x 0.27 = 1.08; 20:1.08) = 18.5 $\mu l/m^2/day$

Slick disappears: (100:18.5 = 5.4 x 5) in 27 days

Biodegradation complete in approximately 1 year. Localized oil accumulations (mousse and clumps) may persist considerably longer.

Biodegradation at winter temperature, 5°C:

Biodegradation will be a negligible removal mechanism during the first 2-3 months following the spill. By the time the rising water temperature allows substantial biodegradation, the oil will be distributed to an extent that anoxic conditions are unlikely to develop. The slick will disappear by mechanisms other than biodegradation. Biodegradation of oil in oxygenated sediments and water should be near completion in one year. Localized oil accumulations (mousse and clumps) may persist considerably longer.

Expected tar residue: 562,800 gallons (2,127,384 ℓ)

Delaware Bay Refinery Piers, Saudi Arabian light crude, 630 gallon spills. Applies to Status A and B.

Covered water surface: (630 x 3785) 2,384,550 ml will cover at 1 ml/m^2 2,384,550 m^2 = 238 ha = 2.4 km^2

Biodegradation at summer temperatures, 26°C
Base rate: 20 μl/m^2/day at 30°C
Rate at 26°C :(30-26 = 4 x 0.27 = 1.08 ;
20:1.08) = 18.5 μl/m^2/day

Slick disappears: (100:18.5) in 5.4 days

Biodegradation complete: (550:18.5) in 29.7 days

Biodegradation at winter temperature, 5°C
Base rate :20 μl/m^2/day at 30°C
Rate at 5°C :(30-5 = 25 x 0.27 = 6.75;
20:6.75) = 2.96 μl/m^2/day

Slick disappears: (100:6.75) in 33.8 days*

Biodegradation complete: in ∿ 100 days**

Expected tar residue: 126 gal (476.3 ℓ) per spill

Status A (9x) 1,134 gal/year Status B (5x) 630 gal/year

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* Flushing by currents and beaching will remove the visible slick before biodegradation could do so.

** Because of the warming weather trend, biodegradation will accelerate with time. Biodegradation at a steady 5°C is calculated to be (550:2.96) 186 days.

Delaware Bay, Anchorage, Saudi Arabian light crude, 84 gallon spill. Applies to Status A and B.

Covered water surface: (84 x 3,785) 317,940 ml will cover at 1 ml/m^2 317,940 m^2 = 31.8 ha

Biodegradation at summer temperatures, 26°C
Base rate :20 $\mu l/m^2/day$ at 30°C
Rate at 26°C :(30-26 = 4 x 0.27 = 1.08 ;
20:1.08) = 18.5 $\mu l/m^2/day$

Slick disappears: (100:18.5) in 5.4 days

Biodegradation complete: (550:18.5) in 29.7 days

Biodegradation at winter temperature, 5°C
Base rate:20 $\mu l/m^2/day$ at 30°C
Rate at 5°C:(30-5 = 25 x 0.27 = 6.75;
20:6.75) = 2.96 $\mu l/m^2/day$

Slick disappears: (100:2.96) in 33.8 days*

Biodegradation complete: in ∿ 100 days**

Expected tar residue: 16.8 gal (63.6 ℓ) per spill

Status A (6x) 100.8 gal/year   Status B(2X) 33.6 gal/year

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* Flushing by currents and beaching will remove visible slick before biodegradation could do so.

** Because of the warming weather trend, biodegradation will accelerate with time. Biodegradation at a steady 5°C is calculated to be (550:2.96) 186 days.

Delaware Bay, Bulk Facility, Saudi Arabian light crude, 945 gallon spill. Applies to Status B.

Covered water surface: (945 x 3,785) 3,576,725 ml, covers at 1 ml/m^2
3,576,825 m^2 = 357 ha = 3.57 km^2

Biodegradation at summer temperature, 26°C
Base rate: 20 $\mu l/m^2$/day at 30°C
Rate at 26°C: (30-26 = 4 x 0.27 = 1.08;
20:1.08)= 18.5 $\mu l/m^2$/day

Slick disappears: (100:18.5) in 5.4 days

Biodegradation complete: (550:18.5) in 29.7 days

Biodegradation at winter temperature, 5°C
Base rate: 20 $\mu l/m^2$/day at 30°C
Rate at 5°C: (30-5 = 25 x 0.27 = 6.75;
20:6.75 = 2.96 $\mu l/m^2$/day

Slick disappears: (100:2.96) in 33.8 days*

Biodegradation complete: in ~100 days**

Expected tar residue: 189 gallon (714.5 ℓ) per spill (4X) = 756 gal/year

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* Flushing by currents and beaching will remove visible slick before biodegradation could do so.

** Because of the warming weather trend, biodegradation will accelerate with time. Biodegradation at a steady 5°C is calculated to be (550:2.96) 186 days.

Delaware Bay, Marcus Hook, catastrophic underway spill, Saudi Arabian light crude, 2,016,000 gallons. Applies to Status A.

Covered water surface: (2,016,000 x 3,785) 7,630,560,000 ml, covers at 1 ml/m^2 7,630,560,000 m^2 = 763,056 ha = 7,630 km^2

The physical confines of the waterway will not allow the slick to spread out to the 1 ml/m^2 distribution. The slick will form a bank-to-bank slug, too thick for effective biodegradation activity.

Biodegradation at summer temperature, 26°C:

Anoxic conditions are likely to develop in sections of the Bay and the River. In the narrow waterway, large amounts of oil will be deposited on shore. Biodegradation will not be a significant removal mechanism until 80-90% of the oil is removed from the spill area by flushing towards the open sea or by beaching. Oil biodegradation is expected to be near completion at the end of the summer of the year following the spill (∿ 14 months). Localized oil accumulations (mousse and clumps) will persist considerably longer.

Biodegradation at winter temperature, 5°C:

Biodegradation will be a negligible removal mechanism during the 2-3 months following the spill. Non-biological removal mechanisms (evaporation, beaching and tidal flushing) will remove much of the oil prior to the increase of water temperatures, and thus a winter spill is less likely to result in anoxic conditions in the water column. Biodegradation will be near completion at 18 months after the spill. Localized oil accumulations are likely to persist longer.

Expected tar residue: 403,200 gallons (1,524,096 ℓ)

Delaware Bay, point between the Capes, catastrophic underway spill, Saudi Arabian light crude, 2,814,000 gallons. Applies to Status B.

Covered water surface: (2,814,000 x 3,785) 10,650,990.000 ml, will cover at 1 ml/m^2 10,650,990.000 m^2 = 1,065,099 ha, = 10,650 km^2

Confinement of the spill here is less severe than in the Marcus Hook area. If the wind direction allows the seaward movement of the slick, biodegradation will contribute substantially to its eventual removal. For reasons discussed earlier (see similar spill in New York Harbor) slick thickness will be greater and biodegradation about five times slower than with smaller spills.

Biodegradation at summer temperatures, 26°C
Base rate: 20 ml/m^2/day at 30°C
Rate at 26°C: (30-26 = 4 x 0.27 = 1.08;
20:1.08) = 18.5 μl/m^2/day

Slick disappears: (100:18.5 = 5.4 x 5) in 27 days

Biodegradation complete in approximately 1 year. Local accumulations of oil may persist longer.

Biodegradation at winter temperature, 5°C

In the first 2-3 months after the spill, biodegradation will make little contribution to oil removal. With warming temperatures biodegradation will increase, but because of the greater oil thickness, its rate is expected to be about five times slower than for a small spill under comparable conditions. Biodegradation should be near completion at the end of the summer of the year following the spill (14 months). Local accumulations (beached mousse and clumps) may persist considerably longer.

Expected tar residue: 562,800 gallons (2.127,384 ℓ)

INTERPRETATION

General. Uncontrolled petroleum spills are generally more destructive in confined waters. Limited surface area and water volume lead to high local petroleum concentrations, oxygen depletion in the water column, extensive shore contamination and slow biodegradation. Conversely, the rapid dispersion of spilled petroleum from less confined waters tends to lower local concentrations, prevents depletion of dissolved oxygen and promotes biodegradation. Oil carried out to sea by wind and currents generally causes less ecological and economic damage than oil driven ashore or incorporated into shallow water sediments. From this point of view, it seems desirable to shift the location of potential spill incidents away from confined waters.

The above general statement, however, needs to be balanced in each case by the ecological and economic value of the areas that are likely to be impacted. An additional consideration is the effectiveness of spill containment and clean-up measures. In sheltered (confined) waters, spill containment measures by floating booms are quite effective, allowing the mechanical recovery of a large portion of the spilled petroleum. Containment of a spill is generally much more difficult in open waters, where wave and current action often renders floating barriers ineffective. As a result, in open waters, recovery can seldom mitigate the effects of petroleum spills, and slow natural processes need to be relied upon to effect eventual clean-up.

The specific spill areas in this report are considered primarily in terms of the biodegradation process and ease of spill containment. Other experts are addressing the distribution of a spill and its ecological and economic impacts.

New York Harbor, Arthur Kill - Kill Van Kull area. The Arthur Kill is a very confined waterway. Slow water movement results in summer (30°C) and winter (3°C) temperatures that are more extreme than at the other locations. A sizable spill will easily exhaust the scarce dissolved oxygen of the confined waters and much of the petroleum will be driven ashore. On the other hand, spill containment by floating barriers is relatively easy and effective. It is routinely used at refinery piers. The Kill Van Kull, though narrow, has fairly strong currents (up to 2.5 knots). Depending on the tidal cycle, a catastrophic underway spill may be flushed either into Newark Bay or through the Kill into the Upper and Lower Bays. The impact of such a spill would be severe. It would probably exceed preparedness for containment and clean-up. Self-purification would be exceedingly slow.

A transition from Status A to Status B will result in reduced number of spills around refinery piers and will lessen the chance of a catastrophic underway spill in the Kills. Mainly because of the latter, I consider Status B as an improvement from the environmental point of view.

Stapleton and Port Jersey region. These waters are more open, have better oxygenation and are subject to strong currents. Transition from Status A to Status B will reduce spills during barge transfer but will create the possibility of spills at the Bulk Oil Receiving Facility. From the environmental point of view, the overall change in this area is insignificant.

Ambrose Channel. A catastrophic underway spill in this area (Status B) would have less severe local effect as compared to a similar spill in the Kill Van Kull (Status A); but the slick will be widely distributed and it may affect ecologically and economically valuable areas. Whether or not this will be the case, depends strongly on the ebb-tide cycle and wind direction. Under favorable circumstances, the slick may be carried out to sea and cause little damage. Under less fortunate circumstances, large portions of the New York Harbor waterfront and/or the recreational New Jersey or Long Island shores may be affected. For self-purification by biodegradation, the Ambrose Channel location is more favorable than the Kill Van Kull. For containment and clean-up measures, both locations present problems.

Delaware Bay - Delaware River area. The changeover from the present Status A to Status B will reduce petroleum spills in the confined waters of the Delaware River at the various Refinery Piers and at the Anchorage site, but will increase them at the Bulk Oil Receiving Facility. Sizable spills in the confined waters of the Delaware River are likely to oscillate with ebb-tide cycles for a prolonged time period and would extensively contaminate shipping and port facilities. Anoxic water conditions may interfere with biodegradation. However, containment and clean-up of spills is relatively easy at the Refinery Piers.

Spills at the Bulk Oil Receiving Facility, located at the lower reaches of the Bay, may be carried out to sea or upriver, depending on the prevailing wind and tide. Economic damage from spills at this site is likely to be less as compared to a similar upriver spill. Biodegradation conditions are more favorable but containment and clean-up of a spill are more difficult at the Bulk Oil Receiving Facility.

A clear benefit of Status B as compared to Status A is the location of a catastrophic underway spill. Currently, such an event is likely to occur in the Delaware River, with highly destructive effects. During Status B, such an event would occur outside of the Bay or at its mouth. Depending on the tidal cycle, the spill may be carried out to sea or may move, at least in part, into the Bay. As compared to the certainty of heavy damage under Status A, Status B offers better biodegradation conditions and the prospect of more moderate economic damage.

CONCLUSION

Oil spills are destructive in any aquatic environment. When one compares their present locations (Status A) with projected sites under Status B, the tradeoffs in terms of affected areas, expected rates of biodegradation and the feasibility of pollution abatement measures are complex. After weighing these factors, it is my considered judgement that the projected facilities to be constructed under Status B in New York Harbor and in Delaware Bay will not worsen the present situation in terms of oil pollution. In respect of catastrophic underway spills, the existing situation will markedly improve.

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EXXON Crude Name: ARABIAN LIGHT Location: SAUDI ARABIA Assay Date: 11/76

	Crude	68/158 (°F)	158/302 (°F)	302/401 (°F)	401/700 (°F)	700+ (°F)	1049+ (°F)	
Gravity °API	33.4	85.5	62.3	49.7	36.6	16.1	6.9	
SpGr	.858	.652	.730	.781	.842	.959	1.022	
Sulfur, Wt%	1.79	.024	.026	.062	1.043	3.197	4.34	
Mercaptan Sulfur, ppm	70	173	108	44	64			
Salt, PTB	3							
Reid Vapor Pres., psi	3.6							
Kin Vis @ -30°F				3.93				
@ 60°F	12.29							
@ 100°F	6.25			.97	3.27	779		
@ 210°F				.54	1.27	34.5	1583	
Ethane, Vol%								
Propane, Vol%	.280							
Isobutane, Vol%	.270							
N-butane, Vol%	1.266							
Isopentane, Vol%	.870							
N-pentane, Vol%	1.651							
Yield, Wt%		3.87	10.54	9.88	29.54	44.94	17.72	
Vol%		5.08	12.32	10.80	29.96	40.00	14.80	
RON, Clear		63.0						
RON 1.5 cc TEL		76.5						
Paraffins, Vol%		94.1	71.0	58.9				80.2%
Naphthenes, Vol%		4.7	18.9	20.2				13.1%
Aromatics, Vol%		1.2	10.1	20.9				6.7%
Smoke Pt., mm				24.0				
Lum. No.				53.6				
Freeze Pt., °F				-90				
Cloud Pt., °F				-94	16			
Pour Pt., °F	-30			-100	10	40	115	
Diesel Index				66	58			
Refractive Index @ 67°C				1.417	1.452			
Concarbon, Wt%						8.46	20.3	
Vanadium, ppm						45.9	115.9	
Nickel, ppm						9.9	25.0	
Iron, ppm						45.4	114.0	
Neut. No., mg/gm	.14				.06	.28		

EXXON Crude Name: ARABIAN HEAVY Location: SAUDI ARABIA Assay Date: 7/76

	Crude	68/158 (°F)	158/302 (°F)	302/401 (°F)	401/700 (°F)	700+ (°F)	1049+ (°F)
Gravity °API	27.9	86.5	63.9	50.2	36.0	11.4	3.0
SpGr	.888	.649	.724	.779	.845	.990	1.052
Sulfur, Wt%	2.85	.006	.013	.099	1.401	4.49	6.0
Mercaptan Sulfur, ppm	10	10	9	5			
Salt, PTB	5						
Reid Vapor Pres., psi	7.5	12.3					
Kin Vis @ -30°F				3.77			
@ 60°F	48.09						
@ 100°F	18.99			.97	3.36	9918	
@ 210°F				.54	1.30	156.9	55268
Ethane, Vol%	.080						
Propane, Vol%	.788						
Isobutane, Vol%	.375						
N-butane, Vol%	1.390						
Isopentane, Vol%	.817						
N-pentane, Vol%	1.419						
Yield, Wt%		3.40	8.16	7.05	24.30	55.41	27.65
Vol%		4.63	9.94	7.98	25.39	49.41	23.19
RON, Clear		67.0					
RON 1.5 cc TEL		81.5					
Paraffins, Vol%		94.1	74.1	59.6			
Naphthenes, Vol%		5.3	18.7	21.6			
Aromatics, Vol%		.6	7.2	18.8			
Smoke Pt., mm				26.9			
Lum. No.				59.9			
Freeze Pt., °F				-86			
Cloud Pt., °F				-90	18		
Pour Pt., °F	-20			-95	10	70	135
Diesel Index				68	56		
Refractive Index @ 67°C				1.416	1.453		
Concarbon, Wt%						14.4	27.7
Vanadium, ppm						102	205
Nickel, ppm						32	64
Iron, ppm						15.2	30
Neut. No., mg/gm	.15					.64	

83.6%
12.1%
4.3%

EXXON Crude Name: Nigerian Medium-Bonny Location: Nigeria Assay Date: 4/71

	Crude	68/158 (°F)	158/302 (°F)	302/401 (°F)	401/700 (°F)	700+ (°F)	1049+ (°F)	
Gravity °API	25.5	78.8	52.8	40.6	28.2	15.6	6.6	
SpGr	.9018	.6730	.7677	.8222	.8862	.9622	1.0246	
Sulfur, Wt%	.210	.002	.004	.031	.132	.356	.651	
Mercaptan Sulfur, ppm	9	6	5	4	4			
Salt, PTB	1							
Reid Vapor Pres., psi	3.1	9.4						
Kin Vis @ -30°F				4.84	100.5			
@ 60°F	30.0							
@ 100°F	12.0			1.12	4.10	1432		
@ 210°F				.62	1.49	33.6	7769	
Ethane, Vol%	.10							
Propane, Vol%	.23							
Isobutane, Vol%	.13							
N-butane, Vol%	.29							
Isopentane, Vol%	.29							
N-pentane, Vol%	.28							
Yield, Wt%		.89	4.84	6.10	44.52	43.20	8.98	
Vol%		1.19	5.68	6.68	45.25	40.43	7.90	
RON, Clear		78.1						
RON 1.5 cc TEL								
Paraffins, Vol%		78.9	24.9	17.6				41.5%
Naphthenes, Vol%		18.2	62.9	65.8				49.3%
Aromatics, Vol%		2.9	12.2	16.6				9.2%
Smoke Pt., mm			24.7	19.8	10.8			
Lum. No.			53.5	43.5	21.1			
Freeze Pt., °F			-126	-105	2			
Cloud Pt., °F			-136	-115	-8			
Pour Pt., °F	-35		-141	-120	-13	71	120	
Diesel Index				47	37			
Refractive Index @ 67°C				1.432	1.473			
Concarbon, Wt%						4.27	18.0	
Vanadium, ppm						3.8	18.0	
Nickel, ppm						13.7	63.9	
Iron, ppm						34.0	159.7	
Neut. No., mg/gm	.69				.13	.45	.66	

EXXON Crude Name: Zarzaitine Location: Algeria Assay Date: 2/68

	Crude	68/158 (°F)	158/302 (°F)	302/401 (°F)	401/700 (°F)	700+ (°F)	1049+ (°F)	
Gravity °API	41.8	82.8	60.1	49.8	38.6	24.9	18.0	
SpGr	.8169	.6603	.7384	.7804	.8319	.9045	.9465	
Sulfur, Wt%	.070	.002	.004	.007	.030	.169	.270	
Mercaptan Sulfur, ppm	4	2	4	7				
Salt, PTB	9							
Reid Vapor Pres., psi	6.7	11.3						
Kin Vis @ -30°F				3.99	82.6			
@ 60°F	5.74							
@ 100°F	3.34			1.02	3.52	209		
@ 210°F				.57	1.32	15.8	163	
Ethane, Vol%	.11							
Propane, Vol%	.96							
Isobutane, Vol%	.48							
N-butane, Vol%	1.51							
Isopentane, Vol%	1.13							
N-pentane, Vol%	1.60							
Yield, Wt%		5.87	14.39	11.05	32.91	33.70	10.49	
Vol%		7.22	15.83	11.49	32.14	30.26	9.00	
RON, Clear		68.00						
RON 1.5 cc TEL		83.20						
Paraffins, Vol%		87.5	55.4	51.4				69.9%
Naphthenes, Vol%		11.0	37.3	33.3				25.4%
Aromatics, Vol%		1.5	7.3	15.3	17.7			4.7%
Smoke Pt., mm			36.9	27.1	19.2			
Lum. No.			82.3	61.4	43.0			
Freeze Pt., °F				-87	23			
Cloud Pt., °F				-91	19			
Pour Pt., °F	5			-97	14	90	65	
Diesel Index				69	65			
Refractive Index @ 67°C				1.415	1.444			
Concarbon, Wt%						2.67	7.90	
Vanadium, ppm						3.2	10.0	
Nickel, ppm						2.6	8.0	
Iron, ppm						10.8	34.0	
Neut. No., mg/gm	.10			.01	.04	.14	.14	

ENVIRONMENTAL IMPACTS

ASSOCIATED WITH A PROPOSED

CRUDE OIL RECEIVING FACILITY

WITHIN DELAWARE BAY

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FINAL REPORT

ENVIRONMENTAL IMPACTS ASSOCIATED WITH A PROPOSED CRUDE OIL RECEIVING FACILITY WITHIN DELAWARE BAY

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December 1981

This report was prepared by the Center for Coastal and Environmental Studies at Rutgers - The State University of New Jersey for the Port Authority of New York and New Jersey.

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EXECUTIVE SUMMARY

The Delaware Bay has been proposed as a possible site for the development of a bulk crude oil transfer facility. Such a facility is suggested as an alternative to a conventional deepwater port on the Atlantic coast of New Jersey. Existing port conditions are inadequate to accommodate modern tankers which require loaded drafts up to 90 feet without extensive dredging.

This study was designed to investigate the impacts from such a facility and its support structures (e.g., pipeline, pump stations, and tank farms) on the biological communities in the Delaware Bay estuary. An ecological characterization (Section I - Part A) has shown that the estuary is important to wildlife and man. Salt marshes, sand beaches/dunes, jetty/groin communities, and benthic and aquatic environments support a wide variety of life. They provide habitat, shelter, and food for wildlife. Many communities serve as migration areas, as well as breeding and nursery grounds.

Physically, the study area is composed of two geologic provinces and three morphologic zones (Section I - Part B). These areas are generally suitable for the development of crude oil pipelines, although active erosion along the Bay's coast will probably require burial to a depth greater than the normal industrial practice of three to ten feet as in the Gulf of Mexico. Deeper burial is required to ensure against the pipelines exposure during the operating lifetime. Selected burial depths will need to be determined on a site specific basis.

Oil spills represent a major threat to the Delaware Bay estuary. Section II of this study describes the physical and chemical parameters of oil spills and various scenarios to predict areas of high risk from the spills. Risk areas vary depending on current, longshore drift, season, wind direction, the size of the spill, and the type of oil spilled, among other variables. A spill of over two million gallons of crude oil would have devastating effects. Long term effects from chronic spills can be expected, although the exact nature of these effects is unknown.

Section III addresses impacts encountered with the construction of a pipeline. Impacts of a logistical nature will be encountered along the onshore segment of the pipeline which is proposed to extend from Big Stone Beach, Delaware to Marcus Hook, Pennsylvania. Also many environmentally sensitive areas are located along this route. Therefore, alternative routing alignments are suggested.

INTRODUCTION

The Delaware Bay is an intensively used area on the east coast of the United States. Recreation, fishing, and shipping are major economic activities which rely on direct use of the Bay. Petroleum refineries and other industries in the upper part of the estuary depend heavily on the access provided by the Bay and its navigation channel.

The importance of the Bay for the delivery and refining of petroleum products cannot be understated. Presently, more than one million barrels of oil a day are processed in the eight refineries in the region. Tankers of up to 135,000 DWT (deadweight ton) capacity bring the oil into the Bay. However, because the draft they require exceeds the depths of the main channel, the tankers must reduce their draft by pumping out part of their crude oil into barges, a process known as lightering. This results in a draft which is sufficient to allow them to proceed up the channel to the refineries.

This system, while currently economical because of the relatively low fixed costs, has several disadvantages associated with it. First, if the number of transfer operations increase, the probability of the occurrence of an oil spill increases (Gaither, 1981). The risk of oil spills is especially threatening to the fishing and recreation industries, as well as to the environmental integrity of the Bay. Second, a continued demand for oil would increase traffic in the already congested Bay.

An alternative oil transfer system has been proposed for the Delaware Bay, consisting of two single point mooring systems north of Big Stone Anchorage, and a pipeline to carry crude to the refineries. A system of this design will allow larger tankers to completely offload their cargo at one point, thereby reducing traffic in the Bay and the River, and reducing the potential for human error. Extensive deepening of the Bay for very large carriers would not be necessary.

The Delaware Bay consists of several biological communities, e.g., marshes, beaches, and benthic communities. These areas support wildlife by providing food and shelter. The Bay is also important for the fishing and shellfishing industries. Because the Bay is important to both wildlife and man, any activity which could disrupt or alter this estuarine system must be analyzed.

This report examines the impacts of a bulk crude oil transfer facility on the biological communities of the Delaware Bay estuary. Oil spill scenarios are used to indicated possible problem areas and to identify areas which are potentially at risk. Chronic low level spills and episodic, large spills are considered. The proposed onshore pipeline is reviewed to identify the issues which may be encountered. Alternative routing alignments are presented which demonstrate the trade-offs available to pipeline planners to mitigate conflicts which may arise.

SECTION I

ENVIRONMENTAL CHARACTERIZATION

Introduction

This section describes the biological and physical characteristics of the Delaware Bay estuary. Biologically, this area is composed of several different ecological communities: sand beach/dune, jetty/groin, marshes, and benthic and aquatic environments. These areas attract and support a wide variety of life by providing habitat, shelter, and food. The estuary also serves as a migration stop-over area, as well as breeding and nursery grounds. Physically, the study area consists of two geologic provinces and three morphologic zones. Climate is mainly maritime influenced.

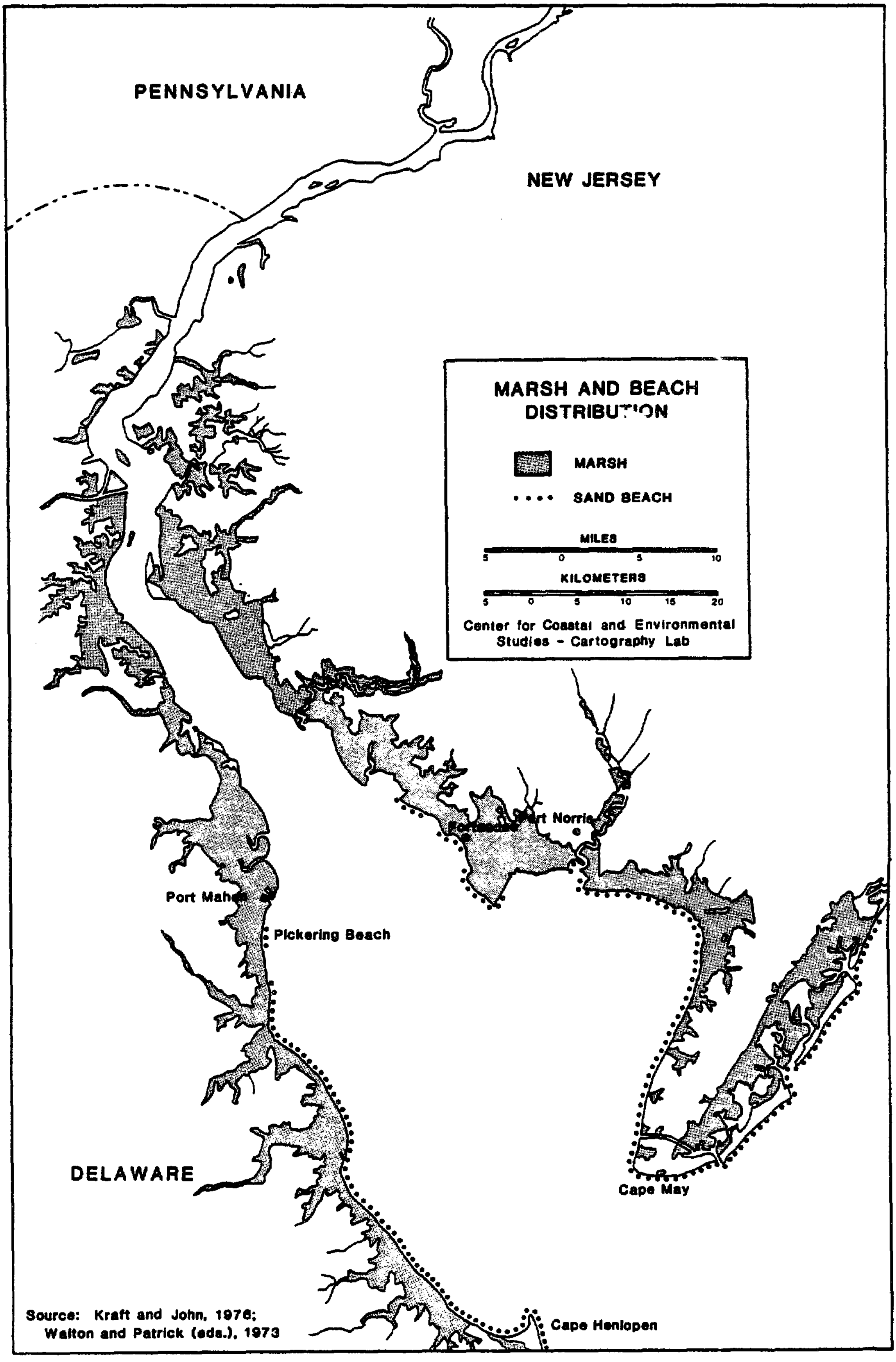
Part A. Biological Review

Sand Beach/Dune Communities

There are several sand beaches which front and/or interrupt marsh formations along both shores of the Bay (Figure 1). Delaware has a concentration of beaches along the southern shoreline from Pickering Beach to Cape Henlopen (U.S.A.C.E., 1968). The beaches and dunes become smaller proceeding up the coast until just south of Port Mahon, where marsh formation extends directly into the water. The beaches are about 3 - 15.2 m wide (at high tide) and are backed by dunes which are approximately 2.5 - 3.5 m high and 15 - 100 m wide (Drew, 1981). On the New Jersey Bay shore, there is a narrow stip of sandy beach from approximately Fortescue to Cape May. In the vicinity of Port Norris, the beach is discontinuous and marsh formation extends into the Bay (Walton and Patrick, eds., 1973).

There is very limited residential, commercial, or industrial development in the southern Bay area. In New Jersey, there are scattered residential developments in Cape May. In Delaware, there are several small coastal communities developed with small trailers, cottages, and houses along the southern Bay area. Most use occurs in the summer but Bower's Beach has a well established fishing community of 286 permanent residents, as of 1977 (Drew, 1981). Big Stone Beach, the landfall location of the proposed pipelines, has a developed section which extends about 0.8 km along the shore with 60 houses. Most of these dwellings are occupied only in the summer months (Drew, 1981).

The beaches are not vegetated due to the lack of stable substrate needed for plants to grow. However, in the intertidal areas of calm embayments green algaes such as Ulva lactuca and Enteromorpha spp. can be found (Maurer, 1974). The dunes are mainly stabilized with marram grass, Ammophila breviligulata, and woody plants, Baccharis halimifolia and Iva frutescens (Drew, 1981). Some dunes are also stabilized with reed grass, Phragmities communis. Maurer (1974) has recorded a sequential pattern of dune vegetation at Cape Henlopen: marram grass with a scattering of sea rocket (Cakile edentula) in the primary dune; the transition zone occupied by panic grass (Panicum virgatum),



PENNSYLVANIA
NEW JERSEY
MARSH AND BEACH DISTRIBUTION
MARSH
SAND BEACH
MILES
5 0 5 10
KILOMETERS
5 0 5 10 15 20
Center for Coastal and Environmental Studies - Cartography Lab
Fortescue
Port Norris
Port Mahon
Pickering Beach
DELAWARE
Cape May
Cape Henlopen
Source: Kraft and John, 1976; Walton and Patrick (eds.), 1973

Figure 1.

some marram grass, and seaside goldenrod (Solidago sempervirens); and the hollow, the area between the primary and secondary dunes, has beach heather (Hudsonia tomentosa) and seabeach orach (Atriplex arenaria).

The dunes harbor small mammals, rodents, insects, and a wide variety of birds, the most representative of which are the terns and sandpipers. Bird nesting sites occur between the primary and secondary dunes.

The beaches are inhabited by a wide range of fauna. However, most are not visible to the human eye. The bayside beaches also have more life forms than those on the oceanside because of the protected nature of the area (Maurer, 1974). The most visible beach life consists of the shorebirds which poke their bills in the wet sand searching for food and the horeshore crab, Limulus polyphemus, which visits one month out of the year to lay eggs. Along the drift line, beach hoppers and some marine insects are present.

Species within the sand and the infauna that live between the sand grains (interstitial species) account for most of the life forms along the beach. The large infauna include mole crabs (Emerita talpoida), numerous polychaete worms, nemerteans, acorn worms (Saccoglossus kowalewskii), and bivalves, such as Mercenaria mercenaria, Ensis directus, Tellina agilis, and Mulinia lateralis (Maurer, 1974). These infauna are specialized, having great burrowing capability or chemical secretions to build permanent burrows within the sand (Riedl and McMahan, 1974). The interstitial species have by far the greatest diversity and density within the beach system. It has been found that representatives of nearly all the main groups of invertebrates have adapted to this environment (Riedl and McMahan, 1974). The dominant biota include diatoms, cilliates, tardigrades, turbellarians, gastrotrich, gnathostomulids, copepods, nemotodes, harpacticids, and kinorhynchs.

These macro- and micro-infauna are important food sources for various organisms. They also form an extensive food filtering system and are important in the breakdown of organic compounds (Riedl and McMahan, 1974). However, knowledge of the dynamics and energy flows within the beach environment is largely unsolved.

Jetty/Groin Communities

There are several jetties and numerous groins in the Bay. Besides providing protection for the shoreline, these structures also provide substrate for flora (e.g., algae) and fauna (e.g., amphipods and hydroids) to grow (Zanaveld, 1972; Maurer and Walting, 1973). Growth on the structures resembles the zonation common to rocky shorelines. The uppermost zone consists of blue-green algae (Calothrix crustacea, Oscillatoria princeps, and Lyngbya spp.), followed by green algae (Enteromorpha spp. and Ulothrix flacca) and invertebrates such as isopods and littorine gastropods. Barnacles (Balanus balanoides) dominate the next zone changing to blue mussels (Mytilus edulis) with brown algaes (Fucus spp.) below. Occurrence of species variety fluctuates with the seasons, summer being the time of greatest development (Maurer, 1974).

Marshes

Delaware's and New Jersey's Bay shorelines are lined with tidal marshes (Figure 1). Field studies completed for the National Science Foundation-

RANN Program indicated that there were approximately 92,700 acres of marsh along the western shore of New Jersey from Camden to Cape May and approximately 81,800 acres on the Pennsylvania/Delaware shoreline from Philadelphia to Cape Henlopen (Walton and Patrick, eds., 1973).

The type and distribution of emergent vegetation is dependent mainly on tidal inundation, drainage, and salinity of water, sediment, and soil. These factors cause both lateral and upstream zonation creating salt, brackish, and freshwater tidal marshes. In disturbed areas of ditching, channelizing, and filling, there are growths of reed grass (Phragmites communis), groundsel bush (Baccharis halimifolia), or high tide bush (Iva frutescens) (Walton and Patrick, eds., 1973). The predominant tidal marsh plants of the area are listed in Table 1.

Freshwater tidal marshes are located north of Salem, New Jersey and Wilmington, Delaware with common species being American three-square (Scripus americanus, Olney's three-square (S. olneyi), smartweed (Polygonum punctatum), wild rice (Zizania aquatica), arrow-arum (Peltandra virginica), spatterdock (Nuphar advena), and species of pickerel weed (Pontederia). spiked loosestrife (Lythrum), sedge (Eleocharis), and arrowhead (Sagittaria) (Daiber, et al., 1976; Walton and Patrick, eds., 1973). In the lower estuary, where salt marsh vegetation is dominant, freshwater species also occur. Zizania and cat tails (Typha spp.) grow around regions influenced by freshwater streams. Around impoundment areas, salt marsh vegetation is reduced and replaced with pondweed (Potamogeton spp.), widgeon grass (Ruppia maritima), Typha, wild millet (Echinoclva), and muskgrass (Chara spp.) (Daiber, et al., 1976).

The lower shorelines of the bay are dominated by salt marsh vegetation. Cordgrass (Spartina alterniflora) occurs nearest the water's edge, in tall form, followed by short form up to the mean high water mark (Moul, 1973). Behind the cordgrass stands, where the area is subject to higher tides, salt marsh hay (S. patens) and spike grass (Distichlis spicata) dominate. Proceeding farther inland to higher elevation, the soils become drier and groundsel bush and high tide bush are interspersed among the grasses. These species represent the upper limit of the salt marsh. Next is the transition zone where drainage patterns extend far inland and water becomes essentially fresh. This area has no predominant vegetation but has plants characteristic of both fresh and salt water.

The plants of the tidal marshes, along with the phytoplankton within the tidal creeks and edaphic algae on the mud surfaces, are primary producers and are therefore the foundation of the total estuarine productivity. Primary production is the amount of plant material made within a growing season. These plants are utilized mainly as a food source after they are chemically broken down (decomposed) by bacteria and fungi. Spartina has proven to be especially important for primary productivity. Phragmites communis, Iva frutescens, and Baccharis halimifolia do not have much nutritive value but are important as nesting and shelter areas (Daiber, et al., 1976).

The important aspects of the tidal marshes are well documented. They provide food and shelter for wildlife, serve as migration stop-over areas, and spawning and nursery grounds. They also act as a buffer against floods and washover and serve as a sediment trap and water quality purifier.

The marshes harbor many invertebrates, birds, and small mammals. Maurer

Table 1. Common tidal plants of Delaware Bay/Lower Delaware River.*

Genus and species	Common name
Acnida cannabina	water hemp
Acorus calamus	sweetflag
Ambrosia trifida	ragweed
Baccharis halimifolia	marsh elder
Distichlis spicata	spikegrass
Hibiscus palustris	marsh mallow
Impatiens capensis	touch-me-not
Iva frutescens	high tide bush
Juncus gerardi	black grass
Jussiaea repens	water primrose
Lythrum salicaria	spiked loose strife
Nuphar advena	spatterdock
Panicum virgatum	switchgrass
Peltandra virginica	arrow arum
Phragmites communis	reed grass
Pluchea purpurascens	salt marsh fleabane
Polygonum punctatum	swartweed
Pontederia cordata	pickerel weed
Sagittaria latifolia	arrowhead
Salicornia europaea	samphire
Scripus americanus	three-square rush
S. olneyi	Olney's three-square
Spartina alterniflora	salt marsh cordgrass
S. cynosuroides (Linnaeus)	big cordgrass
S. patens (Aiton)	salt hay
Typha angustifolia	cat tail (narrow leaved)
T. latifolia	cat tail (broad leaved)
Zizania aquatica	wildrice

*Sources: Daiber, et al., 1976 and Walton and Patrick, eds., 1973.

and Wang (1973) have a comprehensive list of many of the marsh inhabitants. Snails (Melampus and Littorina), fiddler crabs (Uca spp.), and marsh crabs (Sesarma spp.) are found in the lower marsh zones feeding directly on Spartina. The grasses are also utilized by many avian species for food, shelter, and nursery grounds and include clapper rails, seaside sparrow, red winged blackbirds, sharptailed sparrows, and willets. Some of the birds also prey on the invertebrates and insects within the marsh.

Birds are the most characteristic inhabitants of the marsh areas. The most familar are the migratory species. The Delaware Bay is situated along the major flyways of the North American continent and therefore, the marsh areas are highly utilized by migrating species. These include mallards, pintails, blue and green winged teals, black ducks, gadwalls, and Canada geese.

Small mammals such as meadow mouse and muskrat occupy the brackish marsh areas. Raccoons, opposums, woodchucks, weasels, foxes, deer, and rabbits are essentially upland creatures but are known to roam into the wetland areas in search of food.

Benthic Communities

The Delaware Bay benthic community contains an abundance of invertebrate life, some of which is commercially important. Oysters, blue crabs, and hard clams are those that have significant resource value to commercial and recreational fishermen.

Blue crabs (Callinectes sapidus) have a wide salinity range and are found throughout the estuary (Figure 2). The life cycle of the blue crab is carried out in varying salinities (Beccasio, et al., 1980). In the spring they move to low salinity waters and mate from spring to early fall. Females then migrate to higher salinity areas to hatch their young. Within 15 days the young hatch and return to lower salinity waters. Inshore the crabs mature within 12 to 14 months.

Commercial crabbers follow the life cycle patterns of the crabs. In the summer they are potted in shallow waters and during the winter they are dredged. Recreational crabbing is restricted to shallow water locations. In 1980, Delaware harvested 38,450 bushels which was valued at $642,643 (Rick Cole, personal communication). In New Jersey, a total of 29,500 bushels of hard shelled and a total of 60,160 individual soft shelled crabs were caught in 1980 (L. Garrison and J. Dobarro, personal communication).

Oysters (Crassostrea viginica) occur on three types of beds - natural seed beds, planted beds (Leased Oyster Grounds), and adjacent river beds (Maurer and Watling, 1973) (Figure 3). In Delaware, oysters are located from Woodland Beach to Big Stone Beach, with 7,417 acres of leased beds, and are also found in the Broadkill, Mispillion, Murderkill, and St. Jones Rivers (Daiber, et al., 1976; Maurer and Watling, 1973). On the New Jersey side, there are approximately 650,000 acres of natural and planted beds from the vicinity of Arnold Point to Cape May, close to the mouth of the bay. The adjacent river beds are located in Maurice River, Dividing Creek, Nantuxent Creek, Beach Creek, West Creek, and 18 other small creeks (Caruso, 1981). Those in the creeks and rivers extend upstream for 4,000 yards (Maurer and Watling, 1973).

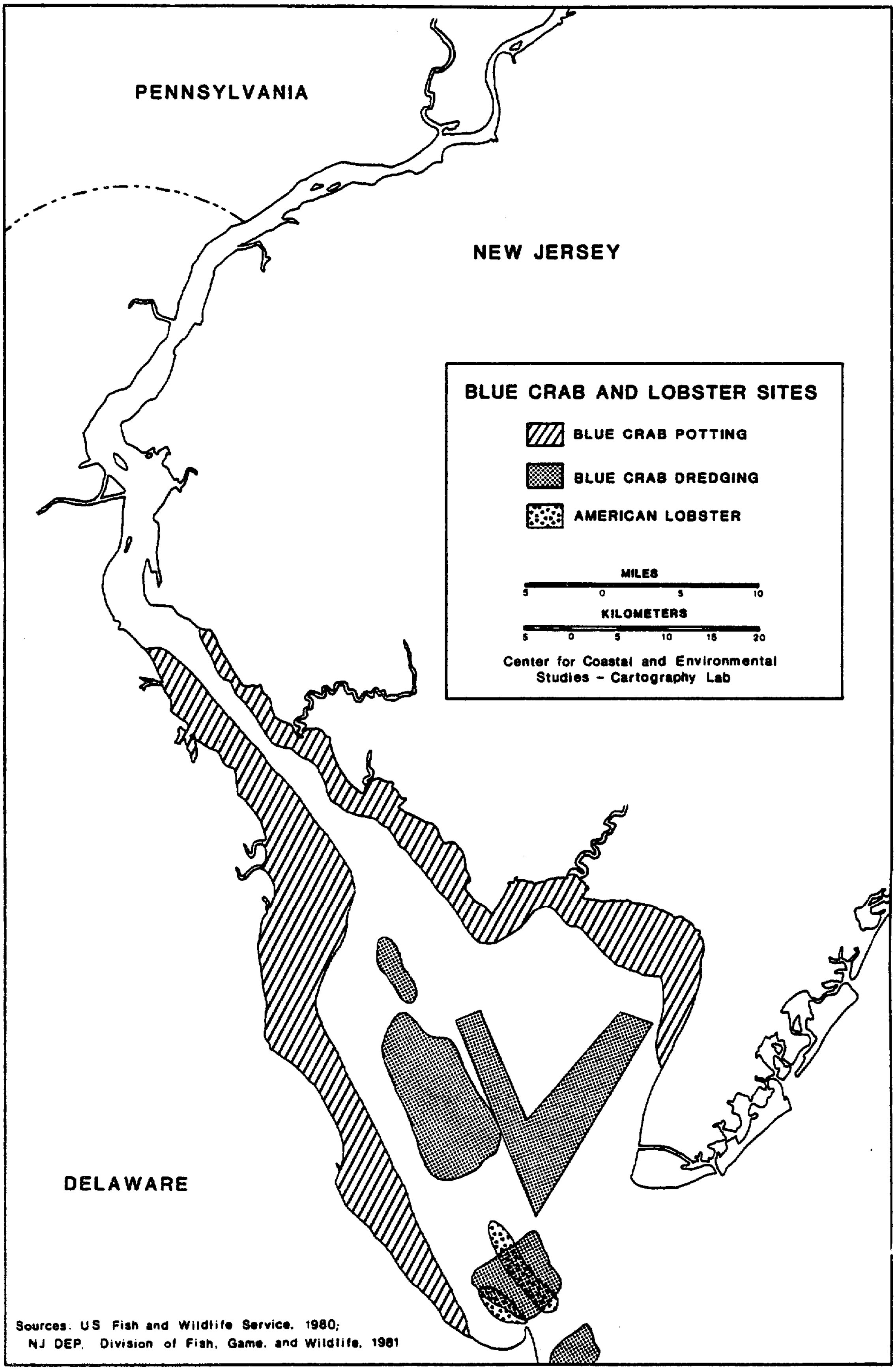

PENNSYLVANIA
NEW JERSEY
BLUE CRAB AND LOBSTER SITES
BLUE CRAB POTTING
BLUE CRAB DREDGING
AMERICAN LOBSTER
MILES
5 0 5 10
KILOMETERS
5 0 5 10 15 20
Center for Coastal and Environmental Studies - Cartography Lab
DELAWARE
Sources: US Fish and Wildlife Service, 1980; NJ DEP, Division of Fish, Game, and Wildlife, 1981

Figure 2.

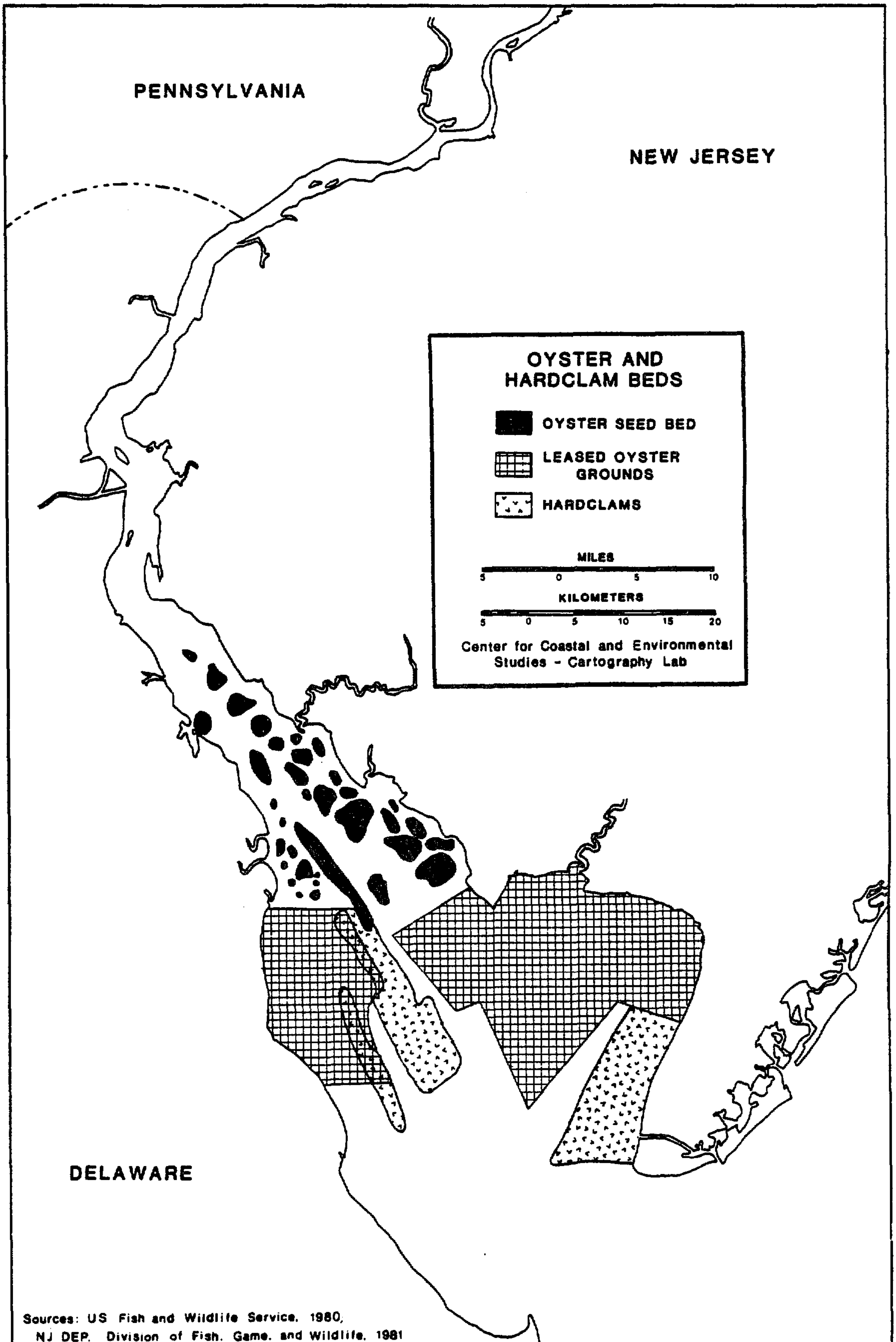

PENNSYLVANIA
NEW JERSEY
OYSTER AND HARDCLAM BEDS
OYSTER SEED BED
LEASED OYSTER GROUNDS
HARDCLAMS
MILES
5 0 5 10
KILOMETERS
5 0 5 10 15 20
Center for Coastal and Environmental Studies - Cartography Lab
DELAWARE
Sources: US Fish and Wildlife Service, 1980,
NJ DEP, Division of Fish, Game, and Wildlife, 1981

Figure 3.

Oysters spawn during the summer and hatch within six to 14 days. Free swimming larvae then settle and attach to hard substrates. They are suitable for harvesting within three to five years. The harvest season usually extends from November to April. In Delaware, oyster landings for 1980 amounted to $822,150 for 91,350 bushels. In New Jersey, the seed bed production amounted to 434,270 bushels; the market harvest figures were valued at $5 million (N.J. DEP, Division of Fish, Game and wildlife, 1981).

There are also 154 invertebrate species associated with oyster beds and they are listed and described in Maurer and Watling (1973). The top 23 species in order of decreasing frequency of occurrence are: Sabellaria vulgaris (polychaete), Conopeum tenuissimum (ectoproct), Panopeus herbsti (crab), Nereis succinea (polychaete), Palaemonetes vulgaris (shrimp), Crassostrea virginica (oyster), Nassarius obsoletus (mud snail), Polydora websteri (polychaete), Membranipora tenuis (ectoproct), Garveia fransiscana (hydroid), Balanus improvisus (barnacle), Diadumene leucolena (sea anemone), Aiptasiomorpha luciae (sea anemone), Melita nitida (amphipod), Obelia longicyatha (hydroid), Alcyonidium polyoum (ectoproct), Sertularia argentea (hydroid), Crangon septemspinosa (shrimp), Hydroides dianthus (polychaete), Eurypanopeus depresses (crab), Modiolus demissus (ribbed mussel), Parapleustes sp. (amphipod), and Hartlaubella gelatinosa (hydroid). The diversity of species decreases up the bay.

Hard clams or quahog (Mercenaria mercenaria) are located in the lower section of the bay in high salinity waters (greater than 15 parts per thousand) (Figure 3). They spawn in the summer and after two to three weeks the larvae settle mainly in shallow waters. In two to three years they reach commercial size. Even though they may be harvested year round they are mainly gathered in the summer months. New Jersey does not harvest hard clams from the bay since the clam bed location is in an area which is closed to shellfishing. Delaware does harvest hard clams, but a 1971 survey has shown a serious depletion in population (Daiber, et al., 1976). Commercial landings for hard clams were not available.

Hard clam areas also have an associated fauna. Large whelks (Busycon carica and B. canaliculatum), sea star (Asterias forbesi), horseshoe crab Limulus polyphemus), rock crab (Cancer irroratus), and spider crab (Libinia emarginate) occur in abundance (Maurer, 1974). Horseshoe crabs also provide substrate for smaller invertebrates such as blue mussels (Mytilus edulis), slipper shells (Crepidula plana, C. convexa, and C. fornicata), ectoprocts (Conopeum tenuissimum and Membranipora tenuis), and polychaetes (Sabellaria vulgaris). Hermit crabs (Pagurus longicarpus and P. pollicaris) utilize empty whelk shells. Hydroids (Sertularia agentea, Garveia franciscana, Obelia spp., and Tubularia crocea) were found attached to dead clam shells.

American lobsters (Homarus americanus) (Figure 2) are found mainly at the Delaware breakwater off Cape Henlopen (Beccasio, et al., 1980) but have been known to extend at least eight miles up the bay on hard sand and rock bottoms in deep channels, e.g., the channel between Old Bare Shoal and the Lower Middle Shoal (Winget, et al., 1971).

Special Status Species

Special status species are those fish and wildlife that are placed on Federal and/or State Endangered or Threatened Species lists. Species within the study area which have special status qualification include three fish, ten birds, two amphibians, and nine reptiles (Table 2). The decline in population of these species attributed to pollution, overhunting/fishing, and/or reduction in habitat, warrants their protection.

The anadromous shortnose sturgeon have been recorded in this area, but its distribution pattern, concentration, and spawning grounds are unknown (Dames and Moore, 1980). The Atlantic sturgeon has known spawning grounds along the New Jersey shoreline between Salem River and the Delaware Memorial Bridge (U.S. Fish and Wildlife Service, 1980). The American shad, listed as threatened in New Jersey, may be designated as endangered due to increasing pollution stresses (Dames and Moore, 1980). The shad utilizes the entire Bay and River during its migration runs.

The endangered and threatened birds include shorebirds, raptors, and wading birds. They nest in different communities of the Bay (Figure 4). Shorebirds, e.g., terns, nest on sandy beaches along the oceanside. Bald eagles, both residents and migrants, nest in tall trees that fringe marshes and tidal creeks. Peregrine falcons have no breeding populations in the area. Other raptors, the hawks and osprey, utilize marsh areas during migration and nesting seasons. Herons on the New Jersey State Threatened Species List nest in areas of northern Delaware and along the oceanside marshes of Cape May County.

Endangered and threatened reptile and amphibian sites, both aquatic and terrestrial, are limited. Those that are terrestrial are found mainly in the Pine Barrens of New Jersey. Pineland's habitat extends to the margins of the Bay so there are several restricted sites within the study area (Figure 5). The aquatic reptiles are all oceanic turtles and thus are not found within the study area. During the summer they deposit eggs along southern oceanside beaches of Delaware. These turtles are included because they could be impacted if a catastrophic spill occurred during the summer and spread to the oceanside beaches.

Aquatic Resources

Finfish

Over 150 species of fish are found in the Delaware Bay (Freeman and Walford, 1974). Over 60 species are known to spawn in the Bay (DeSylva, et al., 1962). The fish either spend their entire lives or part of their lives within the Bay, being anadromous, catadromous, or estuarine-dependent (Beccasio, et al., 1980) (Table 3).

Anadromous species, those that migrate from the ocean through the Bay to spawn in brackish or freshwater rivers, include alewife (*Alosa pseudoharengus*), American shad (*A. sapidissima*), blueback herring (*A. aestivalis*), white perch *Morone americana*), striped bass (*M. saxatilus*), and Atlantic sturgeon (*Acipencer oxyrhynchus*) (Daiber, et al., 1976). The Bay serves as a nursery ground for their juveniles.

Table 2. Species with special status in Delaware Bay Region[1].

Species	Federal Endangered	Federal Threatened	State Endangered	State Threatened
Fish				
Shortnose sturgeon	X		DEL	NJ
Atlantic sturgeon				NJ
American shad				NJ
Birds				
Least tern			NJ	
Roseate tern				NJ
Black skimmer			NJ	
Great blue heron				NJ
Yellow-crowned night heron				NJ
Bald eagle	X		DEL	
Osprey			NJ	
Peregrine falcon	X		DEL	
Cooper's hawk			NJ	
Marsh hawk			NJ	
Terrestrial Reptiles and Amphibians				
Bog turtle			NJ	
Eastern tiger salamander			NJ	
Pine Barrens tree frog			NJ	
Northern pine snake				NJ
Corn snake				NJ
Timber rattlesnake			NJ	
Aquatic Reptiles and Amphibians				
Green turtle[2]		X		DEL
Hawksbill turtle[2]	X		DEL	
Leatherback turtle[3]	X		DEL	
Loggerhead turtle[3]		X		DEL
Atlantic ridley turtle[3]	X		DEL	

[1]Source: Beccasio, et al., 1980.

[2]Oceanic summer visitor.

[3]Oceanic summer resident.

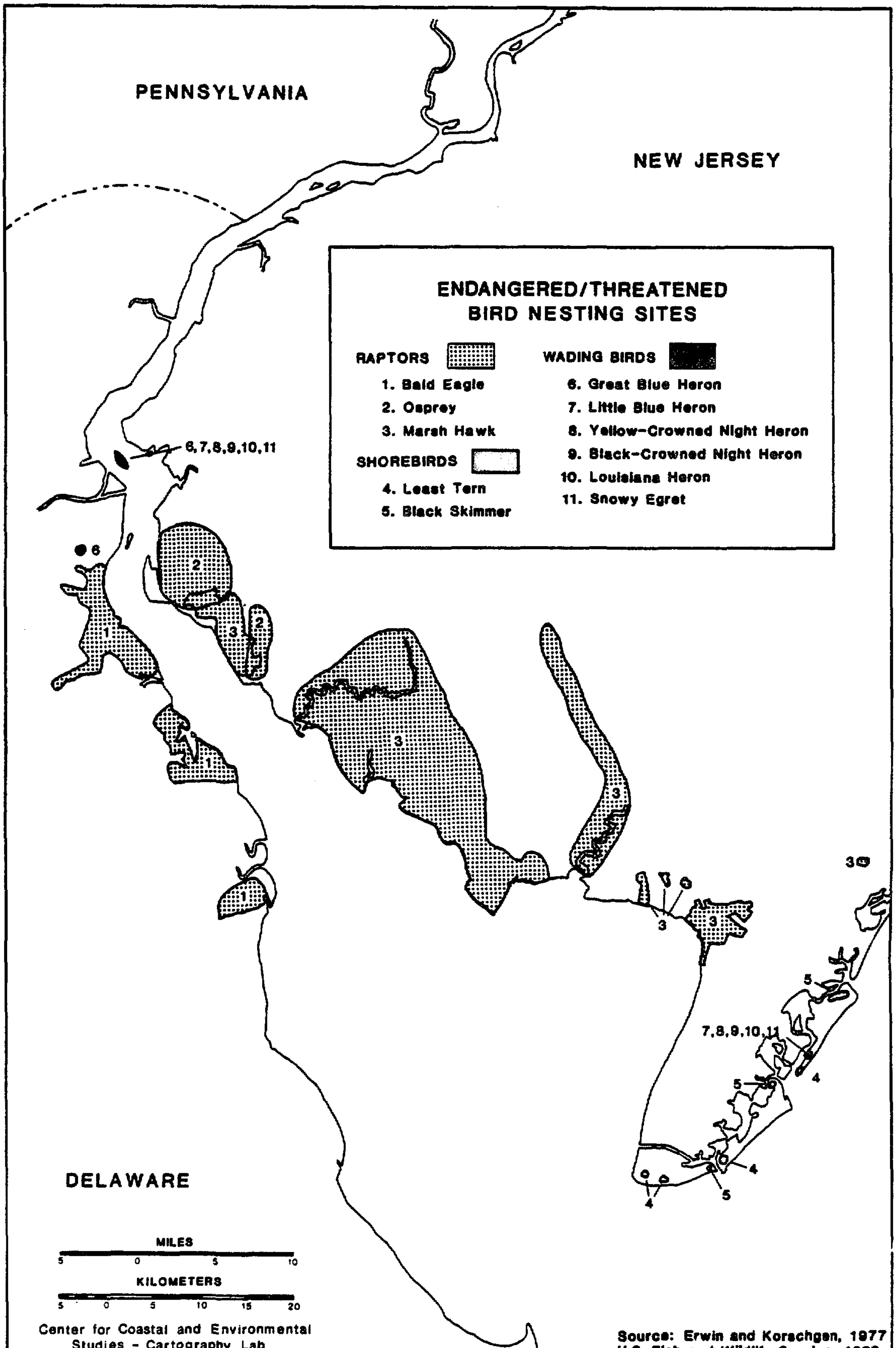

PENNSYLVANIA
NEW JERSEY
ENDANGERED/THREATENED
BIRD NESTING SITES
RAPTORS
1. Bald Eagle
2. Osprey
3. Marsh Hawk
SHOREBIRDS
4. Least Tern
5. Black Skimmer
WADING BIRDS
6. Great Blue Heron
7. Little Blue Heron
8. Yellow-Crowned Night Heron
9. Black-Crowned Night Heron
10. Louisiana Heron
11. Snowy Egret
6,7,8,9,10,11
7,8,9,10,11
DELAWARE
MILES
5 0 5 10
KILOMETERS
5 0 5 10 15 20
Center for Coastal and Environmental Studies - Cartography Lab
Source: Erwin and Korschgen, 1977
U.S. Fish and Wildlife Service, 1980

Figure 4

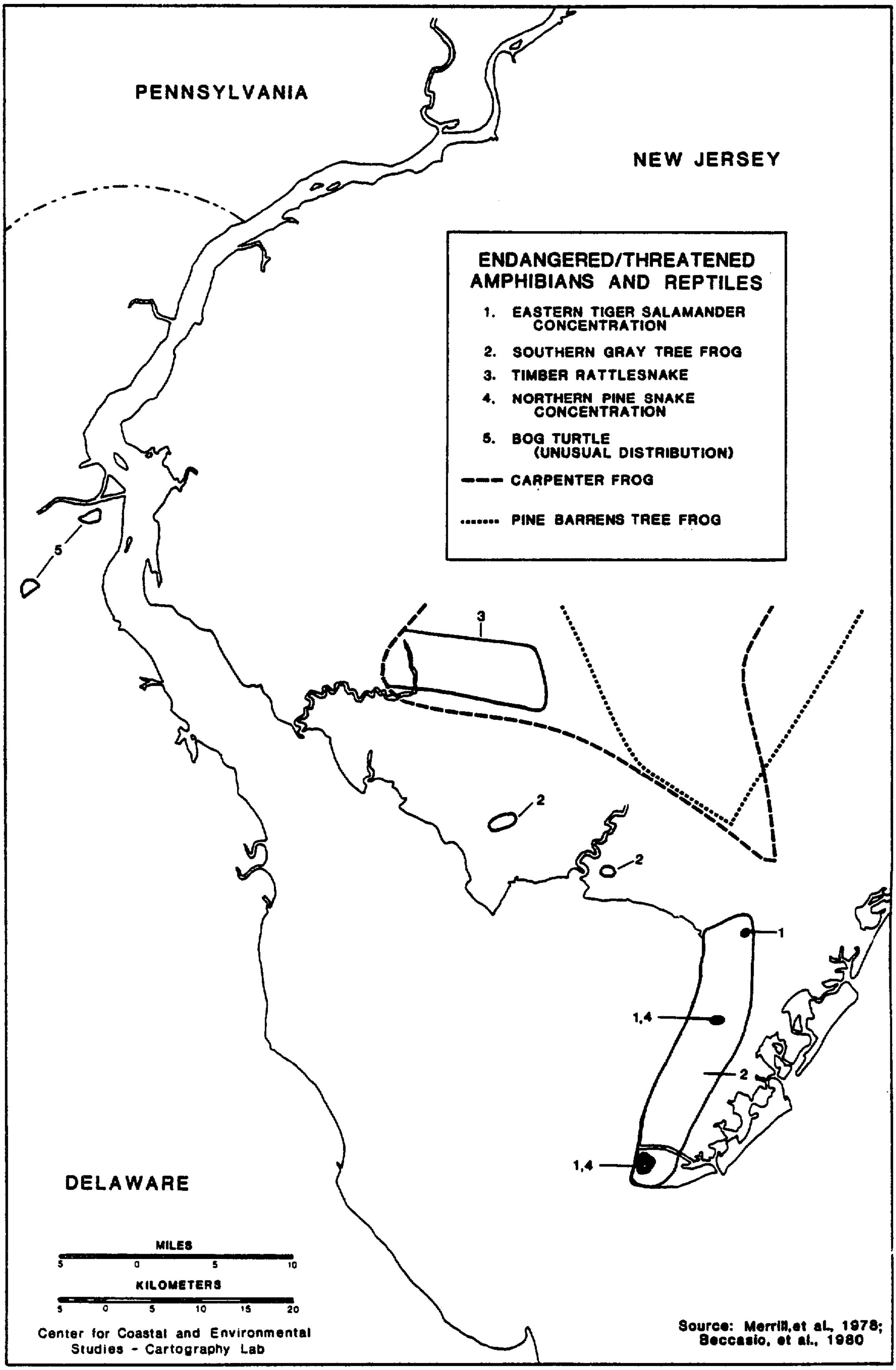

PENNSYLVANIA
NEW JERSEY
ENDANGERED/THREATENED AMPHIBIANS AND REPTILES
1. EASTERN TIGER SALAMANDER CONCENTRATION
2. SOUTHERN GRAY TREE FROG
3. TIMBER RATTLESNAKE
4. NORTHERN PINE SNAKE CONCENTRATION
5. BOG TURTLE (UNUSUAL DISTRIBUTION)
CARPENTER FROG
PINE BARRENS TREE FROG
DELAWARE
MILES
KILOMETERS
Center for Coastal and Environmental Studies - Cartography Lab
Source: Merrill,et al., 1978; Beccasio, et al., 1980

Figure 5·

Table 3. Common and/or important fish species of the Delaware Bay.[1]

Common and Scientific Name	Use of Delaware Bay Estuary migration/ period	spawn/ period	nursery	adult feeding	summering wintering
Clearnose Skate *Raja eglanteria*		lower bay/ spring		X	summering
Little Skate *Raja erinacea*		lower bay/ April-May; Nov.-Dec.		X	wintering
Atlantic Sturgeon *Acipenser oxyrhynchus*	anadromous/ early spring	brackish and fresh-water/April		X	
American Eel *Anguilla rostrata*	catadromous/ Aug.-Nov. to sea; April-May juveniles return			X	
Alewife *Alosa pseudoharengus*	anadromous/ April-May	freshwater and tidal creeks/ spring	nearshore of bay	X	some wintering
American Shad *Alosa sapidissima*	anadromous/ March-May	"	"	X	
Blueback Herring *Alosa aestivalis*	anadromous/ April-May	" not as far up as other herrings	"	X	
Atlantic Menhaden *Brevoortia tyrannus*		lower bay/ March-Oct.	nearshore of bay and tributaries	X	
Bay Anchovy *Anchoa mitchilli*		open waters of bay/May-Sept.	"	X	wintering
Channel Catfish *Ictalurus punctatus*		freshwater/ spring		found in FW[2] areas	
White Catfish *Ictalurus punctatus*		"		"	
Brown Catfish *Ictalurus nebulosus*		"		"	
Mummichog *Fundulus heteroclitus*		marshes/ spring and	X	X	year round resident
Striped Killifish *Fundulus majalis*		nearshore/ May-Aug.	X	X	"

Table 3 (continued).

Common and Scientific Name	migration/ period	spawn/ period	nursery	adult feeding	summering wintering
	Use of Delaware Bay Estuary				
Atlantic Silverside *Menidia menidia*		nearshore/ spring-summer	X	X	year round resident
White Perch *Morone americana*	anadromous/ spring	fresh and brackish/ spring	nearshore and tributaries	X	wintering
Striped Bass *Morone saxatilus*	anadromous/ spring	swift freshwater/ spring	nearshore of upper bay and lower river	X	wintering
Winter Flounder *Pseudopleuronectes americanus*			bottom nearshore of lower bay	X	wintering
Yellow Perch *Perca flavescens*	from brackish to FW[2]/ Feb.-March	shallow freshwater/ March-April			reside in tributaries of bay
Bluefish *Pomatomus saltatrix*				X	found spring - fall
Spot *Leiostomus xanthurus*		deepwater of lower bay/ Oct.-January	nearshore up to C & D canal	X	
Atlantic Croaker *Micropogon undulatus*		lower bay/ Aug.-Dec.	nearshore and tributaries up to C & D canal	X	
Weakfish *Cynoscion regalis*		southwestern section of bay/spring and summer	northern waters of bay	X	
Northern Puffer *Sphoeroides maculatus*		high salinity waters/late spring	X	X	year round resident in high salinty areas
Summer Flounder *Paralicthys dentatus*			nearshore, lower bay	X	summering
Hogchoker *Trinectes maculatus*		mouth of bay/July-Aug.	nearshore and tributaries of entire bay	X	year round resident

1. Sources: Daiber, et al., 1976; Kantor, 1977
2. FW = freshwater

The *Alosa* spp. **are** important sport, commercial, and forage species. Migrations start in the spring with the American shad arriving first, followed by the alewife, and then the blueback herring. It is during these spring migrations that they provide recreational fishing. After spawning, the adults leave the bay in the summer, but the young remain in low saline waters gradually moving downstream. In the fall the young return to the ocean (Beccasio, et al., 1980).

Some or all of the adult populations of white perch and striped bass live within the lower portions of the bay. Striped bass, however, are mainly in the open ocean during nonspawning periods. Migrations to tidal freshwater tributaries start in the spring. Suitable spawning grounds for striped bass have dwindled due to pollution. The major spawning ground of the striped bass has been reduced to the Chesapeake and Delaware Canal (Daiber, et al., 1976).

The Atlantic sturgeon's population has declined immensely in recent years (Daiber, et al., 1976). This species was commercially prized for its flesh and production of caviar, but now it is on the endangered list at the Federal level and considered threatened in New Jersey (Beccasio, et al., 1980). The sturgeon migrates to brackish and freshwater areas during April and May. The juveniles are thought to spend a number of years in the bay before returning to the open ocean.

The American eel (*Anguilla rostrata*) is a catadromous species. From August to November, migrations from freshwater to the ocean occur (Daiber, et al., 1976). It is presumed that they spawn in the Sargasso Sea during winter and then die (Beccasio, et al., 1980). Juveniles return to the Delaware Bay in mid-spring and mature for several years. Eels are caught from March to December with the most productive catch in the fall.

Estuarine-dependent species, those that spend some stage of their life within an estuary, make up the majority of ecologically, recreationally, and commercially important fisheries. Included in this category are weakfish (*Cynoscion regalis*), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogon undulatus*), Atlantic menhaden (*Brevoortia tyrannus*), bluefish (*Pomatomus saltatrix*), silver perch (*Bairdiella chrysura*), summer flounder (*Paralicthys dentatus*), and winter flounder (*Pseudopleuronectes americanus*). These species extensively utilize the bay area as spawning, nursery, and/or feeding grounds but as adults they are also found along the continental shelf (Beccasio, et al., 1980).

One of the most important commercial and recreational fishes of Delaware is the weakfish (Daiber et al., 1976). These fish migrate into the bay during April and May to spawn. The spawning occurs mainly in the southwest portion of the bay in an area south of the Mispillion River and west of the Ship Channel. Juveniles later move to less saline waters in marshes and along the bay shoreline.

The spot and Atlantic croaker spawn offshore but their juveniles utilize the shallow upper estuary marshes. Spot are in the marshes during the early spring and the croaker during early winter.

The weakfish, spot, and Atlantic croaker are taken by both commercial and sport fishermen during the spring through the fall. Best fishing areas tend to be in the high saline waters of the bay and coastal waters.

Atlantic menhaden is the most valuable finfish in New Jersey (Gef Flimlin, personal communication) and, in the Middle Atlantic Zone, has the highest commercial yield of any finfish or shellfish (Beccasio, et al., 1980). However, Delaware has virtually no landings of this finfish. The decline has been attributed to alteration of nursery areas and better fishing techniques which reduce adult populations (Daiber, et al., 1976). This species spawns in the ocean in winter, during March pre-juveniles move into the bay and remain throughout the summer. Juveniles inhabit low saline nursery grounds and move to more saline areas as they develop. Adults stay in the lower portion of the bay for most of the summer and, in October, move back to open waters with the juveniles.

Bluefish are found mainly in the open ocean for most of the year, but juveniles enter portions of the bay to mature in late summer. The adults also move inshore, but not as far upstream as the young. This species is most important as a recreational fishery and has a secondary importance as a commercial fishery.

Summer and winter flounders are commercially and recreationally important estuarine-dependent species. Summer flounders spawn offshore and the adults and juveniles move inshore during the spring and return to the ocean in late summer and fall. This species is fished throughout the year, with sport fishing occurring in the spring and fall and offshore commercial fishing during winter and early spring (Beccasio, et al., 1980). The winter flounder moves inshore during the fall, overwinters in the bay, and spawns in the shallows during January through March. The adults move back to deeper waters as water temperature increases but the juveniles remain.

Phytoplankton

Phytoplankton are minute plants that are found in all water systems, including the Delaware Bay and its tidal creeks. They contribute to the primary productivity of the estuarine system in that they are able to photosynthesize, fix carbon, and produce complex molecules. These organisms are eaten either by zooplankton or by planktivorous fish such as the shad.

Diatoms have been the phytoplankton most studied within the bay region. A general description of diatoms in the bay is in Maurer and Wang (1973). Obeng-Asamoa (1968) identified 139 species from Bombay Hook and 119 from Port Mahon. The most common species were *Acnanthes lanceolota*, *Nitzschia frustulum*, and *N. filiformis*. In a study done by Sullivan (1971) on edaphic diatoms in Canary Salt Marsh, Lewes, Delaware, 104 species were identified. The predominant forms were *Navicula*, *Nitzschia*, *Amphora*, *Denticula*, *Coscinodiscus*, and *Cymatosira*.

Dinoflagellates in the Bay have not been studied extensively. Research has dealt mainly with those species occurring in the ocean. Martin (1928, 1929) conducted studies of species in New Jersey's bays and estuaries. Forty one species were identified with Ceratium being the dominant genus. Other types present include Peridinium, Gymnodinium, Dinophysis, and Prorocentrum. Dinoflagellates occur throughout the year but are abundant during spring and summer.

Zooplankton

Zooplankton are microscopic animals comprised of many different kinds of organisms from many different systematic groups. They are an important link between the primary producers and the higher level consumers. They consume various plant material and in turn are preyed upon by fish and others.

It is difficult to say how many types are present since their numbers and distribution change yearly, seasonally, daily, and even hourly (Daiber, et al., 1976). Zooplankton have been studied in the Bay (Hulbert, 1957; Price, 1962; Cronin, et al., 1962; and Ferrante, 1971) so that an estimation of their types and distribution can be made (Table 4). Ten species, representing eight general, seem to be most common: Acartia tonsa, Eurytemora hirundoides, E. affinis, Pseudodiaptomus coronatus, Centropages typicus, C. hamatus, Temora longicornis, Cyclops viridis, Gammarus fasciatus, and Neomysis americana. A. cartia, Pseudodiaptomus, and Neomysis are distributed throughout most of bay, with distribution varying slightly with the seasons. Centropages and Temora are located in lower reaches of the bay with primary distribution in the ocean. Cyclops and Eurytemora are located in the upper reaches of the estuary, but Eurytemora extends to the lower bay during the winter.

An important characteristic is that they all have multiple spawning seasons (Daiber, et al., 1976), with some species producing as many as six new generations every year. Reproduction is active in spring and summer, which is synchronized with the occurrence of most biological activity.

Mammals

There are many mammals in the Delaware Bay region which have recreational and commercial value. Whitetail deer, eastern cottontail, gray squirrel, and eastern fox squirrel are hunted for sport. These animals mainly inhabit upland areas.

Furbearers include raccoon, oppossum, longtail weasel, striped skunk, gray fox, red fox, muskrat, river otter, and mink (Beccasio, et al., 1980). The river otter and mink are both important commercial species found in streams and marshes. The most valuable and numerous is the muskrat. It is found in tidal marshes. The muskrat's breeding season is from January to October, bearing several litters each year. Higbee Beach, New Jersey, has one of the most productive muskrat areas in the country, with more than one lodge per acre counted at Pond Creek Meadow (Beccasio, et al., 1980). In Delaware, Thousand Acre Marsh (St. Georges Creek) has high trapping value because it is a productive muskrat, otter, and mink area (Daiber, et al., 1976).

Table 4. Principal zooplankton in the Delaware Bay estuary.

Coelenterata
- *Aglantha digitale*
- *Bougainvillia* sp.
- *Nemopsis bachei*
- *Blackfordia virginica*
- *Dactylometra quinquecirrha*

Ctenophora
- *Beroe ovata*
- *Mnemiopsis leidyi*

Chaetognatha
- *Sagitta elegans*
- *Sagitta enflata*

Annelida
- *Autolytus cornutus*
- *Tomopteris* sp.

Arthropoda
- Crustacea
  - Cladocera
    - *Evadne nordmanni*
    - *Podon leuckarti*
    - *Penilia avirostris*
  - Copepoda
    - Calanoida
      - *Acartia tonsa**
      - *Centropages typicus**
      - *Centropages hamatus**
      - *Eurytemora hirundoides**
      - *Eurytemora affinis**
      - *Labidocera aestiva*
      - *Pseudocalanus minutus*
      - *Pseudodiaptomus coronatus**
      - *Temora longicornis**
    - Cyclopoida
      - *Corycaeus americanus*
      - *Cyclops viridis**
    - Harpacticoida
      - *Euterpina acutifrons*
  - Cirripedia
    - Barnacle larvae
- Mysidacea
  - *Neomysis americana**

Arthropoda (continued)
- Amphipoda
  - *Gammarus fasciatus**
- Isopoda
  - *Aega* sp.
- Decapoda
  - *Crangon septemspinosa*
  - *Callinectes sapidus*
  - *Pinnotheres maculatus*
  - zoea
  - megalops
  - caprellids

Chordata
- Tunicata
  - *Oikopleura dioica*
- Fish
  - Larvae of several species

*Indicates most common species

Source: Maurer, 1974.

Birds

Shorebirds, wading birds, waterfowl, songbirds, and raptors all utilize the bay area because of the available varied environments. The marshes provide excellent nesting and breeding areas for migratory birds. Delaware's major wading and shorebird nesting populations are listed on Table 5.

The most common shorebird species in the study area include greater and lesser yellowleg, short-billed dowitcher, several types of sandpipers (pectoral, least, stilt, semipalmated, and western), marbled godwid, blacknecked stilt, gulls and terns (Beccasio, et al., 1980). The more unusual tern species include the royal, caspian, black, and roseate, which is considered threatened in New Jersey.

An important shorebird habitat is Thousand Acre Marsh located in northern Delaware (Beccasio, et al., 1980). At South Cape May Beach, New Jersey, four nesting pairs of common terns and 100 nesting pairs of least terns were counted during 1977 (Erwin and Korschgen, 1979). In Delaware, 20 nesting pairs of least terns were located on Broadkill Beach while at Cape Henlopen State Park 11 nesting pairs of common terns, 92 nesting pairs of least terns, and eight nesting pairs of black skimmers were inventoried by air survey (Erwin and Korschgen, 1979).

During spring and fall, the marsh areas are occupied by many types of wading birds. The most conspicuous are the herons, egrets, and ibises which nest mainly on shrubs and trees. Other common wading birds are the king, clapper, and Virginia rails which frequent marshes for nesting during migration (Daiber, et al., 1976).

There were several important heron nesting sites found in Delaware during a 1977 survey conducted by Erwin and Korschgen (1979). Great blue heron nesting sites were located in woodland habitat near Milton (30 nesting pairs) and along Augustine Creek, south of Delaware City (142 nesting pairs). Pea Patch Island is one of the larger heronries in the Mid-Atlantic Zone and considered a unique breeding area of national significance (Beccasio, et al., 1980). The following nesting pairs were found: great blue heron (2), green heron (2), little blue heron (600), cattle egret (40,000), great egret (250), snowy egret (1,000), Louisiana heron (50), black-crowned night heron (400), Yellow-crowned night heron (40), and glossy ibis (700).

The Delaware River estuary is an important stop-over area during spring and fall migrations for waterfowl. Mallards and black ducks are the most abundant while Canada geese outnumber other geese (Beccasio, et al., 1980). Lesser scaup, redhead, canvasback, and ring-necked ducks are the most common diving ducks. Other waterfowl include pintail, American widgeon, green winged teal, gadwall, shoveler, snow goose, and brant (Daiber, et al., 1976). Also, a large population of loons and grebes remain in the Delaware Bay throughout the year (Beccasio, et al., 1980).

Bombay Hook is an important area for Canada geese with the population peaking at 50,000 (Beccasio, et al., 1980). Near Fortescue, New Jersey, a concentration of snow geese can be found during the winter until ice forces them to migrate south and then reappear in April.

Table 5 Waterbird nesting populations in Delaware during 1977.*

Species	Number of colonies	Total breeding pairs	Mean colony size
great blue heron	3	142	58
green heron	1	2	2
little blue heron	1	600	600
cattle egret	1	4,000	4,000
great egret	1	250	250
snowy egret	1	1,000	1,000
Louisiana heron	1	50	50
black-crowned night heron	1	400	400
yellow-crowned night heron	1	40	40
glossy ibis	1	700	700
herring gull	1	31	31
laughing gull	1	96	96
common tern	6	451	75
least tern	4	166	41
black skimmer	4	27	7

*Source: Erwin, 1979.

The wildlife and refuge areas are also important areas for raptors. The bay area provides a nesting habitat for the endangered bald eagle, with the best known pair nesting at Bombay Hook National Wildlife Area from early December to mid-May (Beccasio, et al., 1980). Bombay Hook, Woodland Beach Wildlife Area, and Little Creek Wildlife Area are prime stop-over areas for the peregrine falcons.

Part B. Physical Characteristics of Delaware Bay

Delaware Geology and Topography

Delaware is located in two geological subdivisions. These are the Appalachian Piedmont province and the Atlantic Coastal Plain province. The fall line, that is, the division between these two provinces, crosses the northern part of the state through Wilmington and Newark. Roughly six percent of the land area of Delaware is north of the fall line in the Piedmont province.

a. The Appalachian Piedmont

The rocks of the Piedmont are very old, hard, and crystalline. These rocks extend seaward, and provide a platform upon which coastal sediments have been deposited.

The Piedmont is characterized by moderate-to-steep slopes and narrow stream valleys. The highest elevations of Delaware are in this province, the highest point at 442 feet (134.7 m) above sea level.

b. The Atlantic Coastal Plain

Rocks of the Coastal Plain are complex, interfingering beds of largely unconsolidated sands, gravels, and clays. The Coastal Plain is essentially part of a trough that includes the offshore submerged Continental Shelf. Active sedimentary basins offshore receive extensive amounts of sediments from the Delaware and other rivers. Sedimentation is also occurring in the Delaware Bay proper.

The exposed Coastal Plain is low and relatively flat. Elevations range from sea-level to sixty feet (18.3 m), averaging about thirty feet (9.1 m). Slopes in this province are generally less than ten percent.

Coastal Morphology

The coast of Delaware has been divided into a number of zones based on local morphology (Kraft and John, 1976). These zones which include the Delaware Bay coast are:

1) A tidal coast against Piedmont, where an upper, deeply incised coastal plain with highlands merges with the tidal Delaware River.

2) A middle coastal plain area, with lesser numbers of highlands merging with the edge of the shoreline area in the vicinity of the lower Delaware River.

3) The broad low-lying coastal plain of southern Delaware adjacent to Delaware Bay. A broad wave fetch results in wave action and littoral drift systems which help to maintain a barrier beach between broad coastal marshes and the Delaware Bay.

The coastal plain of the lower Delaware Bay is characterized by broad thin, low-lying marshes, separated from the Bay by the sand and gravel beach barrier. The barriers become increasingly narrow toward the northwest until they are finally replaced entirely by the coastal marshes.

Delaware Bay Morphology

Delaware Bay has been extensively studied for sediment distribution (Jordon, 1968; Oostdam, 1971) (Figure 6) and morphology (see Weil, 1976). The presence of broad, shallow subtidal flats which comprise approximately thirty-five percent of the Bay's area (Weil, 1976) characterizes the near-shore environment. Active erosion and sediment reworking are important features of these subtidal flats.

The other major morphologic features of the bay are linear sand shoals and channels (Weil, 1976) (Figure 7). The shoals dominate the central portion of the Bay, ranging in height from five to 20 feet (1.5 to 6 meters). These shoals are non-mobile bedforms as evidenced by a review of historical maps and charts (Weil, 1976). Two distinct types of channels exist in the Delaware Bay. The first is the main Delaware River channel which represents the drowned Delaware River and corresponds to the main navigation channel through the Bay. The second type is the smaller, branching, tidally influenced channel which cut the subtidal flats. The smaller channels probably represent the ancient drainage pattern of the flooded Delaware River valley (Weil, 1976; Maley, 1981).

General Climatology

A brief description of general climatological conditions in Delaware is presented along with a separate summary of conditions in the coastal areas of the Bay. This information is presented in terms of winds, waves, and currents.

a. General Climate

Delaware's climate is characteristic of a continental regime, that is, quite variable with a regular sequence of good and bad days alternating in all seasons of the year. It has been shown that about forty percent of the low pressure areas in the United States pass northwestward over the lower Delaware River basin. High pressure systems frequently stagnate over the area for several days in late summer and in the fall (Governor's Task Force, 1972).

The climate is generally mild, with only a few brief periods of hot, humid summer weather, and cold, windy periods in winter. Mean annual temperatures are 55-58 degrees, Fahrenheit (12.7 -to 14.4 degrees, Centigrade).

Annual precipitation is well distributed throughout the year, totaling about 45 inches (114 cm). Average monthly rainfall is over three inches (7.6 cm), with October and November the driest months (2.5 - 3.0 inches; 6.4 - 7.6 cm).

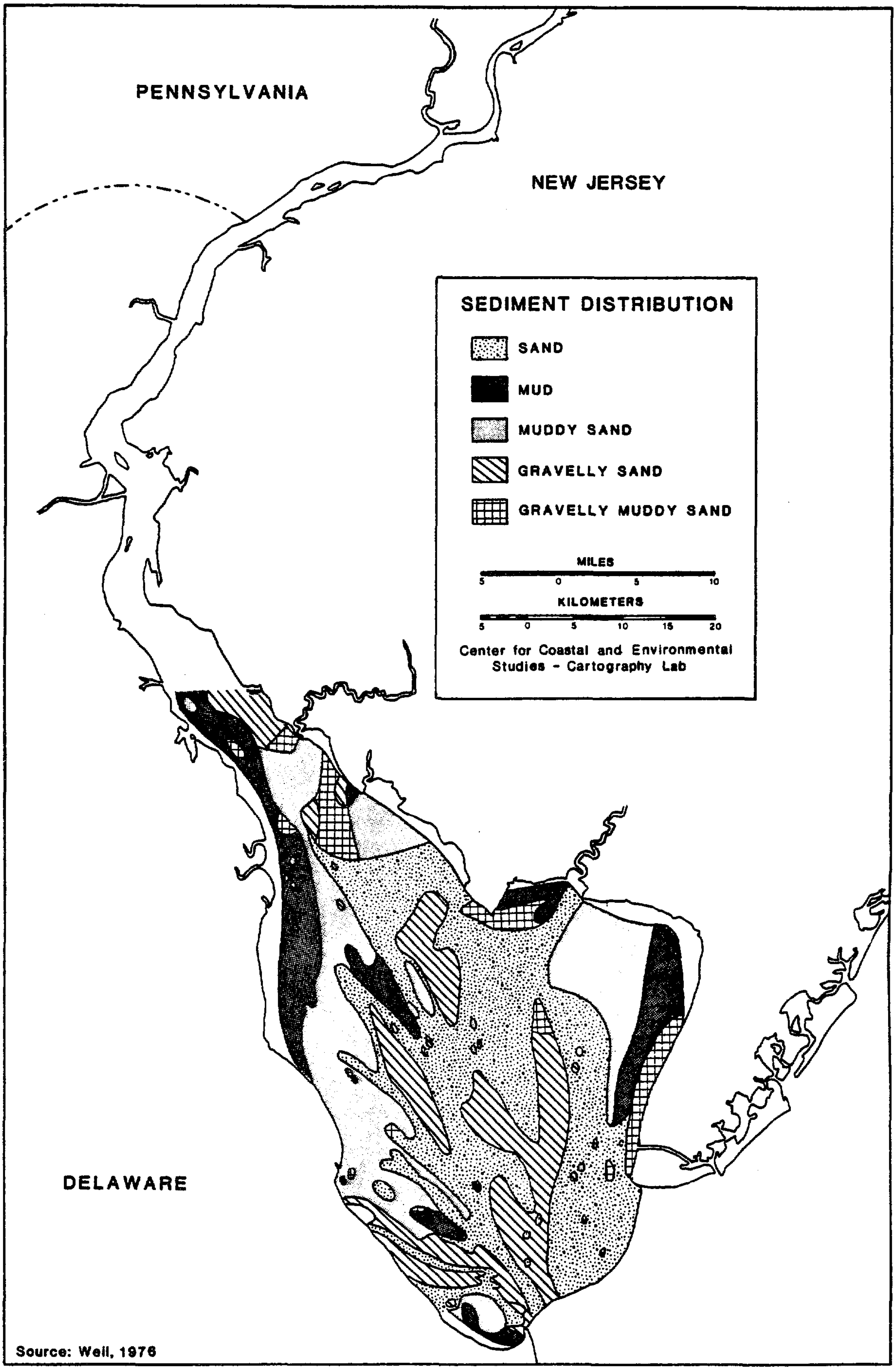
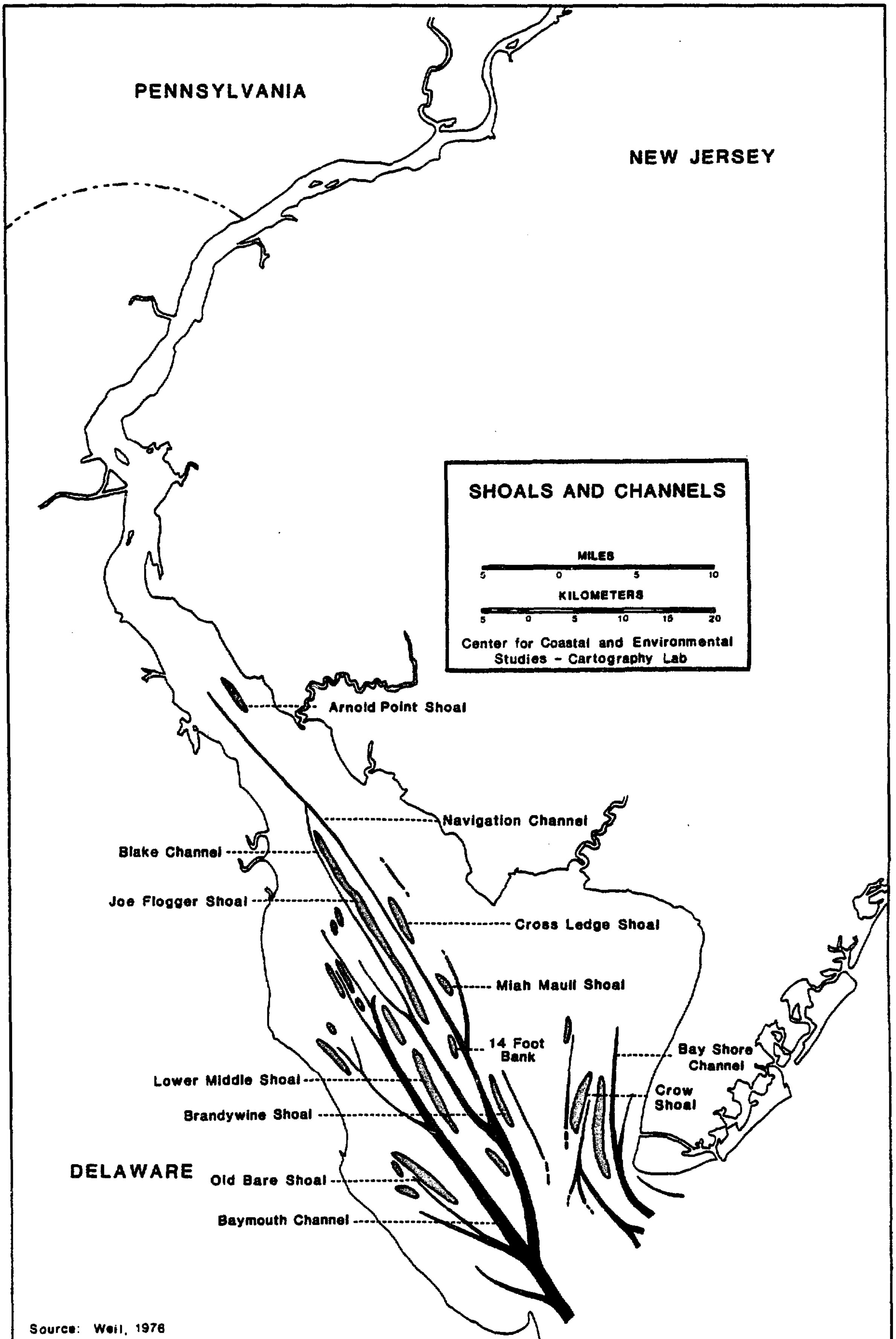

PENNSYLVANIA
NEW JERSEY
DELAWARE
SEDIMENT DISTRIBUTION
SAND
MUD
MUDDY SAND
GRAVELLY SAND
GRAVELLY MUDDY SAND
MILES
5 0 5 10
KILOMETERS
5 0 5 10 15 20
Center for Coastal and Environmental Studies - Cartography Lab
Source: Weil, 1976

Figure 6



PENNSYLVANIA
NEW JERSEY
SHOALS AND CHANNELS
MILES
5 0 5 10
KILOMETERS
5 0 5 10 15 20
Center for Coastal and Environmental Studies - Cartography Lab
Arnold Point Shoal
Navigation Channel
Blake Channel
Joe Flogger Shoal
Cross Ledge Shoal
Miah Maull Shoal
14 Foot Bank
Bay Shore Channel
Crow Shoal
Lower Middle Shoal
Brandywine Shoal
DELAWARE
Old Bare Shoal
Baymouth Channel
Source: Weil, 1976

Figure 7.

Prevailing winds, on an annual basis, are from the northwest. Dominant winds are from the northeast. These winds are more frequent in winter than in summer, when the wind direction shifts more to the west and southwest.

b. Delaware Bay Conditions

1. Winds

Prevailing and dominant winds are the same as for the rest of the state. Along the bay wind speeds are greatest in the winter, least in the summer. Winds of long duration are infrequent, with winds of a specific direction lasting for less than six hours the norm (Drew, 1981).

2. Waves

The correlation of wave distribution with wind speed and direction seems to indicate that most of the waves in Delaware Bay are wind generated (Drew, 1981). Waves are generally low, averaging less that two feet (0.6 m) 80% of the time. Wave energies are, as expected, greater in winter, less in summer.

3. Currents

Tides generate the main currents in the Bay. The tide is semidiurnal with a period of 12.42 hours. Tidal range increases throughout the Bay from 4.3 feet (1.3 m) at the Capes to about 6.7 feet (2 m) at Trenton.

Tidal currents are generally directed along the longitudinal axes of the Bay, except in the low energy environment behind Cape May, New Jersey. Maximum tide flow of 2.0 to 2.5 knots (2.3 to 2.0 km/hr) are attained at periods of local maximum flood and local maximum ebb. Ebb tidal currents are greater than flood tidal currents at all locations (Polis and Kupferman, 1973).

Longshore currents, which are induced by wave action, vary along the coast from place to place and day to day. In Delaware Bay, these currents move southward 74% of the time and northward 26% of the time (Drew, 1981).

SECTION II

OIL SPILLS AND BIOLOGICAL IMPACTS

An oil spill in the Delaware estuary could be a potentially catastrophic event in light of the unique and fragile biota of the area. This section reviews the history of oil spills in the estuary in the recent past, and discusses the influence of background pollution on assessing oil spill effects. The effects of oil spills are addressed for two scenarios. The first assumes that current practices and technologies are employed. In the second, spills from a proposed bulk transfer facility are incorporated. Both scenarios include chronic and episodic oil spills.

Part A. Recent Oil Spill History

Records of the United States Coast Guard's (USCG) Pollution Incident Report System (PIRS), compiled for the years 1974 to 1980, show that oil spill incidents have been decreasing in the estuary (Table 6). This has been attributed to the dramatic rise in the cost of oil, an increase from $2 a barrel in 1960 to $35 in 1980, which has prompted more careful handling on the part of industry (Zakrzewski, 1980). Perhaps more important has been the focus on improving environmental quality which was influenced by interest group activities beginning in the early 1970's.

Crude oil spills from vessels represent 17% of all petroleum spills but have accounted for 43% of all petroleum released into the estuary from vessels. Analyses of the USCG PIRS records have shown that tankers and barges spilled 4,873 gallons of crude while at anchorage, 825,060 gallons while underway, and 46,498 gallons at the piers. Computed in terms of annual chronic spills it is seen that approximately 696 gallons per year are spilled at anchorage and 6,642 gallons per year are spilled at the piers. It is important to note that not all spills reported have had the spilled amount recorded. Therefore, these numbers are estimations.

Although oil spills are world wide occurrences and have been extensively studied for their effects (Table 7), the results of these studies have proven to be of limited value. Results are often conflicting due to the various methodologies and interpretations used to assess impacts and also the different biological and physical factors involved. Oil spill data within the Delaware Bay are available but there is very little information about the effects of chronic and episodic spills on flora and fauna. When large spills occurred in the area, no monitoring groups were prepared to assess impacts, as in the Corinthos incident which released 500,000 gallons of crude into the Delaware River. Additionally, the lack of baseline studies has hindered attempts to study changes in water quality and biota after a spill. This is particularly true in two cases. The Big Stone Anchorage site in the Bay is affected by chronic spills due to the lightering of tankers. Also, the area between Wilmington, Delaware and the oyster seed beds is affected by hydrocarbons released from industrial facilities at Delaware City, which at times present problems to the oyster population (Patrick and Whipple, 1977).

Table 6. Summary of vessel petroleum spills in the Delaware Bay estuary.

Year	Number of Petroleum Spills	Number of Crude Spills	Percent of Crude to All Spills	Amount of Petroleum (gallons)	Amount of Crude (gallons)	Percent of Crude to Total Amount
1974	90	17	18	312,531	17,862	6
1975	83	19	23	601,639	508,882	85
1976	109	12	11	227,722	134,764	59
1977	74	13	17	10,461	813	8
1978	56	8	14	637,269	2,450	.4
1979	64	13	20	229,067	212,400	93
1980	65	10	15	7,595	1,331	17
Total	541	92	$\bar{x}$ = 17	2,026,284	878,502	$\bar{x}$ = 43

Source: Data compiled by Port Authority from USCG PIRS, 1974-1980.

Table 7. Summary of some effects of petroleum products on marine organisms.[1]

Type of Organism Species	Reference	Type of Petroleum Product/ Concentration	Response
MARINE FLORA			
Marsh Plants (*Festuca rubra*, *Distichlis maritima*)	Baker, 1971	crudes and refinery effluents/ single or successive coatings with crude	Inhibition of germination and growth. Repeated coatings cause disappearance of some plants (increasing order of tolerance: shallow rooted plants, shrubby perennials, perennials with large food reserves).
Marsh Plants (*Spartina* spp.)	Lytle, 1975	crude/ poured into pond	Decrease in productivity.
Marsh Plants (*Distichlis spicata*, *Salicornea begeloii*, *Spartina alterniflora*)	Stone, 1972	weathered crude/ .16%, .32%, .65%, 1.31% in solution	10% - 85% survival rate. Long time exposure at high concentrations are quite lethal.
Phytoplankton (diatoms and dino-flagellates)	Mironov, 1970	"oil" / 10^{-1} to 10^{-4} ppm	Inhibition or delay in cellular division.
Phytoplankton (*Phaeodactylum tricornutum*)	Lacaze, 1969	Kuwait crude/ 1 ppm	Depression of growth rate
Phytoplankton (various species)	Moore, *et al.*, 1973	"oil"/ .0001 - 1.0 ml/l; most used .001 - 1.0 ml/l	Death occured at 1 ml/l (1000 ppm); delayed cell division at 1.0 - .001 ml/l (10 - .01 ppm); Does not describe oil used or whether concentrations are soluble or not.

Table 7. Continued.

Type of Organism Species	Reference	Type of Petroleum Product/ Concentration	Response
MARINE FLORA			
Phytoplankton (Prasinophyceae, Halosphaera sp, Pterosperma sp.	Moore, et al., 1973	crude slick/ unknown - incident at Torrey Canyon	Lethal toxicity and reduced population
Green algae (Enteromorpha intestinalis; Chaetomorpha aerea; Ulva californica)	Moore, et al., 1973	crude slick/ heavy coating, incident at Santa Barbara	Slight damage except where completely coated. High intertidal plants where oil dried were damaged.
Green algae (Entermorpha sp.)	Schramm, 1972	crude oil/coating	CO_2 assimilation reduced.
Green Algae (Ulva lactuca)	Davavin, et al., 1975	crude oil/ .1 - 10 ml/1 (100 - 10,000 ppm)	Complete inhibition of biosynthesis of DNA and RNA at higher concentrations.
Phytoplankton (mixed natural samples)	Gordon and Prouse, 1973	Venezuelan crude, No. 2 and 6 fuel oils/ 10-200 ug/1	Stimulation of photosynthesis at 10-30 ug/1, decrease in photosynthesis at 100-200 ug/1 No. 2 fuel oil.
POLYCHAETES			
larvae - Sabellaria spinulosa	Smith, 1968	BP 1002/ 0.5 - 1 ppm	Abnormal irritability in larvae revealed by stiffening out of median setae.
Sabellaria spinulosa	Moore, et al., 1973	BP 1002/ .5 -1 ppm	1 ppm caused 100% mortality; .5 ppm caused abnormal development. Death definitely due to kerosene solvent in BP 1002.

Table 7. Continued.

Type of Organism Species	Reference	Type of Petroleum Product/ Concentration	Response
MOLLUSKS			
Periwinkle (*Littorina littorea*; *L. littoralis*)	Moore, *et al*., 1973	fresh crude oil/ not stated, sprayed on for 1 hr. then washed off	1 - 89% mortality for *L. littoralis*; *L. littorea* very resistant.
Periwinkle (*Littorina littorea*)	Moore, *et al*., 1973	Bunker C/ Arrow Incident	Ingestion of oil, no effect. Oil which passed through digestive system unmodified.
Snail (*Nassarius obsoletus*)	Blumer, *et al*., 1973	Kerosene/ saturated extract diluted 10^{10}.	40% reduction in chemotactic perception of food.
CRUSTACEANS			
Barnacle larvae (*Balanus* sp.)	Mironov, 1970	"oil"/ 10 - 100 ul/l	Abnormal development.
Barnacle (*Pollicipes polymerus*)	Blumer, *et al*., 1971	Crude-Santa Barbara incident/field study after blowout	Apparent decrease in adult brooding; no recruitment in oiled areas.
Barnacle (*Elminius modestus*)	Moore, *et al*., 1973	BP 1002/0-100 ppm Kuwait/1ppm	0-3 ppm of BP 1002 - increase in mortality, some reduction of activity.
Benthic amphipods (*Gammarus oceanicus*, *onisimus affinis*) Isopod (*Mesidotea entomon*)	Percy, 1976	3 crudes/oil-soaked object; oil tainted food	Avoidance of oil masses and oil tainted food for amphipods; neutral response for isopod.
Copepod (*Calanus helgolandicus*)	Spooner and Corkett, 1974	Suspended oil droplets in lab. vessels/10 ppm	Decrease in feeding and metabolic activity among survivors based on amount fecal pellets deposited by controls vs. experimentals.

Table 7. Continued.

Type of Organism Species	Reference	Type of Petroleum Product/ Concentration	Response
POLYCHAETE			
Cirriformia tentaculata	Moore, *et al.*, 1973	fresh fuel oil coating on mud; shore terminal spill	Little damage
MOLLUSKS			
Mussel (*Mytilus edulis*; *Modolus demissus*)	Gilfillan, 1973, 1975	crude/ 1 ppm	Reduction in carbon budget (increase in respiration; decrease in feeding and assimilation).
Mussel (*Mytilus edulis*)	Blumer, *et al.*, 1971	No. 2 fuel oil/ collected from field after spill	Inhibition in development of gonads.
Mussel (*Mytilus edulis*)	Gonzalez, *et al.*, 1976	No. 2 fuel oil/ 10 ppb to 1 ppm	Decrease in filter feeding activity; and byssal thread attachment at the higher concentrations.
Clam (*Mya arenaria*)	Barry and Yevich, 1975	No. 2 fuel oil/ collected from field	Gonadal tumors
Oyster Larvae (*Ostrea edulis*)	Simpson, 1968	BP 1002 / 1 ppm	Inhibition of growth.
Oyster Larvae (*Crassostrea angulata*; *Crassostrea gigas*)	Renzoniz, 1973	Venezuelan crude/ 1, 10, 100, 1000 ppm	Fecundity sharply reduced, could represent enormous reduction of embryos and larvae.
Oyster (*Crassostrea virginica*)	Gardner, *et al.*, 1975	waste motor oil/ greater than 20 ppm	Incidence of lesions in branchial efferent vein, mantle, and gastro-intestinal tract.
Oyster (*Crassostrea virginica*)	Nelson-Smith, 1973	oil/ .01 ppm	Marked tainting,

Table 7. Continued.

Type of Organism Species	Reference	Type of Petroleu Product/ Concentration	Response
CRUSTACEANS			
Shrimp (*Crangon vulgaris*)	Moore, *et al*., 1973	BP 1002/ 5 ppm	24 LD_{50}^{*} = 2 ppm
Pink shrimp (*Pandalus montagui*)	Moore, *et al*., 1973	BP 1002	48 LD_{50}^{*} = 5.8 ppm
Crab larvae (*Pachygrapsus marmoratus*)	Mironov, 1970	"oil"/ 10-100 ul/l	Initial increase in respiration
Crab (*Pachygrapsus crassipes*)	Kittredge, 1971	crude/ dilutions of diethyl ether extracts (1:100)	Inhibition of feeding.
Crab (*Uca pugnax*)	Krebs, 1973	No. 2 Fuel Oil/Field observations after West Falmouth Spill	Adverse effects on sexual behavior. Mortalities in heavily-oiled areas.
Lobster larvae (*Homarus americanus*)	Wells, 1972	Venezuelan Crude/ 6 ppm	Delay molt to 4th stage
Lobster (*Homarus americanus*)	Blumer, *et al*., 1973	crude/ 10 ppm	Effects on chemoreception, feeding times, stress behavior, aggression, and grooming.
Lobster (*Homarus americanus*)	Atema and Stein, 1972, 1974	La Rosa Crude/extracts and whole oil at 1:100,000 (10 ppm)	Delay in feeding with whole crude fractions.
FISH			
Plaice larvae (*Pleuronectes platessa*)	Wilson, 1970	BP 1002/ 0-10 ppm	Disruption of phototactic and feeding behavior.

Table 7. Continued.

Type of Organism Species	Reference	Type of Petroleu Product/ Concentration	Response
FISH			
Herring eggs	Moore, *et al.*, 1973	Russian Crude/ 10^3 and 2×10^4 ppm film	100% of eggs killed.
Menidia menidia	Gardner, 1975	whole fractions/ 140 ppm water-soluble/ 12 ppm water-insoluble/ 588 ppm	Histological damage to chemoreceptors.
Cyprinodon variegatus *Lagodon themboides* *Micropogon undulatus*	Steel and Copeland, 1967	petrochemical wastes/ 0.2-2.0 ppm in addition to 0.4-4.0 phenol	Respiratory inhibition.
Menidia menidia	Gardner, *et al.*, 1975	waste motor oil/ greater than 20 ppm	Incidence of lesions in vascular systems (pseudobranch, heart, arterial system).
Thread herring (*Ophistonema onglinum*)	Moore, et al., 1973	crude oil and emulsifers/ Ocean Eagle San Juan incident	95% of schools near spill had lesions.

[1]Source: Maûrer, 1974; Hyland and Schneider, 1977.

*LD_{50}: Lethal Dose for 50% of test group within given time, e.g., 24 hours or 48 hours.

Part B. Biological Damage from Oil Spills

Background Pollution

Petroleum products have been and continue to be released into the Delaware Bay estuary from a number of sources. Besides oil spills from vessels, petroleum is released into the water by other sources. Petroleum refinery residuals constitute another major source, as do urban runoff, municipal effluent and other industrial effluents (Patrick and Whipple, eds., 1977). It has been contended that serious degradation of the marshes along the Delaware River can be attributed to refinery operations (Maurer, 1974).

The presence of other pollutants in the estuary complicates the assessment of oil spill-related effects. Heavy metals, ammonia, and carbonaceous materials are relased into the estuary from sewage treatment plants, sanitary landfills, power companies, chemical industries, and paper companies (Walton and Patrick, eds., 1973). The concentrations of heavy metals are sufficient to produce acute toxicity in estuarine species, and the organic and nitrogenous material consume oxygen so as to produce levels that are, at times, low enough to be lethal to local species. It is of interest to note that synergistic effects can occur from the interaction of petroleum and other chemicals such as heavy metals (Patrick and Whipple, eds., 1977).

In the Delaware Bay estuary, the upper portion from Wilmington, Delaware to Trenton, New Jersey is heavily polluted. The area around Delaware City is also polluted as a result of the heavy industrial concentration in the region. Relatively pollution-free areas of the estuary are upstream of Trenton and in the lower Bay.

Fate of Spilled Oil

Crude oil when spilled in water begins to undergo chemical and physical alteration almost immediately. Spilled oil almost always forms an emulsion of oil and water referred to as a "mousse". The mousse forms the bulk of most slicks. Some of the spilled oil is also dispersed as tiny droplets in the water. As the mousse spreads over the water a large oil/air interface is formed which promotes the evaporation of more volatile compounds. Some volatile light crudes could potentially lose up to 50% of their mass in this fashion (Milgram, 1978). Other heavier oils may lose less than 10% to evaporation. Depending on temperature, most evaporative loss is completed before the first week.

In addition to evaporation, the volatile portions are susceptible to dissolution in water. As the slick spreads, the mousse attains a thickness ranging from 1 millimeter to a few centimeters. It forms localized patches called "pancakes" which have roundish to irregular outlines and uniform thickness. As the mousse begins to localize, a natural fractionation of the oil occurs and the lighter, more volatile compounds begin to spread out from the edges of the pancakes (Galt, 1978). These lighter hydrocarbons form an irridescent to gray sheen approximately 10 μm thick. The sheen appears to be continually fed by this fractionation process and fills in much of the space between mousse accumulations. The sheen, in return, aids in the localization of pancakes in that its higher spreading pressure helps to contain the mousse (Milgram, 1978). A typical oiled surface would be expected to be composed of approximately 60% sheen, 40% open water, and <1% thick pancakes (Grose, 1978).

After several days the majority of the oil slick can be expected to have been dispersed as tiny droplets into the water column. These droplets may remain suspended for an indeterminate length of time, and may be removed from the water column in several ways. These include bacterial and other biodegradation, adherence to passing organisms, absorption by suspended sediment particles, and absorption onto suspended particles forming composites that are heavy enough to sink. Particles may also dissolve in seawater, and some may possibly reaggregate to form larger droplets which may travel up or down in the water column.

Weathered oil slicks a few weeks old have stopped producing sheen. As the lighter hydrocarbons are being fractioned off, the remaining ones are heavier and more likely to be dispersed in the water column by waves. A certain portion of the remaining oil becomes heavy enough to sink and becomes incorporated into the bottom sediments. Part of the remaining floating oil can be oxidized and forms a weathered crust on top of the mousse. Sunlight helps to break down a certain fraction of the floating hydrocarbons. This photolysing also breaks down the majority of hydrocarbon vapors produced by evaporation.

The majority of dispersed oil can be expected to have been biodegraded or incorporated into bottom sediments after one year. Hydrocarbons still remaining at the surface would be weathered into a viscous crust which is broken up by wind and waves and shaped into floating tar balls. Floating oil can beach at any time, and as such can be incorporated into beach sediments. The type of deposit depends on the degree of weathering. Tar balls would form very discrete flattened "pebbles," whereas fresh mousse would form a thick, uniform blanket over a beach or coastline (Grose and Mattson, 1977). Weathered mousse would leave scattered, thick accumulations of crust, possibly with a thorough uniform coating of heavy oil on the areas in between (Figure 8).

Oil Spill Effects

The damage which occurs to the biota from a spill is dependent on many factors. These include:

1. the amount and type of oil spilled;
2. the location of the spill;
3. the physical conditions of the Bay (tides, currents, wave action, turbidity);
4. the weather conditions;
5. the type and life stage of the biota (NAS, 1975).

Mertens (1973) has identified two other factors which are important. They are the history of oil and other pollutants' exposure in the area, and the ways in which the spills are treated.

Petroleum products differ in their compositions, even though they may have the same name. This is due to the great variety of geochemical conditions and types of organic material that formed the oil.

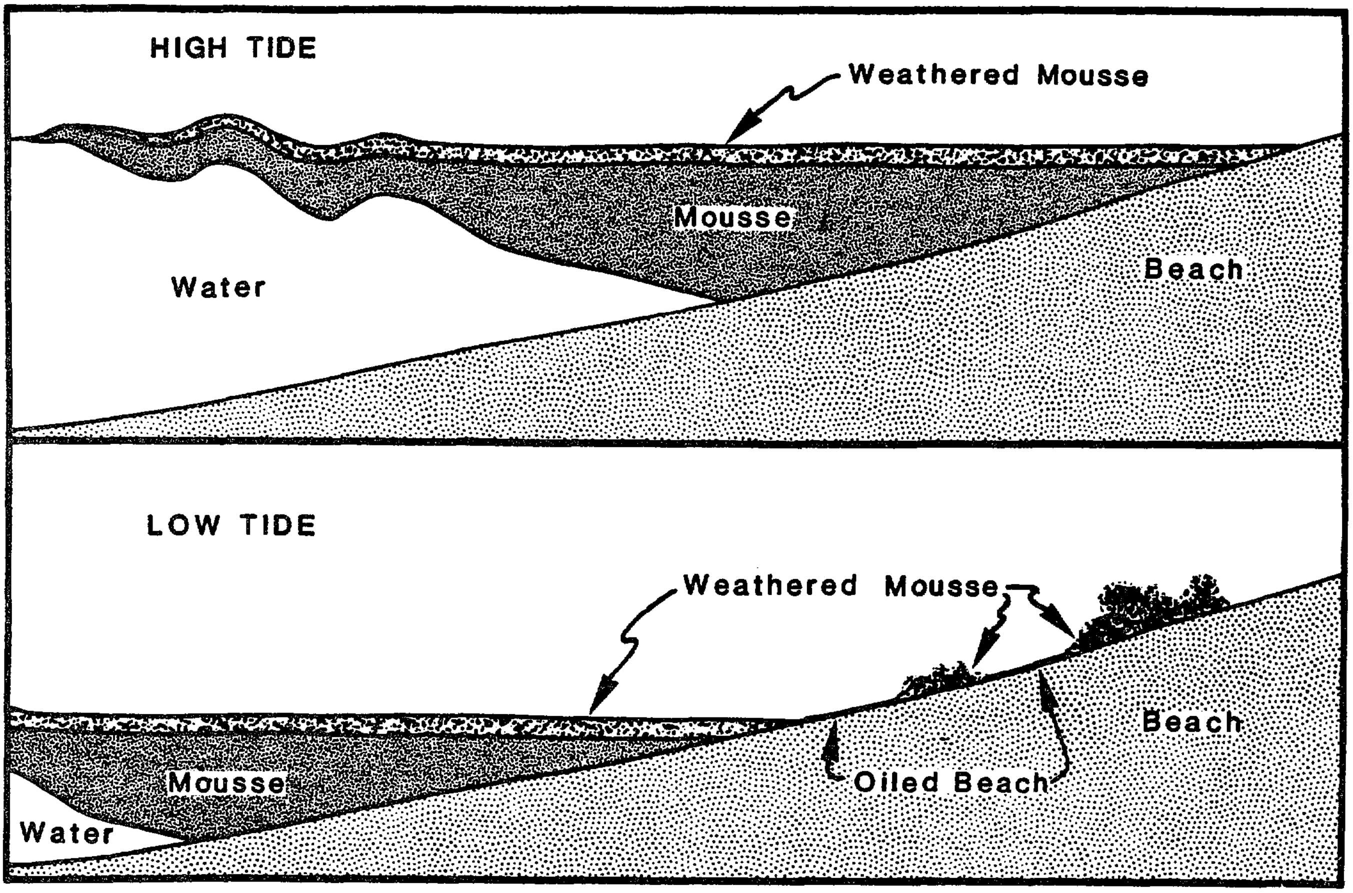


Figure 8 . Process of oil being impinged on the beach from wind and waves (After Galt, 1978).

The toxicity of oil on flora and fauna varies with the type of oil and the type of organic matter. When considering toxicity, it is best to consider only the soluble aromatic hydrocarbon derivatives (S.A.D.) since they are the primary cause of organism mortality (Moore, 1973). Number 2 fuel oil, for example, which has a high concentration of S.A.D. is considerably more toxic than an equal amount of crude or residual product.

The following statements summarize the effects of oil on organisms:

1. coating of weathered crude (exposed to sunlight) is significantly more toxic than unweathered crude;
2. larvae are more sensitive than are adults;
3. crustaceans and burrowing animals are the most sensitive organisms;
4. fish and bivalves are moderately sensitive;
5. gastropods and flora are least sensitive.

It is also important to note that, just as the invertebrates are most susceptible during their larval stage, other life forms have similar periods of increased susceptibility. Oil will seriously affect fish during their spawning runs. It will also affect their fry returning to their habitat. Impacts on birds are magnified if a spill occurs during the nesting season.

Large and chronic spills cause community structural changes by the reduction of species numbers and diversity and/or replacement by an opportunistic species (Michael, 1977). After a large spill, mortality will be close to 100 percent. Over time, the environment should recover. Recent studies have shown that chronic spills, as opposed to a single massive spill, may be a more serious ecological problem. Studies of geographic areas which are prone to oil spills on a continuing basis have shown that certain opportunistic species occur in large numbers throughout the habitat (Michael, 1977) while the environment progressively deteriorates (Cowell, 1971).

Sand Beaches/Dunes

Oil which is washed ashore can cause a variety of environmental impacts. Smothering, fouling, and direct toxicity of infauna in the sand beaches usually occurs. A large spill typically will cause extensive mortality while a small spill may only cause minor localized effects. In either case, a decrease in the infauna represents a reduction of food for the organisms which feed upon them. If the oil is cleaned up soon after a large spill, infauna should be able to recover within a year.

A second type of impact can occur from the oil mixing with the salt spray. An oily saltwater spray, if blown onto the dune areas, would reduce stands of Marram grass which acts as the major dune stabilizer. Thus, the integrity of the dune system would be threatened by wave-and-wind induced migration. This in turn could disrupt shorebird nesting habitats (Maurer, 1974).

An obvious impact of oil reaching landfall is on the recreational opportunities which a beach provides. Businesses which rely on tourist activities, such as swimming and fishing, could face major economic disruption from a summer oil spill.

Jetty/Groin Communities

Flora and fauna of jetty and groin communities are usually less susceptible to oil contamination as opposed to the sandy beach/dune community, because of the high wave energy which acts as a diluting force. Small frequent spills are most harmful to organisms at the high water mark, where death could occur from oil drying while the tide is out (Maurer, 1974).

Marshes

In spill situations, oil usually contaminates the first three to six feet of the marsh fringe (Castle, 1977). Oil can enter beyond the fringe by way of tidal creeks at stages of high tide. Should this occur during periods of seed production and spring growth, the impacts would be substantial.

Data from studies to date have shown that marshes can recover from single oil spills. Chronic spills, however, have been shown to be detrimental to marsh environments. This type of situation usually leads to a rapid decline in vegetation, from which recovery is slow if it occurs at all.

The loss of marshland can have far-reaching impacts. The loss of plants would lead to decreased productivity, reduction of food supply, and ultimately loss of wildlife habitat. Oil from spills has been shown to be "stored" in the marshes and later released (Burns and Teal, 1971). Such a release, which may occur years later, could be detrimental if it occurred near spawning and nursery areas (Blumer, et al., 1970).

Fish

The degree of impact of an oil spill on fish will depend, of course, on the time of year of the spill, type of oil, duration of the spill, whether it occurs during spawning and breeding activities, weather conditions, and the extent (areawide) of the spill. Oil spills can have lethal impacts on fish eggs and/or fry in spawning areas. Alternatively, anadromous fish such as shad, striped bass, or menhaden may be particularly vulnerable to a spill occurring in critical or shallow estuarine waters during migration periods.

Mammals

The greatest dangers to mammals from an oil spill are indirect (i.e., loss of habitat or food source). Possible direct effects, which have yet to be documented, might arise from the ingestion of oil droplets during grooming, the loss of thermal insulation and/or waterproofing, and irritation to the eyes and mucous membranes (Hyland and Schneider, 1976).

Birds

The estuarine marshes of Delaware and New Jersey provide habitat for over 300 species of birds in the Mid-Atlantic Zone. A large majority of these birds are present during migrations, with large waterfowl concentrations in the spring, fall, and winter.

Oil spills are a considerable potential threat to the bird populations in the region. If oil should impact the marshland habitats of the Delaware Bay, bird populations can be reduced through loss of habitat or food supplies. Direct impacts on the birds themselves can be attributed to: 1. the disruption of their feather surfaces, causing a loss of their insulatory features; this can lead to drowning (loss of buoyancy) or pneumonia (loss of thermal insulation); 2. the ingestion of oil droplets from excessive preening; 3. accelerated starvation, as a result of increased metabolic activity (to compensate for the loss of body heat) coupled with a decrease in feeding; and 4. reduced hatchability of eggs if contaminated by oil (Hyland and Schneider, 1976).

Migratory waterfowl are probably among the most susceptible to oil spills due to their flocking habits. Impacts would be most pronounced during the spring and fall migrations.

Benthic Communities

Benthic communities, which are important as a commercial resource (i.e., clams, oysters, crabs) and as a food source for important finfish and shellfish species, will suffer significant adverse effects from an oil spill because of their sedentary nature. The significance of the impacts of an oil spill on a benthic community are best exemplified by the results of a study conducted by Dow and Hurst (1976). The study, initiated after a large spill off Sears Point, Maine, focused on the effects of spilled oil on hard clams. They found immediate mortality, and a continuance of the mortality over a span of three and one-half years. Out of an expected harvest of 157 metric tons, only 22 metric tons survived.

A parallel can be drawn from this study to identify the impact of an oil spill on the shellfish resources of Delaware Bay. These impacts will be twofold: the first can be considered as water quality changes which generally will not kill the shellfish resource but will contaminate it so that it cannot be safely used for human food; the second, the oil spills can result in habitat changes which significantly alter the viability of the resource or its continued existence (Golden, et al., 1980).

Planktonic Communities

The effects of an oil spill on planktonic communities are primarily dependent on the distribution, concentration, and makeup (phytoplankton or zooplankton) and the time of year the spill occurs. For instance, the phytoplankton are found in an area known as the euphotic zone, which can be defined as that area through which light penetrates in sufficient quantities to support the growth of green plant life. The impact on the phytoplankton, should a spill occur during May or June (when phytoplankton concentration is high), would be significantly more damaging than one occurring in December or January when the concentration is lower. In any case, recovery from the spills should be rapid due to the short reproductive cycle of the phytoplankton.

Part C. Analysis of Cases

Description of Cases

Case A: No substantial change in current marine delivery of crude oil.

Assumptions are as follows:

Location of Spills	Annual Frequency	Size (gals.)	Total for year (gals.)
Anchorage Area	6	84	504
Refinery Piers	9	630	5,670
Off Marcus Hook 30° 48' N. Lat. 75° 25' W. Long.	N.A.	2,016,000	2,016,000

The chronic spills of the anchorage area are assumed to be off Big Stone Beach, Delaware, with a total of six spills per year. For the nine chronic spills at the refinery piers, a 2,2,2,2,1 distribution from the farthest upriver location to the farthest downriver location is assumed. (This theoretical condition assumes two spills each for the following locations: Westville, NJ (Texaco), Philadelphia, PA (Arco and Gulf), Paulsboro, NJ (Mobil and Seaview), and Marcus Hook, PA (Sun and BP). One spill for the year is projected at Delaware City from the Getty facility). The episodic spill off Marcus Hook is not included in the annual frequency, since it is assumed to occur while underway from collision, ramming, or grounding and is assumed to be a worst case scenario with an undefined frequency.

Case B: A bulk crude facility is built in the Delaware Bay.

Assumptions are as follows:

Location of spills	Annual Frequency	Size (gals.)	Total for year (gals.)
Anchorage Area	2	84	168
Bulk Facility	4	945	3,780
Refinery Piers	5	630	3,150
Between the Capes 38° 50' N. Lat. 75° 04' W. Long.	N.A.	2,814,000	2,814,000

The bulk facility, predicted to have four small spills per year, is to be located north of the anchorage area, which is predicted to have two small spills per year. A 1,1,1,1,1 distribution is assumed for the chronic refinery spills. This assumes one spill per location for the following areas: Westville, NJ; Phila., PA; Paulsboro, NJ; Marcus Hook, PA; and Delaware City, DE, with a total of five spills per year. The worst case scenario for an episodic spill, if the bulk facility is built, is between Cape Henlopen and Cape May, approximately one mile NNE of Cape Henlopen.

Methodology for Analysis

In order to determine which of the above cases would have the worst environmental impact, a set of oil spill simulatins were compiled. These simulations attempted to predict the path a spill would follow and the areas which would be most severely affected by such a spill. Twenty large and small spill simulations were developed for representative winter (January) and summer (July) months during maximum ebb and flood tides. The small spills were assumed to start from the refinery piers and Big Stone Beach, Anchorage. The locations for catastrophic spills include Marcus Hook and between Cape Henlopen and Cape May.

The present state-of-the-art is such that oil spill trajectory predictions are subject to many assumptions and difficulties. These arise from a limited understanding of the physical properties of oil slicks and the vagaries inherent in the directions and intensities of the vectors which move them. A number of studies have been done which were intended to help quantify the parameters which are important for oil spill trajectory. A review of these studies may be found in Stolzenbach, et al., 1977.

Parameters which must be included in insure as realistic a simulation as possible are as follows:

1. currents;
2. wind direction and velocity and their effects on current direction and direct wind stress on floating oil;
3. the set of many factors contributing to the spreading rate of oil on water;

4. the effect of littoral drift on position and extent of oil spill impact areas;
5. the effects of evaporation, dispersal, and biodegradation on the life expectancy of an oil spill; and
6. how different current and wind directions would alter the outline of a very large slick.

These parameters are discussed below:

The currents in the Delaware Bay and the lower Delaware River are dominated by the tides. Therefore, the general direction of the flow in the River is subject to periodic reversals and consequent changes in current velocity. Oil spilled at maximum ebb would run downstream for a few hours, begin to deflect to the right bank slightly as the tide prepares to reverse, and then flow upstream for about six hours. It would then deflect again to the right bank as the tide turns and closes the loop, finally flowing downstream past the point of the initial spill. When maximum ebb is again reached there will be a net seaward displacement of the spill center relative to the initial spill site. This is because the ebb current velocities in the bay are somewhat greater than the flood current velocities. Thus, when considering only tidal currents, the path of spilled oil would be expected to spiral toward the Bay mouth.

Winds have both a direct and indirect effect on floating oil. Winds generate waves which are able to render floating oil more mobile and act as important movers of oil in nearshore areas (Galt, 1978). As well as producing currents which alter tidal and other currents, winds can also exert stress directly upon floating oil.

There are various multipliers for calculating the total velocity imparted to an oil slick by the action of winds. Traditionally, a wind-drift vector of 3.5% (of the wind velocity) in the down-wind direction is used for floating oil (Grose and Mattson, 1977). This figure is the sum of the effect of wind modification of currents and the effect of direct wind stress on floating oil. For the Delaware Bay, the eastward component of the current modification portion is reduced to compensate for the prevailing eastward wind effect inherent in the annually averaged tidal current charts.

Although tidal current and wind-generated vectors can probably be used to predict the positions which a given oil spill will reach, other factors must be considered. Perhaps the most important of these is the rate at which the oil slick will spread. However, our ability to predict quantitatively the spread of oil is severely limited (Milgram, 1978). It is over simplistic to estimate the area that will be covered by a spill by determining the thickness of the oil spread over a given volume of water and then dividing into the volume spilled, as previous studies have done. Oil and water emulsion (mousse) has a different surface tension and density of the original oil. As the mousse begins to spread, a fractionation begins on the water's surface and a sheen with a high spreading pressure begins to form (see Fate of Oil Spills). Thus, the thickness of the spill quickly becomes non-uniform. Temperature also will affect viscosity and evaporation rates. Wave intensity seems to severely inhibit the spreading of oil. Fractionation increases viscosity of the remaining oil, as does evaporation (Grose, 1978). As time passes, the area may increase, reach a maximum and then decrease (with an accompanying increase in thickness).

The effect of longshore currents, which was so devastating in the case of the Amoco Cadiz spill (Galt, 1978), is something that cannot be predicted in the Cases of the Delaware Bay. Longshore current direction on any given beach may be subject to daily reversals. Probabilistic predictions of longshore currents around Delaware Bay do not yet exist. Consequently, potentially high risk areas are probably more extensive than those predicted on the simulations.

Twenty oil spill simulations were completed. For each contingency, the initial spill location was plotted, then each subsequent hourly position of the spill center was located and plotted. These were based on: 1. the location of the previous hour's spill center, 2. the present hour's current velocity and 3. the direction and average speed of the prevailing winds for the chosen time of year (Kupferman, et al., 1974) and 4. the outline of the river and Bay to help determine potential landfalls.

The small spill simulations were continued until they left the bay or were impacted onto the shoreline. High risk is assigned to areas which were closely passed by the spill center or landing on the shoreline. In reality, the longshore currents could highly modify this event.

If a two million gallon spill occurs within the bay, and the center remains in the bay for any appreciable length of time, it is assumed that the entire lower Bay will have a high chance of being affected. In the Marcus Hook episodic spill, the entire downstream area was considered to be potentially high risk, pending the introduction of new longshore current information. However, high risk areas which would be impacted immediately could be seen. Large spills between the Capes are run for 48 hours or until the center leaves the mouth of the bay. The location and extensiveness of high risk areas are dependent on the amount of time the oil slick's center remains in the bay. These large spills are assumed to occur instantaneously. More realistic slow or continuous large spills would have correspondingly more extensive high risk areas.

Discussion

After analysis of the different oil spill simulations, the communities and organisms that would be adversely impacted are predicted (Table 8). In general, spills occurring in the summer would have more biological damage than in the winter. For instance, plankton are present throughout the year but would be impacted to a greater degree during the summer season when their populations are greater. Also, large spills have immediate devastating effects, whereas, the chronic spills may have long term effects that may not be presently noticeable. The worst chronic scenario of each Case and the worst episodic spill are presented.

Spills off the northern refineries would have minimum environmental effects. As previously stated, the area between Wilmington and Philadelphia is highly polluted and the aquatic life is depressed in terms of species diversity. The life forms present reflect the degraded water quality, such as an abundance of obligochaete worms and leeches (Walton and Patric, eds., 1973). These invertebrates, plus a few species of diatoms and fish (*Fundulus* spp.) are all very tolerant to the polluted condition of the area. In addition, there are no marsh areas to impact.

Table 8. High risk communities and organisms as predicted from oil spill simulations.

COMMUNITIES AND ORGANISMS	LARGE SPILLS								CHRONIC SPILLS							
	Marcus Hook Case A				Between the Capes Case B				Refinery Piers[1]				Anchorage Area[2]			
	winter		summer		winter		summer		winter		summer		winter		summer	
	ebb	flood	ebb	flood	ebb	flood	ebb	flood	ebb	flood	ebb	flood	ebb	flood	ebb	flood
BEACH/DUNE					X	X	X	X								
JETTIES					X	X	X	X					X	X	X	X
MARSH	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BENTHIC	X	X	X	X			X	X					X	X	X	X
PLANKTON	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FISH	X	X	X	X	X	X	X	X			X	X			X	X
MAMMALS							X	X								
BIRDS			X	X	X	X	X	X	X	X	X	X	X	X	X	X
OTHERS[3]					X	X	X	X					X	X		

1. Refinery piers refers to oil spills only off Getty. See text for further information.

2. Spills from the anchorage area also include facility for Case B.

3. 'Others' refers to areas outside the bay area, these include oceanside beaches and marshes of New Jersey and Delaware. How far the oil disperses on the oceanside depends on the longshore current,

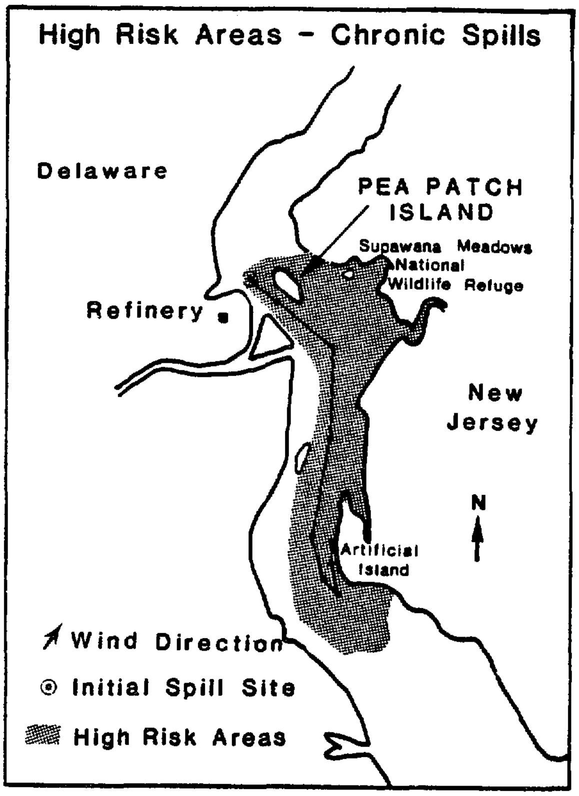


Figure 9.

In Case A, the most detrimental environmental effects of a small spill would be off Delaware City (Getty Refinery) in summer during maximum ebb tide (Figure 9). Oil spill simulation was run for eight hours with the prevailing winds averaging 5.1 knots from SSW.

The oil is predicted to impact mainly on the New Jersey side. Areas affected would be Pea Patch Island and Supawana Meadow National Wildlife Area to Artificial Island.

Pea Patch Island is one of the larger heronries in the Middle Atlantic Zone and considered a unique breeding area of national significance (Beccasio, 1980). This area also has an abundance of endangered and threatened herons (see page 21).

The high risk areas on the New Jersey shoreline have biological indications of organic enrichment This enrichment is evidenced by species of blue green algae, green algae, and oligochaete worms. Unlike the northern refinery situation of polluted waters with a limited number of species, this area has a diverse amount of life. There are a scattering of freshwater marshes which are inhabited by several species of wading birds, waterfowl, and the bald eagle which is a federally endangered specie. Chronic spills may in the long term cause decreased species diversity as in the northern refinery area. (It is important to note that this area would also be impacted if a spill occurred in the winter during maximum flood tide.)

In Case B, the most detrimental biological effects for chronic spills would occur in the lower Bay during summer at maximum flood tide (Figure 10). Six spills, with a total of 3,948 gallons/year are predicted from the anchorage area and the bulk facility site. This is almost eight times as much oil as in Case A where 504 gallons/year is predicted if current practices continue. Such an increase would adversely affect this area. Within 72 hours a small spill from the bulk facility would reach Maurice River Cove, New Jersey. Communities and biota considered in high risk areas are marshes, beaches, benthic assemblages, plankton, fish, and birds. Marshes could become degraded because of the chronic nature of the oil. In the long term, marsh loss would cause a decrease in productivity and habitat. Beaches in the area would become oiled and species on and within the beach would be impacted. The degree of impact on fish and plankton is dependent on the spreading of oil (which can not be predicted). Local populations would be affected since they are present in large numbers in the summer. Fish that use the area as a nursery during the summer (these include striped bass, blueback herring, Atlantic menhaden, and American shad, which is threatened in New Jersey)

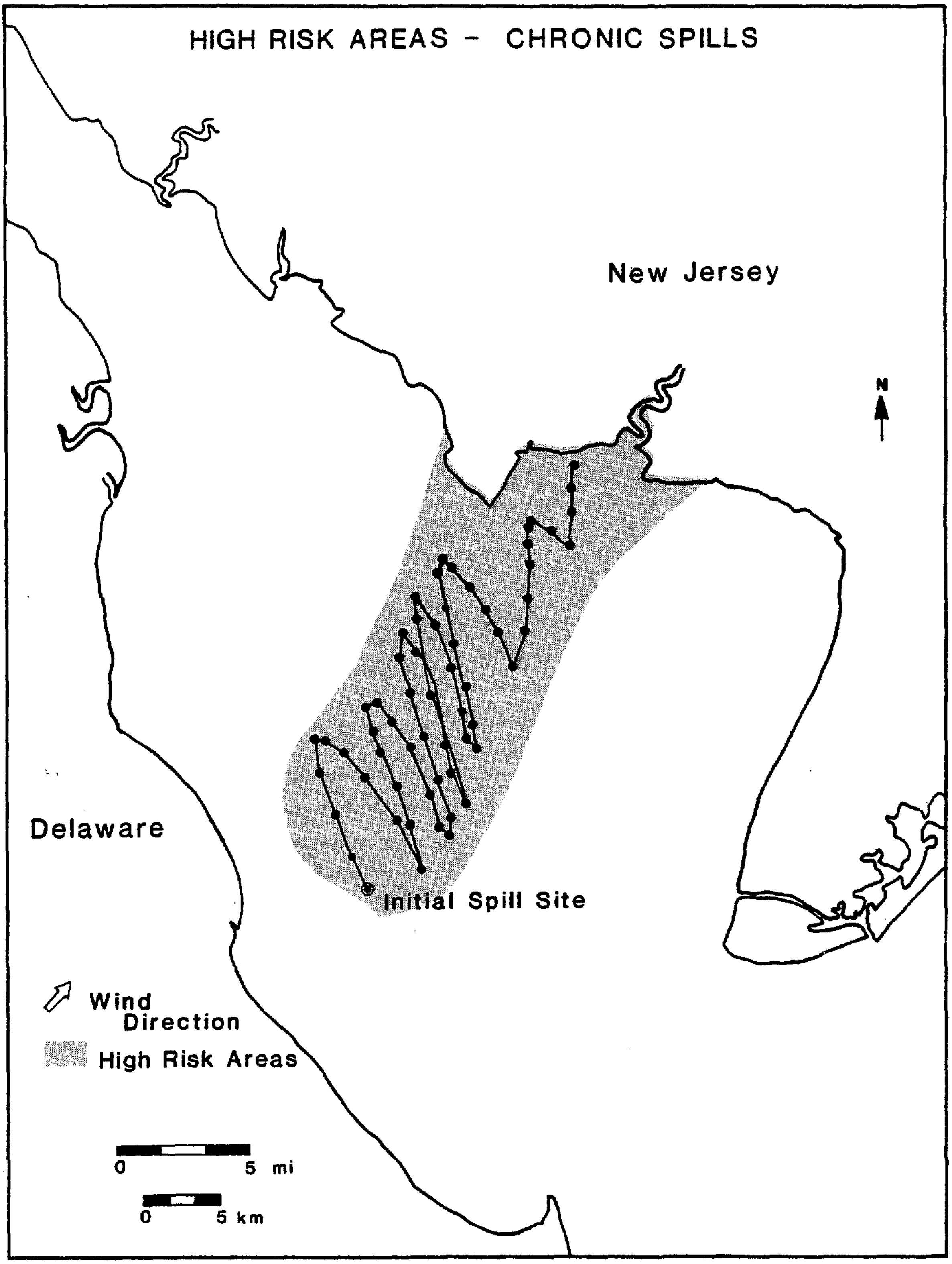

HIGH RISK AREAS - CHRONIC SPILLS
New Jersey
N
Delaware
Initial Spill Site
Wind Direction
High Risk Areas
0 5 mi
0 5 km

Figure 10.

would be locally impacted. Shellfisheries may be impacted depending on the amount of oil that reaches the bottom sediments.

The worst case for the episodic spills is Case B, between the Capes (Fig. 11). (However, a spill off Marcus Hook has the potential for being the worst Case. But because of the confined nature of the river, the majority of a spill should be cleaned up before reaching the lower Bay). Out of the two seasons analyzed, summer had more detrimental effects. Flood or ebb tide had little bearing on the high risk areas. The simulations were run for 48 hours with winds from the SW averaging 11.2 knots. After 48 hours, the center of the spill still remained within the Bay area with some spreading to oceanside shorelines of New Jersey and Delaware. The extent of oil along both Bay and oceanside shorelines will depend on the longshore currents.

A spill with quantities over two million gallons would be devastating. There would be mass mortalities in all biological communities. It is beyond the scope of this report to predict the recovery rate. From an economic standpoint, a spill of this nature would be disastrous for fisheries and for summer recreational businesses.

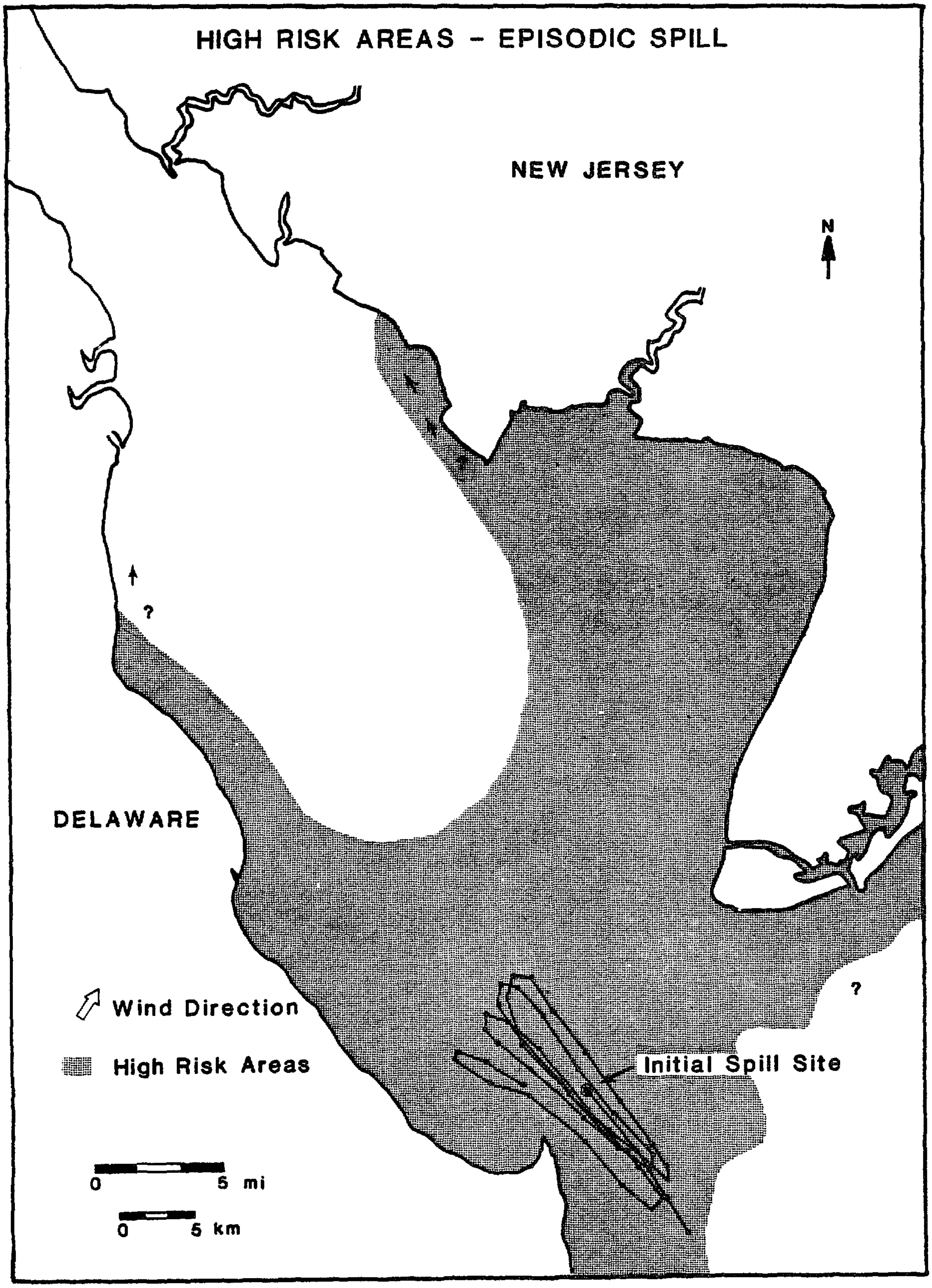

HIGH RISK AREAS - EPISODIC SPILL
NEW JERSEY
N
DELAWARE
?
?
Wind Direction
High Risk Areas
Initial Spill Site
0
5 mi
0
5 km

Figure 11.

SECTION III

ALTERNATIVE CRUDE TRANSSHIPMENT SCENARIOS

Overview

This section describes the proposed bulk facility for the Delaware Bay and the routing scenario for the accompanying onshore pipeline. Biological, geological, and institutional conflicts which can be expected should construction occur, are identified as are logistical siting problems. Potential impacts described in the theoretical primary route. In the process, potential tradeoffs among these factors (i.e., technological, socio-economic, institutional, and environmental) will be identified. The final route alignment will incorporate the impact factors and the advantages and disadvantages of alternative pipeline route alignments.

Description of Crude Oil Transshipment Facility

The crude oil transshipment facility for the Delaware Bay region will consist of two single point mooring systems, pipelines (offshore and onshore), pumping stations, and tank storage at Delaware City and Marcus Hook (Figure 12).

a. The Bulk Facility

Single point mooring (SPM) systems will service tankers of the very large crude carrier (VLCC) class. A tanker would moor in the SPM north of the Big Stone Anchorage in sufficiently deep water where the crude would be offloaded via floating hoses through an SPM to underwater pipelines. Two mooring buoys would be installed, one to be used for backup, each connected to a 48-inch pipeline to carry the crude onshore.

There are three general types of SPM's which have been constructed or planned throughout the world:

1. Single Anchor Leg Mooring System (SALM)
2. Catenary Anchor Leg Mooring System (CALM)
3. Articulated Columns

The Catenary Anchor Leg Mooring System has been the most common type of SPM installed. It has been used in shallow to moderate depths and relatively calm environments and would s-em to be appropriate for the Delaware Bay facility. The various SPM's have been described in detail in a recent report by NERBC (1981).

b. Offshore Pipelines

Two 48-inch pipelines would be routed from an area north of Big Stone Anchorage, through the Bay waters approximately five miles to landfall at Big Stone Beach, Delaware. In light of current pipeline installation technologies, this area presents no out right prohibitions to the construction and operation of submarine pipelines. Site-specific studies will be necessary to obtain detailed information on the local bathymetry and sediments.

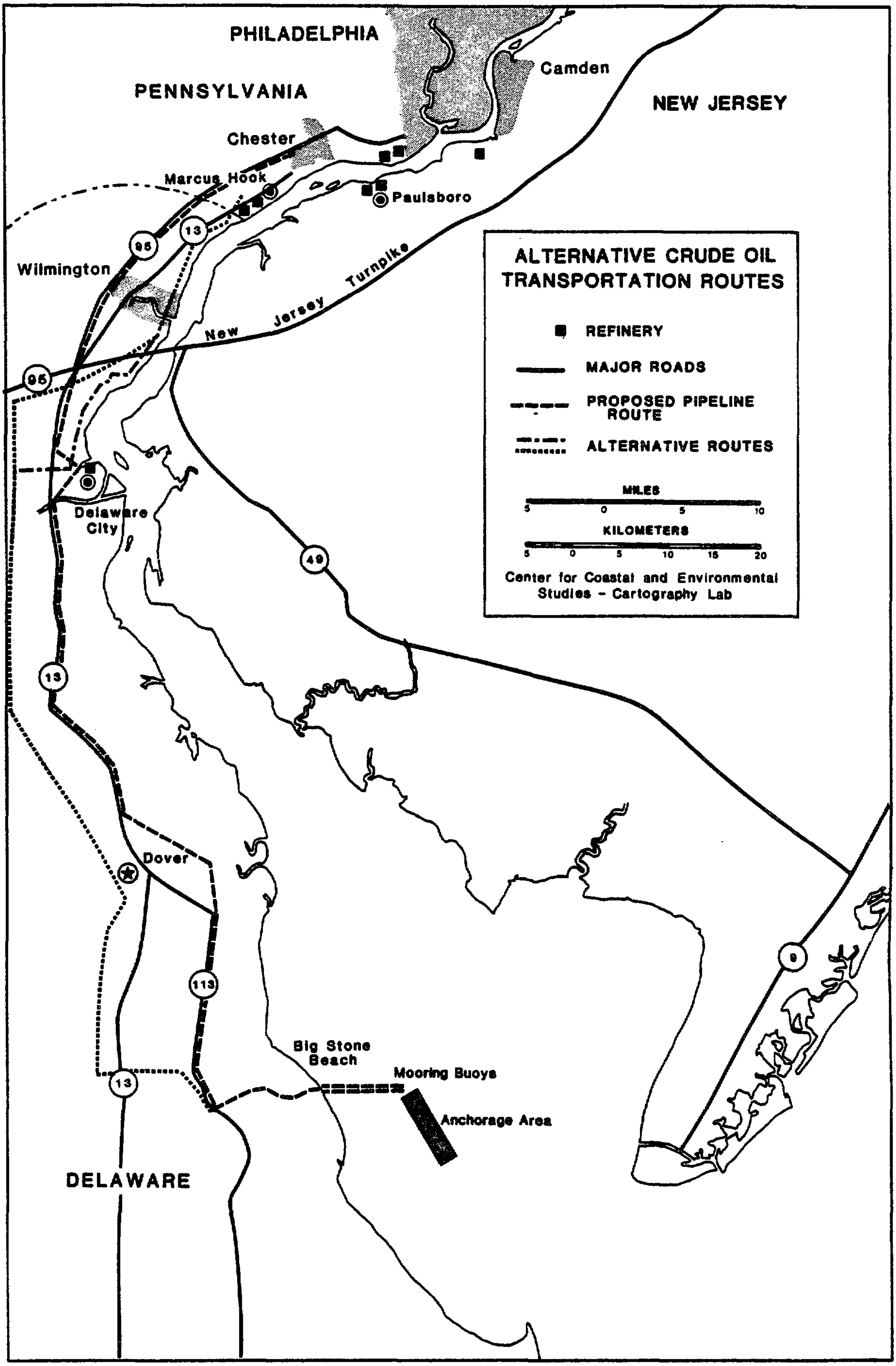

PHILADELPHIA
PENNSYLVANIA
Camden
NEW JERSEY
Chester
Marcus Hook
Paulsboro
Wilmington
95
13
New Jersey Turnpike
ALTERNATIVE CRUDE OIL TRANSPORTATION ROUTES
REFINERY
MAJOR ROADS
PROPOSED PIPELINE ROUTE
ALTERNATIVE ROUTES
MILES
5 0 5 10
KILOMETERS
5 0 5 10 15 20
Center for Coastal and Environmental Studies - Cartography Lab
Delaware City
49
Dover
113
9
Big Stone Beach
Mooring Buoys
Anchorage Area
DELAWARE

Figure 12.

The proposed pipeline would be routed through blue crab potting and dredging areas. Pipelines in navigable waters are required to be buried below the natural surface, which involves the dredging of a trench. Trenching is the primary cause for four major environmental disturbances associated with the construction of a pipeline (Golden, et al., 1980). These are:

1. the direct loss of bottom organisms;
2. turbidity effects;
3. habitat alterations; and
4. alterations of physical and chemical characteristics of the ecological system traversed.

These impacts can be expected to be temporary, with some long-term habitat destruction.

c. Landfall

The pipelines are planned to come onshore at Big Stone Beach, Delaware, which is a summer community of approximately 60 homes. This portion of the Delaware coast has a sand-gravel barrier which is migrating landward and upward across low-lying tidal marshes (Kraft and John, 1976). Erosion has been occurring at a rate of 2 meters/year (Weil, 1976), a condition which will subject the pipeline to shallow water stresses if not properly planned for. Burial of the pipeline to a depth which incorporates anticipated long-term shoreline changes over the economic life of the pipelines will be necessary (Golden, et al., 1980).

d. Pumping Stations

From landfall, the two 48-inch pipelines would proceed inland for approximately one mile to a pumping station. This facility would occupy about 1000 square feet (93 sq meters), and serve to raise the throughput pressure of the crude oil. However, the presence of the tidal marsh and the Milford Neck Wildlife Area in the vicinity of the proposed location of the pumping station may preclude this siting. A recommended alternative is to site the pumping station closer to landfall. This will serve the purpose of minimizing disturbance to the wetlands, both from the pumping station construction and the right-of-way width necessary for the dual line system.

From the pumping station a single 48-inch pipeline is planned to carry the crude to the refineries at Delaware City, Delaware and Marcus Hook, Pennsylvania. The proposed route is described here.

e. The Onshore Pipeline

Pumping Station to Route 113 - The pipeline would follow a light duty road from Big Stone Beach to 113, a distance of about seven miles. This road passes through the Milford Neck Wildlife Area part of the way and is bounded by private property elsewhere. This area is an important habitat for adult concentrations of whitetail deer (U.S. Fish and Wildlife Service, 1980a).

Route 113 to Route 9 at Dover AFB - Route 113 is a four lane highway with two lanes each northbound and southbound. Around the Murderkill River section of Route 113, adult concentrations of wading birds and various songbirds would be encountered. There is also a nesting site for wood ducks in this locale. In additon to the Murderkill, the pipeline would also cross the Saint Jones River.

Route 9 to above Little Creek - At the intersection of Routes 113 and 9 is an area used by plovers during migration. Proceeding along Route 9 the Little Creek Wildlife Area, which is an area for migratory shorebirds, wading birds, rails, and waterfowl species, is encountered. In this section of the pipeline route it is critical that construction occur during non-migratory and non-nesting seasons to minimize adverse impacts on these communities.

Dover Air Force Base represents an area of high population concentrations and activities. Route 9 passes on the eastern border, then proceeds through privately owned farmland until it reaches the town of Little Creek (population less than 1,000).

The pipeline would avoid traversing Little Creek by proceeding across the farmlands. The proposed route would continue in a northerly direction on State Route 9 where it heads west until it again meets Route 113. This section of the route involves a crossing of Little River.

Route 113 to Saint Georges - Route 113 crosses the Leipsic River just north of the town of Bethel. The Leipsic is a major migratory route for anadromous fish species (see Section I, Part A).

Another river crossing occurs at Appoquinipink Run, from which point Route 113 proceeds north to the Chesapeake and Delaware Canal and Saint Georges. The Canal would constitute a major river crossing. Besides requiring a specialized work crew, traversal of the Canal by the pipeline would present significant problems with boat traffic for the length of the construction period. If traditional river crossing techniques were to be employed, wherein dredging would take place, impacts on striped bass spawning grounds could become significant. The crossing of the Canal may necessitate the use of boring rather than dredging which would minimize these potential impacts.

North of the Canal at Saint Georges, the pipeline heads northeast toward the Getty Oil Refinery at Delaware City, Delaware. This involves passage through Dragon Creek, where there are adult concentrations of wading birds, overwintering waterfowl, nesting sites for wood ducks, and an area for migratory songbirds (U.S. Fish and Wildlife Service, 1980b). An alternative to passing through this marsh area is suggested and is presented in Part f of this section.

From a point one mile west of the Getty Refinery, the pipeline route would proceed in a northwesterly direction to meet Route 13.

Route 13 to I-95 at Wilmington - The pipeline enters an area of high population density at this point, joining with Interstate 95 in the City of Wilmington. This section of the route also involves the crossing of the Christina River and the Brandywine Creek, both of which are spawning and nursery grounds for the American shad, which is a threatened speces in New Jersey (Beccasio, et al., 1980).

With the presence of high population densities along the route, logistical problems with respect to constructing the pipelines, and the extraordinary costs involved in proceeding along this segment of the route, alternative pipeline routing alignments for this particular segment of the route should be considered. One such alternative is presented in Part f.

I-95 to Marcus Hook - After connecting with I-95 in Wilmington, the pipeline would proceed to a point one mile east of Marcus Hook, Pennsylvania, where the refineries of British Petroleum and Sun Oil are located. At this point a tank farm would be constructed with nine 400,000 barrel tanks and ten 250,000 barrel tanks. A tank farm of this size would require a minimum of sixty-one acres (A. Baragona, personal communication).

f. Alternative Routing Alignments

There are many possible routing alignments for the proposed pipeline. This section presents two alternatives, describing each briefly. It should be noted that these are not recommended routings, but are presented to highlight the broad range of environmental and institutional issues associated with each potential pipeline route. More importantly, they are presented to illustrate that regardless of which route is selected, the final siting will involve trade-offs among a host of different factors.

Alternative 1 - Penn Central Right-of-Way

The use of an existing right-of-way (ROW) could eliminate much of the disruption of or interference with environmentally sensitive areas or human uses. Acquisition of lands for a right-of-way with one leaseholder could be less complicated than if numerous ROW agreements had to be negotiated with a larger number of individuals.

The Penn Central railroad presents an existing right-of-way which possibly could be utilized. The railroad, which is situated approximately fifteen miles inland from the pipeline landfall at Big Stone Beach, runs directly northward passing just west of the proposed pipeline terminus at Marcus Hook. Joint utilization of this ROW, however, if permitted, would present different logistical problems to construction crews since it passes near or through many towns. These logistical problems could be circumvented by deviating the route slightly so as to utilize rural farmland on the outskirts of those towns.

The feasibility of pipeline construction within the right-of-way of an operating rail line will depend primarily upon the characteristics of the particular line, such as the amount of traffic and width of the ROW (Golden, et al., 1980). Generally, the placement of a pipeline in a rail line which accommodates light train traffic is more feasible than in a heavily travelled service route.

The Penn Central line under consideration is alternately a single track and then a double or multiple track system below the Chesapeake and Delaware Canal. Above the Canal it remains double or multiple in character. One major factor which will play a role in whether joint utilization could occur is rail usage. Depending on the volume of traffic along the rails, there may be difficulty in scheduling construction to avoid interrupting service along the line.

Alternative 2 - Selected Modifications of Proposed Route

This alternative addresses two sections of the proposed route which upon initial investigation appears to possess a number of special problems. Suggested alternatives have been developed following the general guidelines of minimizing mileage and adverse impacts.

A. Saint Georges to Marcus Hook

As stated earlier the proposed route passes through Dragon Creek, a wetland marsh which is important for the unusually rich flora and fauna found there (Part e, page 53). From Saint Georges it would head NE through Dragon Creek to a point west of the Getty Refinery, then head NW to meet Route 13. The total distance for this section to the junction with I-95 at Wilmington is sixteen miles (26 km).

Avoiding the Dragon Creek area would substantially decrease adverse impacts on wildlife while keeping the mileage to Wilmington the same. This alternative follows Route 113 north from Saint Georges to a Penn Central line above the community of Corbitt, at which point it would follow the line eastward to the Getty refinery and the proposed new tank farm. The pipeline would then proceed along Route 9 to the outskirts of Dobbinville, head north to again meet a Penn Central line, and then traverse industrial areas of New Castle. The pipeline would then follow the Penn Central line to a point south of Wilmington. This alternative has the added benefit of favorably situating the pipeline route so as to avoid the downtown area of Wilmington, as originally proposed.

B. Wilmington, Delaware to Marcus Hook, Pennsylvania

The proposed route for this section has several problem areas, as described in Part e. By continuing along the route in Alternative 2-A of this Part, these problems may be avoided. However, this alternative involves the use of a railroad ROW, and should be viewed in light of the impacts associated with joint utilization of a ROW of that type.

From Wilmington, the Penn Central line discussed in 2-A above passes just west of Marcus Hook and the BP and Sun refineries. This is an area of high industrial concentration and wasteland. Few if any important biological resources are located along this part of the coastline which is in fact, highly polluted. The distance involved with the use of this alternative is approximately seven miles (11 km), as compared to the slightly longer ten miles (16 km) in the proposed route.

CONCLUSIONS

The development of a bulk crude oil transfer facility in the lower Delaware Bay will have definite impacts upon the overall environmental quality of the region in general and on the biological communities in particular. The construction of an onshore pipeline to carry the crude oil through Delaware to the refineries at Delaware City, Delaware and Marcus Hook, Pennsylvannia will interfere, at least temporarily, with the cultural and ecological systems through which it passes.

Under the current system used to bring crude oil into the region, a number of spills occur each year. Most of these take place in the upper reaches of the Bay near the Getty reinery and in the Delaware River at Marcus Hook. With the bulk facility in operation, spills will be displaced from the already polluted areas of the estuary to the lower reaches of the Bay which are relatively unpolluted. Chronic low level spills are expected to occur as part of the standard operating procedure. Though the exact effects of these spills are unknown, and it is difficult to attribute them directly to the spills, negative impacts in the long term can be expected. An episodic, large spill would be catastrophic, causing immediate mass mortality in all biological communities. The recovery period of a large spill is unknown.

The shellfisheries of the Delaware Bay are very important to the regional economy. The fact that most species are very sensitve to the degradation of water quality, and that this facility will almost certainly result in such a degradation, suggests that a major conflict between these two uses will occur. Possible mitigating measures include transplanting the beds, or direct compensation to the fishing industry for loss of revenue.

The wetlands along the Delaware Bay and River provide nutrients to the estuarine system and serve as important habitat for wildlife, especially migratory birds. The vegetation is susceptible to numerous, low level spills while oil has been shown to persist in marshes after large spills. Both chronic and episodic spills are detrimental to wetlands, which in turn upset the balance of the estuarine system.

The proposed pipeline routing alignment from Big Stone Beach to Marcus Hook involves numerous water crossings, follows heavily utilized transportation corridors, and passes through wildlife areas and residential areas. Although conflicts of this nature will arise on every selected route, careful planning and consideration of the trade-offs involved can result in the reduction of conflicts and will lessen the negative impacts which may occur. This is evidenced in the two alternative routing alignments presented in Section III.

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THE CURRENT STATUS OF THE OYSTER COMMUNITY IN DELAWARE BAY AND ITS PROJECTED STATUS IF A CRUDE OIL RECEIVING FACILITY WERE TO BE BUILT IN DELAWARE BAY

A Report

to

The Port Authority of New York and New Jersey

By

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The Current Status of the Oyster Community in Delaware Bay and Its Projected Status if a Crude Oil Receiving Facility Were to be Built in Delaware Bay

Introduction

This report is presented in five sections. The first is a general description of the oyster population in Delaware Bay, emphasizing the major environmental factors that influence and limit it and indicating the importance of its association with other species in the community. The second section outlines the life history of the oyster to provide background for an understanding of its sensitivity to changes in its environment and of the basic operations of the oyster industry designed to enhance the productivity of the population. The third section discusses the present status of the oyster industry that has such a vital interest in, and is completely dependent on, the successful management of this public resource. The fourth section details some recent work of this laboratory* in establishing threshold concentrations of petroleum hydrocarbons for damage to adult oysters and to oyster larval stages. The fifth and last section points out that the projected changes in oil spill frequency and location would probably have little or no influence on the oyster population, but that a massive accident with a supertanker within the Bay would be completely devastating .

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I. The Oyster Community in Delaware Bay

The most important commercial fishery in the Delaware estuary, the oyster industry, is based on the native oyster populations that extend from the Hope Creek beds, below Artificial Island, to the vicinity of Brandywine Shoals in the lower bay (figure 1). The populations thus range over 33 nautical miles measured along the central axis of the bay. At mean river flow salinities at the upper edge of this range vary around 5 o/oo* and at the lower edge are about 30 o/oo (figure 2, 3). The oyster is thus quite tolerant of salinity over a broad range, although, as discussed below, it does not grow, reproduce and condition equally well over its entire salinity range.

In addition to favorable salinities oysters require a stable substrate. They do not carpet the entire bay bottom within favorable salinity limits, but grow naturally in discrete beds, the most prominent of which comprise the natural seed beds in the upper bay. Over a century ago oystermen began the practice of oyster culture in which they transplanted small oysters from natural beds to growing and fattening grounds, frequently prepared by first establishing a layer of shells to stabilize the bottom and to prevent the young seed oysters from settling into the softer sandy and muddy sediments. About the turn of the century, by act of the legislature, the New Jersey portion of the bay was divided into two general areas: the natural seed beds and the planting grounds (figure 1). The Southwest Line was established as the boundary between the two areas. The planting grounds are available for lease by the State to individual citizens of the State. The seed beds are held under State management and are traditionally opened in the spring of each year when planters may dredge seed oysters for planting on their individual leased grounds.

*Parts per thousand.

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Approximately 28,500 acres are under lease in the New Jersey planting area and the major producing seed beds total about 13,000 acres. The State of Delaware oyster bottoms are similarly divided, though the producing seed beds and leased planting areas are smaller at 900 and 8,950 acres, respectively.

The planting and harvesting practices have been developed empirically by the oystermen and result from several generations of experience. Two biological and/or ecological principles underlie this empirical system: (1) that although the oyster can exist over a broad range of salinities, in Delaware Bay from approximately 5 to 30 parts per thousand, at the lower salinities it grows more slowly, does not condition well and fails to reproduce as abundantly. (2) the second principle is that over geological time most of the animal species inhabiting the estuary have invaded from the sea and they differ in their abilities to withstand the lower salinities as they penetrate the inner reaches of the estuary. Consequently the numbers of animal species associated with the oyster declines with the decreasing salinity or increasing distance from the sea. We find for example about 150 species of animals in the "oyster community" on the planted grounds below Egg Island Point (Ismail, 1980), while on our uppermost seed beds, the species list drops to about 40. Similar species distributions along the salinity gradient are reported on Delaware oyster beds (Mauer and Watling, 1973). Among the species in the oyster community that drop out at the lower salinities of the upper beds are, most importantly, the oyster drill which is the principal oyster predator, some of the mud crabs, and, in addition, several species that compete with the oyster for food and space.

The result is that at the upper Bay end of its salinity range, the oyster is in a natural sanctuary where it is free of several of its major enemies as well as of many space and food competitors. This means that although the oyster does not reproduce as freely here, those that settle from the plankton have generally much higher survival rates than those settling down bay. Here beyond reach of drills and some of the mud crabs they grow slowly over several years until they reach a size less attractive (or vulnerable) to the oyster drills and crabs. They are then moved down bay and after one or two growing seasons on the planted grounds they are ready for harvest.

II. Oyster Life History

To understand further the interplay of environmental factors affecting the oyster community one must know at least the highlights of the oyster life cycle in the Bay. Adult oysters are immobile members of the benthic epifauna (non-burrowing bottom dwellers). Sexes are separate, sex products are discharged into the water where fertilization occurs and these reproductive events are largely temperature-controlled. As waters warm in late spring and early summer, eggs and sperm mature, but are not released until temperatures reach about 25°C.* The spawning stimulus is usually a sharp increase in the temperature sometime after general bay temperatures reach about 22°C, usually in late June or July. Fringe populations in shallower waters and in the mouths of creeks and rivers may thus spawn in advance of the populations in the deeper, cooler waters of the planting grounds and major seed beds. As oysters on a bed begin to spawn - usually males will discharge sperm before the first

*77°F.

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females discharge eggs - the presence of sex products (gametes, i.e. egg and sperm) in the water is an additional stimulus for the remaining members of the population. This stimulus increases the probability of mass spawning and thus of successful fertilization of the discharged eggs.

Within 24 hours of fertilization the larvae have developed to a free-swimming stage and already bear a delicate, transparent shell, about 60-65 µm in length. In approximately two weeks, if food conditions are favorable and temperatures remain at 25°C or above, the planktonic larvae will increase in size and complexity and be ready to "set", i.e. settle to the bottom, find a clean hard surface and cement themselves fast, where they remain fixed for the rest of their lives. At "setting" the larvae are approximately 250-300 µm in length (about 1/75th of an inch).

The planktonic larval period is an especially critical one in the life of the oyster. The larvae must have readily available food consisting of phytoplankton of the right size and quality. Storm events during this period can lead to the suspension of greater amounts of sediments, increasing turbidity and thus reducing photosynthesis and the production of food and also interfering directly with filter feeding. Storms may also alter the usual current systems so that larvae are carried to unfavorable areas or may be completely flushed from the Bay. The planktonic oyster larvae may also be directly preyed upon by other plankton feeders, such as the Ctenophora (comb jellies) and schools of menhaden. In our annual surveys of planktonic oyster larvae, loss of entire broods has been a common experience following the advent of swarms of "comb jellies" or schools of menhaden.

The behavior of the microscopic oyster larvae themselves, in response to certain environmental cues, is of critical importance in their survival within the Bay. For the first seven or eight days of their planktonic existence they are found throughout the water column. In the last 6 or 7 days their position in the water column varies with the local stage of the tide. At slack water they are on or near the bottom and they remain there during ebb tide. On flood tide they rise in the water column and are carried up bay. Thus, on the average, early stage larvae move seaward with the net down bay drift of water. In contrast, the later stage larvae, by rising on flood tide and sinking on the ebb, have a net up bay movement and some are able to return to upper bay beds and beds in the lower reaches of tributary creeks and rivers. Studies in this laboratory have demonstrated that the environmental cue to which the late stage larvae are responding is a change in salinity. With flooding tide in the Bay salinity at a given location slowly increases, stimulates swimming and the larvae rise in the water column. With slowly decreasing salinity on the ebb tide, the larvae cease to swim and settle to the bottom.

This account of the reproductive activities of the oyster from the development of the gametes, to external fertilization, to growth and development of the planktonic larvae to the setting state is intended to emphasize the hazards of this portion of the life cycle. Failure at any one of several points can result in loss of a larval brood or an entire year class. Toxic substances introduced into the Bay obviously could conceivably kill adult oysters, but they also could be destructive of the

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populations if they interfered with gamete development, physiological processes involved in mass spawning, the production of suitable larval foods, responses of larvae to various environmental cues, etc.

The early post-setting period is equally hazardous for the young oyster "spat". Many of the associated species in the oyster community also have planktonic larval stages which, at setting, compete with the oyster spat for space. Some of these, such as bryozoans, sponges, tube-building polychaete worms, barnacles, etc. may overgrow the oyster spat, smothering it or retarding its growth. Some of the species compete with the oyster for food (phytoplankton feeders, such as barnacles, bryozoans, sponges, other bivalves, etc.). Others are predators, such as the oyster drill, several of the mud crab species, and a polyclad flat-worm. General browsers and scavengers, such as the mud snails, other crabs, larger worms, etc., as they work over the shell bottom, can easily kill the delicate oyster spat. Again through effects on the variety of species that interact with the oyster, particularly in these early life-cycle stages, toxic materials may be either harmful or possibly even beneficial to the oyster. Fouling of the setting surfaces by toxic materials could be destructive of the entire benthic community.

III. Present Status of the Oyster Industry

Presently the Delaware Bay oyster industry is slowly recovering from a low point reached 20 years ago after a series of grave misfortunes, some of which are not completely understood. These will be discussed briefly using the readily available statistics of the New Jersey industry. The history of the Delaware industry roughly parallels that of New Jersey, as would be expected since it is based on a section of the same oyster community, although it has not always been managed in exactly the same way.

In approximately the first 50 years for which landings are available (1883-1929) total oyster harvests in New Jersey were highly variable, ranging from 1 to 3 million bushels annually and averaging about 2 million bushels. In the next two decades (1930-1950) annual landings were relatively steady averaging about 1 million bushels (Table 1). Cause or causes of the halving of average production, starting in 1930, are obscure. Beginning in the early 1950's production of oyster seed declined sharply and planters began to import seed from the Chesapeake. By the mid 1950's even with these imports, landings had dropped to a little over half a million bushels and then with the advent in 1957 of a new oyster disease, called "MSX" (Minchinia nelsoni), plummeted sharply to a record low of approximately 24,000 bushels in 1960. It is important to note that the decline starting about 1950 was not caused by MSX. In our judgment this was most probably a direct result of mismanagement and over-fishing of the natural seed beds. In 1945 power boats were legally able to work on the New Jersey natural seed beds for the first time. Until then seed oysters could be dredged from the State-controlled beds only by boats under sail, and the season legislated for this was the two months, May and June. The season was not shortened on conversion to power-dredging. Dredge boats of all sizes under power were able to work more efficiently and in areas where sailboats could work only with certain combinations of wind and tide, or not at all. It is commonly held that some smaller inshore beds were dredged out of existence in the late 1940's. Setting on the major lower beds (New Beds and Bennies) became irregular and scant and a serious shortage of seed developed. Our Oyster Research Laboratory in 1953 made its first recommendations for restriction of seed bed dredging to permit rebuilding of brood stocks in the upper bay. Brood stocks were further seriously depleted by MSX kill. We estimate that in 3 years, starting in 1957, 90 - 95% of all oysters on the planted grounds and about 60% of the stocks on the seed beds up to and including Cohansey Bed were killed by this disease (figures 1, 4 and 5).

Over the intervening years there have been two major developments that now shape the industry: (1) The seed beds have been brought back into more regular production; and (2) the native bay stocks, under continuing disease pressure, have developed a level of resistance to kill that enables the industry to maintain production of market oysters though at a seriously reduced level compared to the pre-1950 period. The seed bed production figures and the official harvest data (Table 1) highlight some questions on the current status of the industry.

In the pre-MSX years the long term experience in the Delaware Bay industry was to get 1 bushel yield of market oysters for every bushel of seed planted with seed oysters at 600-800 per bushel and market oysters averaging 250-300 per bushel. This means that, on average, half to two-thirds or more of the seed oysters died before harvest. Oyster drill predation was recognized as a principal cause of this mortality.

From more recent experience a "background mortality" of about 1% monthly, i.e. death from unrecognized causes, could be expected. With planting cycles of two to three or four years, such background mortality would account for a substantial portion of the total mortality experienced.

MSX has changed the traditional planting practice. Oysters on the lower-salinity seed beds are under substantially less disease pressure than those on the planting grounds and the present practice is to allow, whenever possible, oysters on the seed beds to grow almost to marketable size, and then plant for 1 growing and fattening season only before harvest. This exposes the oysters to a single MSX infection period in the lower bay and substantially reduces disease loss as well as loss to predators. Careful study of disease-related mortality for more than 20 years enables us to draw some firm conclusions on mortality levels. On the average in the first year after planting 17% of the oysters will be killed by predators and 37% will die of other causes. Whenever soft parts of recently dead oysters have been recovered, they have been examined histologically and two-thirds of these have shown MSX infections. We can thus estimate that since MSX began to kill oysters in 1957 two-thirds of 37% or approximately 25% of all oysters planted, have died with MSX within their first year. If oysters are held a second year the non-predation kill increases to 50% and by the end of the third year to 56%.

One would expect that with the MSX mortality of planted oysters added to all the other mortalities that existed before MSX appeared, the ratio of harvest oysters to seed planted would be sharply reduced below the traditional 1:1. As a matter of fact, however, for the first eight years (1966-1973 inclusive) of consistent improved seed production after MSX was well entrenched a total of 1,279,165 bushels of seed yielded 1,459,600 bushels of market oysters for a ratio of 1.14! In contrast, for the next seven years (1974-1980 inclusive) with a conspicuous increase in seed planted, 2,679,740 bushels of seed yielded only 1,317,129 bushels of market oysters for a ratio of 0.49. How, with no overall increase in MSX losses in the last 7 years can we account for the dramatic reduction in ratio of oysters harvested to seed planted?

Some of this reduction is probably the result of planting smaller oysters - with a record heavy set in 1972 followed by a series of good general setting years, smaller, younger oysters have been mixed in with the larger seed. Although they add to the bulk of the seed planting, they are too small to be marketed in the first harvest season following planting. If culled out and returned to the planted ground a higher proportion dies before the next year's market season. Examination of shucking house shell piles indicates that as many as one third of the oysters run were too small to shuck and were passed through and died on the piles. There is also a good probability that landings are under-reported, and it may be that this practice has increased in late years.

In light of the history of the New Jersey Delaware Bay oyster industry over the past 25-30 years as reviewed above, it is very encouraging that the seed beds have made a strong recovery and have produced an average of slightly over 380,000 bushels of seed annually since 1974. Since MSX has not caused substantial mortalities on the seed beds except in drier years, we know of no reason why the seed beds should not continue to improve to approximately double the current annual seed production, thus equalling the pre-1950 production. What yield of market oysters can we reasonably expect from such an increased seed production?

Assuming that the seed are similar in size and quality to that currently available we could expect that doubling the planting would, on the average, double the harvest. Based on official current landing figures this would mean a harvest of about 400,000 bushels annually. As indicated above, however, actual present landings are probably substantially higher than reported, and the 400,000 bushel estimate would then be increased proportionately.

Obviously the present utilization of small seed is wasteful and costly and shifts in management will be explored. In the spring of 1981, areas immediately above the Southwest Line were leased for planting 122
for the first time in our history. Expansion of this above-the-line area will probably provide an opportunity for the planters to grow their small "plants" for a year or two in relative safety from heavy MSX kill. Then, in a second transfer, the larger oysters resulting may be moved for a brief period, perhaps from late summer to early fall down bay for rapid market conditioning with little or no risk of loss to MSX. If with such a system the 1:1 seed to yield ratio (obtained as recently as in the 1966-1973 period) is realized, an annual harvest of about three-fourths of a million bushels would be obtained. This is our current management objective, and we think that it is realistic, barring unforeseen catastrophes.

IV. Oil and the Oyster Populations of Delaware Bay

Nearly 10 years ago, as exploration for oil deposits began immediately off the New Jersey coast, it seemed likely that transport of oil in and through the Delaware Estuary might increase in volume. We asked the question of what such an increase might mean to the oyster population and in 1974 began to examine this question under a 3-year research contract with the National Science Foundation. This work was part of a larger effort on all aspects of "The Petroleum Industry in the Delaware Estuary", undertaken cooperatively by the Academy of Natural Sciences of Philadelphia and Rutgers University under Grant No. ENV 74-14810-A03 of the RANN program of the National Science Foundation. Chapter 7 of our final report, entitled "Oil and the Oyster Industry in the Delaware Estuary" contains detailed information from which relevant findings are extracted in the following pages.

The general objective of the "oyster and oil project" was to identify and evaluate the effects of petroleum and its derivatives on the oyster community of the Delaware estuary. Identification of petroleum-related materials particularly hazardous to the oyster community could then aid in defining maximum levels of petroleum-related pollutants that would still permit survival of the oyster beds.

Substances may be hazardous through direct action on adult oysters or on developmental stages, such as the pelagic larvae. They may also operate through influences on the oyster food supply, primarily the phytoplankton, or through other species associated in the oyster community. Because of these considerations our experimental work fell into three general categories, and is reported as follows: (a) chronic exposure of adult oysters to petroleum hydrocarbons; (b) acute and chronic exposure of larvae; (c) effects of a crude oil on growth of selected phytoplankton species known to be utilized by the oyster.

Much of the literature relating filter-feeding bivalves to oil pollution deals with the concentrations of oil-derived materials in shellfish following oil spills or in chronically polluted waters. Earlier work in the Gulf of Mexico area (Mackin and Hopkins, 1961) found oysters relatively insensitive to oil damage except for oily flavors, which were rapidly lost on return of oysters to clean water. More recently Mackin (1973) has critically reviewed papers dealing with oil spills and their effects on benthic communities. Oysters were included in a long-term study of benthic organisms and environment in the wake of a spill of #2 fuel oil at West Falmouth, Mass. by Blumer and his co-workers (Blumer, Souza, and Sass, 1970; Blumer, 1971; Blumer, Sanders, Grassle, and Sampson, 1971; Blumer and Sass, 1972; Blumer and Sass, 1970; 1972; Sanders et al, 1980). Blumer reported that oysters, contaminated with #2 fuel oil, retained that oil unchanged in composition or quantity for as long as six months.

Concentration of oils by a variety of shellfish in polluted waters has been reported. Ehrhardt (1972) finds high concentration of aromatic hydrocarbons in oysters from Galveston Bay; Farrington and Quinn (1973) report accumulation of petrochemicals by the hard clam *Mercenaria mercenaria* in Narragansett Bay. Accumulation of petroleum hydrocarbons from the Lagoon of Venice by mussels (*Mytilus edulis*) has been reported by Fossato and Siviero (1974). Elimination of these hydrocarbons when the mussels are transferred to clean water has been studied by Fassato (1975).

The oyster has been included in the group of estuarine animals studied by the Texas A & M group in its evaluation of the effects of a variety of crudes and refined products (Anderson and Anderson, 1973; Neff, 1973; Anderson et al, 1974; Anderon and Anderson, 1975). Using water-soluble extracts of the oils and oil-in-water dispersions they have exposed animals to high dosages for relatively short uptake periods and have then studied cleansing after removal of the oysters to clean water. They report the naphthalenes as the petroleum hydrocarbons accumulated to the greatest extent and also as the last to reach undetectable levels during the cleansing process. They find the oyster quite resistant to damage by petroleum hydrocarbons and report no mortalities in their studies.

Two groups have exposed shellfish to comparatively low levels of oil over long periods of time. One of these, Stegeman and Teal (1973) studied the accumulation and release of hydrocarbons with oysters held in running sea water containing 106 ppb of #2 fuel oil for a period of 50 days. Incomplete cleansing occurred in the following period of 30 days in clean water. No mortalities were reported. The second group, Fossato and Canzonier (1976) working with mussels in Italy, absorbed #2 fuel oil on kaolin clay and then exposed the mussels for a long time (41 days) at low levels (0.2 - 0.4 ppm). They report accumulation at 1000 x the exposure levels and substantial mortalities!

In Delaware Bay, a highly turbid bay, oysters are probably more likely to be exposed to petroleum hydrocarbons absorbed on silts and clays than to water soluble extracts (WSE) in solution. The general use of WSE's experimentally seems to have developed from the idea that water soluble fractions will be most active biologically and/or the fractions to which animal populations are most likely to be exposed. These ideas may not be valid for filter-feeders in turbid estuaries. Any fraction of oil, absorbed on clay-silt particles, or other particulate matter of food size, may be taken into the digestive tract of the oyster, whether larval or adult. In addition, the slow release of absorbed petroleum fractions from sedimented particles may, in nature, prolong the exposure of benthic populations to material derived from an oil spill, urban runoff, refinery discharge, etc. Dredging of shoaling sediments from up-river areas and release in the lower estuary also provides a mechanism for rapid transport of oil-contaminated sediments to the bay area. These considerations led us to expose oysters, both adults and larvae, to petroleum hydrocarbons absorbed on kaolin clay.

Although there is an extensive literature on effects of heavy metals, detergents, and a great variety of pesticides and organic solvents on bivalve larvae (Davis, 1961; Hidu, 1965, Davis and Hidu, 1969; Calabrese, 1972; Calabrese, et al, 1973), only Renzoni (1973 and 1975) seems to have studied effects of crude oils on fertilization and larval development of oysters. He reports abnormalities in development and toxicity to larvae in response to chronic exposure to water-soluble fractions of the oils.

In recent years considerable effort has been concentrated on effects of various oils or oil fractions on the growth or carbon fixation of natural phytoplankton populations, or of various phytoplankton species grown in culture (Gordon and Prouse, 1973; Kauss et al, 1973; Nuzzi, 1973; Dunstan et al, 1975; Kauss and Hutchinson, 1975; Prouse et al, 1976; Winters et al, 1976). These compounds have the potential to alter the productivity of aquatic systems (Grodon and Prouse, 1973), or, due to differential sensitivity between species (Nuzzi, 1973; Dennington et al, 1975; Dunstan et al, 1975; Prouse et al, 1976), alter species composition in the water column. Such qualitative changes in the phytoplankton community could have serious consequences at higher trophic levels.

While much is known of the feeding habits of the oyster (Ukeles, 1969; Dupuy, 1974), little is known of the effects of petroleum hydrocarbons on those species of phytoplankton utilized as food. In this report, we examine the effects of a Nigerian crude oil on five species of phytoplankton commonly fed on by *Crassostrea virginica*.*

Materials and Methods

A. Preparation of Oil for Treatments

Water-soluble extracts (WSE) were prepared by stirring 9 columns of filtered bay water under a layer of 1 volume of Nigerian crude oil for 72 hours at 5° C until diluted for use. The mean total oil concentration of 41 WSE's was 10.47 ± 0.65 ppm (95% confidence interval of mean) as determined by extraction with carbon tetrachloride and infra-red spectrophotometry (Gruenfield, 1973).

*The commercial oyster species of the eastern coast of North America.

Oil has been adsorbed on fine kaolin clay of grain size approximately 0.1 μm by three methods. In initial studies crude oil was dissolved in pesticide grade pentane and added to a thin slurry of clay in pentane, shaken thoroughly and evaporated at 45° C to dryness under vacuum. The resulting oil-clay mixture was stored in glass containers at 5° C. In earlier #2 fuel studies this oil was mechanically mixed with kaolin with mortar and pestle and also stored at 5° C. In later studies both crude and #2 fuel oils were dribbled directly into a thin slurry of clay and sea water, resulting in a uniform mixture of oil-clay in sea water with no indication of emulsion formation. This mixture was prepared daily and immediately before use. This last method was evolved and used to simulate more closely the estuarine situation in which oils spilled into water would be exposed only to previously-wetted clays and silts. Valid objections had been raised to the first two methods in that the absorption of oil on dry clays rather than wet might result in quite different bonding, and, secondly, that storage of dry oil-on-clay in air provided opportunity for production of oxidation products conceivably more toxic than the oil under test.

In most experiments the ratio of oil to clay was 1:9 or 10%, but 1% oil-on-clay was also used. The oil-clay test was suspended in a sea water slurry in all cases.

Use of river sediments. Several samples of silty clay were dredged from the Paulsboro-Schuylkill area of the Delaware River and were stored in 5-gallon glass bottles at 5° C until use in larval studies. Preliminary analysis indicated approximately 50 percent water content and total oils at 4400 μg/g dry weight (carbon tetrachloride extraction and IR analysis). For bioassay, at each larval change, a slurry of this sediment was prepared and added to the cultures at concentrations ranging from 0.1 to 1.0 g/l wet weight. This approximates total oil concentrations of 0.22 to 2.2 ppm.

Algae grown in WSE. Some larvae were exposed to oil by feeding on algae that had been cultured with WSE in the medium. Subcultures of *Monochrysis lutheri*, *Isochrysis galbana* and *Dunaliella euchlora* were prepared weekly by inoculation of 140 ml. f/2 medium (Guillard and Ryther, 1962) with cells to reach a final density of 2 x 10^6 cells/ml. When the subcultures were in log phase, they were inoculated with either a 72-hour water-soluble extract of Nigerian crude to give a final concentration of 2, 3, 4 ppm (dependent upon the experiment) or an equal volume of enriched sea water. After exposure to oil for 1 week in a closed system, the subcultures were used to feed oyster larvae maintained in filtered sea water. This was done by measuring cell density in both the oil and control subcultures. The volumes of algal culture necessary to provide equal amounts of food to the larval beakers were determined. These volumes were centrifuged at low speed , decanted, resuspended in filtered sea water and fed to the appropriate beakers of larvae.

B. Chronic Exposure of Adult Oysters

The chronic exposure studies were all conducted at the Rutgers Shellfish Laboratory at Monmouth Beach on the Shrewsbury River which is equipped with a flow-through sea water system operated year-round. Salinities ranged between 17 and 25 o/oo. The water passed through a coarse screen and heat exchanger before flowing into the oyster tanks. All oysters (2 - 5 years old) were dredged from the lower Delaware Bay, cleaned of fouling organisms and acclimated in the tanks at Monmouth

Beach for 3 - 4 days before oil treatment. In most instances treatments were done in duplicate tanks, each containing 100 - 200 oysters with minimum flow rates at 4 l/min/200 oysters. Appropriate river water and clay controls were run. Tanks, glass tubing and oil-clay containers were washed daily to prevent build-up of detritus and oil-clay films.

To insure that experimental concentrations of oil would permit full pumping activity by the oysters in the chronic studies, threshold concentrations for inhibition of pumping were determined in a series of acute exposures. Pumping rates were measured as described by Galtsoff (1964). Actively pumping oysters at 18° C were exposed to oil-clay suspensions at oil concentrations of 0.3, 0.6, 0.9, 1.2 and 1.5 ppm. Pumping rates dropped precipitously at 1.2 ppm and over. Clay controls did not inhibit pumping. In our chronic studies oil concentrations were held at 0.8 ppm and below.

Oil slurries were prepared and replaced daily. Oyster activity was observed daily, and any dying oysters were removed. At approximately two-week intervals, samples of oysters were frozen for chemical analysis and others were fixed in Davidson's fluid (Shaw and Battle, 1957) for histological study. In most of the studies the exposure period ranged from 5 to 10 weeks followed by a depuration period of 2 to 7 weeks.

<u>Spawning</u>. In four of the chronic exposures of adults (I, II, VI, and VII), the effect of the oil treatment on gonad development and "spawnability" was studied. When studies I and VI were begun, the oyster gonads were in winter or early spring condition in 1975 and 1976, respectively. Studies II and VII were begun in summer with the oysters naturally

conditioned in Delaware Bay and with gonads therefore in varying stages of gamete depletion or rebuilding. In studies I and II spawning with all exposed and control stocks was attempted periodically throughout the exposure period, using the method of Loosanoff and Davis (1963) of elevated temperatures and additional stimulation with stripped oyster gametes. In studies VI and VII spawning attempts were made only at the end of the exposure period and early in the depuration period.

From spring through fall studies were run at ambient river temperatures. In the cooler seasons temperatures were held at 15 - 20^{o} C when the heat exchanger capacity permitted. Length of exposure period was partially a function of temperature, since onset of mortalities occurred earlier and rates were higher at higher temperatures.

C. Exposure of Larvae

1. Acute Exposure of Larvae

Oyster larvae reared on native Delaware Bay phytoplankton at the Cape Shore Laboratory were used in these studies. Thirty-five to forty swimming larvae were placed in a small reaction chamber in subdued yellow-green light and their activity observed by binocular dissectoscope (Haskin, 1964). Bay water flowed through the chamber at approximately 1 ml/min. During a control period of 1 or more hours the number of actively swimming larvae was tallied at about 5-minute intervals. The bay water was then replaced by various dilutions of WSE or oil-clay suspension over a period of several hours. Fresh bay water was re-introduced during a recovery period. Swimming activity was monitored throughout.

2. Chronic Exposure of Larvae

Various stocks of oysters under test for disease resistance at the Cape Shore Laboratory on Delaware Bay were spawned to provide larvae for these studies using methods described by Loosanoff and Davis (1963). Fertilized eggs and larvae were adjusted to densities of 30 - 50 per ml. in 800 ml beakers.

From 48 hours post-fertilization the cultures were changed daily with water from the lower Delaware Bay containing the natural phytoplankton; quality of this food was monitored. Cultured algae (*Monochrysis*, *Isochrysis* and *Dunaliella* - see Davis and Guillard, 1958) were used only in experiments in the fall, when the natural food species declined in the bay. Fresh oil treatment was added initially and at each water change the necessary precautions were taken to avoid contamination between beakers. All treatments, including controls, were maintained in duplicate. As the larvae approached setting size, a small piece of clean *Spisula* shell was placed on the bottom of each beaker to provide a setting surface; a new piece of shell was substituted daily. The temperature in the beakers ranged from 20 to 28^{o} C.

At intervals throughout each experiment two 5 - 15 ml samples (volume dependent on larval density) were collected after thoroughly mixing each beaker. The samples were counted and the lengths of the first fifteen larvae randomly encountered were measured. No samples were withdrawn after setting began. The number of larvae set on each piece of shell was recorded.

The larval sampling program provides data on growth, density, delay in set and amount of set in each beaker. Although these four parameters varied greatly between broods of larvae - probably as a function of brood stock differences, variation in food supply, ambient temperature, etc. - the concentrations of oil at which effects were observed were generally consistent.

A variety of treatment patterns was used in the chronic exposure experiments, the details of which will be given along with the results. To understand the treatments it is necessary to know that the larval development of the oyster is conveniently divided into several morphological stages named as follows:

Straight hinge	- 14 hrs. to 2 days	after	fertilization
Early umbo	- 3 to 5 days	"	"
Late umbo	- 5 to 7 days	"	"
Mature	- 8 to 12 days	"	"
Eyed	- 13 to 14 days	"	"

With good developmental conditions metamorphosis of larvae to juvenile stage (loss of swimming and crawling structures), known as "setting," occurs in about 14 days. When setting is delayed, sometimes as much as a week or 10 days, the stages indicated here are correspondingly longer.

D. Effects of Oil on Phytoplankton

Unialgal cultures of *Nannochloris oculata*, *Monochrysis lutheri*, *Isochrysis galbana*, and *Dunaliella euchlora* were used, as well as three locally isolated clones of *Skeltonema costatum*. The cells were raised in Guillard and Ryther's f/2 medium (1962) at 22° - 23° C, under an

18-hour light, 6-hour dark cycle. The salinity averaged 22 o/oo for all experiments. Logarithmically growing stock cultures were used to inoculate experimental culture tubes (18 mm O.D.) containing a total volume of 15 ml of medium. Growth was measured by hemacytometer cell counts periodically for one week following inoculation.

As a considerable amount of the petroleum hydrocarbons found in the water column may be absorbed onto particulate material, initial experiments were performed subjecting Skeletonema and Nannochloris to a suspension of Nigerian crude oil absorbed on kaolin clay. Controls consisting of equivalent amounts of clay with no oil absorbed, as well as controls with no oil or clay, were used.

A second series of experiments on all five species utilized a water soluble extract (WSE). The aqueous extract was pressure filtered (Millipore, 0.45 μm) to reduce any bacterial contaminants that may have been introduced from the oil. Oil levels in solution were determined by the infrared spectrophotometric method (Gruenfeld, 1973). The extract was then diluted with sterile enriched sea water in the culture tubes to produce 15 ml of media containing the desired oil concentrations. As Dunstan et al (1975) have shown that the loss of volatiles from water soluble extracts is extremely rapid under open culture conditions, cotton plugs were replaced with rubber stoppers for these experiments.

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Results

A. Chronic Exposure of Adults

1. Mortalities

This series of studies was initiated in the spring of 1975 to determine influence of low levels of petroleum hydrocarbons on reproductive activity of the oyster. In the first study, using a Nigerian crude oil, mortalities in the exposed stock were approximately 3-1/2 times those in the controls (Table 2, and figure 6). This unexpected finding was confirmed in the second study. The rest of the series, in addition to exploring effects on reproduction, has been devoted to determining: (1) threshold concentration for mortality; (2) relative toxicities of various oils; (3) that the method of adsorbing oil on clay does not seriously bias the results.

The results of the mortality studies are summarized in Tables 2 and 3 and illustrated in figures 6 through 16. Several points are readily apparent.

(1) In all studies, without exception, mortalities in the oil-exposed oysters exceeded those in the controls.

(2) Mortalities in clay controls did not differ significantly from those in river water controls. In some studies, when tank space was limited, clay controls were omitted (III, IV, and V).

(3) For a given oil, mortality levels are a function of concentration. To illustrate this point, for each treatment a mortality index has been calculated as the ratio of number of oysters dying in that treatment to the number dying in the control. Where treatment tanks and/or controls were in duplicate, the means of the numbers were used in calculating the mortality index (Table 3 and figure 16).

The calculated lines of best fit (figure 16) indicate that #2 fuel oil is approximately twice as toxic to oysters as the Nigerian crude; i.e., for a given mortality index the corresponding #2 fuel concentration is about half that for the Nigerian crude.

(4) The Iranian light crude is much less toxic than the other two oils under test. In study VII, at 0.6 ppm, mortality was 1.3 x controls for the Iranian crude in contrast to 3.1 x and 5.1 x for the Nigerian crude and #2 fuel oil respectively. (Tables 2 and 3 and figure 12). In study VIII, mortality in oysters exposed to Iranian crude at 0.5 ppm does not differ from mortality in controls.

(5) In study VI, with Nigerian crude adsorbed on clay at 1%, the mortalities (2.1 x controls) were not appreciably less than those in study IV (2.4 x controls) in which the 10% oil-on-clay was used (Tables 2 and 3 and figures 9, 11 and 16).

(6) In study VIII, in which the oils were adsorbed on wet clay, it is of interest that at 38 days' exposure, when mortalities in #2 fuel oil at 0.15 ppm were no greater than in controls, only 17 and 21 oysters in the #2 fuel tanks were showing new shell growth in contrast to 36, 44, 44 and 50 in the four control tanks. At the same time 19 and 22 were showing new shell in the Iranian crude at 0.5 ppm; 4 and 3 in the #2 fuel oil at 0.5 ppm; and 3 and 5 in the Nigerian crude at 0.5 ppm.

(7) In study X - an "oily-natural sediment" - dredged from a tanker anchorage site was nearly as toxic as an equivalent amount of Nigerian crude on clay.

2. Reproduction

Beginning in the fifth week of exposure to oil (10% oil-on-clay at 0.8 ppm) in chronic study I, attempts were made to stimulate all surviving oysters to spawn. These were repeated periodically throughout the study. Oysters spawned as indicated in Table 4. (The totals 34, 51 and 1 in Table 4 include some repeat spawnings by several individual oysters. If these are excluded, the totals become 30, 47 and 1, respectively.)

In chronic Study II, spawning attempts were begun in the third week and repeated periodically. Successful spawnings are indicated in Table 5. (Excluding repeats, the totals 29, 25 and 5 in Table 5 reduce to 21, 24 and 5.)

In chronic exposure study VI (1% oil-on-clay at 0.3 ppm) at the end of the 53-day exposure period on June 18, 1976, all survivors were taken to the Cape Shore Laboratory on Delaware Bay to commence the depuration period and to test for spawnability. On two successive days (June 18 and June 19) attempts were made to spawn groups of 10 oysters each of river controls and oil-treated animals. Of the 20 river controls so tested, 8 spawned. Of the 20 oil-exposed oysters, 9 spawned. Three days later, on June 22, an additional 20 each of the oil-exposed oysters and controls were brought from the depuration trays on the tidal flats to the laboratory for a spawning attempt. None of the

40 oysters spawned. In a repeat attempt on the following day, no spawning occurred. It is most probable that these oysters had spawned on the tidal flats between June 18 and June 22.

In chronic study VII (comparing Nigerian and Iranian crudes with #2 fuel oil all at 0.5 ppm), survivors after 31 days' exposure were brought to the Cape Shore of Delaware Bay on July 29, 1976, for depuration and testing for spawnability. Thirty of each group of oysters (3 treatments plus controls) were stimulated. Within 48 hours of arrival at the Cape Shore the numbers of oysters spawning in each group were as follows:

Controls	#2 fuel	Nigerian	Iranian
16	1	13	10

Repeated attempts to spawn the oysters exposed to #2 fuel on the 3rd, 11th and 20th days of depuration also failed. It is possible that unobserved spawning may have occurred in the depuration trays on the tidal flats some time after the 3rd day.

B. Exposure of Larvae

1. Acute Exposure

In the summer of 1974 swimming oyster larvae were exposed to various dilutions of WSE with the average oil concentration of 10.47 ± 0.65 ppm.

(1) With WSE at 1:1, activity of oyster larvae was reduced by 50% in one hour, by 75% in 4 hours, and by 95% after 8 hours. Little or no increase in activity occurred after return to bay water.

(2) At 1:10, closely similar effects on activity have occurred, though 50% recovery in bay water has been observed (figure 17).

(3) With WSE at 1:100, activity in several experiments dropped to 60 - 70% of control activity. In one experiment at 1:100, there was no real difference from the control.

In the summer of 1975 effects of acute exposure of actively swimming larvae to Nigerian crude oil absorbed on clay were explored. Activity of mature and eyed larvae was decreased by as much as 50% in some experiments at oil concentrations as low as 0.4 ppm. With other groups of larvae some variability in effects was apparent with concentrations as high as 1 - 1.5 ppm required to decrease activity by 50%. After exposure to the higher concentrations the larvae usually did not recover activity after return to fresh bay water for periods of at least several hours.

2. Chronic Exposure of Larvae

For three larval seasons, beginning in early summer 1974, oyster larvae were exposed to low levels of petroleum hydrocarbons from fertilization of egg to setting stage. In 1974 only Nigerian crude WSE's were used in various dilutions. In 1975 larvae were exposed to Nigerian crude absorbed on clay and in 1976 these oil-on-clay studies were extended as detailed below.

(a) Summary of WSE Studies of 1974

Growth In larval cultures with Nigerian crude WSE at 1:100, growth of larvae was indistinguishable from controls, but initiation of setting was delayed from 1 - 3 days. With WSE at 1:10, growth lagged behind controls by about 20%, but the larvae continued to setting. At WSE 1:1, growth ceased and all larvae were dead by the 6th day after fertilization. Freshly fertilized eggs exposed to 1:1 concentrations of WSE do not develop beyond the straight hinge stage.

Survival Throughout the experiments larval counts declined from initial values at 20/ml to less than 5/ml at onset of setting, but only at the highest concentrations of WSE, i.e. 1:1, did the reduction in numbers differ significantly from the controls.

Setting Compared with controls at 100%, larvae reared from the straight hinge stage in WSE at 1:100 set 78%; in WSE at 1:10, the set was only 13% of controls.

(b) Summary of Oil-on-Clay Studies in 1975

In this season a series of chronic larval studies (CLS) explored the effect of concentrations of Nigerian crude primarily on survival and setting of larvae. From experiment to experiment results varied, probably due, at least in part, to differences in brood stocks, natural food supplies, etc. One experiment, CLS-11 has been chosen to illustrate results obtained.

In CLS-11 effects of six concentrations of Nigerian crude on survival and setting were determined (Table 6 and figure 18). Numbers and percentages in Table 6 are based on totals of duplicate beakers for each treatment. It is clear from this table that survival and setting at 0.25 and 0.50 ppm differed insignificantly from controls. At concentrations of 0.625 - 0.875 ppm, both survival and setting were reduced substantially from control values, but within this range of concentration did not vary significantly. At 1.0 ppm survival of larvae and setting were further reduced strikingly. Figure 18 illustrates these same relationships and also indicates delay in onset of setting in oil treatments as compared with controls.

(c) Oil-Clay Studies in 1976

As noted for the earlier work with larval bioassays, growth, time of setting and amount of set all vary greatly among broods of larvae, but the levels of oil at which effects are noted are generally consistent. The results summarized here deal largely with amount of set, but these are usually reinforced by the data on growth, survival and delays in setting.

(1) Toxicity of Nigerian Crude at 10% on Clay

In all, 11 experiments with larvae from five different brood stocks dealt with Nigerian crude on clay at 10%. At 0.5 ppm Nigerian crude, set, compared with untreated controls, was reduced by 31 - 99% ($\bar{x}$ = 73%). Larvae, in various experiments, were exposed at different stages of development. Most set was recovered when larvae were first treated in their late stages (mature or eyed), 2 - 3 days before setting began.

At 1.0 ppm Nigerian crude, the set was further reduced - by 70 - 100% ($\bar{x}$ = 91%) - with again the greater set in beakers whose treatment was delayed until development was nearly complete.

At 1.5 ppm, set was recovered only in 3 of the 11 experiments - those in which exposure occurred only at mature and eyed stages. Set reduction here averaged 95%.

Points summarized above are illustrated by the results of one experiment graphed in figure 19.

Growth data are shown in figure 20 for a single experiment in which the larvae were treated at various oil levels from fertilization to setting.

In a single experiment with larvae exposed to 0.25 ppm Nigerian crude as well at 0.5 and 1.0 ppm, there was no difference between control larvae and those at 0.25 ppm.

(2) Toxicity of Nigerian Crude at 1% on Clay

Larvae of two brood stocks were used in four experiments with the Nigerian crude adsorbed on clay at 1% by weight, compared with 10%, as in the earlier studies. At chronic exposures of 0.5 ppm Nigerian crude, the mean reduction in set was 77% for the 1% oil-clay, falling well within the range of values reported for the 11 experiments at this oil concentration, using the 10% oil-clay (31 - 99%). At concentrations of 1.0 and 1.5 ppm no setting occurred.

(3) Toxicity of an Iranian Crude and a #2 Fuel Oil Compared with Nigerian Crude

In four experiments with three brood stocks, #2 fuel oil, on oil-clay at 10%, was found to be highly toxic to oyster larvae at concentrations as low as 0.25 ppm. At this level, chronically exposed larvae did not develop to setting size. At 1.0 and 1.5 ppm, larvae were lost within 1 week of treatment, and at 0.25 and 0.5 ppm they survived 3 - 4 days longer. Setting occurred only when treatment was delayed to the later larval stages and then at less than 10% of controls.

In two experiments with two brood stocks, chronic exposure to Iranian crude, adsorbed at 10% on clay at 0.5, 1.0 and 1.5 ppm did not produce consistent effects. Setting occurred at all concentrations, indicating the relatively low toxicity of this oil, but in one of the two experiments with increasing oil concentration there was a decreasing number of set and increased delay in beginning of set.

(4) Recovery of Larvae After Exposure to Oil

One brood of larvae was treated with 1.0 ppm Nigerian crude at 10% oil-on-clay. With various duplicate beakers, treatment was terminated after 2, 5, 9, 13 and 17 days' exposure, corresponding to straight hinge, early umbo, late umbo, mature and eyed stages, respectively. After return to untreated bay water, even after exposure to oil for as long as 17 days, larvae still surviving were able to recover and set as well as those which had received no oil treatment. That is, of larvae present at beginning of set, the percentages completing set were as high in oil-treated larvae as in controls.

Larvae treated only through the straight hinge and early umbo stages began to set at the same time as the controls. Exposure through late umbo delayed setting by two days and those exposed through mature and eyed stages delayed setting by 5 - 6 days. The peak of setting was delayed progressively as treatment was prolonged.

(5) Sensitivity of Larvae to Oil Toxicity at Various Developmental Stages

Larvae were exposed to toxic levels of Nigerian crude at 10% oil-on-clay, beginning at different stages in development. With treatment begun at straight hinge, early umbo or late umbo and continued through setting, oil produced a great reduction in set at 0.5, 1.0 and 1.5 ppm (less than 1/4 of controls in all cases). With treatment begun at mature or eyed stage, larval setting, even at 1.5 ppm was no less than 1/4 of controls, and, at 0.5 ppm ranged between 50 - 60% of controls.

These results combined with those of (4) indicate that the length of exposure time to oil rather than stage of development is chiefly responsible for the reduction in set.

(6) Delaware River Sediments

At 0.1 gm/l river sediment (total oils at 0.22 ppm) larval set equalled that of controls. At 1.0 gm/l (2.22 ppm total oil) survival to setting equalled controls, but growth was delayed (154 µm vs. controls at 178 µm) and no setting occurred.

In a second experiment with the river clays, at the end of the summer, intermediate concentrations of 0.25, 0.5 and 0.75 gm of wet clay per liter were applied. With setting low even in controls (4% compared with 19% in the first experiment), no setting occurred either in the 0.75 or 1 gm concentration; the 0.5 gm beakers were lost.

(7) Toxicity to Larvae of Food Algae Cultured with WSE of Crude

Three species of algae, well-documented as good food species for developing oyster larvae (*Monochrysis lutheri*, *Isochrysis galbana*, *Dunaliella euchlora*) were cultured successfully with water soluble fractions of Nigerian crude at 2, 3, and 4 ppm. The oil-cultured algae were in turn fed to oyster larvae. Control oyster larval cultures were fed on the same concentrations of the three algal species, cultured, however, without crude WSE. Control setting was low, and poor end-of-season conditions prevailed, but a weak trend is seen in the two experiments. With food algae cultured with 2 ppm WSE, the larvae lagged behind controls in growth, but set actually exceeded controls. On food cultured with 3 ppm WSE, setting was sharply reduced (16% of controls), and on 4 ppm WSE food, no setting occurred.

(8) Development of Larvae from Adults Chronically Exposed to Nigerian Crude Oil

Larvae spawned from oysters that had been chronically exposed to 0.3 ppm Nigerian crude for 53 days were reared and compared with larvae from control oysters not exposed to the oil. Development was normal in each of the two broods tested and there was no inhibition of growth nor reduction in set.

C. Growth of Phytoplankton

1. Exposure to Oil-Clay

The two species tested were relatively insensitive to oil presented in this form. Both *Skeletonema* and *Nannochloris* failed to show any significant inhibition at concentrations up to 10 ppm. Concentrations greater than 10 ppm did inhibit the growth of *Skeletonema*, but as hydrocarbon concentrations in the water column rarely, if ever, are this great, this series of experiments was terminated.

2. Exposure to WSE

Dunaliella was relatively unaffected by WSE at concentrations up to 5 ppm. Likewise, *Nannochloris* demonstrated only slight inhibition at 4.3 ppm. *Monochrysis* is inhibited at 5 ppm, but is relatively unaffected by concentrtrations of less than 3 ppm (see figures 21 and 22). Similarly, *Isochrysis* (figures 23 and 24) is inhibited at 5 ppm, but the effect is transitory, not being observed by the fifth day of the experiment. Similar decreases of toxicity with time were also noted for *Skeletonema*, discussed below. This decrease in toxicity is probably associated with the loss of the more volatile fractions, which still occurs to some degree despite the use of a closed system (Dunstan *et al*, 1975).

The experiments with <u>Skeletonema</u> differ from those previously discussed in that three clones, designated MB-4, MB-6 and MB-7, were utilized. All were isolated from a single water sample at Monmouth Beach, N.J. All three clones appear far more sensitive than the other species tested, in general exhibiting inhibitory responses at 2.5 ppm or less. However, the nature of the response varied markedly among the three clones. Clone MB-7 was totally inhibited at 2.25 ppm, and exhibited intermediate inhibition at approximately 1 ppm (figure 25). By day six of the experiment the inhibitory effects are no longer noted at the two lower concentrations (figure 26). Clone MB-4 was totally inhibited at concentrations as low as 0.56 ppm throughout the seven day duration of the experiment (figure 27). In contrast, MB-6 was stimulated at concentrations of 0.5 and 1.1 ppm, and did not show significant inhibition at concentrations up to 2.6 ppm (figure 28).

Discussion of Results

A. Chronic Exposure of Adults

1. Survival

The finding that significant mortalities occur in adult oysters exposed to low levels of crude oil for long periods of time is new. Other laboratory studies of oysters exposed to oil have resulted in findings that oysters are quite resistant to kill by oil (e.g. Mackin and Hopkins, 1961; Anderson and Anderson, 1973). This difference is most probably due to method of exposure of the oysters to the oil. Oil adsorbed on clay may include oil fractions not found in water soluble extracts of oil or volatile fractions readily lost to the atmosphere from films of oil layered on the surface of laboratory aquaria. In addition, the clay particles, with a sorbed oil, are filtered from the water by the oyster and are taken into the gut as food particles, thus insuring introduction of the oil into the oyster.

The threshold concentrations for significant oyster mortality are approximately established. Nigerian crude at 0.3 ppm produces mortalities at least double those in control oysters, as does #2 fuel at 0.1 ppm. The Iranian crude tested appears relatively benign with mortalities about 1.3 x controls at a concentration of 0.5 ppm (Table 3).

With background level of total oils * in the lower Delaware Bay at about 0.04 - 0.05 ppm and total oils in the River and upper Bay approximating 0.5 ppm (soluble and particulates), on occasion, the oyster may have a narrow margin of safety for survival. Critical for an evaluation of this situation is knowledge of the nature of total oils in the lower Bay, including an estimate of their toxicity to oysters.

2. Reproduction

In four chronic exposure studies with adults, ability of oil-treated oysters to spawn has been tested. In two of these, oysters treated with Nigerian crude at 0.8 ppm spawned weakly or not at all (CES I and II). In the other two, oysters treated with Nigerian crude at 0.3 and 0.5 ppm equalled the controls in spawning as did those treated with Iranian crude at 0.5 ppm. Oysters exposed to #2 fuel at 0.5 ppm failed to spawn (CES VI and VII). Together, these four studies indicate a Nigerian crude

* Determined by infrared spectrophotometry in accordance with EPA procedures, using samples taken on the lower bay near Bivalve, N.J., over a period of over two years.

threshold concentration for inhibition of spawning somewhere between 0.5 and 0.8 ppm. The corresponding threshold concentration of the #2 fuel oil is less than 0.5 ppm. It appears that oysters may reproduce successfully at any oil concentration at which they can survive, since the threshold for survival is apparently below that for delay in gonadal development and discharge of gametes.

B. Exposure of Larvae

1. Acute Exposure Studies

Swimming activity is reduced at concentrations of Nigerian crude in the range of 0.4 to about 1 ppm. The slow recovery of activity at the higher concentrations may indicate permanent damage to the larvae that could interfere with feeding. This may in turn result in the observed retardation in growth and delay in setting in the larvae.

2. Chronic Larval Studies

The concentrations of Nigerian crude oil at which retardation in development and reduction in setting consistently occur agree well with those which inhibit swimming activity in the larvae (0.5 - 1.0 ppm). It is also of interest that the larval stages of the oyster appear to be no more sensitive to damage by oil than the adults, and perhaps even less so. Adults are killed by chronic exposure to 0.3 ppm of Nigerian crude, while larvae at 0.25 - 0.5 ppm frequently survive, grow and set as well as do the controls. The length of time of exposure to the oil must, however, be considered in such comparisons. In the chronic adult studies significant mortalities separating oil-exposed animals from controls usually did not occur over the first few weeks.

Studies of the effect of treatment of oyster larvae with oil at different stages of development yielded important results. For a given concentration of oil (1.5 ppm or less) the effect of the treatment is progressively reduced by delay to later and later developmental stages. Even in oil at 1.5 ppm substantial setting will occur if the larvae are not exposed to the oil until they are within a day of onset of setting. Conversely, larvae treated with oil at their earliest developmental stages and then withdrawn from treatment at various stages recovered from the oil exposure. Those surviving the period of exposure set as well as those never exposed. These observations clearly have application in interpreting probable events in the estuary as larval broods may be moved into and out of areas of local oil pollution or as concentrations of oil resulting from spills are moved through the oyster territory.

Although it was shown earlier that chronic exposure of adult oysters to Nigerian crude oil will strongly inhibit spawning, larvae were obtained this year from adults exposed to crude at lower concentrations. These larvae developed and set as well as those from unexposed (control) adults. This is an important observation in that it indicates that petroleum-derived oils, reputedly concentrated in molluscan gonads, may not be concentrated sufficiently to endanger early stage larvae through their stored food supply.

Important questions had been raised on how realistic it was to be exposing oysters and larvae to oil-on-clay at 10% by weight and oil that had been adsorbed on dry clay rather than wet, as would occur naturally in the estuary. The opinions were: (1) that the adsorption on dry clay and storage in air before preparation of slurry would allow for the production of oxidation products more toxic than the crude itself and (2) the unrealistically high proportion of oil to clay might serve to concentrate the oil on sensitive oyster epithelia, thus increasing the toxicity. Three findings reported here answer, in great part, these questions.

(a) Oil on clay at 1% is as toxic as oil on clay at 10% to both oyster adults and larvae (CES VI compared with CES IV).

(b) The slurries prepared by adding crude oil and #2 fuel directly to wet kaolin clay in a mixer are about as toxic as those obtained by adsorbing the petroleum and fuel oil on dry clays, suspended in pentane, followed by evaporation of the pentane.

(c) Delaware River natural sediments with high oil content (4400 μg/g dry weight) are as toxic to oyster larvae at 10% oil on clay at the same total oil concentration.

C. Growth of Phytoplankton

The results presented here indicate that Nannochloris, Monochrysis, Isochrysis, and Dunaliella exhibit considerable tolerance to the petroleum hydrocarbons of Nigerian crude oil, assuming that the clones used are representative of their respective species. The concentrations required to reduce their growth were far in excess of those found in Delaware Bay under normal conditions, and may even exceed concentrations found immediately following an oil spill. The rapid decrease in toxicity with time, presumably due to a loss of the volatile fraction, indicates that any major inhibition of growth following a spill would be very transitory in nature.

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A number of problems in interpreting the data appear, however. Each type of oil or oil fraction is distinctly different in its hydrocarbon composition, which can result in differential toxicity. For example, #2 fuel oils have been shown in general to be more toxic than crude oils (Gordon and Prouse, 1973; Nuzzi, 1973), and considerable differences between various #2 fuel oils have also been demonstrated (Winters _et al_, 1976). Therefore, tolerance to one oil at certain concentrations does not necessarily imply tolerance to all petroleum hydrocarbons at similar concentrations.

The second major problem involves the differential response between algal clones of the same species, as was demonstrated with _Skeletonema_. Most studies to date employing algal cultures to test the effects of possible environmental toxicants have utilized only one clone of each species. This could possibly lead to erroneous conclusions, and caution is urged in interpreting such data. It appears probable that a large amount of genetic variability exists in phytoplankton populations, making it very difficult to characterize a species response based on only one genotype in culture.

These several algal species important as oyster foods have been shown to be less sensitive to crude oil, as judged by their growth, than are either adult or larval oysters. Limited studies also indicate that larval food species grown in water soluble fraction of crude oil do not concentrate petroleum fractions sufficiently to endanger the larvae which feed upon them. Tentatively, it appears that the oyster populations of the estuary are not endangered through their phytoplankton food web. A firm conclusion on this, however, would be premature until more is known of algal sensitivity to oil-derived compounds from other than Nigerian crude oil.

V. Effect of a Crude Oil Facility in Delaware Bay on Status of the Oyster Community and Oyster Industry

The field and laboratory studies summarized in the preceding sections of this paper indicate strongly that with ambient hydrocarbon concentrations found in the lower Delaware Bay area in the mid 1970s (averaging 40 - 50 ppb) there is a margin of safety for the oysters living there. If the total ambient hydrocarbons there are as toxic as Nigerian crude, their concentration might be increased about 6 X before adult oysters suffered oil-related mortality. Oyster larvae in this lower bay area would have about the same margin of safety. We have, however, no direct knowledge of the toxicity of the ambient hydrocarbons, and if they are as toxic as #2 fuel oil, the margin of safety would be cut to 2 X rather than 6 X.

In the upper Bay and lower River (from Bennies Bed up, figure 1,) we have less information on ambient hydrocarbon concentrations. Samples taken by us in the wake of the *Corinthos* and *Olympic Games* spills had values in this area ranging up to 0.6 ppm (600 parts per billion). Two months after the *Olympic Games* spill concentrations of approximately 0.2 - 0.5 ppm were still in the upper seed bed area. There is here, then, cause for concern about damage to the oyster population through chronic exposures to petroleum hydrocarbons perhaps being slowly released from shores and marshes oiled during and following a major spill.

In estimating probable effects of a crude oil facility in the Big Stone Beach area of the Bay on the oyster populations, it is necessary to consider: (1) effects on ambient oil concentrations in the Bay and (2) probable effects of a major oil spill within the Bay.

A. Probable Effects on Ambient Oil Concentrations in the Bay of Establishment of a Crude Facility in the Big Stone Beach Area

As indicated in the above discussion of the effects on oysters of chronic exposure to low concentrations of petroleum hydrocarbons, I have estimated that under present ambient conditions in the upper Bay area there is now a safety factor of 2 to 6. That is, hydrocarbon concentrations could be increased 2 to 6 times before one would expect oyster mortalities or inhibition of reproduction. Under the oil spill conditions described in the attachment to the letter of agreement with the Port Authority of New York and New Jersey, it is highly unlikely that any measurable change in ambient petroleum hydrocarbon concentrations in the estuary would occur. Construction of the oil receiving facility would lead to an estimated increase in total spillage from 6,174 gallons to 7,098 gallons annually or 924 gallons. The spillage would be redistributed in the estuary, however, with the lower Bay (anchorage site - oil facility) receiving 3,948 gallons annually rather than the 504 gallons estimated under current practice.

If it is assumed that a single spill of 945 gallons occurs at the bulk facility site and this is mixed with the water in a segment across the estuary with a thickness equal to a single flood tide excursion (approximately 30,000 feet), the resulting concentration would approximate 2 parts per billion.* If the estimated annual spillage for a proposed facility (3948 gallons) in the lower Bay area occurred in a single event, the expected concentration under the same mixing conditions would be approximately tripled. This concentration would pose no threat to the lower Bay oyster grounds.

The mixing volume would be a function of not only tidal currents but also wind-driven currents. The latter at the time of the spill and shortly thereafter would be particularly important in determining the extent of the lateral spread as well as the depth of mixing. Delaware Bay is turbulent, and its waters are frequently highly turbid with suspended silts and clays which adsorb petroleum hydrocarbons. As these settle toward the bottom, they would be transported in the general upbay drift of the bottom waters. Although the details of spreading pattern and exact dilution, volumes would be highly variable from spill to spill, the consequences, as far as the oyster community is concerned, would probably be negligible for 945 gallon spills projected.

* This is based on mixing 126 cubic feet of oil (945 gallons) with 68 billion cubic feet of water, the estimated high tide volume of the 30,000 foot segment across the Bay. This tidal excursion would occur between stations 400 and 500 (Army Corps of Engineers systems based on thousands of feet below Philadelphia). Low tide volume in the Bay segment between these two stations is 163 billion cubic feet; intertidal volume is 43 billion cubic feet for a total high tide volume of 206 billion cubic feet. The tidal excursion would occur over about 1/3 of the total distance between the stations and the dilution volume would thus approximate 68 billion cubic feet. Figures taken from Manuscript Report (unpublished) from the Woods Hole Oceanographic Institution, Reference 52-103, entitled "The Distribution of Salinity in the Estuary of the Delaware River" by Bostwick H. Ketchum, December 1952.

B. Probable Effects of a Major Spill at the Crude Handling Facility

A major spill, involving a partially lightened 260,000 DWT tanker, at the crude oil receiving facility, would be a totally different story. Such a ship could carry 1,800,000 barrels, but would have to be lightened to 1,100,000 barrels or 46,200,000 gallons of crude oil. Assuming that the worst possible case would be the loss of 2,814,000 gallons of this cargo to the Bay, in a northeast storm or westerly blow, the results would be utterly disastrous.

If the whole cargo were mixed in the high tide volume of the entire estuary, from Trenton to the Capes, the oil concentrations would be 729 ppb,* or about 2½ times the threshold for oyster toxicity. Of course this volume of oil would not be uniformly mixed throughout the estuary. Concentrations would be considerably higher throughout the lower estuary before there would be substantial escape of the oil through the Capes and seaward. With the Bay surrounded by extensive salt marshes interspersed with tidal creeks and rivers, one could confidently expect a thorough oiling of the marshes with consequent slow release to the estuary, probably over a period of years.

Some probable long-term effects of such a spill may be indicated by reference to the well-documented study of the West Falmouth Spill of September 1969 (Sanders et al., 1980). In that spill 650,000 to 700,000 liters of number 2 fuel oil were spilled into Buzzards Bay from a grounded

* Calculated as follows: 2,814,000 gallons of crude equals 376,203 cubic feet figured at 7.48 gallons per cubic foot. The high tide volume of the estuary is taken as 516 billion cubic feet (Ketchum 1952, as cited above).

barge. The oil was driven by a strong SSW wind into the Wild Harbor River in North Falmouth and penetrated the sediments of the River with highest concentrations in the intertidal and subtidal zones. Oil spread seaward from these areas of highest concentrations for <u>at least five years</u> when oil was still detectable in marsh peat and river sediments. Faunal mortalities were immediate and severe at nearshore subtidal stations and within five years the fauna in Wild Harbor River had only "slightly recovered". Faunal changes in stations farthest from shore were relatively slight.

The enlargement of this scenario, with a spill approximately 17 times greater than that of the *Florida* in mid-Delaware Bay, indicates clearly that a massive oiling of the marshy shores of the Bay would be extremely destructive of the benthic communities and would in all likelihood provide concentrations of oil lethal to the resident oyster populations for a period of at least several years.

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Table 1

NEW JERSEY OYSTER PRODUCTION IN BUSHELS (Calendar Year)

Year	Seed * Planted	Oysters ** Marketed	Year	Seed Planted	Oysters Marketed	Year	Seed Planted	Oysters Marketed
1930	4,255,138	1,406,064	1949		1,012,243	1968	145,100	220,000
1931	2,690,182	1,456,210	1950		1,206,967	1969	82,000	176,500
1932	1,138,337	953,634	1951		960,217	1970	123,000	112,833
1933	937,000	874,904	1952		1,065,840	1971	172,000	145,167
1934			1953		1,060,562	1972	165,825	285,500
1935	852,880	949,741	1954		916,113	1973	227,840	232,667
1936			1955	Beds closed	650,563	1974	395,755	168,167
1937	1,072,550	754,165	1956	512,000	687,725	1975	370,425	162,000
1938	1,549,610	1,006,563	1957	Beds closed	453,333	1976	335,975	233,767
1939			1958	450,850	138,167	1977	298,000	204,167
1940	785,970	893,504	1959	Beds closed	34,333	1978	385,140	194,038
1941			1960	" "	23,829	1979	460,175	209,413
1942	612,700	711,533	1961	166,000	137,513	1980	434,270	145,577
1943	487,500	860,614	1962	172,000	194,175	1981	458,800	
1944	253,600	846,892	1963	Beds closed	64,425			
1945		973,409	1964	170,700	137,213			
1946			1965	Beds closed	87,183			
1947		836,143	1966	221,300	115,733			
1948		855,471	1967	142,100	171,200			

*Figures from 1930-56, Federal statistics; from 1956-81, N.J. Oyster Research Laboratory

**All harvest data from Federal statistics

Table 1 (continued)

DELAWARE OYSTER PRODUCTION IN BUSHELS (Calendar Year)

Year	Seed Planted	Oysters Marketed
1970	18,600	30,857
1971	43,000	45,000
1972	77,975	72,000
1973	41,095	56,114
1974	52,060	25,128
1975	16,625	27,857
1976	24,425	37,471
1977	21,725	18,214
1978	14,280	9,751
1979		1,263
1980	112,395	91,350
1981	70,015	

Above data from Delaware Dept. of Natural Resources;
Personal communication from Richard Cole

Table 2

TABLE Summary of Data from Chronic Adult Exposure Studies (Studies I-X)

Study #	Treatments		Days Exposure	Mortality-Exposure Phase Total Cum.	Mortality-Exposure Phase Cum. as % Initial	Days Depuration	Final Mortality Exposure & Dep. Total Cum.	Final Mortality Exposure & Dep. Cum. as % Initial	Temp. Range (°C)	Mean Temp. (°C)	Oil-Clay Characteristics
I	Nigerian Crude 0.8 ppm			35	35		48	48			10% Oil-Clay
	Control		70	9	9	42	13	13	20-24	21.4	Pentane
	Clay Control			6	6		15	15			Adsorption
II	Nigerian Crude 0.8 ppm			159	80		159	80			10% Oil-Clay
	Control		36	47	24	0	47	24	24-27	25.4	Pentane
	Clay Control			38	19		38	19			Adsorption
III	Nigerian Crude	O_1		54	30		70	39			10% Oil-Clay
	0.7 ppm	O_2		51	28		69	38			Pentane
	Control	C_1	30	14	8	28	21	12	19-22	20.5	Adsorption
		C_2		12	7		19	11			
IV	Nigerian Crude	O_1		19	9		31	14			10% Oil-Clay
	0.3 ppm	O_2		18	8		27	12			Pentane
	Control	C_1	49	8	4	49	11	5	14-20	16.5	Adsorption
		C_2		12	5		13	6			
V	#2 Fuel Oil A										
	0.1 ppm	O_1		2	3		13	19			10% Oil-Clay
	0.3 ppm	O_2	58	13	19	33	23	34	12-24	16.9	Mechanically
	0.6 ppm	O_3		10	15		29	43			Mixed
	Control			3	4		7	10			

Table 2

TABLE - (cont'd)

Study #	Treatments		Days Exposure	Mortality-Exposure Phase: Total Cum.	Mortality-Exposure Phase: Cum. as % Initial	Days Depuration	Final Mortality Exposure & Dep.: Total Cum.	Final Mortality Exposure & Dep.: Cum. as % Initial	Temp. Range (°C)	Mean Temp. (°C)	Oil-Clay Characteristics
VI	Nigerian Crude	O_1		21	11		40	20			1% Oil-Clay
	0.3 ppm	O_2		19	10		30	15			Pentane
	Control	C_1	53	5	3	41	15	7.5	15-30	23.1	Adsorption
		C_2		5	5		9	9			
	Clay Control			2	1		10	6			
VII	Nigerian Crude 0.5 ppm		31	45	23	27	49	25			10% Oil-Clay
	#2 Fuel Oil 0.5 ppm			74	37		82	41			Pentane
	Iranian Lt. Crude 0.5 ppm		44	18	9	15	22	11	22-26	24.0	Adsorption
	Control			12	6		16	8			
	Clay Control			12	6		16	8			
VIII	Nigerian Crude 0.5 ppm			29	13.5		45	22.5			10% Oil-Clay
	Iranian Lt. Crude 0.5 ppm			11	5.5*		--	----			Wet Adsorption
	#2 Fuel Oil B 0.5 ppm		76	44	22	35	58	29	12-23	16.7	
	#2 Fuel Oil B 0.15 ppm			13	6.5		22	11			
	Control			12	6		14	7			
	Clay Control			8	4		13	6.5			

Table 2

TABLE - (cont'd)

Study #	Treatments		Days Exposure	Mortality-Exposure Phase: Total Cum.	Mortality-Exposure Phase: Cum. as % Initial	Days Depuration	Final Mortality Exposure &Dep.: Total Cum.	Final Mortality Exposure &Dep.: Cum. as % Initial	Temp. Range (°C)	Mean Temp. (°C)	Oil-Clay Characteristics
IX	#2 Fuel Oil										
	0.05 ppm	O_1	63	3	1.5	0	6	3			10% Oil-Clay
	0.5 ppm	O_2		90	45		90	45			Wet
	Nigerian Crude										
	0.15 ppm	O_1	77	5	2.5	56	14	7			Adsorption
	0.5 ppm	O_2		26	13		34	17			
	Control	C_1		5	2.5		12	6			
		C_2		3	1.5		11	5.5			
X	Nigerian Crude 0.5 ppm		49	34	17	49	58	29			10% Oil-Clay Wet Adsorption and "Naturally" Oily Sediments
	Oily Delaware River Sediment ∿ 0.5 ppm			18	9		43	22			
	Control			10	5		10	5			
	Clay Control			6	3		8	4			

*Discontinued after 38 days exposure

Table 3 Mortality Indices in Chronic Exposure Studies with Adult Oysters

Note: The mortality index is the ratio of number of oysters dying in a given oil treatment to the number of oysters dying in the control.

Treatment	Study No.	Number of Oysters Dying Oil Treatment	Number of Oysters Dying Control	Mortality Index
Nigerian Crude				
0.8 ppm	I	48	14	3.4
0.8 ppm	II	80	21.5	3.7
0.7 ppm	III	38.5	11.5	3.3
0.5 ppm	VII	25	8	3.1
0.3 ppm	IV	13	5.5	2.4
0.3 ppm	VI	15	7	2.1
#2 Fuel Oil				
0.6 ppm	V	43	10	4.3
0.5 ppm	VII	41	8	5.1
0.3 ppm	V	34	10	3.4
0.10 ppm	V	19	10	1.9
Iranian Crude				
0.5 ppm	VII	11	8	1.3

Table 4 Spawning Results for Study I

Days of Exposure	Number of Oysters Spawned: River Control	Clay Control	Oil-Clay
42	-	6	-
64	26	25	-
69	7	20	1
71	1	-	-
	34	51	1

The totals 34, 51 and 1 include some repeat spawnings by several individual oysters. If these are excluded, the totals become 30, 47 and 1 respectively.

In chronic study II, spawning attempts were begun in the third week and repeated periodically. Successful spawnings are indicated in Table 5.

Table 5. Spawning Results for Study II

Days of Exposure	Number of Oysters Spawned: River Control	Clay Control	Oil-Clay
15	-	1	1
20	3	5	-
21	-	2	-
23	9	1	4
25	14	15	-
32	3	1	-
	29	25	5

Excluding repeats, the above totals reduce to 21, 24 and 5.

Table 6. Effect of Different Concentrations of Nigerian Crude Oil on Survival and Setting of Oyster Larvae

Note: Counts and percentages are based on total number of larvae in duplicate beakers of 800 ml. each.

<u>Chronic Exposure of Larvae</u>

<u>CLS-11 - July-August, 1975</u>

	Controls	0.250 ppm.	0.500	0.625	0.750	0.875	1.000 ppm.
Initial Count $\times 10^3$	45.1	48.4	44.1	51.9	58.9	55.0	56.0
Count at onset of setting $\times 10^3$	18.6	19.2	9.0	12.4	12.3	11.2	5.6
Total Set $\times 10^3$	4.43	4.32	3.70	1.51	1.25	1.56	0.16
Set as % of Control	100%	97%	84%	34%	28%	35%	4%
Set as % of initial count	9.8%	8.9%	8.4%	2.9%	2.1%	2.8%	0.3%
Set as % of count at onset of setting	23.8%	22.5%	40.9%	12.2%	10.1%	13.9%	2.9%

Figure 1

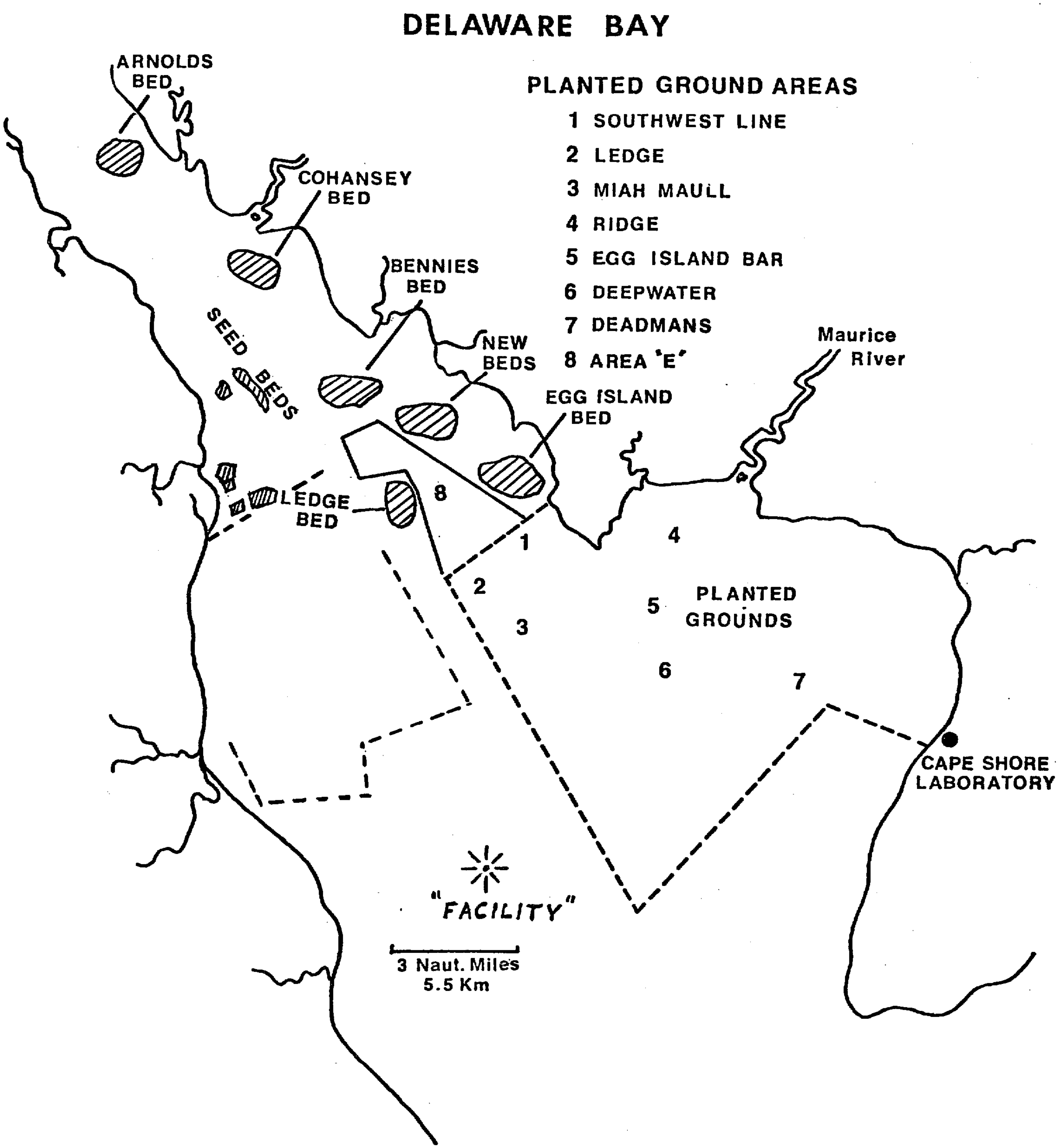
DELAWARE BAY
PLANTED GROUND AREAS
1 SOUTHWEST LINE
2 LEDGE
3 MIAH MAULL
4 RIDGE
5 EGG ISLAND BAR
6 DEEPWATER
7 DEADMANS
8 AREA 'E'
ARNOLDS BED
COHANSEY BED
BENNIES BED
NEW BEDS
SEED BEDS
EGG ISLAND BED
LEDGE BED
Maurice River
PLANTED GROUNDS
CAPE SHORE LABORATORY
"FACILITY"
3 Naut. Miles
5.5 Km
1
2
3
4
5
6
7
8

Figure 2

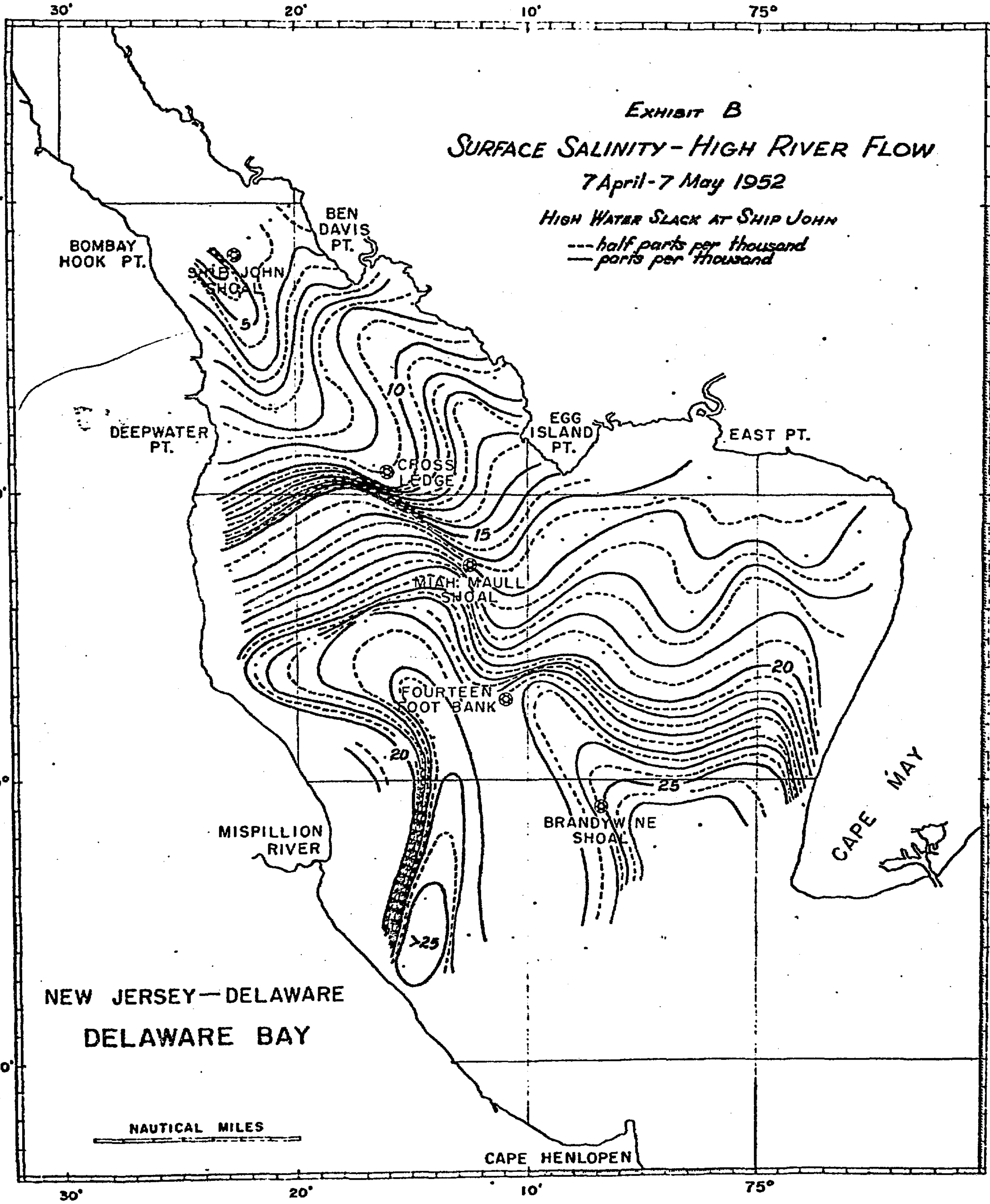
EXHIBIT B
SURFACE SALINITY - HIGH RIVER FLOW
7 April - 7 May 1952
HIGH WATER SLACK AT SHIP JOHN
--- half parts per thousand
— parts per thousand
BOMBAY HOOK PT.
SHIP JOHN SHOAL
BEN DAVIS PT.
DEEPWATER PT.
CROSS LEDGE
EGG ISLAND PT.
EAST PT.
MIAH MAULL SHOAL
FOURTEEN FOOT BANK
BRANDYWINE SHOAL
MISPILLION RIVER
CAPE MAY
CAPE HENLOPEN
NEW JERSEY—DELAWARE
DELAWARE BAY
NAUTICAL MILES
5
10
15
20
25
>25
30'
20'
10'
75°
39°
50'

Figure 3

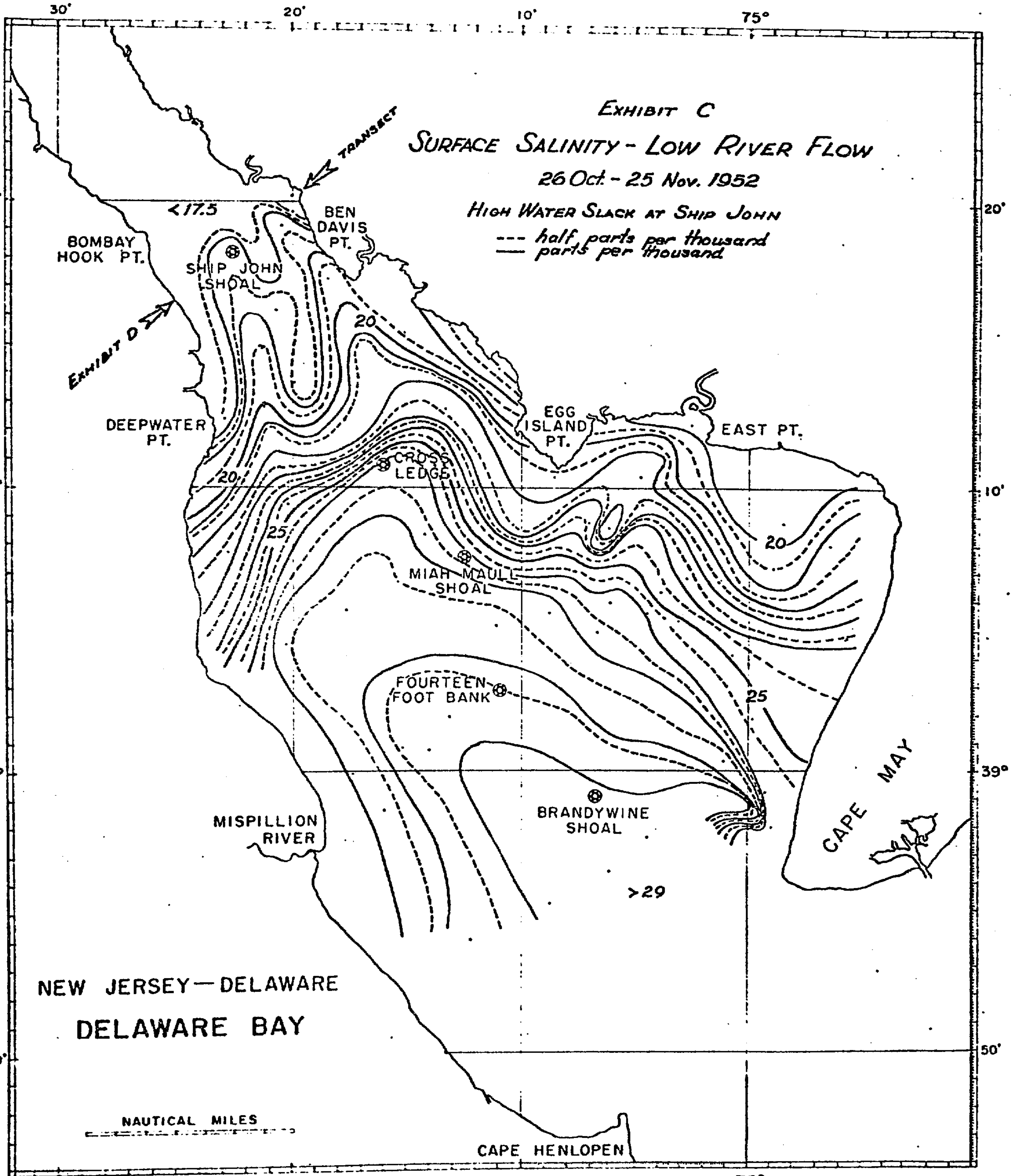
EXHIBIT C
SURFACE SALINITY - LOW RIVER FLOW
26 Oct. - 25 Nov. 1952
HIGH WATER SLACK AT SHIP JOHN
--- half parts per thousand
— parts per thousand
TRANSECT
EXHIBIT D
BEN DAVIS PT.
BOMBAY HOOK PT.
SHIP JOHN SHOAL
DEEPWATER PT.
EGG ISLAND PT.
EAST PT.
CROSS LEDGE
MIAH MAULL SHOAL
FOURTEEN FOOT BANK
BRANDYWINE SHOAL
MISPILLION RIVER
CAPE MAY
CAPE HENLOPEN
<17.5
>29
NEW JERSEY—DELAWARE
DELAWARE BAY
NAUTICAL MILES

Figure 4

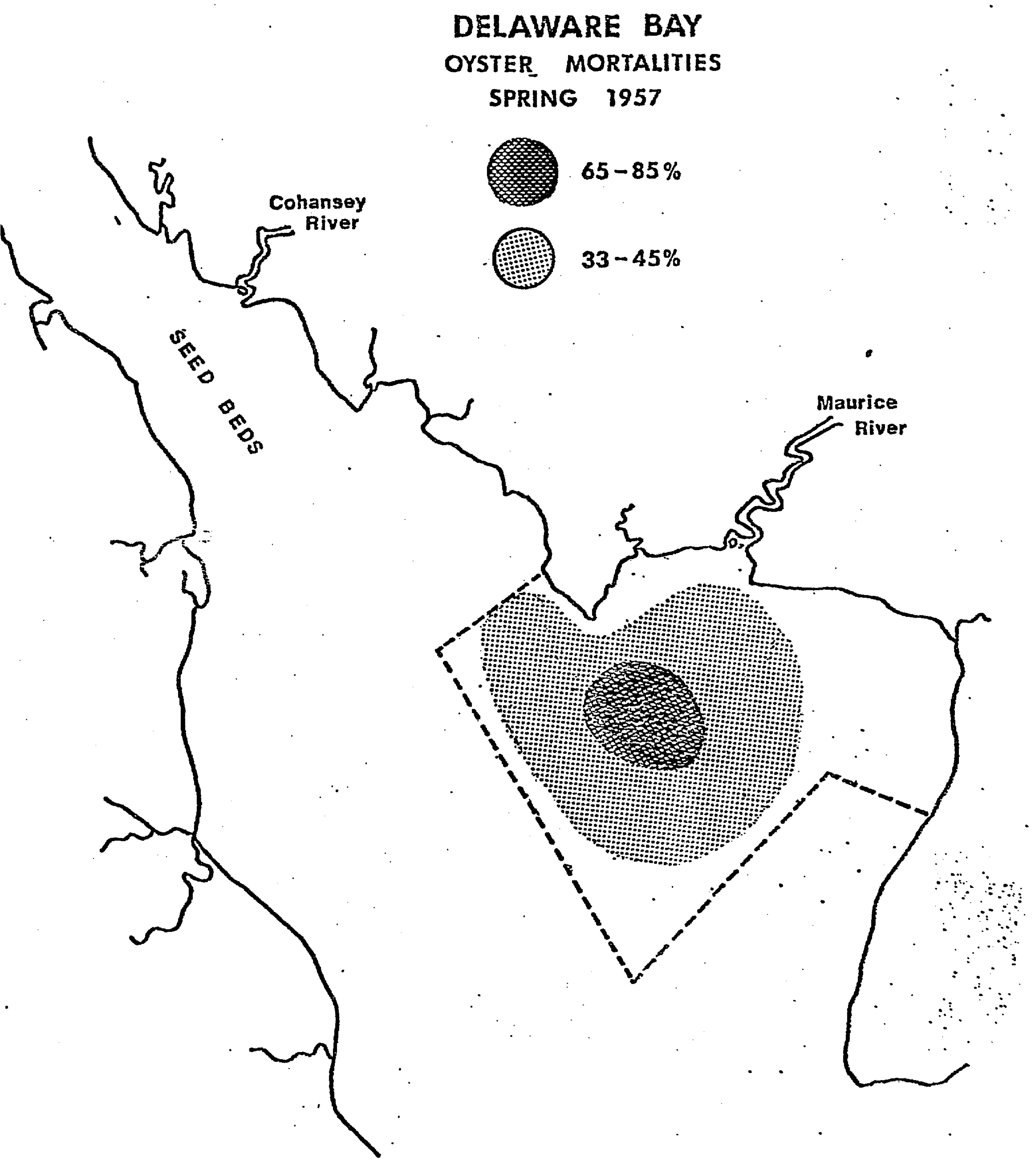
DELAWARE BAY
OYSTER MORTALITIES
SPRING 1957
65-85%
33-45%
Cohansey River
SEED BEDS
Maurice River

Figure 5

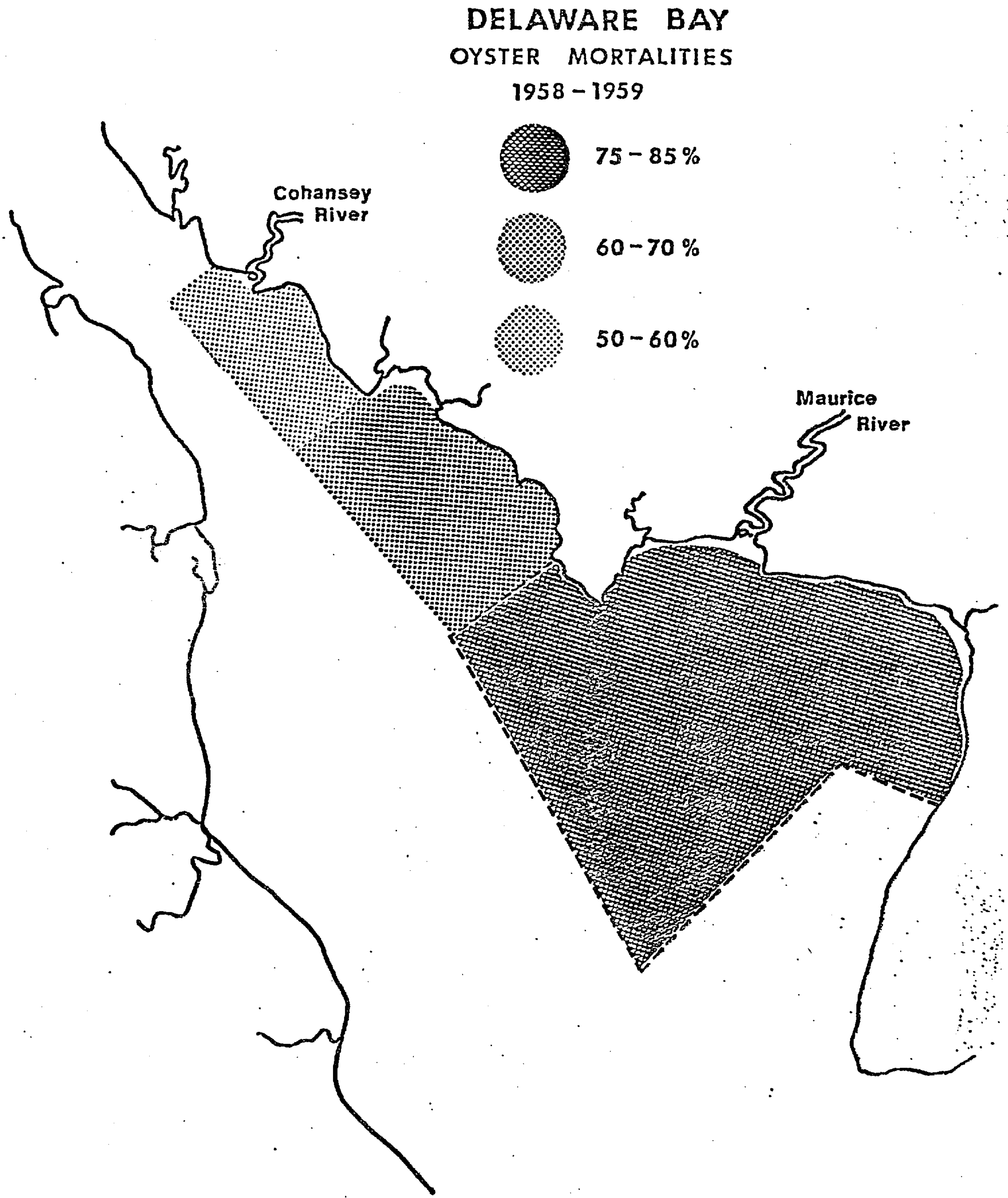
DELAWARE BAY
OYSTER MORTALITIES
1958 - 1959
75 - 85 %
60 - 70 %
50 - 60%
Cohansey
River
Maurice
River

Figure 6. Adult Chronic Exposure Study I.

Cumulative mortality of oysters and average weekly temperature plotted against weeks of exposure to Nigerian crude oil at 0.8 ppm.

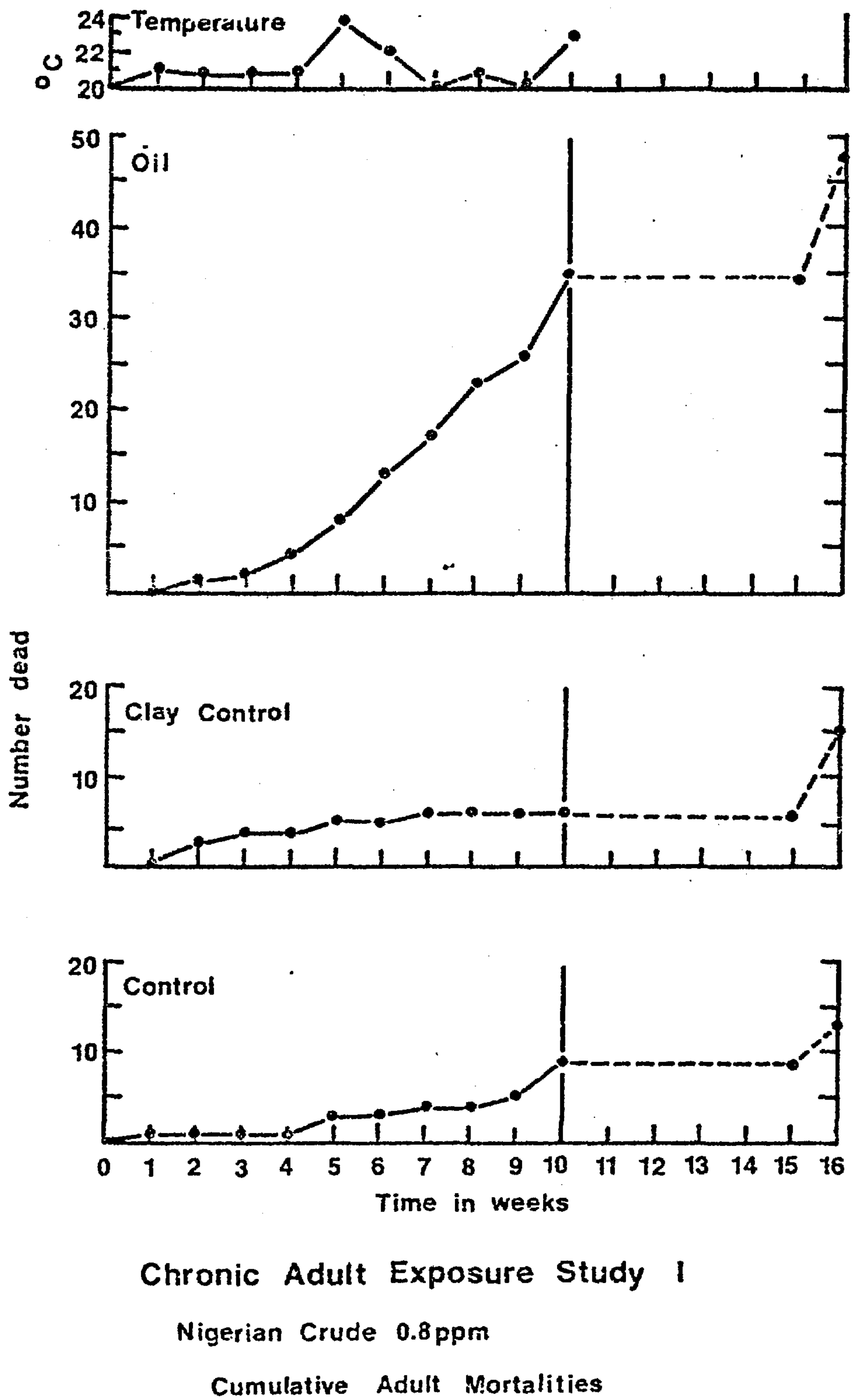

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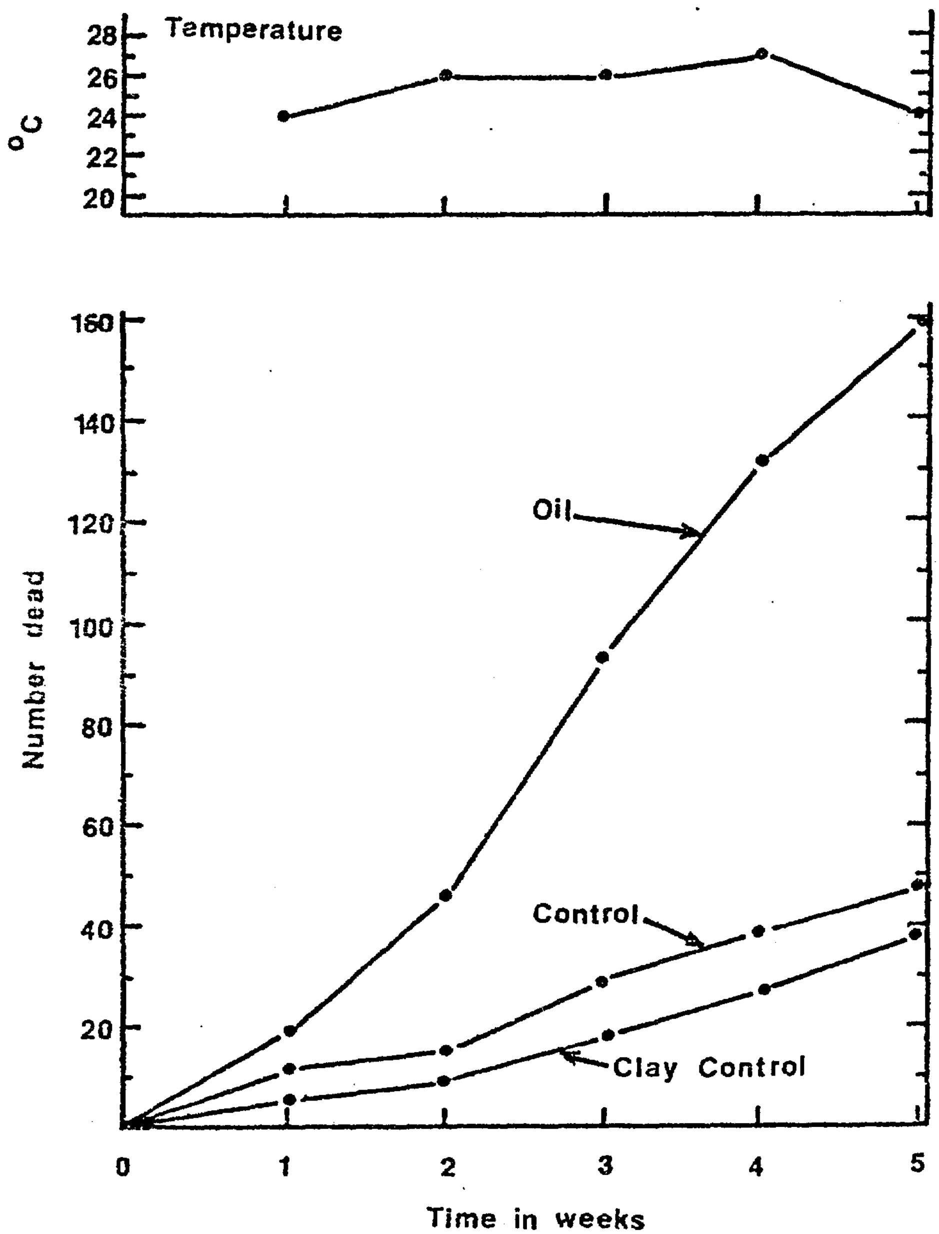
Figure 7 Adult Chronic Exposure Study II.

Cumulative mortality of oysters and average weekly temperature plotted against weeks of exposure to Nigerian crude oil at 0.8 ppm.



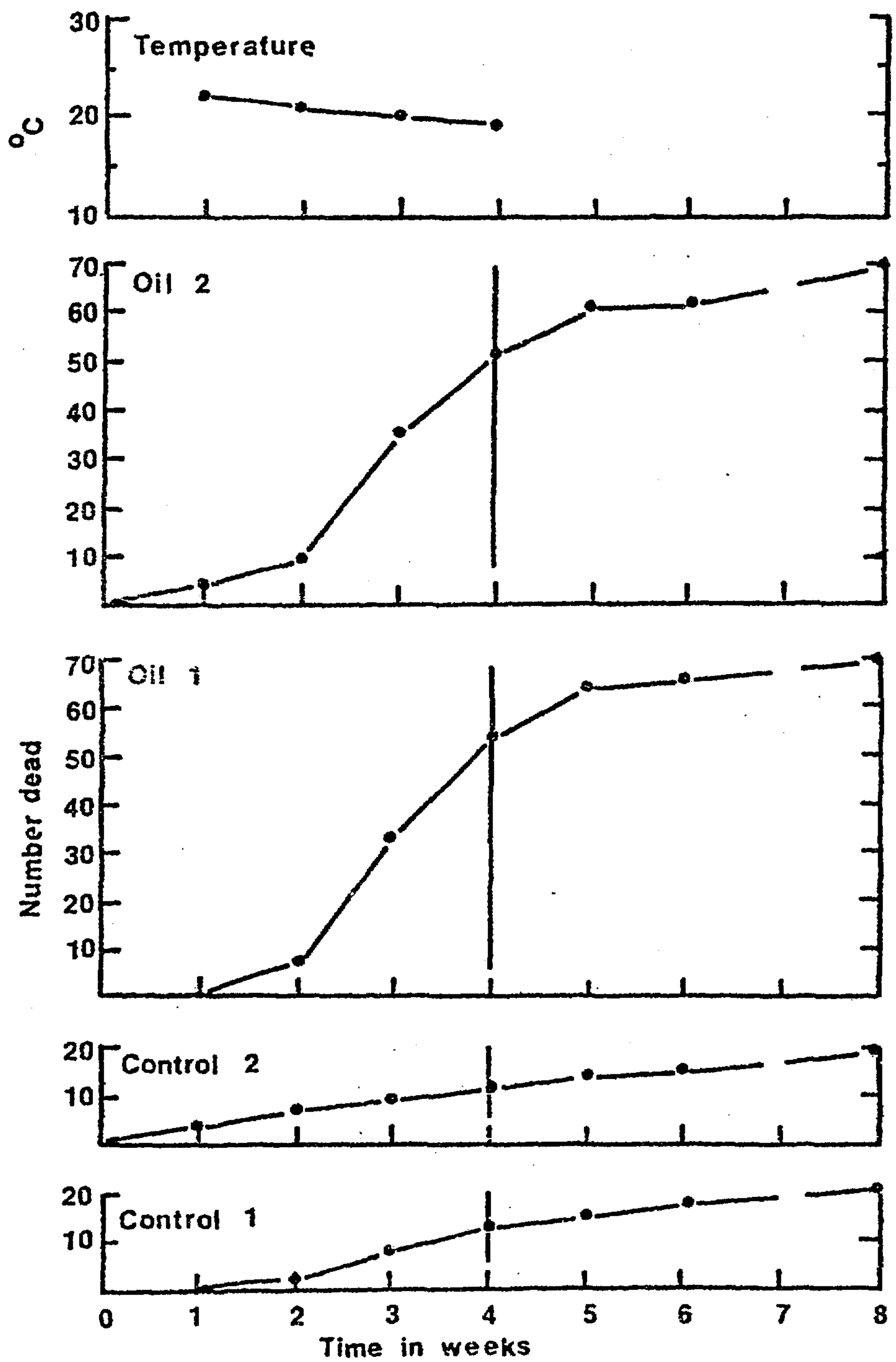
Chronic Adult Exposure Study II

Nigerian Crude 0.8 ppm

Cumulative Adult Mortalities

Figure 8 Adult Chronic Exposure Study III.

Cumulative mortality of oysters and average weekly temperature plotted against weeks of exposure to Nigerian crude oil at 0.7 ppm.



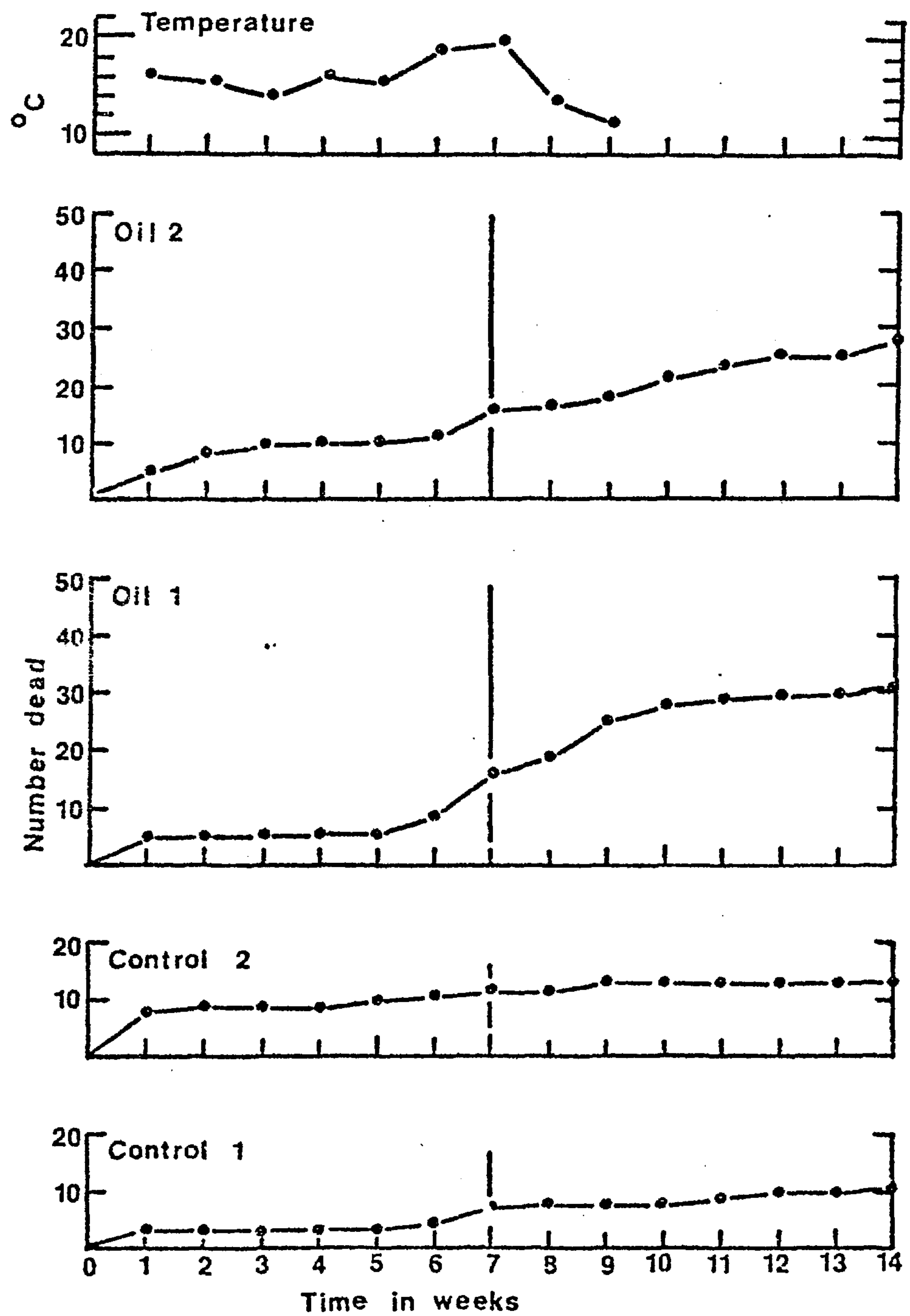
Chronic Adult Exposure Study III

Nigerian Crude 0.7ppm

Cumulative Adult Mortalities

Figure 9 Adult Chronic Exposure Study IV.

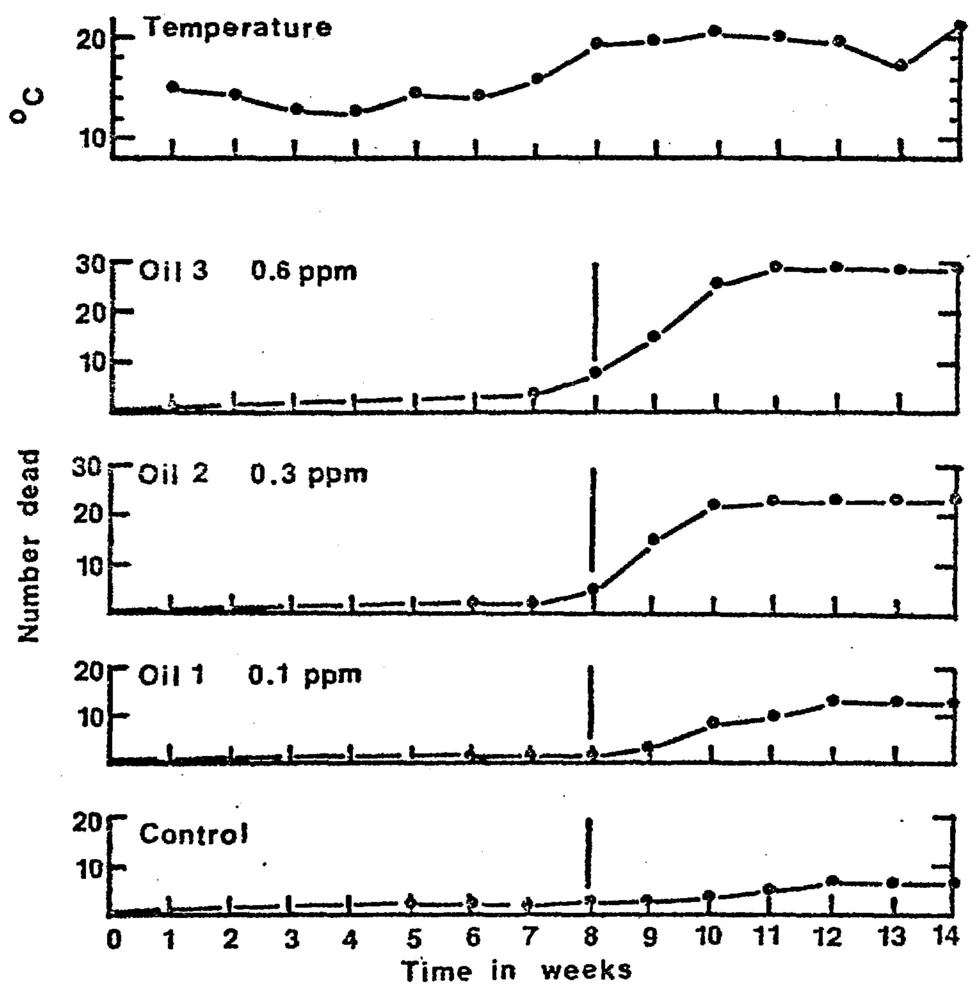
Cumulative mortality of oysters and average weekly temperature plotted against weeks of exposure to Nigerian crude oil at 0.3 ppm.



Chronic Adult Exposure Study IV
Nigerian Crude 0.3 ppm
Cumulative Adult Mortalities

Figure 10 Adult Chronic Exposure Study V.

Cumulative mortality of oysters and average weekly temperature plotted against weeks of exposure to No. 2 fuel oil at 0.1, 0.3, and 0.6 ppm.



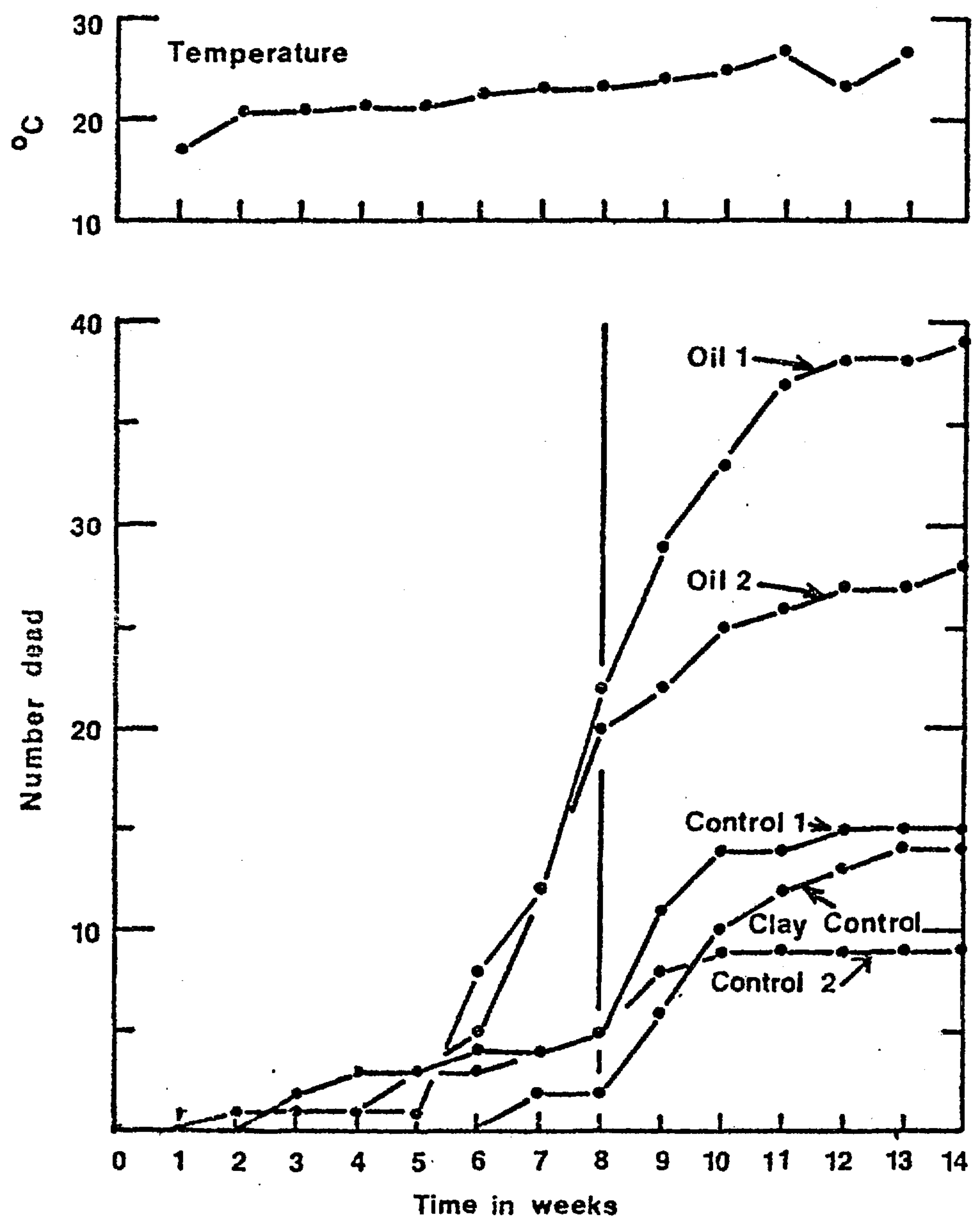
Chronic Exposure Study V

No. 2 Fuel Oil

Cumulative Adult Mortality

Figure 11 Adult Chronic Exposure Study VI

Cumulative mortality of oysters and average weekly temperature plotted against weeks of exposure to Nigerian crude oil at 0.3 ppm.



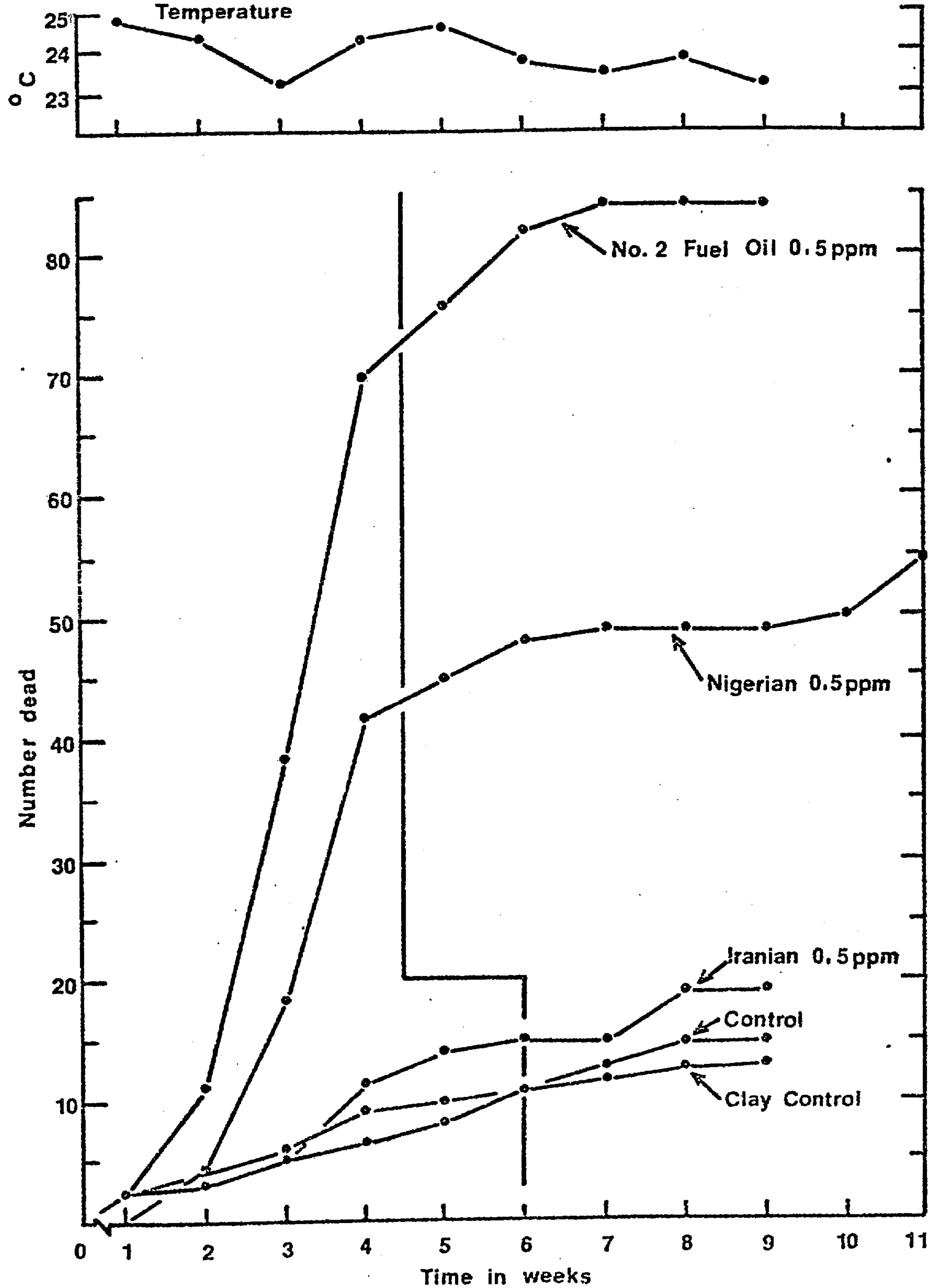
Chronic Adult Exposure Study VI

Nigerian Crude 0.3 ppm

Cumulative Adult Mortalities

Figure 12 Adult Chronic Exposure Study VII

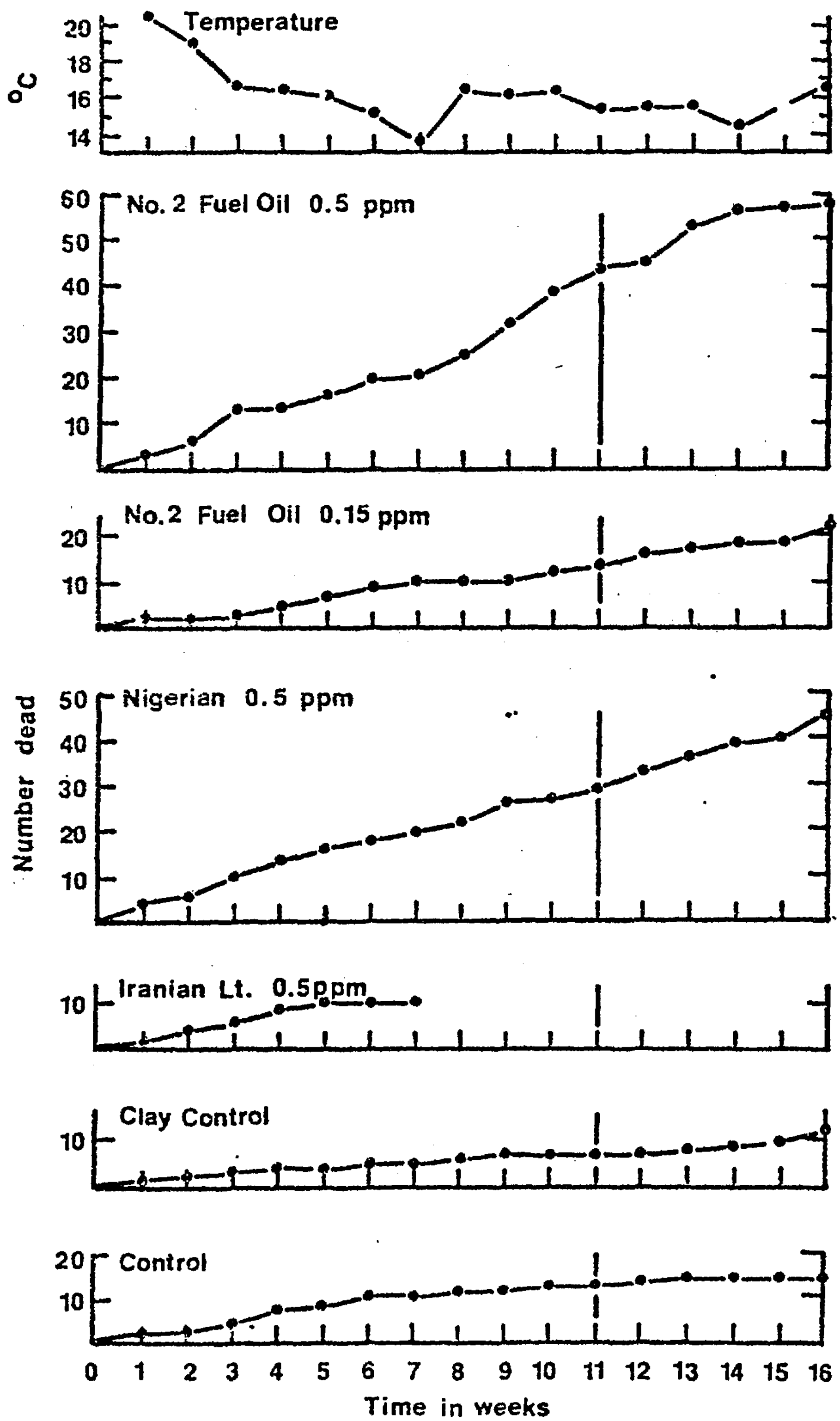
Cumulative mortality of oysters and average weekly temperature plotted against weeks of exposure to 0.5 ppm each of Iranian light crude oil, Nigerian crude oil, and No. 2 fuel oil.



Chronic Adult Exposure Study VII
Cumulative Adult Mortalities

Figure 13 Adult Chronic Exposure Study VIII

Cumulative mortality of oysters and average weekly temperature plotted against weeks of exposure to 0.5 ppm each of No. 2 fuel oil, Nigerian crude oil, Iranian light crude oil, and 0.15 ppm. No. 2 fuel oil.

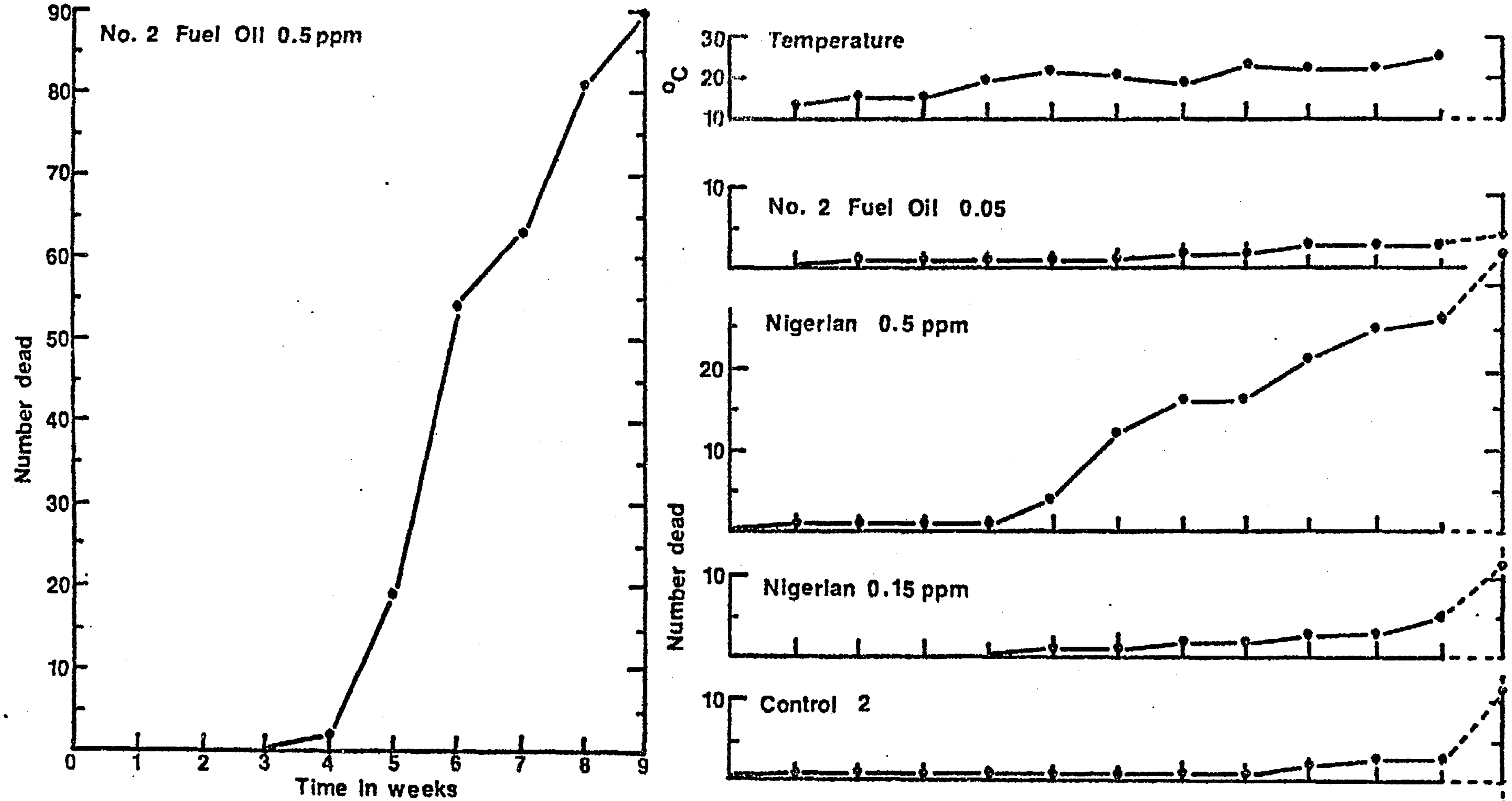


Chronic Adult Exposure Study VIII

Cumulative Adult Mortality

Figure 14 Adult Chronic Exposure Study IX

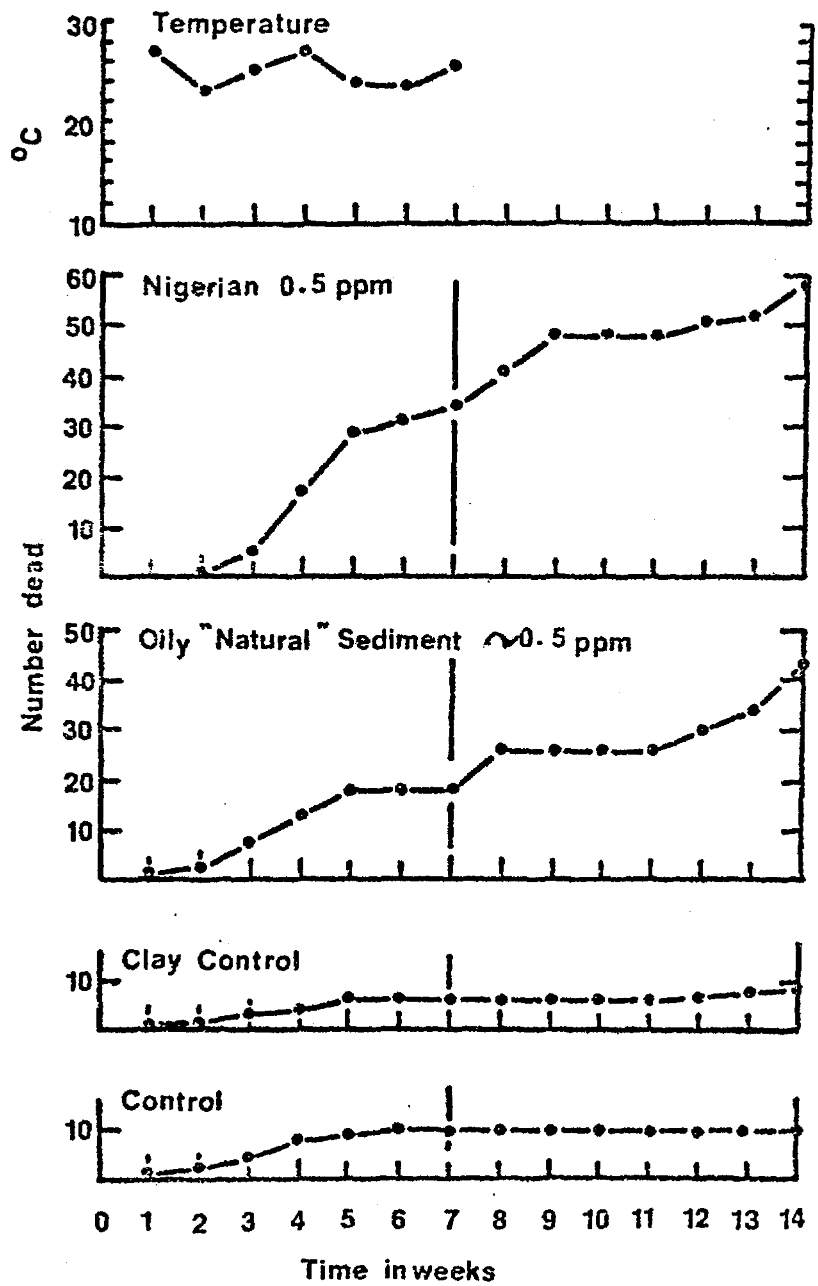
Cumulative adult mortality of oysters and average weekly temperature plotted against weeks of exposure to 0.5 ppm each Nigerian crude oil and No. 2 fuel oil, 0.15 ppm Nigerian crude oil, and 0.05 ppm No. 2 fuel oil.



Chronic Adult Exposure Study IX
(Exposure Period)
Cumulative Adult Mortality

Figure 15 Adult Chronic Exposure Study X.

Cumulative adult mortality of oysters and average weekly temperature plotted against weeks of exposure to 0.5 ppm Nigerian crude oil and about 0.5 ppm "naturally" oily sediment.



Chronic Adult Exposure Study X

Cumulative Adult Mortality

Fig. 16- Comparison of toxicity of #2 fuel oil with Nigerian crude by use of mortality index. Regression lines are calculated for best fit. Correlation coefficients: #2 fuel - 0.906; Nigerian crude - 0.952.

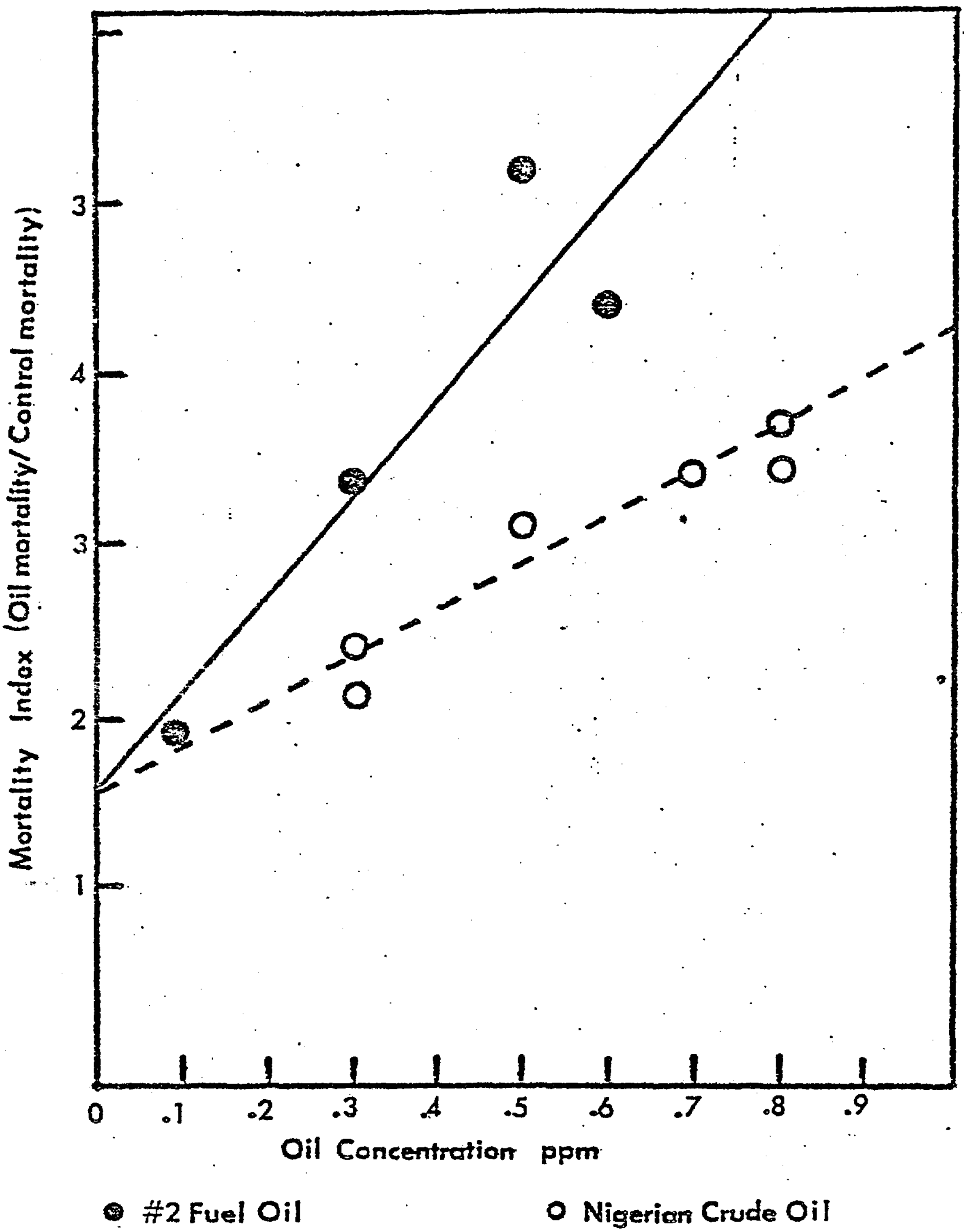
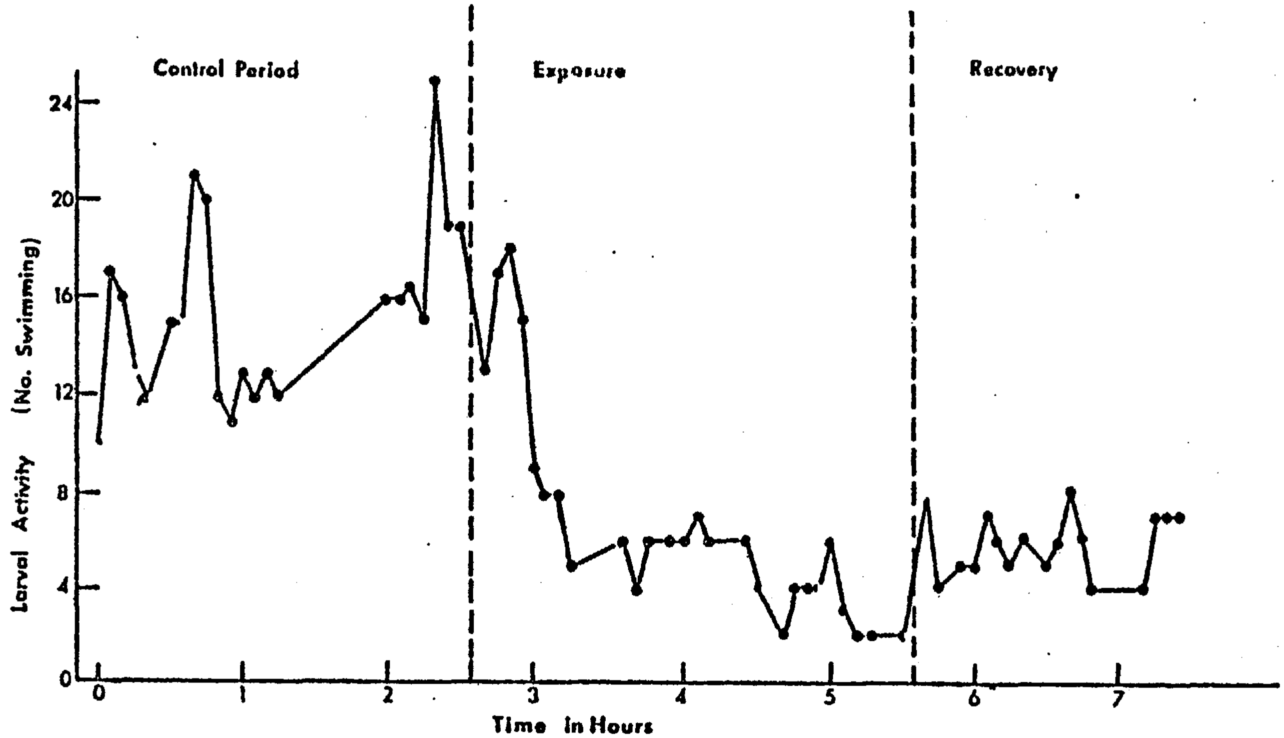


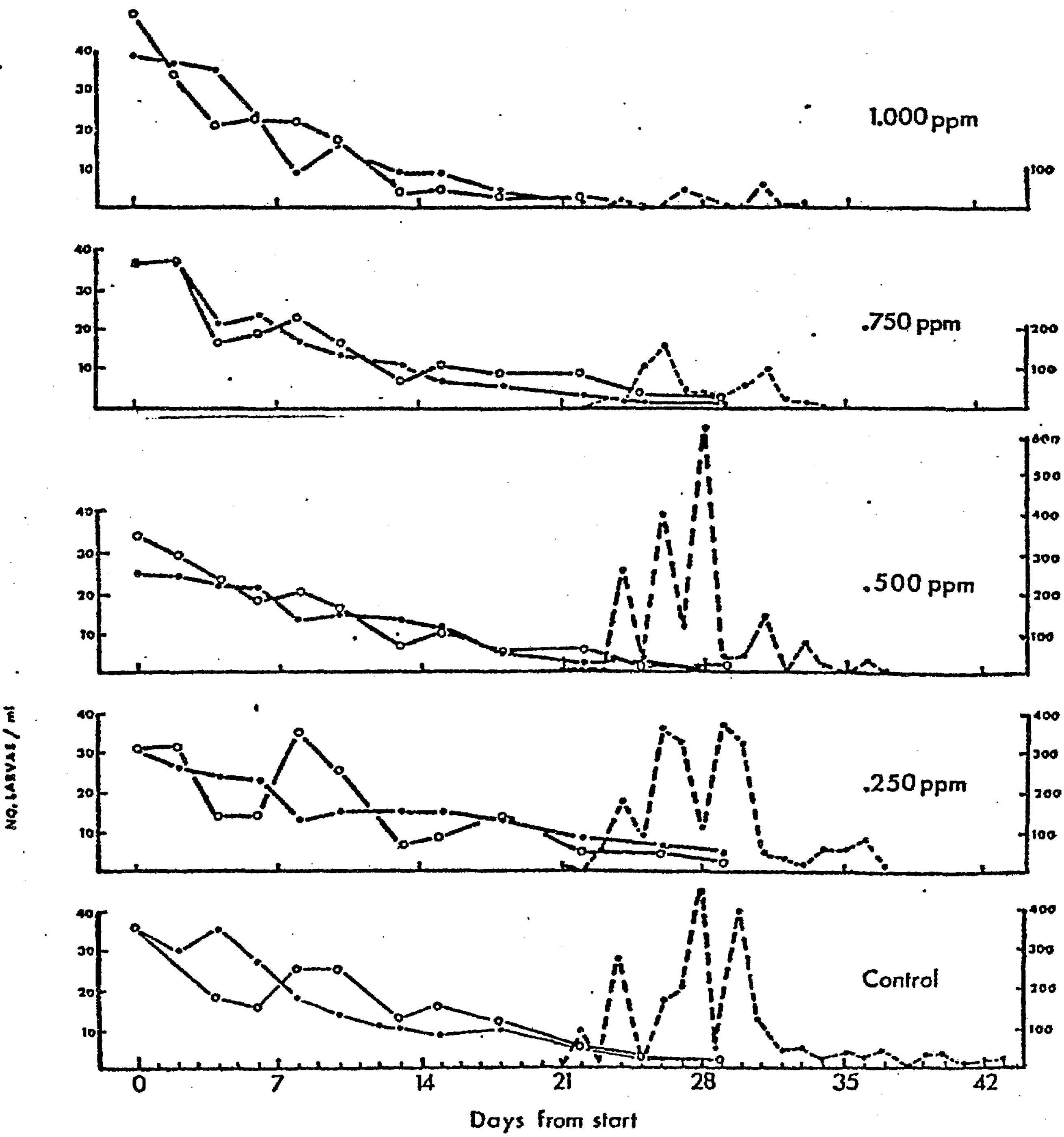
Fig. 17 - Effect of water soluble extract of Nigerian crude oil at 1:10 dilution on swimming activity of oyster larvae. Acute exposure reduces the number of active larvae by about two-thirds.



Acute Exposure - Larvae

Nigerian Crude WSE (1:10)

Fig. 18 - Chronic larval study 11. Effects of different concentrations of Nigerian crude oil on survival and setting of oyster larvae. Axis on left and solid lines indicate numbers of larvae per milliliter of culture. Axis on right and dotted lines indicate number of larvae setting per day.



LARVAL EXPOSURE TO OIL-CLAY CLS-11-OC

Fig. 19 - Effect of concentration of Nigerian crude oil and duration of treatment on set. At higher concentrations set is obtained only when treatment is delayed. Dotted line in upper graph indicates result of stopping oil treatment (1.5 ppm) after 11 days and before setting began in controls.

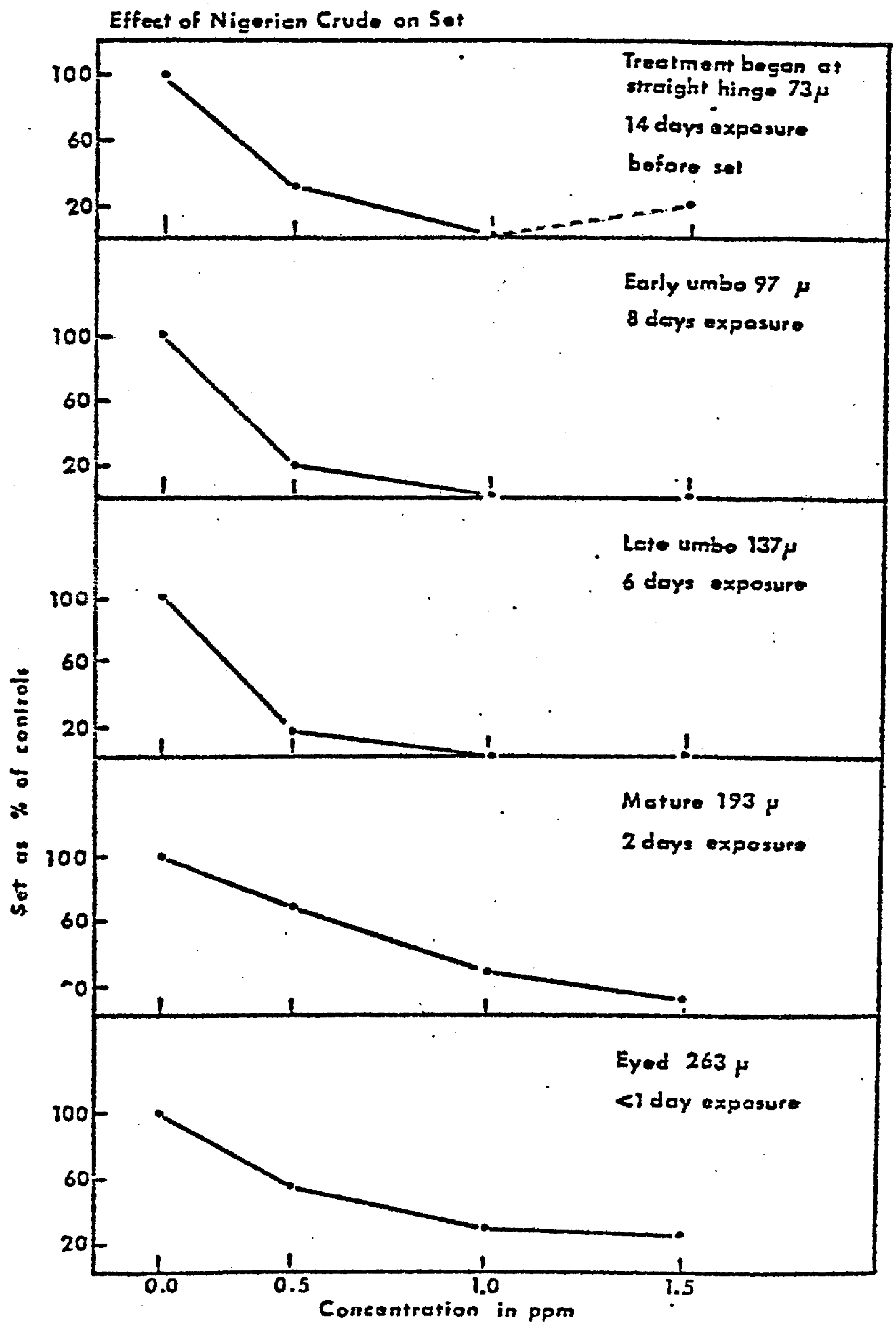


Fig. 20 - Effect of concentration of Nigerian crude oil on growth of oyster larvae

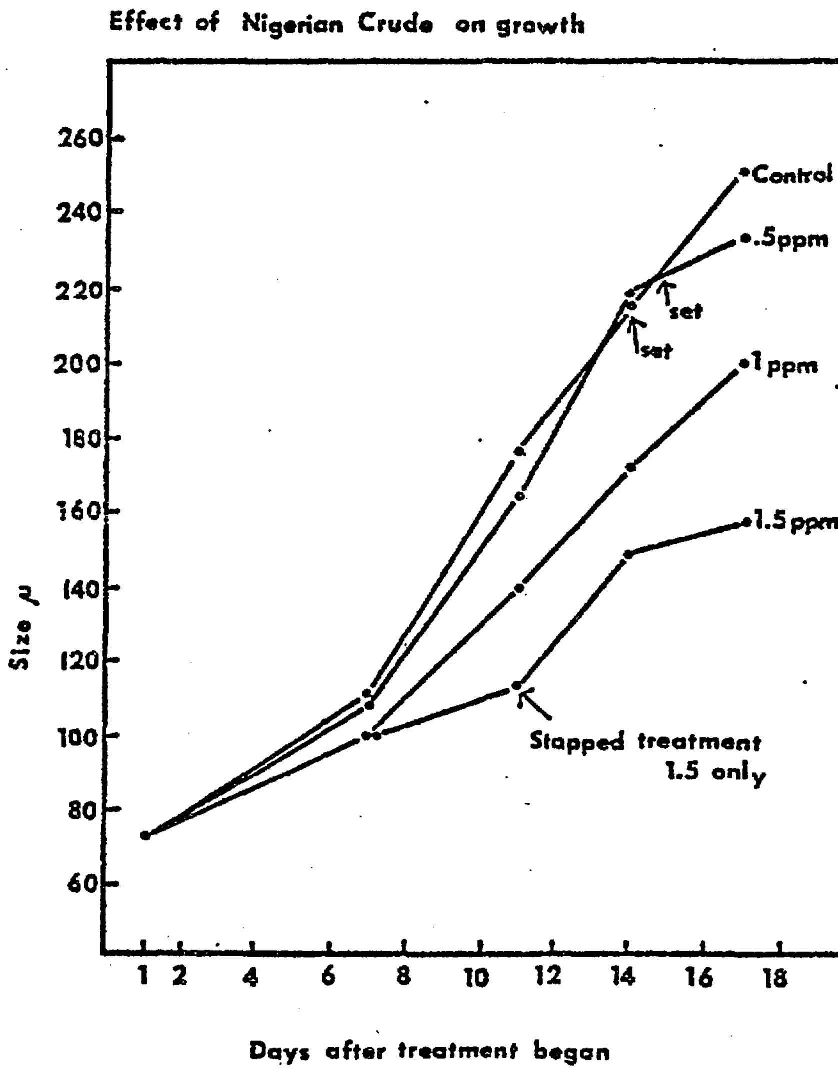


Fig. 21 and 22 - Effect of WSE on <u>Monochrysis</u> <u>lutheri</u>. Each point represents the mean of three replicate cultures ± Least Significant Interval

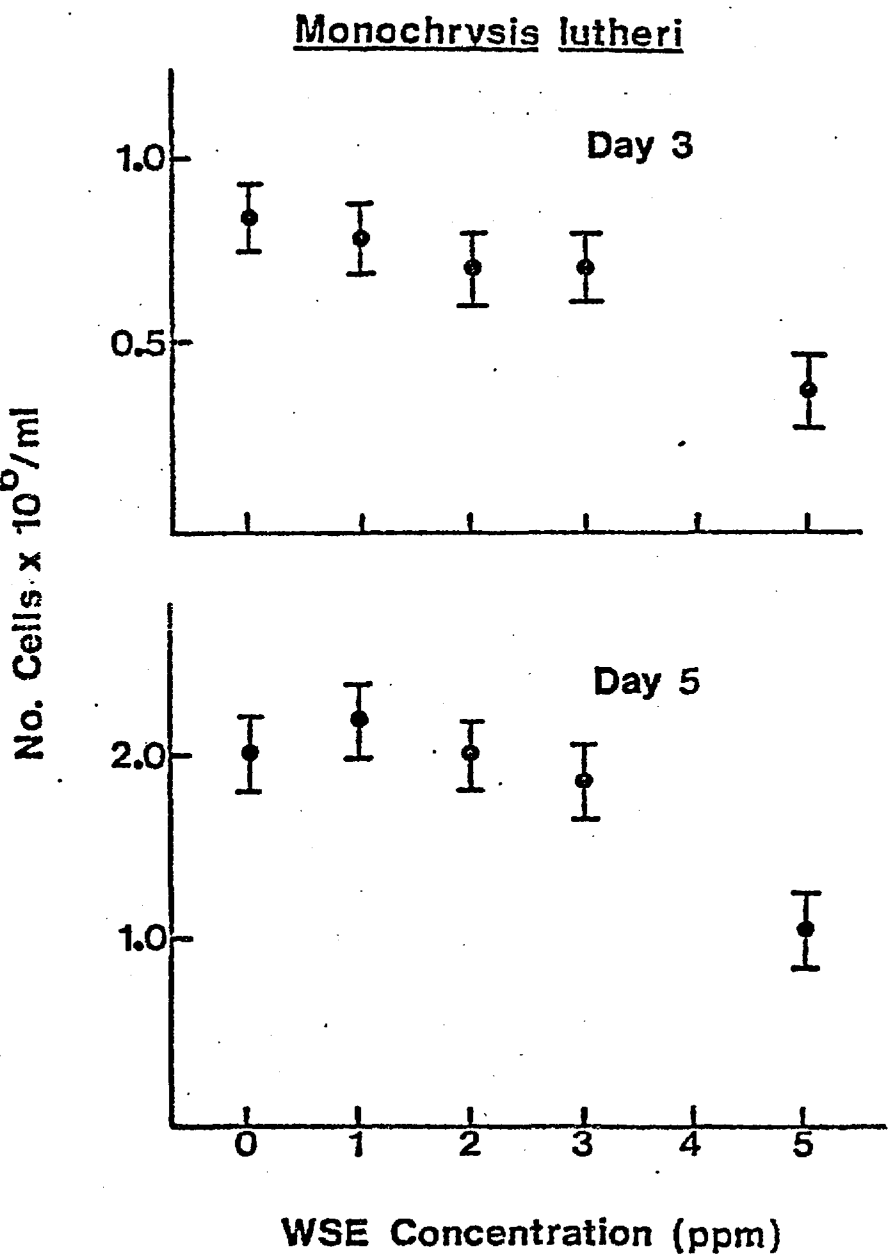


Fig. 23 - Effect of WSE on Isochrysis galbana. Each point represents the mean of three replicate cultures ± Least Significant Interval.

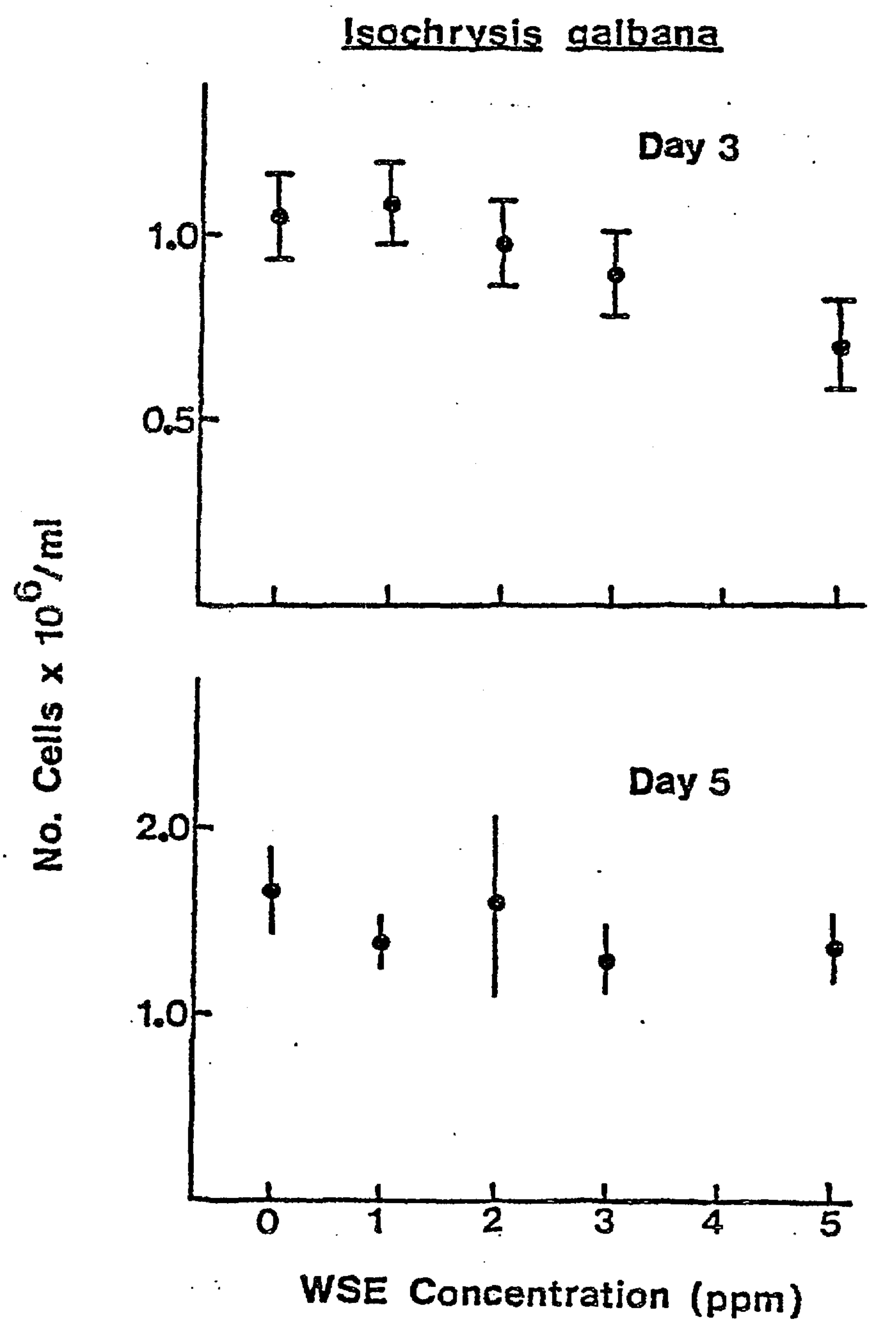


Fig. 24 - Effect of WSE on Isochrysis galbana. Each point represents the mean of three replicate cultures ± Standard Deviation (ANOVA results not significant at P = 0.05)

Fig. 25 - Effect of WSE on <u>Skeletonema</u> <u>costatum</u>, MB-7, Day 3. Each point represents the mean of five replicate cultures ± Least Significant Interval

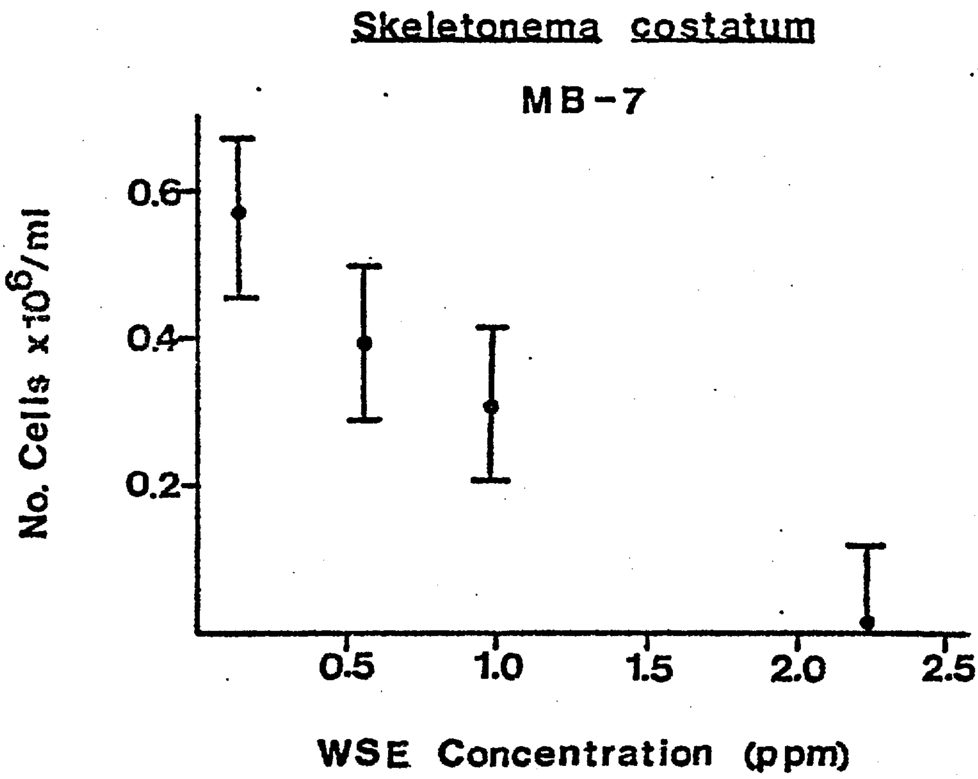


Fig. 26 - Effect of WSE on Skeletonema costatum, MB-7, Day 6. Each point represents the mean of five replicate cultures ± Least Significant Interval

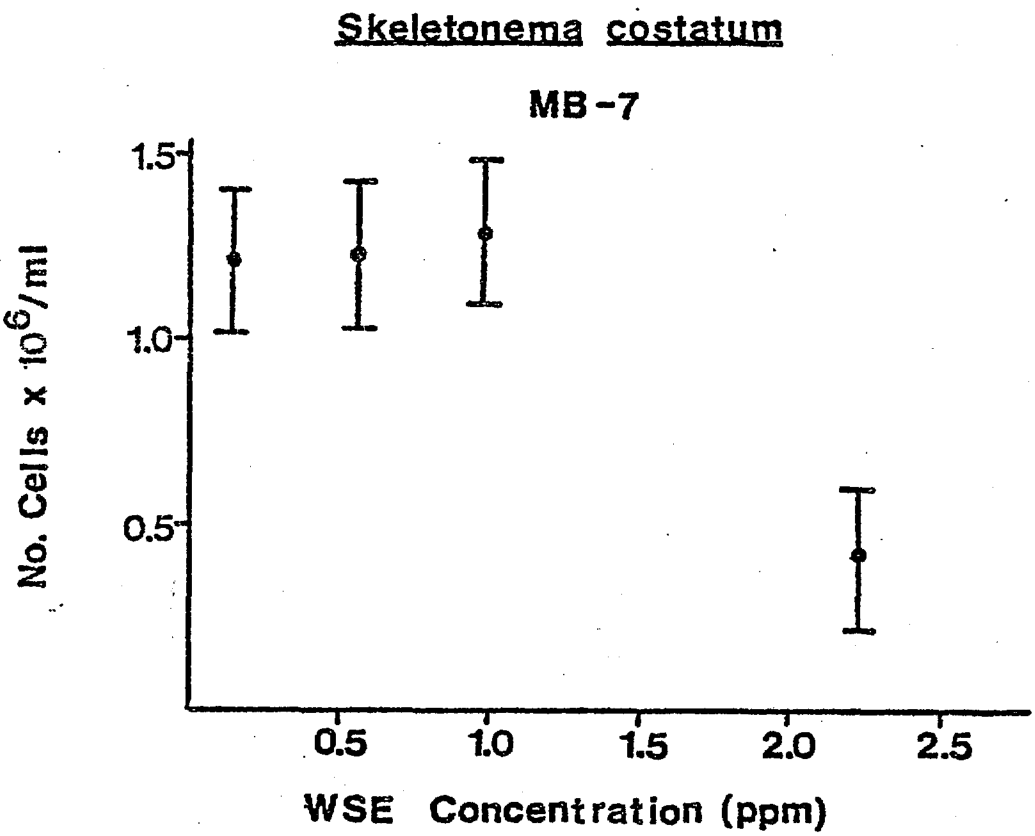


Fig. 27 - Effect of WSE on <u>Skeletonema</u> <u>costatum</u>, MB-4, Day 7. Each point represents the mean of ten replicate cultures ± Least Significant Interval

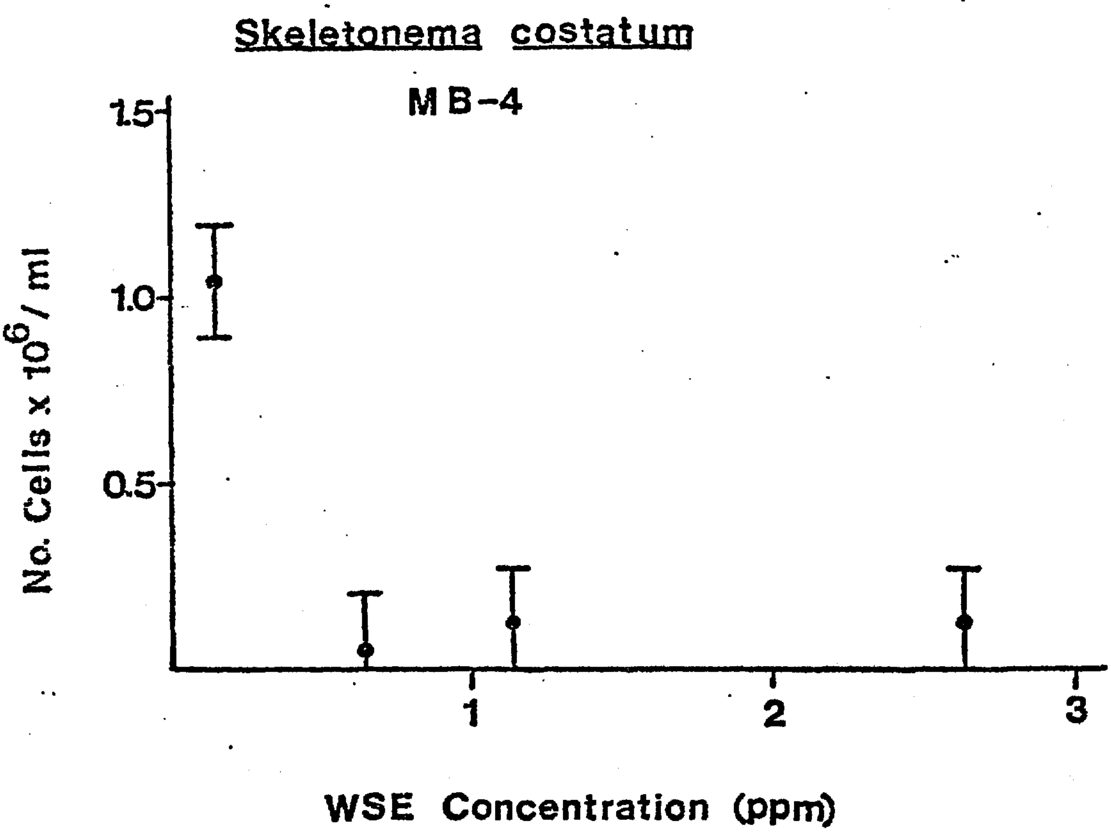
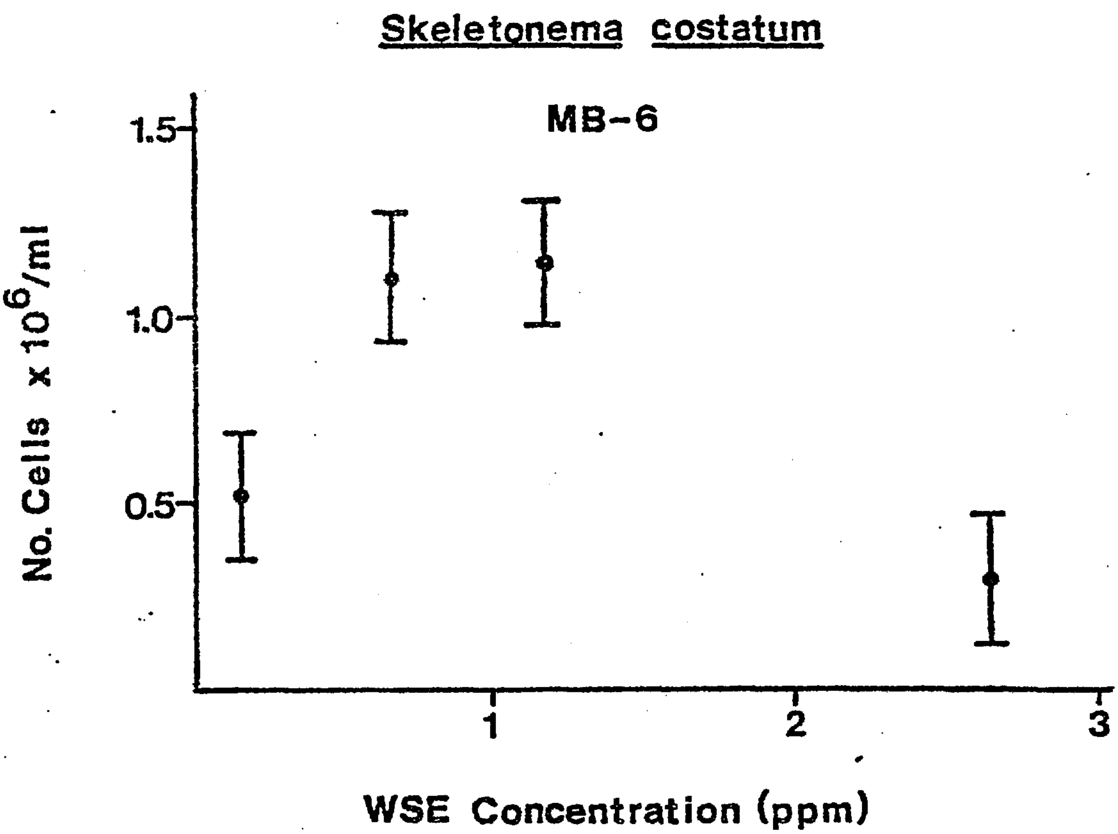


Fig. 28 - Effect of WSE on Skeletonema costatum, MB-6, Day 6. Each point represents the mean of five replicate cultures ± Least Significant Interval



PREDICTION OF OIL SPILL TRAJECTORIES

IN NEW YORK HARBOR

by

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LIE-YAUW OEY, Ph.D.

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Report Prepared For

THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY

October, 1981

1. INTRODUCTION

This present study is one part of an integrated environmental-economic feasibility analysis for the establishment of a crude oil receiving facility within New York Harbor. The chief objective of the work reported here was to compare the trajectories of oil spills expected to occur under the present oil handling practices within the Harbor with those which could be projected if a crude oil receiving facility were established. The several oil spill scenarios considered in this work were specified by staff members of the Port Authority of New York and New Jersey as a result of their statistically based analyses of spill records. The present investigation was undertaken to determine where such spills could be expected to be carried by the currents in the Harbor. The complementary studies by Professor R. Bartha and by Professor A. Farmanfarmaian serve to predict how long the spills will persist as surface slicks and to determine the effects of the spills on the biota in the Harbor region. Thus, the three combined studies together with the Port Authority's analyses provide answers to the following questions concerning the environmental effects of oil spills:

(i) Where will spills occur; at what frequency; and in what amount under present practice and with a crude oil receiving facility? (Port Authority).

(ii) Where will the spills go? (Present Trajectory Analysis)

(iii) How long will the spills persist as identifiable surface slicks? What will be the annual accumulation of residue from these spills? (Bartha).

(iv) As the spill products move through the Harbor, what will be their effects on Marine life? (Farmanfarmaian).

It is apparent from the above that the predicted trajectories are but one part of the answer to what are the effects of oil spills in New York Harbor, and, more importantly, what will be the change in these effects if a crude oil receiving facility is established.

The trajectory predictions presented in this report represent our best effort within the constraints of the level of effort appropriate for a preliminary feasibility study. For a particular spill location and amount of spilled oil there has been no attempt to predict trajectories under all possible combinations of environmental factors. For example, we find that the trajectory may vary significantly with the timing of the spill relative to the phase of the tide. Clearly, it is expected that the trajectory will differ depending on whether the tidal currents are flooding (flowing upstream or inland from the sea) or ebbing (flowing toward the sea). It is found, however, that very small changes in the time of occurrence of the spill of the order of an hour or less (compared to a typical period* of $12\frac{1}{2}$ hours for one complete tidal cycle) will lead to remarkably different trajectories. In this preliminary work it was not possible to investigate all possible phase relationships between the time of the spill and the stage of the tide. In addition to the tidal currents it is expected that the local winds will have an important influence on the trajectory of an oil slick. Thus, an exhaustive study would encompass a systematic variation in the time of spill relative to the tidal phase together with a variation in the prevailing winds. This type of comprehensive study would be appropriate at a later stage of planning for a crude oil receiving facility as in the preparation of a final Environmental Impact Statement. For the present preliminary assessment we have considered a very limited number of cases which are representative rather than exhaustive. These first results serve as a starting point for further more detailed studies which would be required as the proposed port evolves from conceptual to final design.

In the following section of this report the particulars of each spill scenario are presented. In section 3 the results of the trajectory calculations are presented. In section 4 the major features of these results are discussed. In section 5, we present a summary of the chief conclusions which can be drawn from this study and make some recommendations for future work. Finally in section 6 the method used to determine the spill trajectories is described together with a detailed account of the assumptions on which it is based.

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*We define the period of a tidal cycle as the time interval between exact repetitions of phase, e.g., the time interval between one high water and the next.

2. OIL SPILL SCENARIOS

One fundamental objective of the overall Deepwater Port Study is to compare the environmental effects of the present practice for the marine delivery of crude oil to the predicted effects with the establishment of a crude oil receiving facility. Thus, the major division of the possible spill scenarios is between those which can be projected if the present practice continues and those which would be expected with the crude oil receiving facility. The present practice consists of the following elements: (1) large tankers enter the Harbor and anchor off Stapleton on Staten Island where their cargo is partially unloaded into barges for transport to the Exxon and Chevron refinery piers on the Arthur Kill. (2) These large tankers with reduced drafts then proceed to the Exxon and Chevron piers as well. (3) Smaller tankers with drafts less than 35 feet are used to deliver crude oil directly to the Exxon and Chevron piers. With a bulk crude oil receiving facility built either at Stapleton or at Port Jersey then very large tankers could moor at a fixed pier and deliver crude oil via pipelines to Exxon and Chevron. The effect of the facility would be to reduce the number of tanker visits to the Harbor as well as tanker and barge movements through the Kills. The expectation then is that with the facility there would be fewer spills during crude oil transfer at the Stapleton Anchorage and at each refinery pier.

With the present crude oil delivery system the following oil spill projections have been formulated by staff members of the Port Authority of New York and New Jersey:

Location of Spill.	Number of Spills Expected in One-Year	Average Size of Spill in Gallons
Stapleton Anchorage	4	42
Refinery Piers		
Exxon	3	336
Chevron	2	336
Kill van Kull* off Bergen Point	-	1.68×10^6

*This has been calculated by the Port Authority to be "The most credible worst case". An annual frequency has little meaning for this worst case sceanario.

With the establishment of a deepwater channel and a crude oil handling facility either at Port Jersey or at Stapleton the following oil spill projections have been made:

Location of Spill	Number of Spills Expected in One-Year	Average Size of Spill in Gallens
Stapleton Anchorage	2	42
Refinery Piers		
Exxon	1	336
Chevron	1	336
Crude Oil Handling Facility at either Stapleton or Port Jersey	1	504
Ambrose Channel*	-	2.814×10^6

The locations of each possible spill site are shown in Figure 1b. The only change to the harbor when a crude oil receiving facility is established which could possibly alter the trajectory of oil slicks is the required deepening of Amrose Channel to 60 feet from its present 45-foot controlling depth. Trajectory changes will occur only if the channel deepening changes the magnitude or phase relationships of the tidal currents. Thus, one of the first tasks of our study was to determine if any significant change in tidal currents could be detected in the tidal hydraulics model when the depth of the Ambrose Channel was changed.

For the non-catastrophic spills with sizes ranging from 42 to 504 gallons, the surface oil slick was treated in the computer model as if it were a particle. This particle could be released at each location at any phase of the tidal cycle and its subsequent path through the harbor could be determined. For the catastrophic spills a different approach was adopted in which it was assumed that such a spill would release oil to the water over a substantial period of time. For these

*Again this is the "most credible worst case". Since fewer vessel movements per unit time, are anticipated with the facility the interval within which a worst case could happen is longer with the facility than without it.

cases, we simulated the effect of a continuous release of oil at the spill site by introducing a particle every twenty three minutes throughout the course of a complete tidal cycle. The trajectory of each particle is determined and the positions of all of the particles at particular subsequent times were plotted.

The procedure for the catastrophic spills produces not one but 32 different trajectories; one for each of the particles released at 23-minute intervals throughout the duration of a complete tidal cycle. Since we label each particle by numbering them consecutively from 1 to 32 we, therefore, can keep track of each particle at subsequent times. Consequently, we can assume that the spill begins at the time of release of <u>any</u> of the 32 particles.

3. RESULTS

A comparison of the tidal hydraulics model results for the cases of a 45-feet deep Ambrose Channel (present siutation) and a 60-foot deep channel (needed for the crude oil receiving facility) revealed no significant differences in tidal currents or elevation. The level of significance for currents was taken as 7.5 cm/s (0.15 knot) and for elevation it was 2.5cm. This result provides the rationale for assuming that the trajectories of spills from Stapleton anchorage and from the refinery piers will be the same for both the present situation and with the facility. In view of their applicability for both cases the predicted oil spill trajectories from these three sites will be presented first.

The Exxon refinery pier is located on the northern portion of the Arthur Kill (see Figure 1). In an attempt to bracket the effects of tidal phase, spills were initiated at two end points; at the times of the slack water before ebb currents begin, and the slack water before flood currents. For the Arthur Kill the ebb direction is taken as towards Raritan Bay i.e., generally southward. The trajectory for a spill at the Exxon pier at the slack before flood is shown schematically in Figure 2. The small numbers at points along the trajectory represent the number of tidal cycles which have elapsed since the time of the spill. Thus, after one complete cycle the oil slick has moved through the Kill van Kull and is found off Stapleton. After two complete cycles it is in Lower Bay and finally after six cycles (about three days) the oil has left the modelled domain. The trajectory for a spill at the Exxon refinery pier at the time of slack before ebb is shown in Figure 3. For this case the oil is moved initially down the Arthur Kill as would be expected, and it requires three cycles to have it transported into Upper Bay. Once this spill reaches Lower Bay it becomes trapped in the low velocity regime in Raritan Bay for four tidal cycles before it rounds Sandy Hook and moves southward along the New Jersey coastline. The time for this spill to leave the model domain is 11 tidal cycles or about six days.

It is interesting to note that if the spill were assumed to occur at the Exxon pier one hour before the slack water preceding ebb then the predicted trajectory will include a significant intrusion into Newark Bay which did not occur for the spill exactly at the time of slack water. In a similar manner, if the spill at Exxon were at one hour earlier than the time of slack water before flood, the predicted trajectory includes movement of oil over nearly the entire length of Newark Bay. These significant changes in trajectory with small changes in the time of release serve as a first example of the sensitivity of our results to the time of release of oil within a tidal cycle.

The predicted trajectory for a surface oil slick from a spill at the Chevron refinery pier, assumed to occur at slack water before flood at the pier, is shown in Figure 4. The trajectory is complex. The oil moves the length of the Arthur Kill twice, it repeatedly intrudes into Newark Bay for five tidal cycles, then on the ninth tidal cycle following the spill it is moved through the Narrows to Lower Bay. Finally, after seven additional tidal cycles the oil from the Chevron pier leaves the Harbor region. For a spill at the Chevron pier at the time of slack water before ebb, the oil is found to move repeatedly into Raritan Bay and then back into the Arthur Kill with no apparent net displacement. The trajectory for this case is shown for the first eleven tidal cycles following the spill in Figure 5. After an additional 30 tidal cycles have elapsed we find no significant displacement of the oil beyond the oscillatory movements illustrated in Figure 5.

The trajectory for an oil spill at the Stapleton anchorage at the time of slack water before flood is shown in Figure 6. The trajectory for a spill at this location at the time of slack water before ebb is shown in Figure 7. The contrast between these predicted trajectories is remarkable. For the spill occuring at the beginning of flood currents, the oil is moved repeatedly into the Lower Hudson and East River for 8 tidal cycles before finally entering Lower Bay. After several excursions from Lower Bay back into Upper Bay, this oil is finally ejected from the Harbor nine days (17 tidal cycles) after the occurence of the spill. The situation for a spill just before the onset of ebb currents is, in contrast with that for slack water before flood, very simple as illustrated in Figure 7. The oil moves directly into Lower Bay on the first tidal cycle and leaves the Harbor after only $3\frac{1}{2}$ tidal cycles.

The "most credible worst case" spill for the present practice of crude oil delivery is taken as a release of 1.68 million gallons into the Kill van Kull off Bergen Point. We assume that this release is continuous over one complete tidal cycle. The spill is assumed to start at the slack water prior to the onset of ebb currents in the Kill van Kull, which by convention are directed towards Upper Bay. Our procedure is to follow the paths of 32 particles injected into the Kill van Kull at twenty three minute intervals over the first complete tidal cycle following the spill. The position of each particle released in this manner at the end of this first tidal cycle is shown in Figure 8a. Most of the particles are found in Newark Bay with just 5 particles distributed in the Kill van Kull and along the Staten Island side of the Narrows Region. The distribution of oil after two complete tidal cycles is shown in Figure 8b. Again the particles are largely confined to Newark Bay although two particles have reached Lower Bay. The distribution after four complete tidal cycles is shown in Figure 8c. Nearly one-third of the particles have reached Lower Bay at this time, but thirteen are still in Newark Bay. It is particularly interesting to note the positions in Figure 8c of particle No. 15 and particle No. 16. The time interval between the release of No. 15 and No. 16 was only 23 minutes. After four tidal cycles particle No. 15 is in Newark Bay and No. 16 in in Lower Bay. This is a more dramatic example of the variability in trajectory which can result with only small changes in the time of release.

Some care must be exercised in interpreting the results of the very large spills such as those shown in Figures 8a, b and c. We have made no attempt to model the formation and spreading of a surface slick. Our results simply indicate where portions of a continuous slick should be found. It is probably misleading to pursue a determination of the particle locations beyond a few tidal cycles since the behavior of the very large surface slick must affect the movement of its various parts. It would appear that one of the most interesting features of the results for the large spill is the very long

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residence time for a significant part of the oil in Newark Bay.

A crude oil terminal for deep draft tankers could be located at either Stapleton on Staten Island or at Port Jersey. In Figures 9 and 10 we present the trajectories for a spill at the proposed facility at Stapleton at the time of slack water before flood and of slack water before ebb respectively. Similarly, Figures 11 and 12 show the trajectories for a spill at Port Jersey at both slacks at this site. The trajectories at both sites for a spill at the slack before flood are similar in character to that found for spills at the same slack at the Stapleton anchorage. It appears that the oil would leave the Harbor after nine tidal cycles for a spill at the slack water before flood at Stapleton while, for similar conditions for a spill at Port Jersey the oil will remain in the Harbor region for 12 tidal cycles. In like manner, the oil from a spill at slack water before ebb at Stapleton will clear the Harbor after five tidal cycles while the corresponding spill at Port Jersey will leave after about eight cycles.

The 2.8 million gallon, most credible worst spill with the facility, which is assumed to occur in the Ambrose Channel in Lower Bay was treated in an analogous manner to the large spill in the Kill van Kull. We again inject particles at the spill location at 23-minute intervals over a complete tidal cycle. The spill is assumed to start at the time of slack water before flood. The distribution of the thirty two particles after two cycles is shown in Figure 13a. The phase of the tide for this picture is slack water before flood at the spill location. In Figure 13b the distribution after $2\frac{1}{2}$ tidal cycles (at the slack before ebb) is presented and in Figure 13c the distribution after five complete cycles is given. In this last figure the thirteen particles lying along the southern boundary of the modelled domain in the ocean off Sandy Hook have, in fact, left the domain. It is important to recognize that these results suggest a southward drift of the large oil slick along the northern coastline of New Jersey.

All of the results presented thus far have been calculated in the absence of wind effect on the oil slick. In narrow or confined waterways such as the Arthur Kill, Kill van Kull, or Newark Bay the presence of wind likely will serve to increase the chance of beaching of an oil slick. The wind would not change significantly where the oil would be transported in the Kills or Newark Bay but it could force the slick to one side of the Kills or the other. Alternately, the wind could act to retard or to advance the movement of the slick through these waters. It is expected that the wind will exert its greatest influence on the oil trajectories in regions where it has sufficient room to act. This would be in Raritan Bay, Lower Bay and the ocean area outside of the Sandy Hook-Rockaway Point transect.

The average wind speed in the New York Harbor region is about 10 knots (5 meters/second). This speed would provide for the movement of a surface oil slick at the rate of 3% of 10 knots or 0.3 knots (0.15 m/s). Since one knot is one nautical mile per hour then a ten knot wind speed acting over one complete tidal cycle ($12\frac{1}{2}$ hours) would produce a displacement of the slick of about $3\frac{1}{2}$ miles in the direction towards which the wind is blowing.* Thus, it would only require about five tidal cycles for a west wind to move an oil spill from the mouth of the Arthur Kill through the entire length of Raritan Bay and then out of the Harbor through the Sandy Hook-Rockaway Point transect. A westerly wind will also serve to push the oil trajectories in Lower Bay towards the Brooklyn-Coney Island-Rockaway Point side of the Bay. A westerly wind would also tend to force the oil to move along the south shore of Long Island after it leaves the Harbor.

It should be apparent that a wide variability in possible trajectories can be presented for winds of varying strengths and directions. In the preceeding paragraph we confined attention to westerly winds. If we consider generally easterly winds some opposite effects will be obtained. An easterly wind will keep oil from a spill in the lower Arthur Kill, for example, confined to the western end of Raritan Bay. It would push oil moving through the Narrows region into Raritan Bay. The combination of weak tidal currents in Raritan Bay and an easterly wind would delay the flushing of this oil for a substantial length of time. Finally oil which clears the Harbor will be pushed onto the New Jersey coastline as a result of an easterly wind.

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*Wind directions are always reported as the direction <u>from</u> which the wind is blowing. The direction of slick travel is reported as the direction <u>towards</u> which the slick is moving. Thus a west wind will produce an easterly drift of the oil slick.

Since the major effects of winds can be readily deduced without extensive computation and in view of the large number of wind scenarios which could be developed we have not included the effects of wind in the computations of trajectories for most of the previously discussed spills. We were particularly interested, however, to determine what a moderate wind would do to the oil slick from a spill at slack water before ebb at the Chevron pier. Without wind this slick never moved more than about one mile into the western end of Raritan Bay (see Figure 5). To investigate the effect of wind on this slick we imposed a southwest wind of 10 knots for this spill. The result of this imposed wind was to force the oil to move slowly along the south shore of Staten Island until it became trapped in Great Kills Harbor. The computed trajectory is presented in Figure 14.

4. DISCUSSION OF RESULTS

There are three important features of the results obtained for oil spill scenarios for the present practice of crude oil delivery. The first is the somewhat unexpected sensitivity of the trajectories to the time of the spill relative to the phase of the tide. The second is the lack of net transport of oil from the western end of Raritan Bay in the absence of wind. Finally, for the most credible worst case, it was of interest to determine that the spill would be contained in Newark Bay for several tidal cycles.

Upon serious reflection on the current conditions expected throughout the Harbor it is not entirely surprising that the trajectories would vary with the time of spill. The phase differences in the tidal currents at various locations throughout the Harbor are substantial. For example, slack water in the Kill van Kull occurs nearly simultaneously with maximum current speeds in Upper Bay. Another example is at the entrance to Newark Bay where slack water on the Kill van Kull side occurs about one hour earlier than slack water on the Arthur Kill side of the Bay entrance. Such remarkable differences in tidal current conditions over short distances may lead to substantial differences in a particle's trajectory depending on the precise timing of its arrival at various points along its path.

The sluggish net circulation in the western end of Raritan Bay is not surprising. Ayers et.al. (1949) provide an estimated net movement of between 1/4 and 1/2 mile each day. For these rates the time required for a particle at the western end to move out of Raritan Bay is between 20 and 40 days. It should be evident that with such long residence times there could be a succession of wind events to either accelerate or impede the passage of oil through this Bay.

Our procedure for the initial tracking of the worst case spills was not intended to provide detailed predictions of all regions where the slick could be encountered but to illustrate in general terms where the oil would be initially carried by the currents. The apparent delay in the departure from Newark Bay of the oil from the projected catastrophic spill could be useful to attempts to contain and remove this oil.

The deepening of Ambrose Channel from 45 to 60 feet did not change significantly the currents in the Harbor. The only region where a detectable but hardly significant change could be found was along the Ambrose Channel in Lower Bay. This small change in current speed could be attributed to the minor change in cross-sectional area which would result from the deepening of Ambrose Channel, i.e. if the volume flux entering or leaving the Harbor with the tide remains nearly the same, then an increased cross-sectional area should lead to slightly reduced tidal currents at, for example, the Sandy Hook-Rockaway Point transect.

The spills which can be anticipated at a crude oil receiving facility at Stapleton or at Port Jersey lead to trajectory predictions similar to those found for a spill from Staplton anchorage. The time for a spill to leave the Harbor is one or two days longer for the Port Jersey site which would be expected since it is located farther upstream and in a region of weaker currents than those encountered at Stapleton. The most credible worse case with the establishment of the facility (the 2.8 million gallon spill in the Ambrose Channel) produced a distribution of oil which remained confined to Lower Bay until it began to move out of the Harbor and down the New Jersey Coast after just a few tidal cycles. It seems clear that the action of the tidal currents will prevent this spill from intruding into most of the Harbor region but this large mass of oil would pose a hazard to the coastal zone of New Jersey. Alternatively, appropriately directed winds could force this oil to move eastward along the south shore of Long Island. In either case, this particular catastrophic spill is likely to impact, in a substantial manner, waters which are extensively used for recreation and for sport and commercial fishing.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on our computer simulations for the scenarios described in Section 2, we have provided answers to the question, "Where will the spills go?" This information now may be used in an assessment of the effects of these spills on marine life in the New York Harbor region.

Trajectories of surface oil slicks resulting from moderately small oil spills at Stapleton anchorage, the Exxon and Chevron refinery piers, and the proposed crude oil receiving facility at either Stapleton or Port Jersey have been calculated. The effect of tidal currents is to move the oil for all but one of the possible spill scenarios through the Harbor and then to discharge it into the ocean in elapsed times ranging from three to eight days. It is only for spills at the Chevron pier at times close to that of slack water before ebb that the tidal currents are ineffective in flushing the oil out through Raritan Bay. We can find no significant differences in where oil will be carried from the modest-size, annually expected spills whether there is or is not a facility established. Wind can serve to alter the trajectories of these spills but it would act in the same manner on spills from either a new facility or from the present anchorage and refinery piers.

The catastrophic spill scenario for the present marine delivery system for crude oil would produce a surface slick which remains in Newark Bay and the Kill van Kull for one to two days. With the facility in place the projected catastrophic spill is in Ambrose Channel in Lower Bay. In the absence of wind the oil from this large spill begins to move south down the New Jersey ocean coastline after just one or two days. Southwesterly winds could just as readily push this oil onto the south shore of Long Island. We must conclude that this very large spill poses a threat to the recreationally important coastal waters of both New Jersey and Long Island. It should be noted that the liklihood of large spills should be less with a crude oil receiving facility than with the present practice.

The calculation of trajectories in this study relied heavily on the use of an available tidal hydraulics model of the Harbor region. This model represents just an initial phase in an ongoing development of a far more complete model of circulation in the Harbor. It is anticipated that in the near future we could use this more complete model to predict the following quantities:

1. The combined velocity field which results from the tides, the estuarine circulation and the wind.

2. The trajectory and <u>spread</u> of a surface oil slick.

3. The trajectory of spill products contained in the water column. For this we could include the effects of horizontal advection, horizontal diffusion and vertical diffusion.

In order to make a full assessment of the impact of a crude oil facility we would recommend that this complete model be employed to determine spill trajectories for a reasonable range of environmental conditions. We would include a consideration of spills at all phases of a tidal cycle. We would allow for the actual variability in tidal range and, therefore, in tidal current amplitude. We could account for variability in the circulation resulting from changes in the fresh-water discharge through the estuary. Finally, we could include wind effects i.e. we could model some typical variations in wind speeds and directions over one or two week periods. A sufficient number of cases would be needed to allow for a reasonable assessment of environmental impact. We could also expand the modelled domain to include the ocean waters off the Long Island and the New Jersey shorelines. What we have accomplished in this report is a preliminary study of oil spill trajectories. What we are proposing in this further study would be a comprehensive, exhaustive and thorough investigation of oil spill movement through the Harbor and adjacent coastal ocean regions. An undertaking such as that sketched above would require a <u>substantial</u> investment.

6. PROCEDURE FOR CALCULATION OF TRAJECTORIES

The surface slick which forms when oil is spilled on water will be transported by the near surface velocity field in the water. If the velocity distribution in space and in time is specified then the path followed by the slick is readily determined from the appropriate time integration of this velocity field. Thus, the chief problem of finding the oil slick trajectories is that of determining the detailed near surface velocity distribution. In the waters comprising the New York Harbor region, this velocity distribution results from a combination of the tides, the characteristic estuarine circulation, and the wind.

The tidal variation in sea surface elevation at the ocean boundaries of the Harbor, i.e., along the line from Sandy Hook to Rockaway Point and at the Long Island Sound end of the East River, give rise to tides and tidal currents throughout the region. In fact tides propagate over the entire length of the Hudson River to the Federal Dam at Troy, New York. Correct to a first approximation* the tidal currents may be considered to be constant over depth although they vary in time and with horizontal position. Thus, if x and y are taken as horizontal position co-ordinates, z is in the vertical direction and t is time then the tidal velocity field, $\vec{V}_T$ may be expressed as a function of only x, y, and t i.e.,

$$\vec{V}_T = \vec{V}_T\ (x,y,t).$$

In a very general way, one associates the tidal currents with an oscillatory (or reversing ebb and flood) flow. Depending on the phase relationship between the stage of the tide and the currents and depending on the specific geometry of the harbor basin, the oscillatory tidal currents can lead to "net" circulation patterns and to "net" exchanges of water

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* The bottom boundary layer, where the velocity must decrease to zero at the boundary, is assumed, solely for the purpose of these introductory remarks, to be of no importance.

between different parts of the harbor. The term "net" used in the preceding sentence refers to the residual current which would be found after averaging the tidal current velocity over one or more complete tidal cycles.

The estuarine circulation which arises from the upstream inflow of fresh water and the intrusion of sea water from the downstream end of the estuary represents a second contribution to the net circulation. In a typical partially mixed estuary, of which New York Harbor is an example, there is a net downstream flux of a mixture of fresh and salt water in the near-surface layer. In the near-bottom layer there is a net upstream flow of higher salinity water. The energy for the vertical mixing between the upper, less salty, and lower, higher salinity, layers is provided by the tides. Far more complete descriptions of estuaries and their characteristic circulations can be found in recent books by Dyer (1973) and Officer (1976). The significance of the nature of the estuarine circulation in New York Harbor for the present purpose is that it leads to important variations with depth of the velocity field. If the estuarine circulation contribution to the actual velocity field is denoted by $\vec{V}_E$ then we expect that

$$\vec{V}_E = \vec{V}_E\,(x, y, z, t).$$

It should be noted that in our calculation of the trajectory of a surface oil slick we must take into account the combined effect of the tidal current and the estuarine velocity at the water surface i.e. we must consider the vector sum of $\vec{V}_T = \vec{V}_T\,(x,y,t)$ and $\vec{V}_E = \vec{V}_E\,(x,y,z{=}o,t)$

The effects of winds on the circulation in an estuary are complex. The direct effect of the wind is to cause the near surface layers to move in the direction* of the applied wind stress. An often used rule of thumb

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* In deep, unstratified water Ekman (1905) showed that the surface current should be directed at angles up to 45^{o} to the right of the wind. For typical water depths in New York Harbor (10m. or less) we expect the wind induced current to be co-directional with the wind.

is that a surface oil slick will be transported with a velocity vector co-directional with the wind and at a speed equal to 3% of the wind speed. The wind speed is taken as that which would be measured at a height of 10m. above the sea surface. The less direct effect of applied wind stress distributions is to set up variations in sea surface elevation which may lead to substantial alterations in the overall circulation patterns.

Our procedure for determining the velocity distribution in the New York Harbor waters was centered on the availability for our use of a numerical model for the tidal hydraulics. This model has been developed for the Harbor by the authors of this report as one stage in an overall program supported by the New Jersey Sea Grant program to produce a fully three dimensional, time dependent model of the circulation and salinity distributions in these waters. The comprehensive model when adapted to New York Harbor will provide predictions of the combined effects of the tides, the estuarine circulation and the wind-induced currents. The tidal hydraulics model predicts the distributions of the vertically integrated current and the surface elevation. The complete numerical model was originally described by Blumberg and Mellor (1978). The following description of the application of the tidal hydraulics model to the Harbor is based on a report presently in preparation by Oey, Mellor and Hires.

The underlying mathematical equations for the model express the conservation of momentum (Newton's second law for a fluid) in the two horizontal (x,y) directions and the conservation of mass. The water is assumed to have a constant density. The three equations (two component equations for momentum and one for mass) are integrated over depth from the bottom $z = -h\ (x,y)$ to the surface $z = \eta\,(x,y,t)$; where $h = h(x,y)$ indicates that the water depth relative to mean sea level, $z = 0$, is allowed to vary with horizontal position; and where $\eta = \eta\ (x,y,t)$ represents the tidal variation in sea surface elevation about mean sea level. The effects of the constant density assumption together with the vertical integration serves to allow the pressure gradient force in the momentum equations to be written solely in terms of derivatives of η . The vertical integration reduces the complexity of the frictional terms in the momentum equations by requiring only specification of the surface and bottom stresses. The surface stresses would be the applied wind stress. The bottom stresses (τ_x, τ_y) are related to depth-averaged velocity field (U_T, V_T) by

$$\tau_x = k\,U_T\,(U_T^2 + V_T^2)^{\frac{1}{2}}, \quad \tau_y = k\,V_T\,(U_T^2 + V_T^2)^{-\frac{1}{2}}$$

where k is a friction coefficent. We assume a typical value of $k = 2.5 \times 10^{-}$ In the absence of wind and with k specified we arrive at a set of three partial differential equations for three dependent variables, namely; the surface elevation η, and the depth-averaged velocity components U_T and V_T. No further simplification of the equations than that listed above has been made i.e., we retain the coriolis force, arising from the earth's rotation, and the non-linear advective terms in the momentum equations. The required boundary conditions for solving the set of equations are the spatial and time variations in the sea surface elevation along open (water) boundaries of the modelled region and that the velocity component perpendicular to land boundaries must be zero at the shoreline.

The partial differential equations are solved by first formulating the appropriate finite difference analogues for these equations. The modelled region of the harbor is covered by a rectangular, 65 x 65, grid with horizontal spacing (Δx or Δy) of 0.53 km. For numerical stability the time step for the calculations, ΔT, is taken as 15 seconds. For each grid interval values of U_T, V_T and η are calculated. Thus, we solve three equations at 4225 locations at about 3000 time steps for a typical tidal period. For the computer, it is a more efficient procedure to carry out calculations at all grid points whether over land or over water and then at a subsequent stage specify whether there is land or water at each location. An innovative aspect of our model is that we have extended the modelled region to include major portions of the Hudson, Raritan, Passaic, Hackensack and East

Rivers. These rivers are represented as one-dimensional extensions from the Harbor region, which means we compute just cross-sectionally averaged velocities in these rivers. The representation of these rivers does preserve, however, their correct cross-sectional areas and average depths. The rivers are placed within the rectangular, 65 x 65, computational grid at locations which are land areas in the Harbor region. The complete computational domain is shown in Figure 15. Jamaica Bay has also been included in the computational grid in a similar fashion. The major advantage of extending the modelled region to include contiguous rivers and bays is that it places less emphasis on the <u>exact</u> specification of boundary conditions which, without the extensions, would be required at the points where these water ways intersect the Harbor region.

The tidal hydraulics model has been shown to predict the characteristics of the tide (surface elevations) and the tidal currents in New York Harbor with a high degree of accuracy. The National Ocean Survey (NOS), Tide Tables provide information on the average range* of the tide and on time differences in the times of occurrence of high and low water at many points throughout the Harbor region. In Figure 16 values of the average tidal range observed at various locations within the Harbor are plotted against computed values obtained when the model is subjected to the average tidal range at the ocean boundary. The tight clustering of plotted points about an ideal 45° line, which would represent an exact simulation, demonstrates the model accuracy. Similarly good correlations are found between predicted and observed time differences for the occurrence of high and low water.

Comparisons of predicted and observed tidal currents show similarly good agreement. The most comprehensive observations of currents in New York Harbor have been collected by the National Ocean Survey during the 1950's. These observations have been reduced to consistent tidal

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* Tidal range is defined as the difference in elevation between one high (or low) water and the next low (or high) water. In New York Harbor, tidal range varies from one tidal cycle to the next and more significantly over a two-week cycle of low (neap) and then large (spring) ranges. We shall confine our attention to average tidal conditions in the Harbor.

conditions* and are presented in graphical and tabular form in the eighth edition of the NOS Tidal Current Charts of New York Harbor. At a majority of the NOS current observation stations currents were measured at three depths; near surface, mid-depth and near bottom. From the graphical and tabulated data available in the tidal current charts it has been possible to find depth-averaged values of currents at 13 stages of an average tidal cycle. These depth-averaged current vectors derived from observations are compared in Figures 17 and 18 in a side-by-side manner with the predicted vectors at the time of maximum ebb and maximum flood currents at the Narrows. In each figure the current vectors are shown at each grid point for the model output and at each current meter station for the NOS data. The agreement in current direction and in relative magnitudes is excellent. Detailed comparisons at particular points of the predicted and observed variation of currents over a complete tidal cycle revealed excellent agreement in magnitude and phase in the Lower Hudson, in Upper Bay and in most of Lower Bay. Good agreement was obtained in Raritan Bay and in Newark Bay while in the Kills the agreement was only fair. We believe the difficulty in the Arthur Kill was the result of our not adequately accounting for the volume flux of water through the extensive marsh areas along the northern half of this waterway. At the present time we are in the process of resolving this diffculty in the model. For the oil trajectory predictions, however, we "corrected" the model predictions in the Kills to insure excellent agreement with observations since there was insufficient time to develop the model to include the effects of the marsh areas. Thus, the tidal hydraulics model gives very accurate predictions of the tidal current component of the total velocity field at extremely high resolutions spatially and in time. The predicted velocity field from this model for an average tide forms the basic data set for the calculation of oil spill trajectories.

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* The current data is presented as <u>if it were</u> obtained simultaneously at all stations at thirteen stages of a typical tidal cycle. The actual data were obtained sequentially in 1952 and in 1958-59.

The contribution of the estuarine circulation to the actual velocity distribution could have been predicted if the complete three-dimensional model of the Harbor region were further along in its development. For the present purposes, however, it was necessary to adapt results of observations in order to account for the vertical variability in currents which arises from the estuarine circulation. Again, the compilation of NOS current data summarized in the Tidal Current Charts provided sufficient information to "correct" the tidal hydraulics model results to give predictions of <u>surface</u> rather than depth-averaged currents. The procedure was to find the averaged-over-a-tidal cycle difference between the near surface NOS current observations and the calculated depth-averaged values of the NOS data. This tidal-averaged difference was found to be generally greater than 0.5 knot (0.25 m/s) and directed seaward along the deep channels through Upper and Lower Bay. These corrections reflect our expectation that the surface currents will be stronger on the ebb and weaker on the flood than the depth-averaged currents. The corrections throughout most of the remainder of the Harbor region are less than 0.2 knots (0.1 m/s).

Once the tidal-averaged differences between surface and depth-averaged currents were found for the sixty-five available NOS current stations it was necessary to apply the correction to every computational grid point. An interpolation scheme was devised which maintained the exact value of the correction at each cell which contained an NOS station, and allowed for a smooth variation at intervening grid locations. The procedure we adopted treated the velocity corrections as if they were diffusing from the various points where their values were held constant. In fact, the interpolation scheme was based on repeated application of a finite difference analogue of the diffusion equation, i.e.,

$$\frac{\partial \phi}{\partial t} = K\left(\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2}\right) \qquad (1)$$

where Ø is a measure of the quantity being diffused. For our application, Ø becomes a velocity component correction and the finite difference analogue of equation 1 is integrated over a sufficient numer of time steps to achieve the final steady state distribution.

The effect of wind on a surface oil slick is usually modelled by assuming that the slick will move in the direction towards which the wind is blowing at a speed of 3% of the wind speed at anemometer height. Although the effect of an applied wind stress can be directly incorporated in the tidal hydraulics model, for the present purpose it was considered sufficient to apply this simpler "3% rule". The wind induced velocity is then simply added vectorially to the tidal and estuarine components.

Once the velocity field is completely specified, the computation of the trajectory of an introduced particle is relatively straightforward. It is assumed that the velocity field at an instant of time will vary linearly over the extent of each computational grid space (with dimensions of 530 meters on a side at prototype scale), i.e., the velocity at each grid interval was assumed to be the value at the center of the cell, and further, the velocity was assumed to vary linearly from one grid center to the next. A time increment of 1.25 minutes was chosen for computation of the trajectory. Longer time increments were found to lead in some instances to "grounding" of the particles, which means that the incremental change in location, $\Delta\vec{r}$, in the time interval Δt could be sufficient to cause the particle to cross a land-water boundary. Once a particle is displaced from the fluid domain of the model it is in a region of no velocity, and remains stationary at that location. For smaller time increments, the requirement that the velocity component perpendicular to a land boundary must vanish at that boundary is sufficient to avoid "groundings". At a particular time, t_o, we take the particle's position to be given by the co-ordinates x_o, y_o; the velocity at this point has components, u_o, v_o, and by using values of the velocity components, in adjacent computational cells we can find approximate values for the velocity gradients, $\partial u_o/\partial x$ and $\partial v_o/\partial y$. With the foregoing established at the time, t_o, we can find the particle position; x, y, at time $t + \Delta t$ from the following equations:

$$x = x_o + u_o \Delta t + u_o(\partial u_o/\partial x)(\Delta t)^2; \quad y = y_o + v_o \Delta t + v_o(\partial v_o/\partial y)(\Delta t)^2.$$

This procedure can be repeated until either the particle has reached a boundary of the modelled domain or the specified time limit for following the particle is exceeded.

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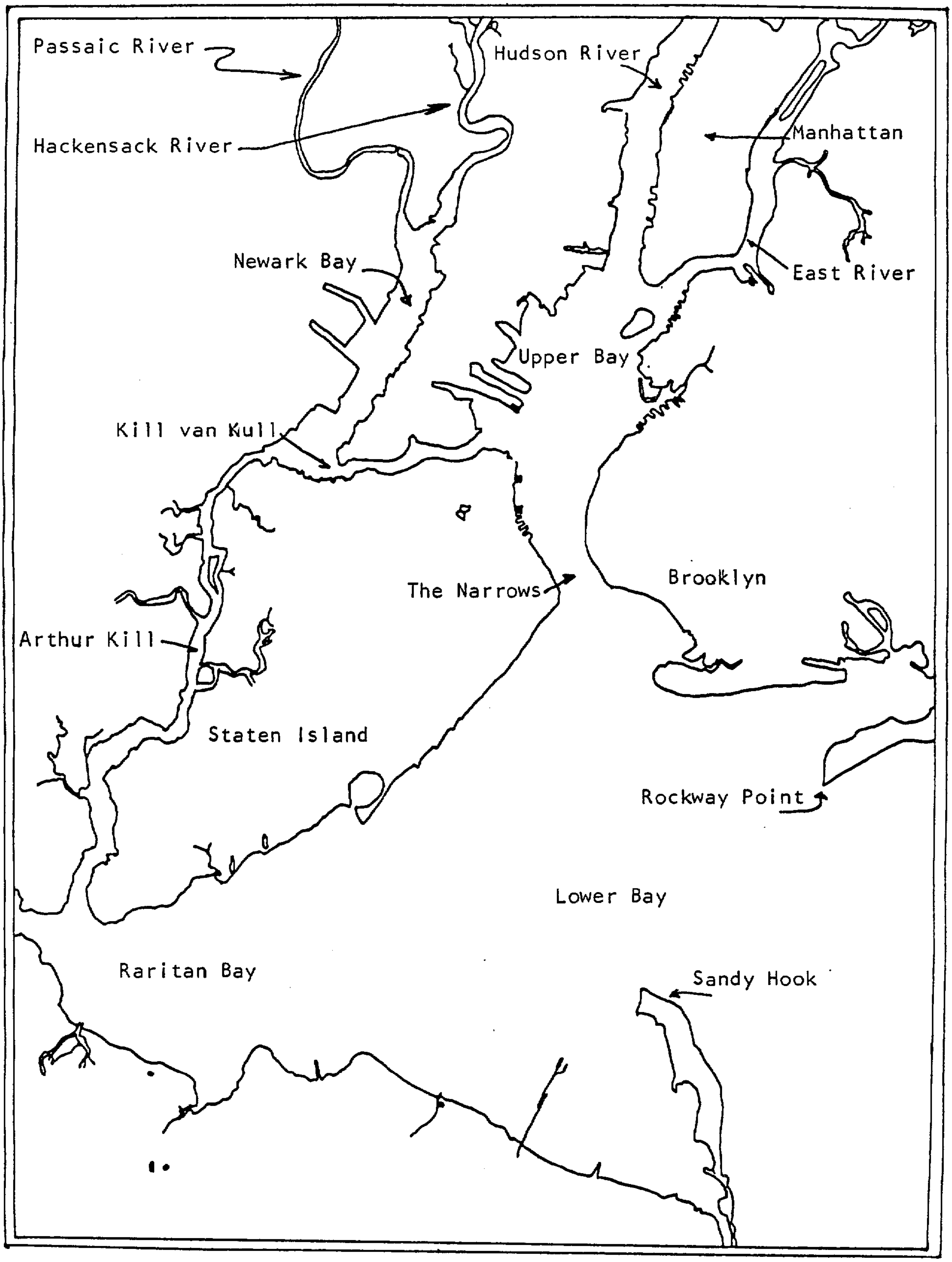

Figure 1a. Location map for New York Harbor region.

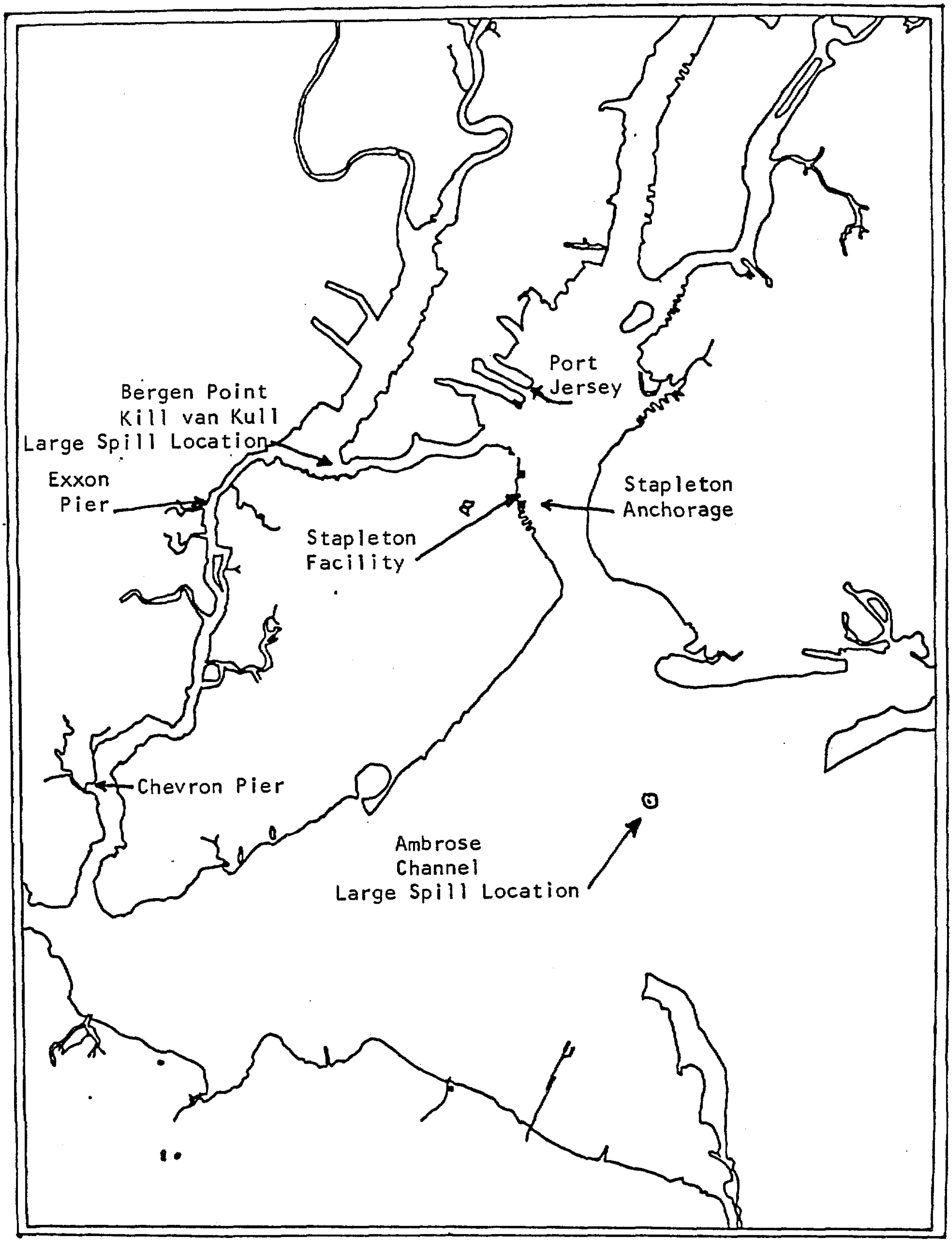

Figure 1b: Map of possible oil spill locations.

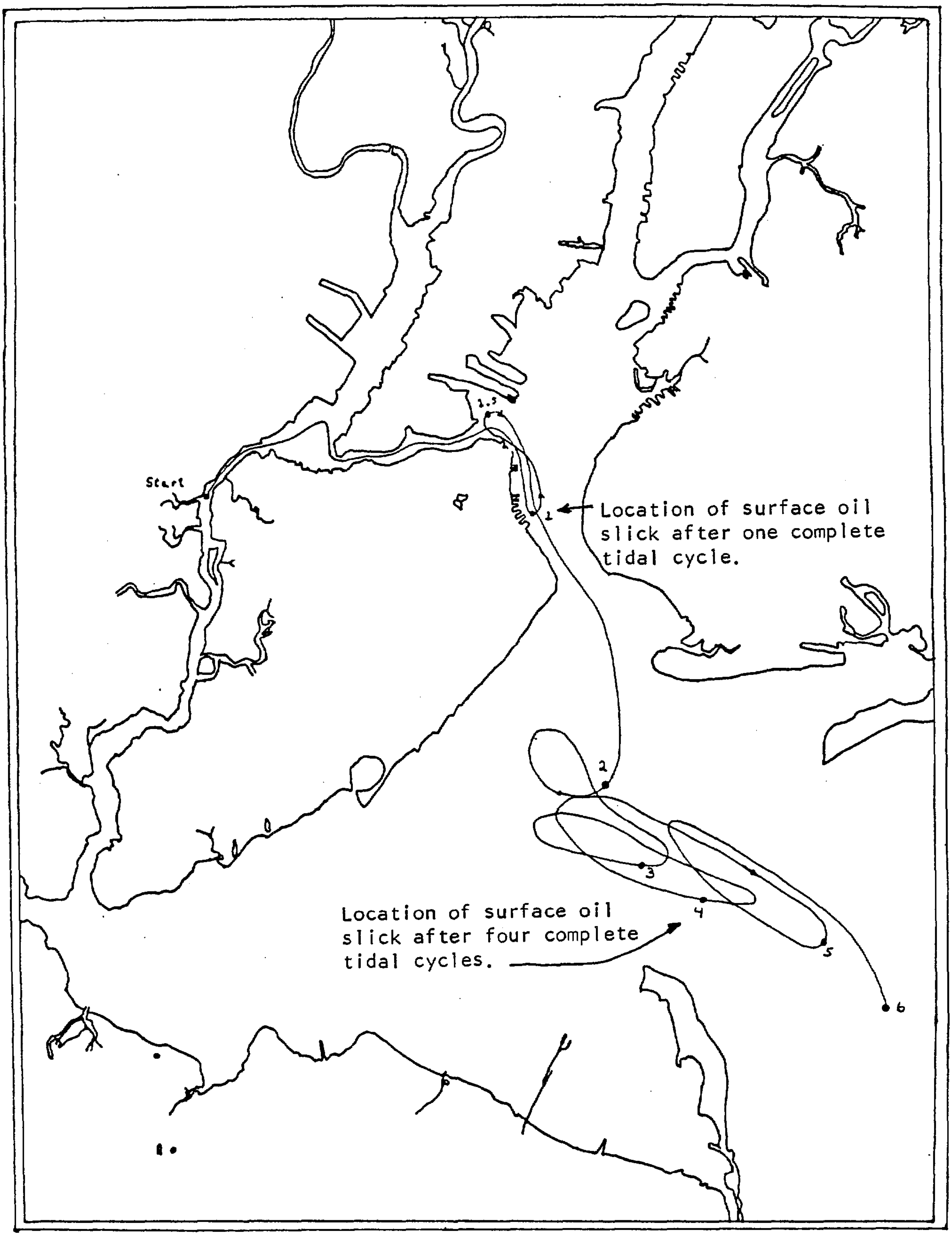

Figure 2. The predicted trajectory for an oil spill at the Exxon refinery pier at slack water before flood.

Figure 3. The predicted trajectory for an oil spill at the Exxon refinery pier at slack water before ebb.

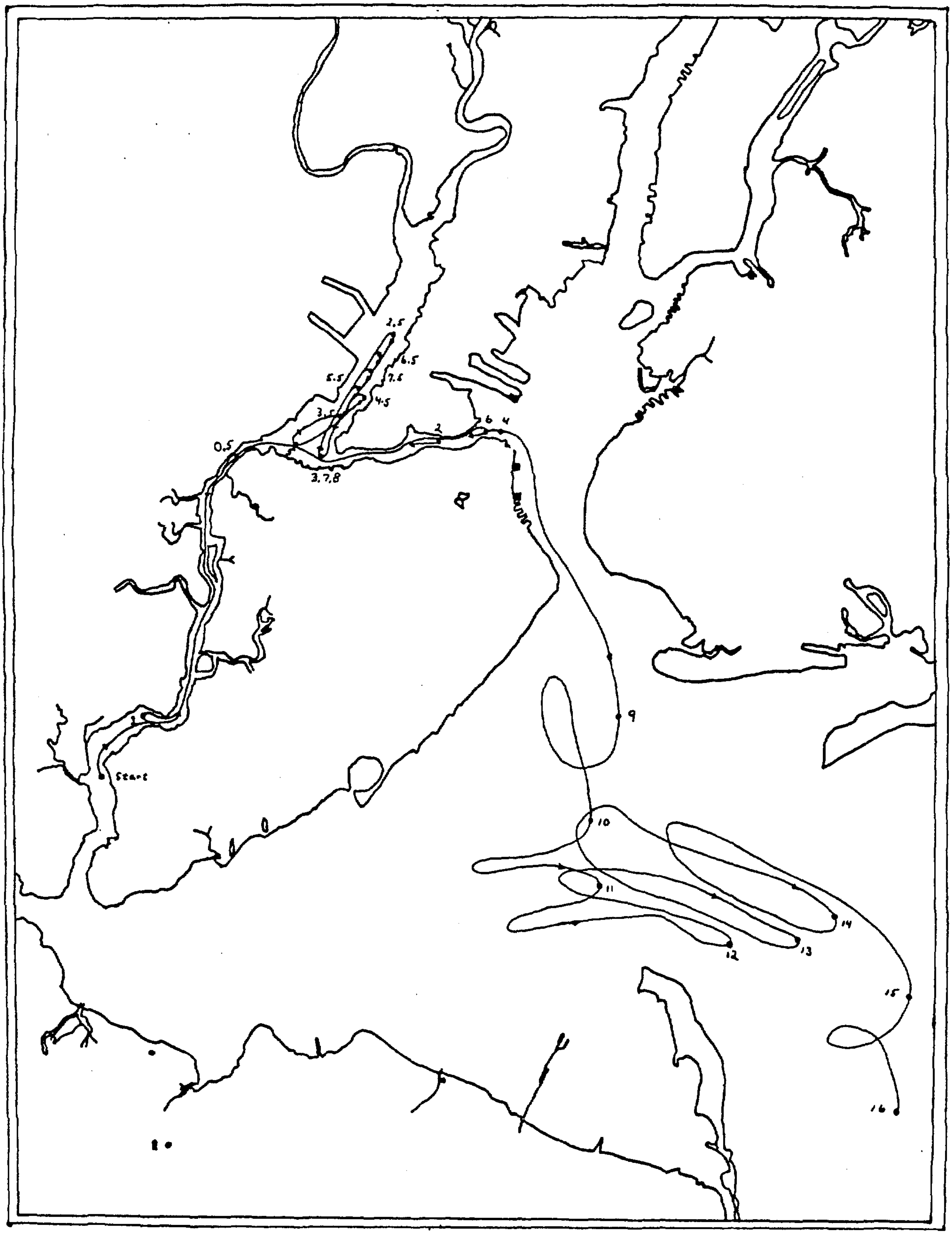

Figure 4. The predicted trajectory for an oil spill at the Chevron refinery pier at slack water before flood.

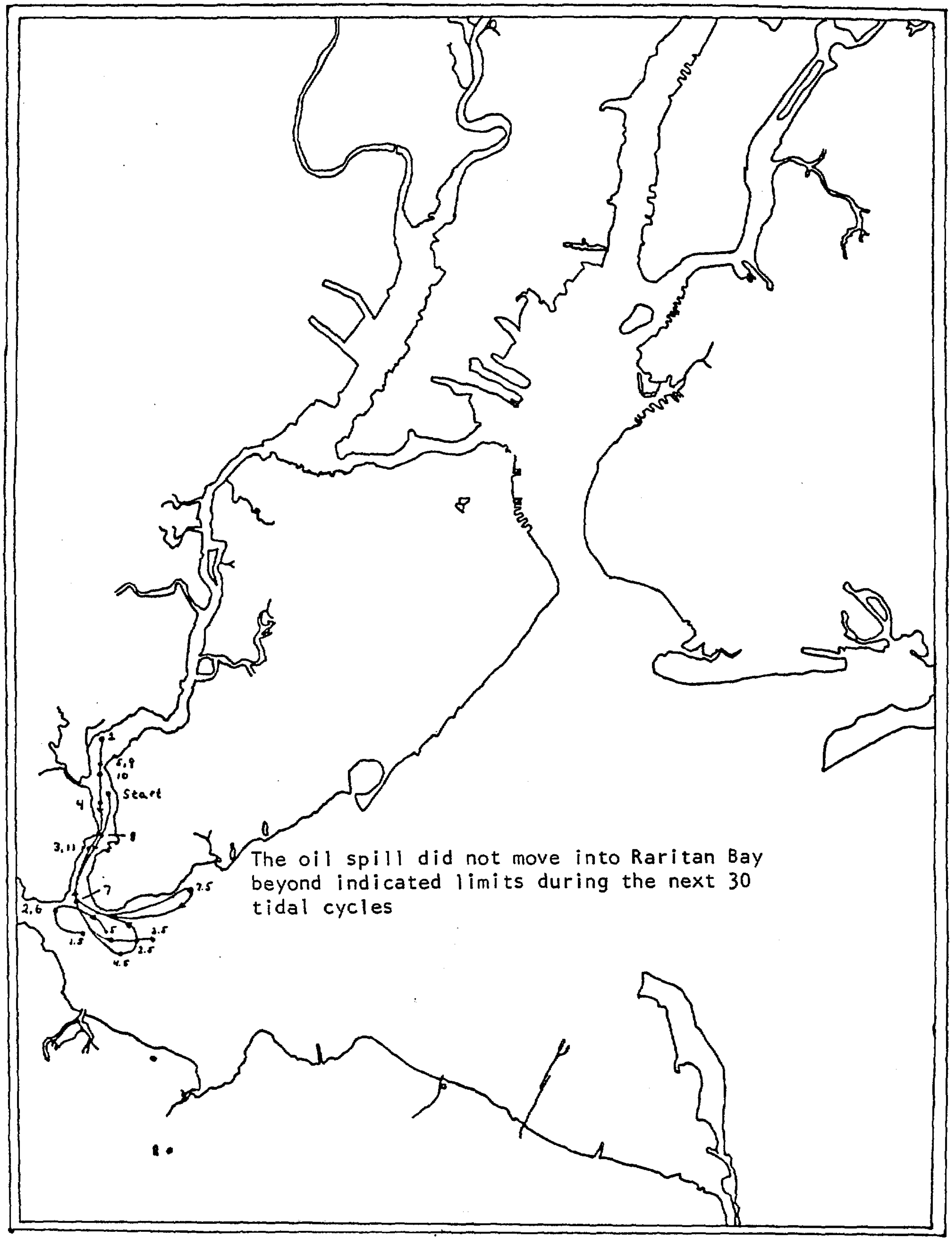

Figure 5: The predicted trajectory for an oil spill at the Chevron refinery pier at slack water before ebb

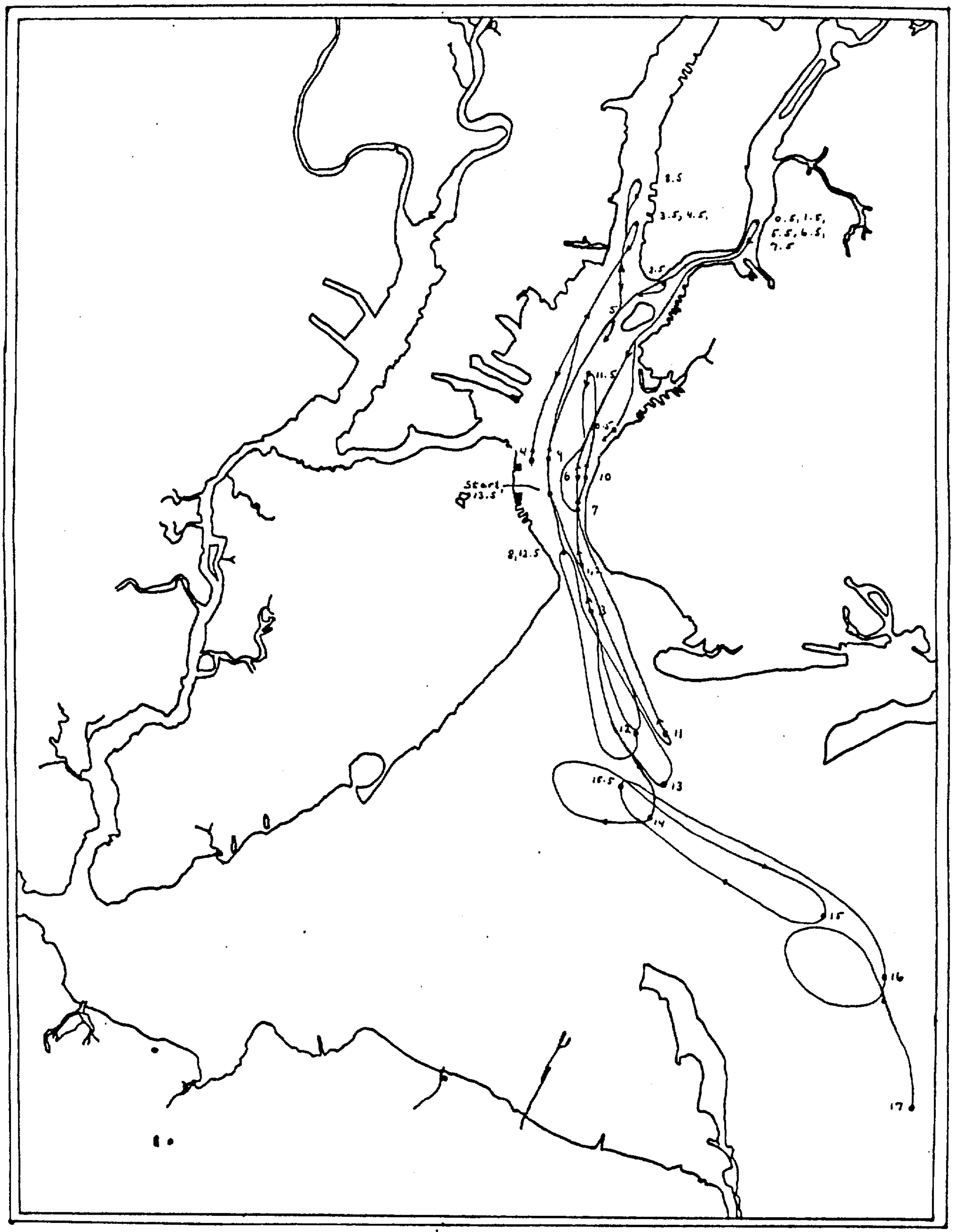

Figure 6: The predicted trajectory for an oil spill at the Stapleton Anchorage at slack water before flood.

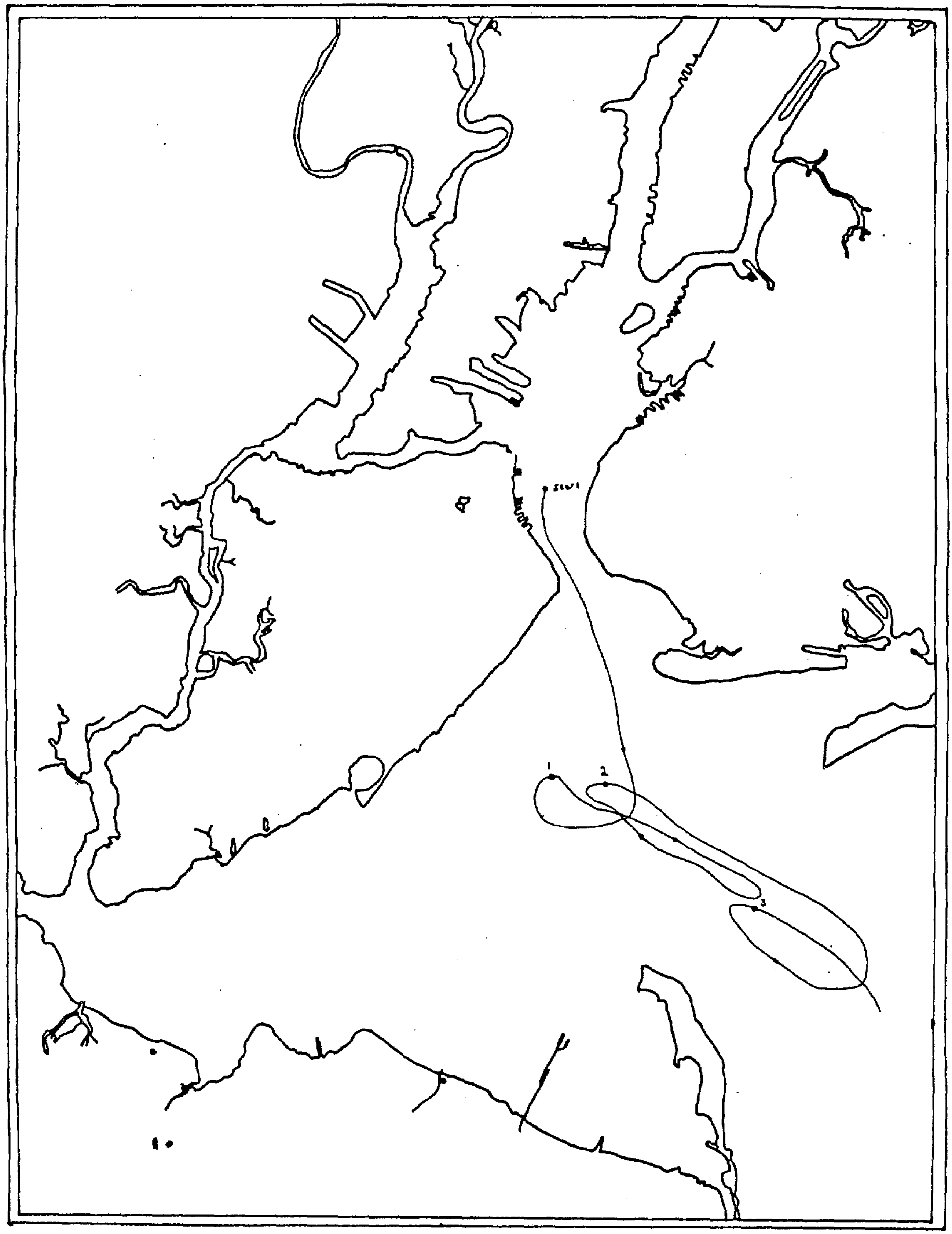

Figure 7. The predicted trajectory for an oil spill at the Stapleton Anchorage at slack water before ebb.

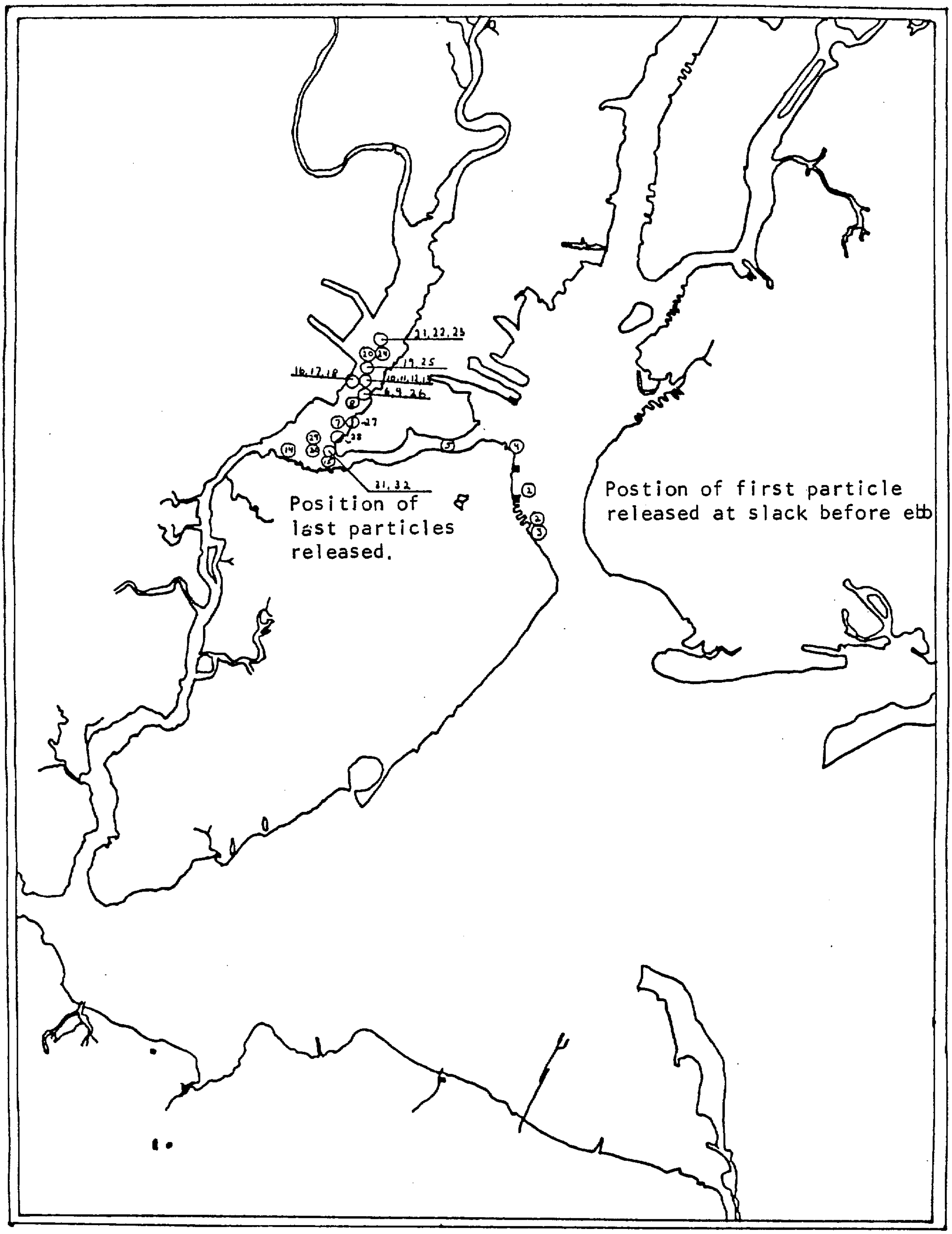

Figure 8a: The distribution of a continuous release of oil in the Kill van Kull at the end of one tidal cycle.

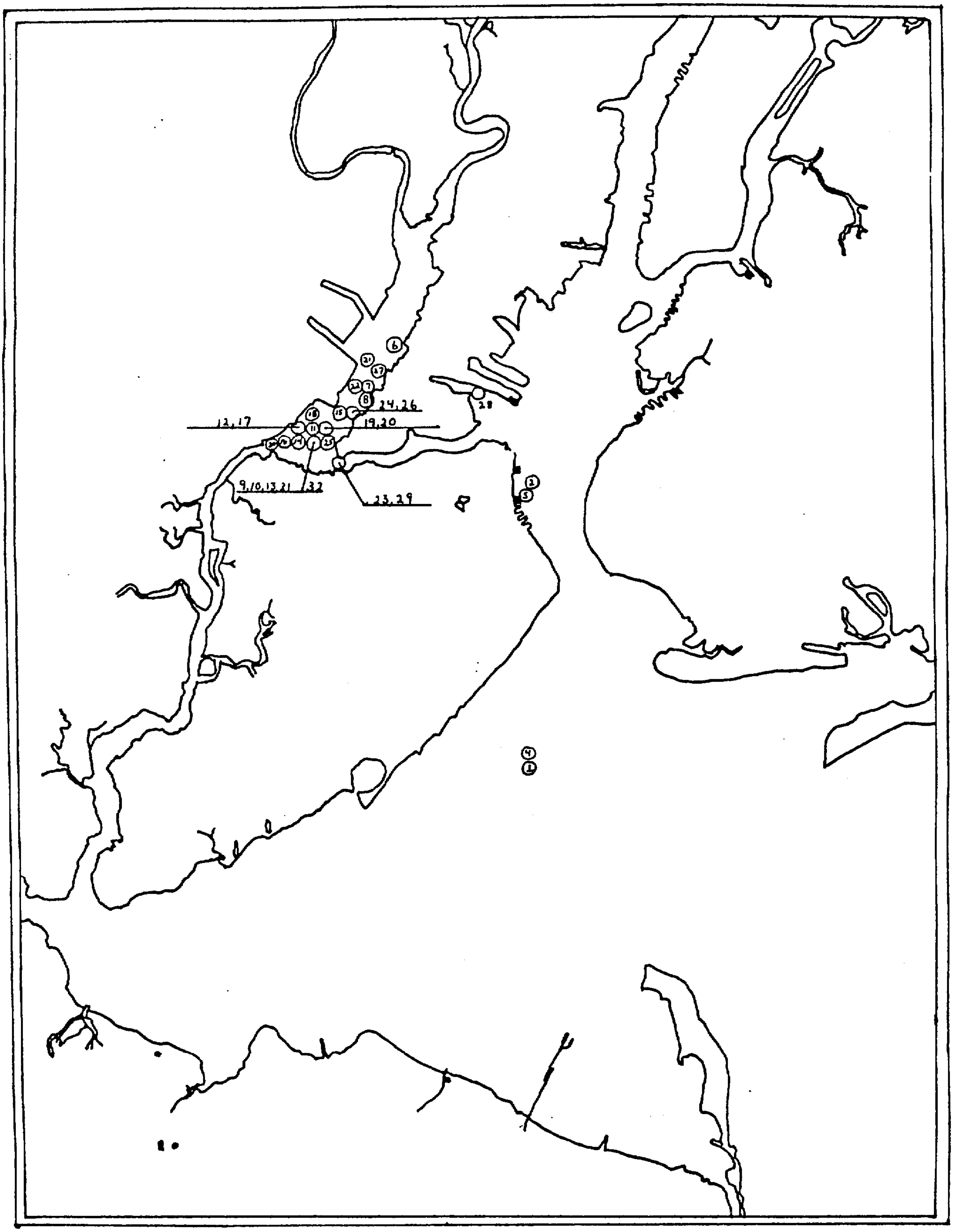

Figure 8b: The distribution of oil after two tidal cycles.

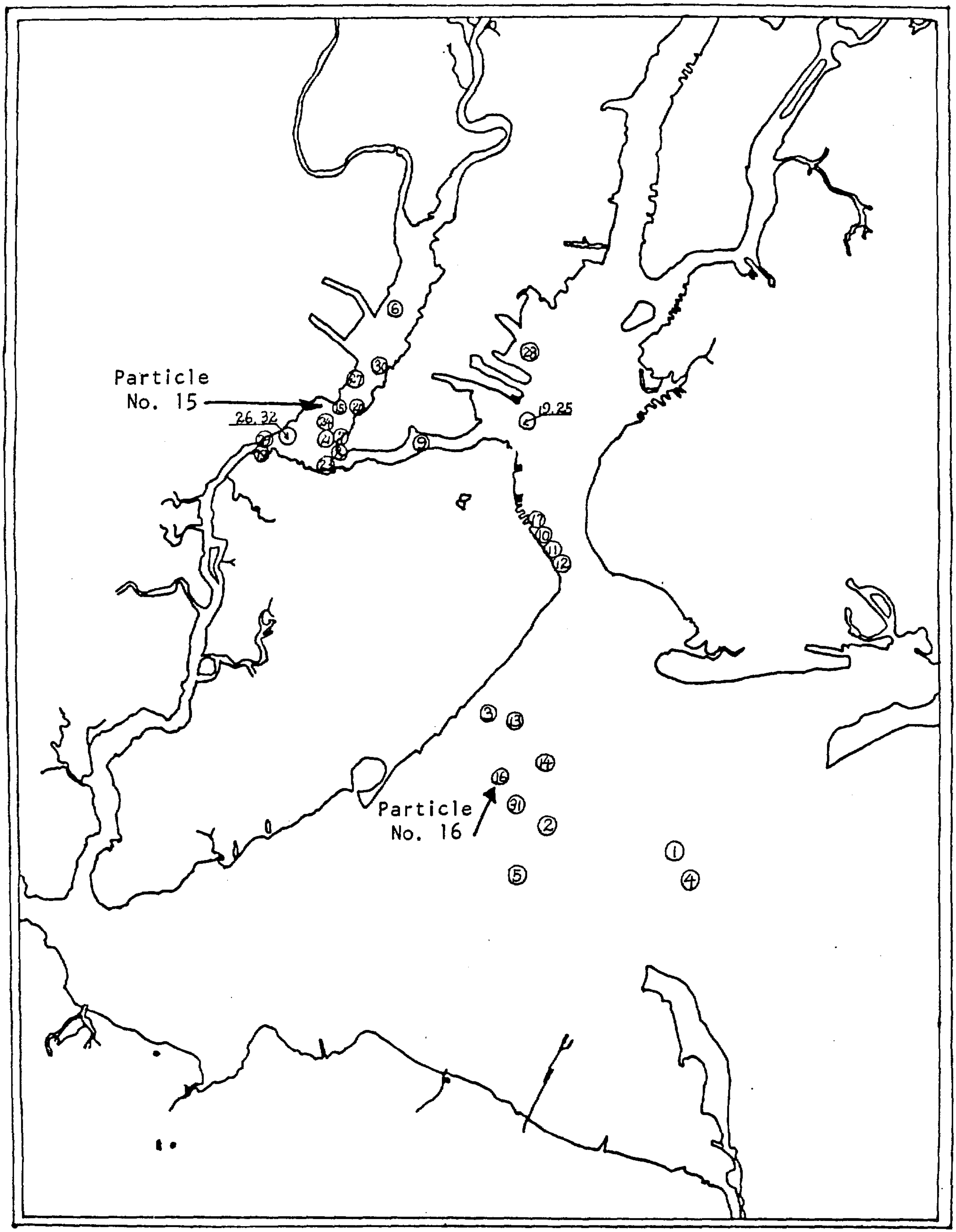

Figure 8c: The distribution of oil after four tidal cycles.

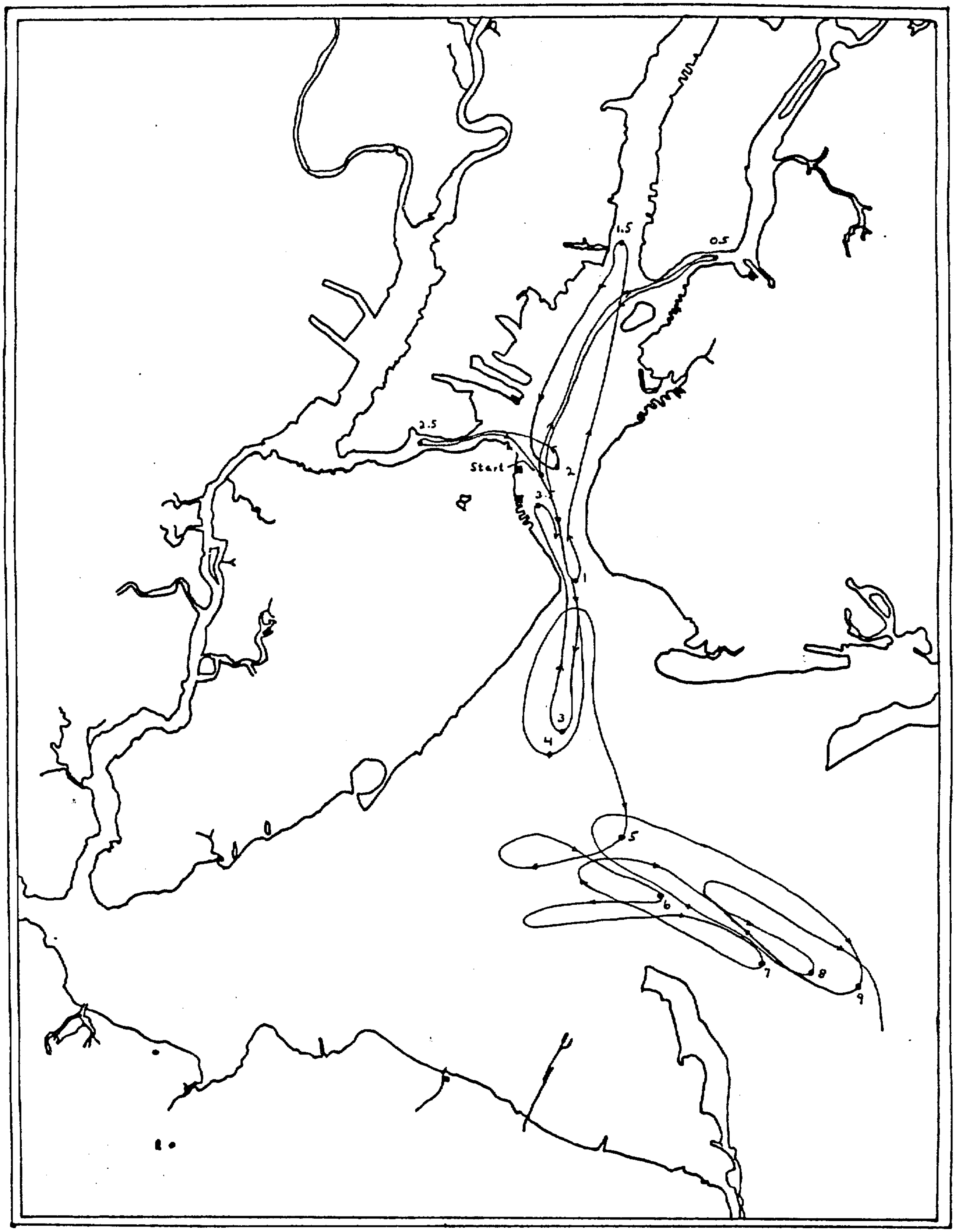

Figure 9: The predicted trajectory for an oil spill at a crudé oil handling facility at Stapleton at slack water before flood.

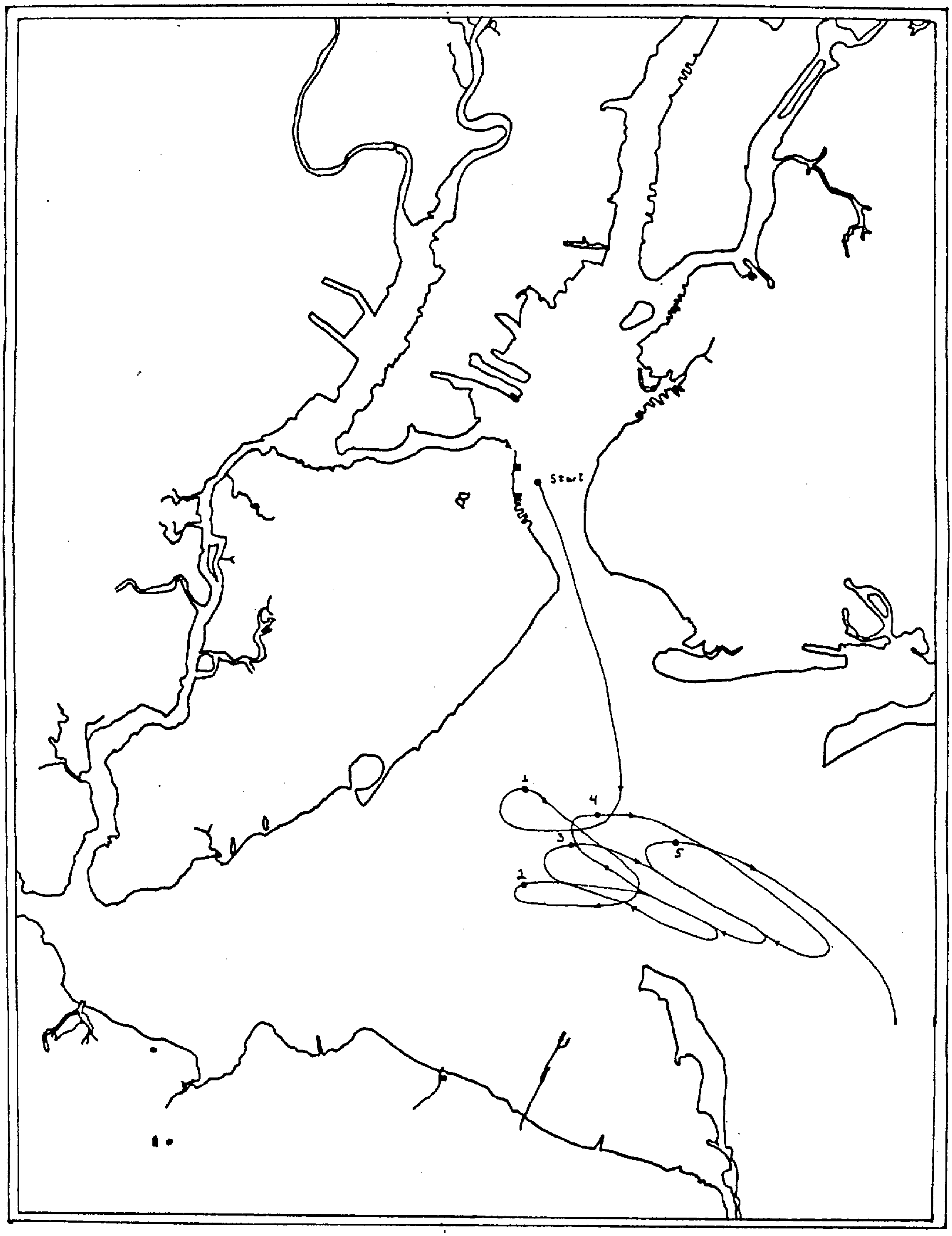

Figure 10: The predicted trajectory for an oil spill at a crude oil handling facility at Stapleton at slack water before ebb.

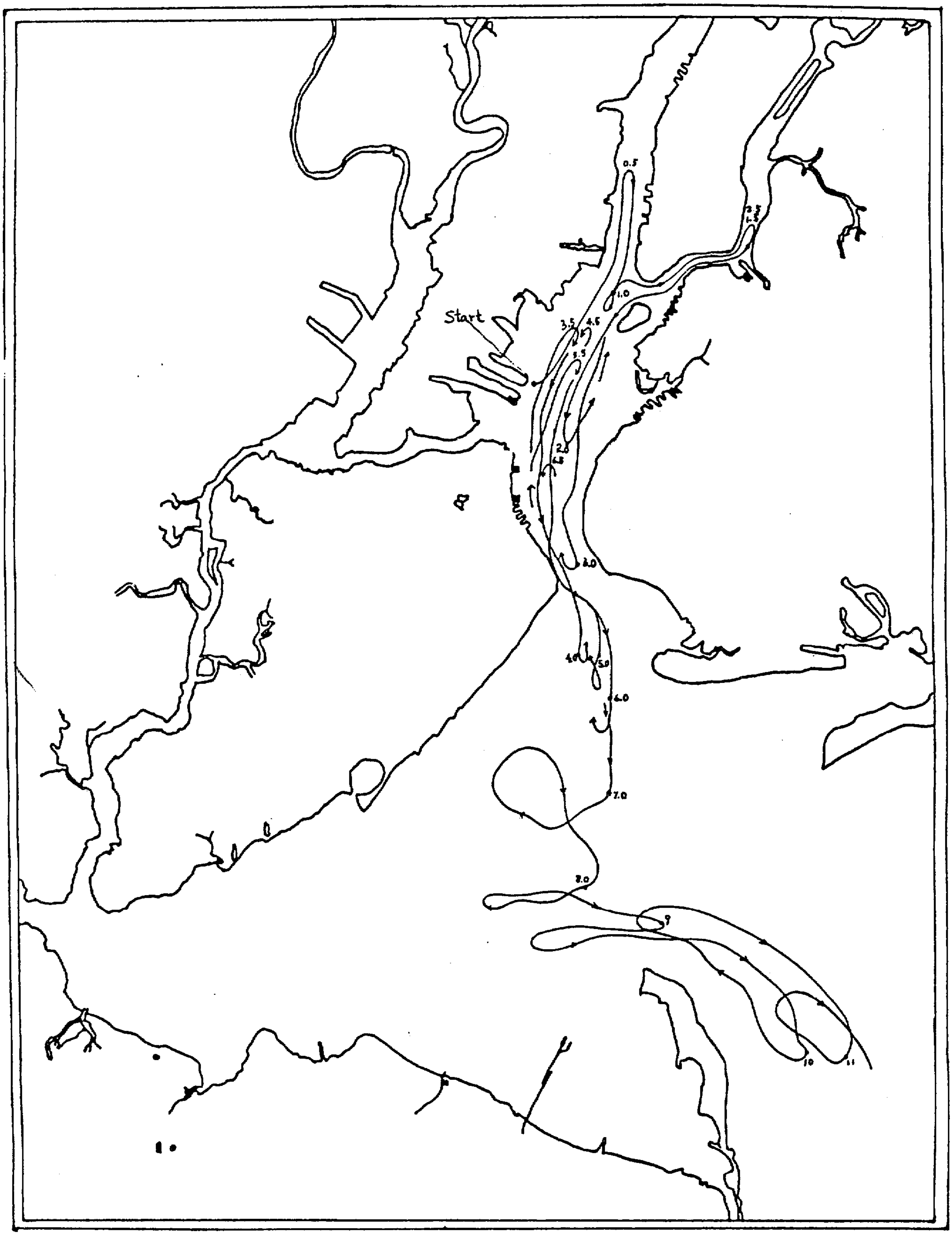

Figure 11: The predicted trajectory for an oil spill at a crude oil handling facility at Port Jersey at slack water before flood.

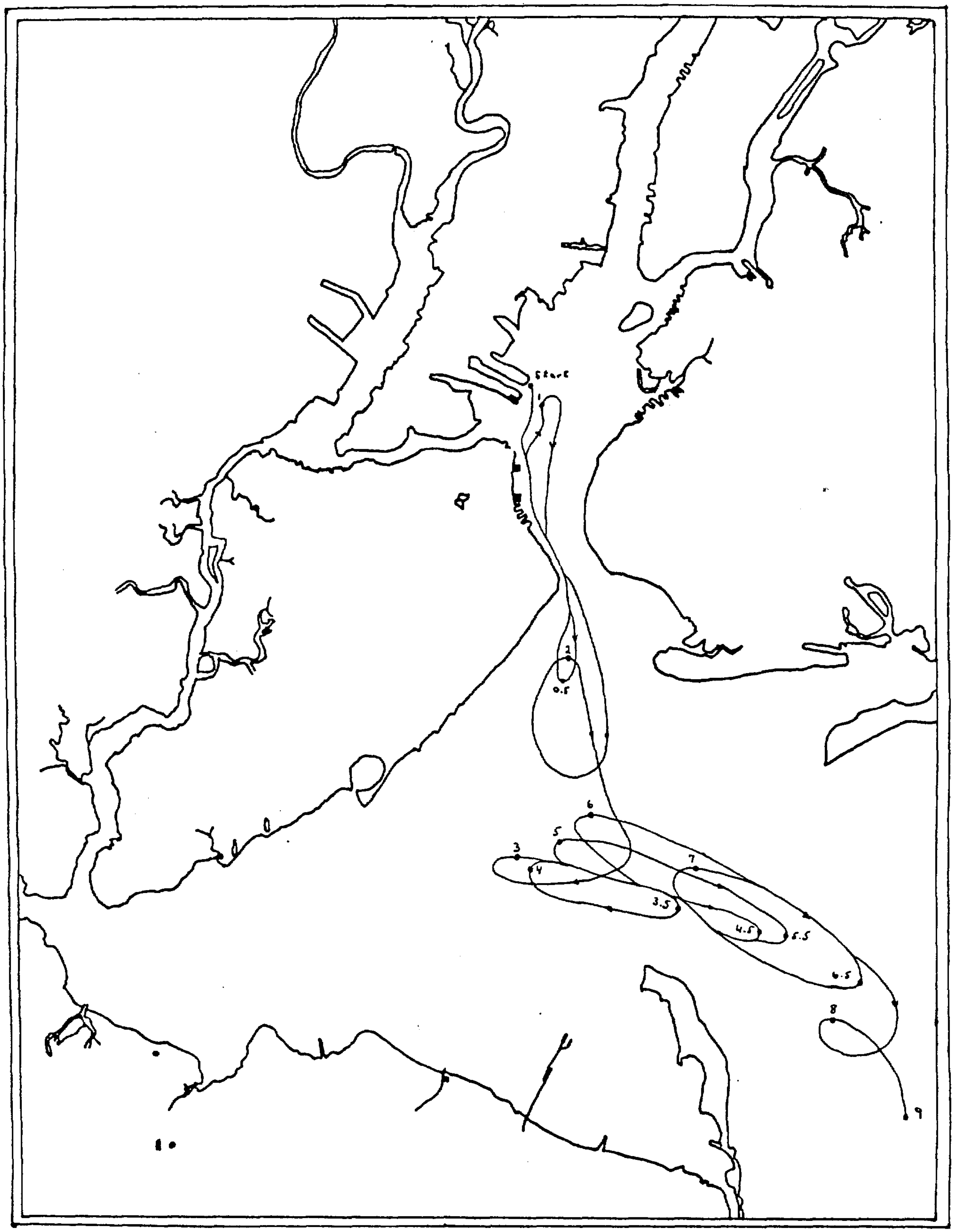

Figure 12: The predicted trajectory for an oil spill at a crude oil handling facility at Port Jersey at slack water before ebb.

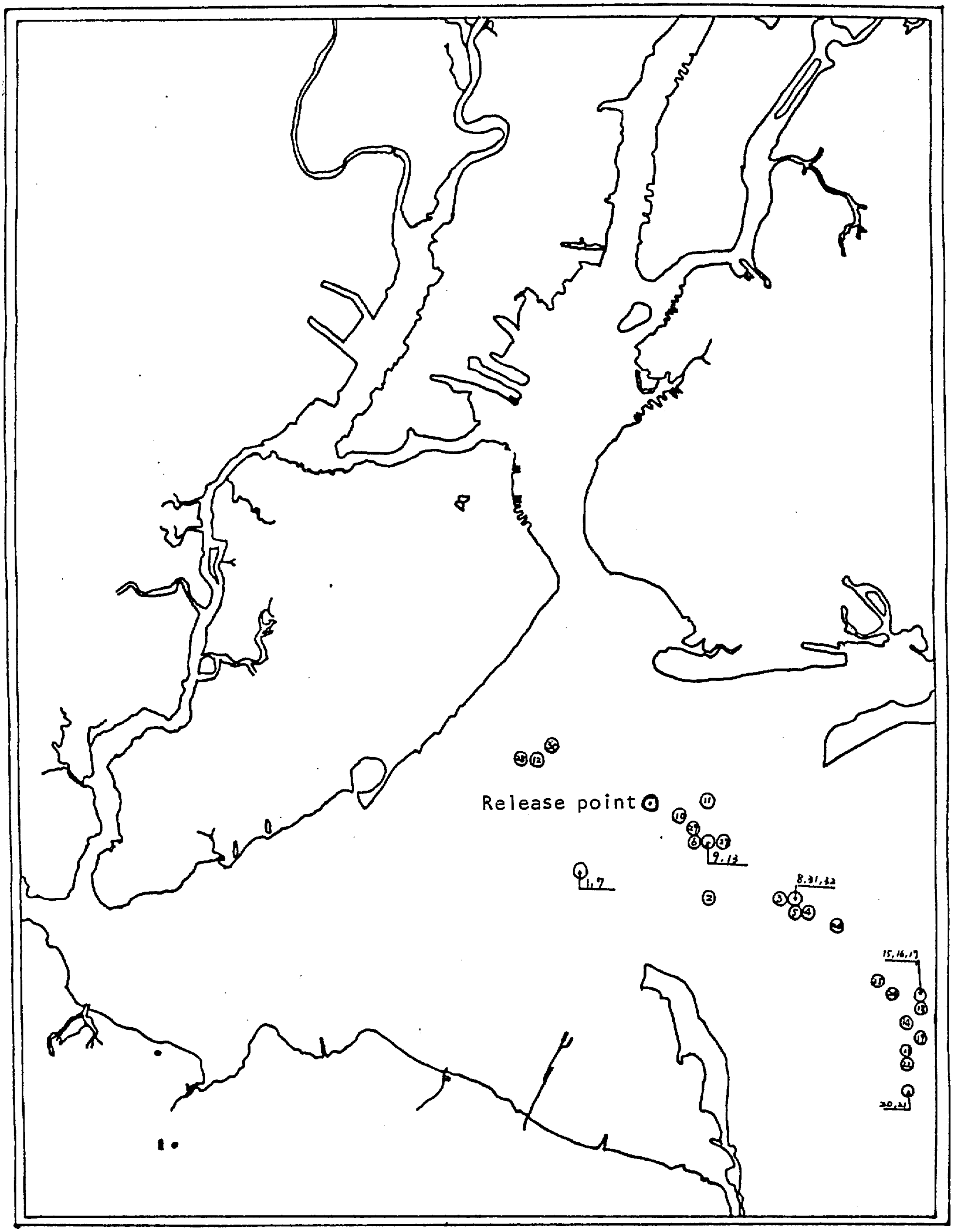

Figure 13a: The distribution of a continuous release of oil in Ambrose Channel after two tidal cycles. This distribution is at the slack before flood begins at the release point.

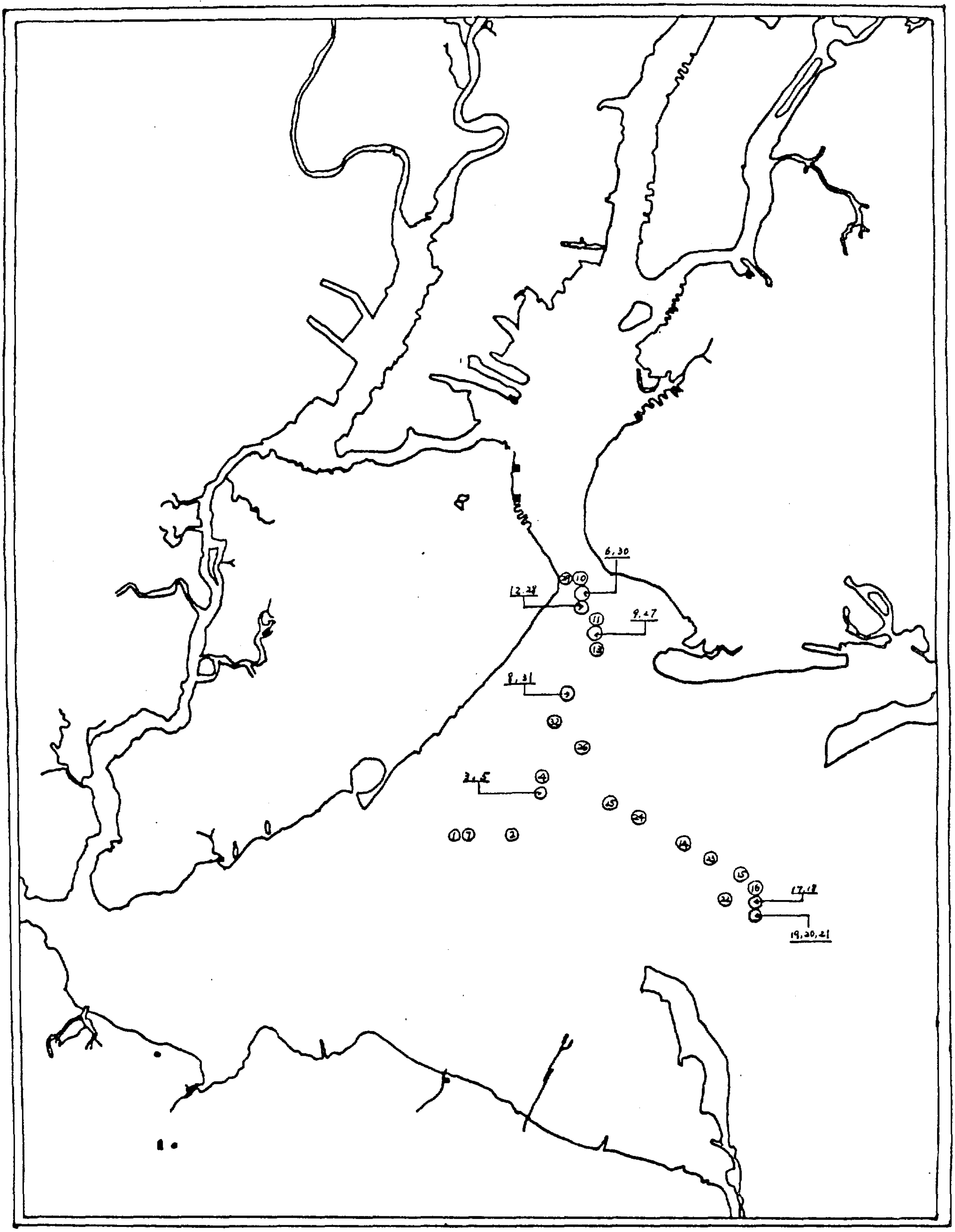

Figure 13b: The distribution after two and one-half cycles. The time of this distribution is at slack before ebb.

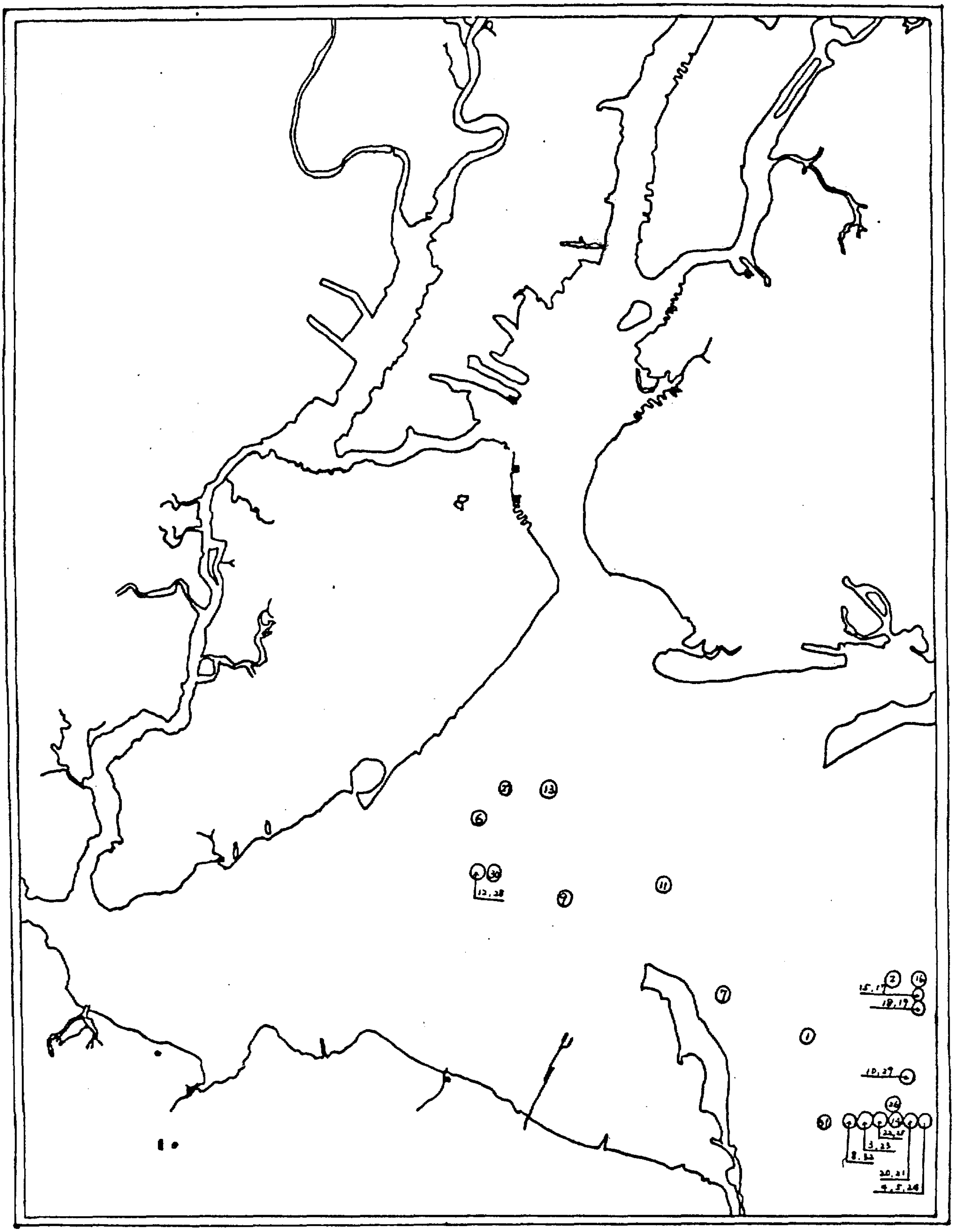

Figure 13c: The distribution after five tidal cycles. The time of this distribution is at slack before flood.

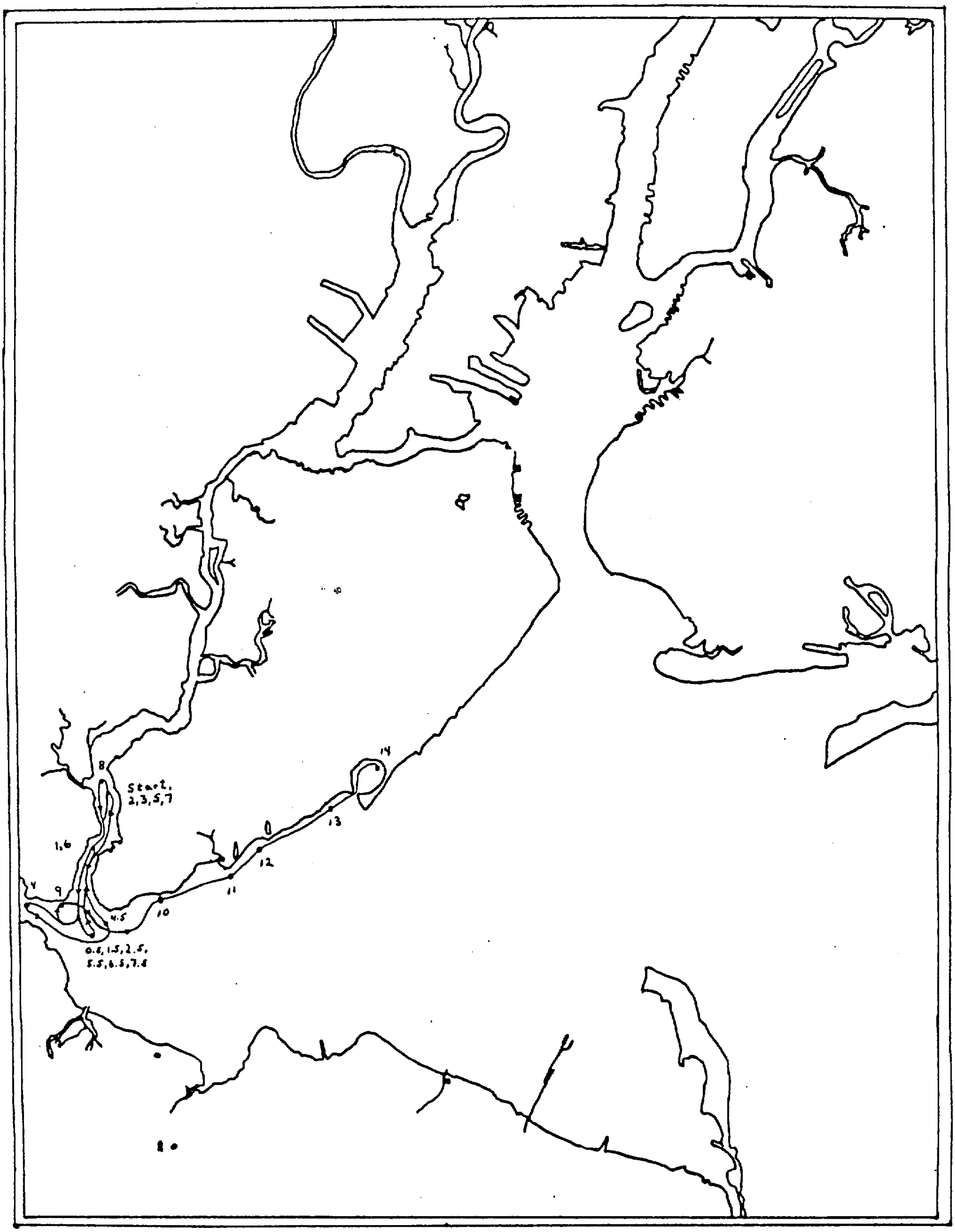

Figure 14: The predicted trajectory for an oil spill at the Chevron refinery pier at slack water before ebb under the influence of a southwest wind with speed of 10 knots.

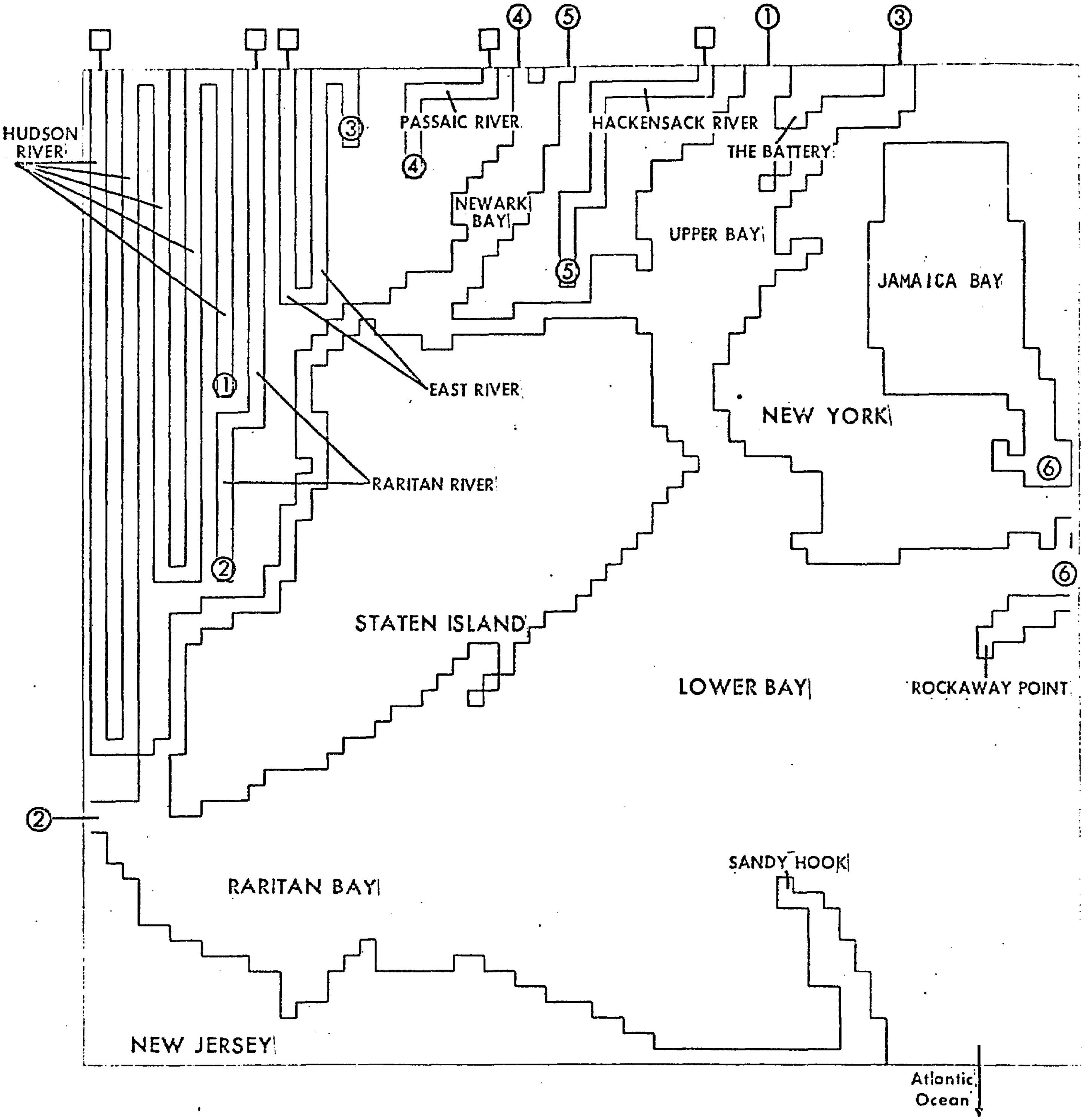

Figure 15: The computational grid for the tidal hydraulics numerical model.

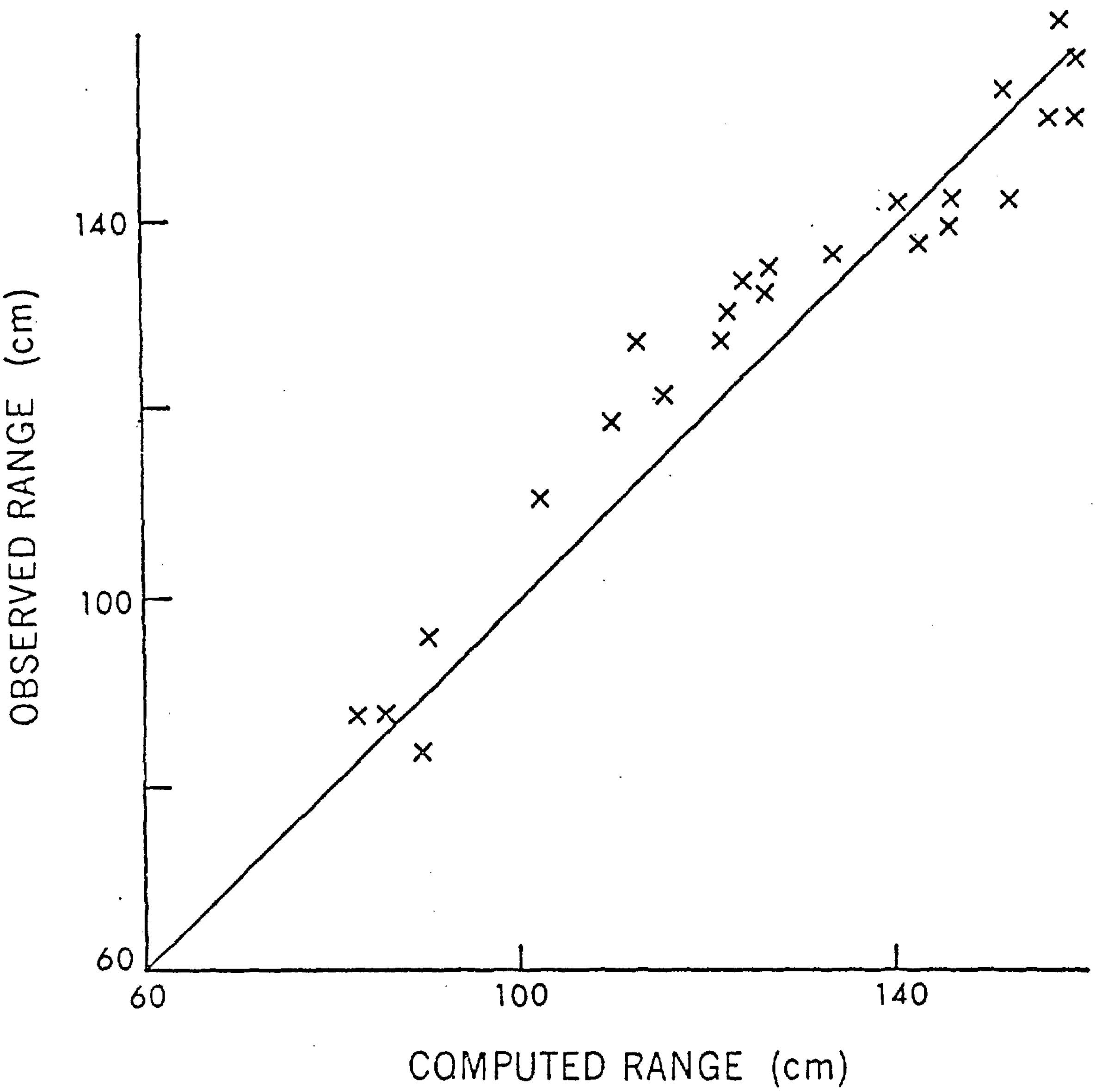

Figure 16: Comparison of observed and computed tidal ranges in New York Harbor

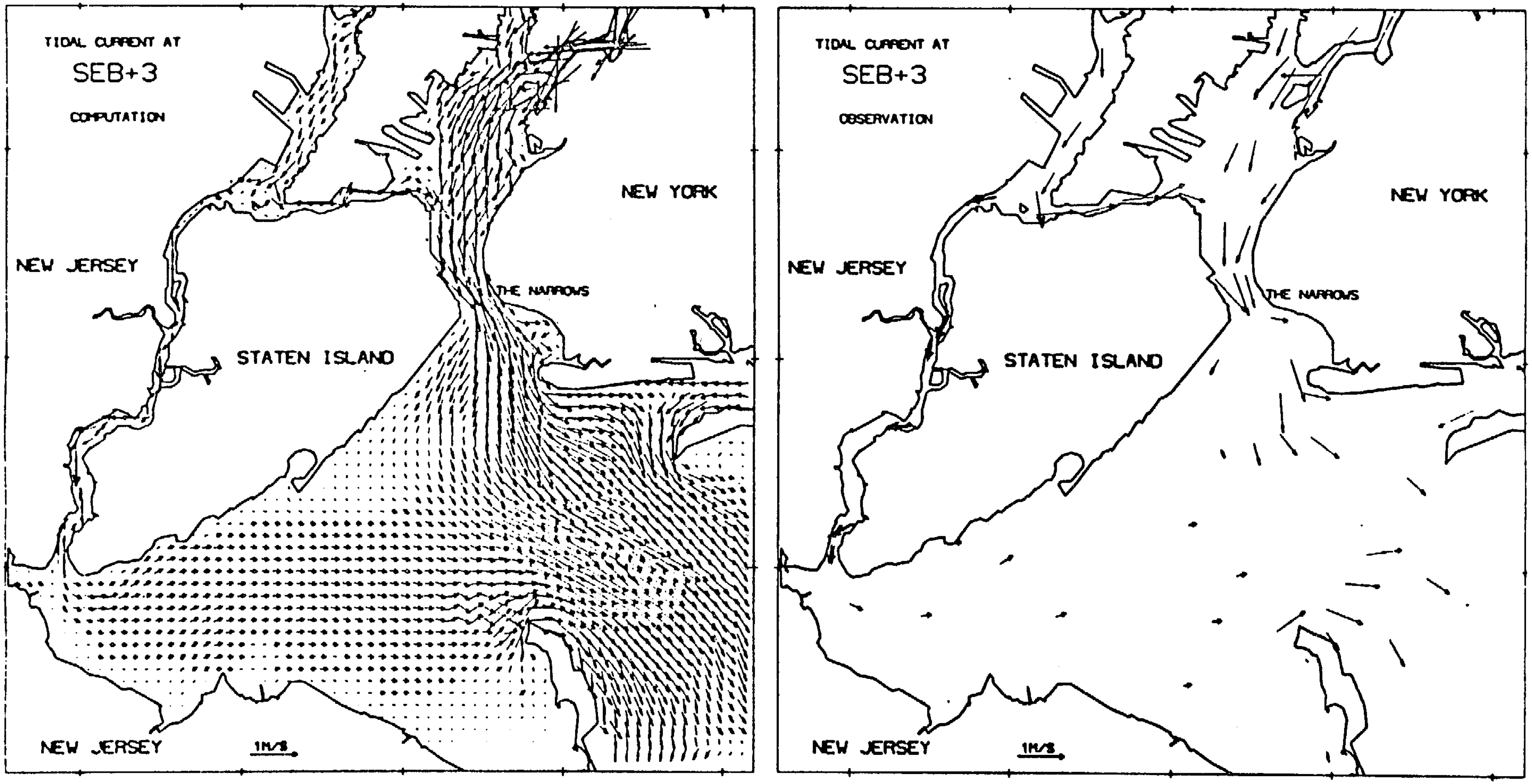

Figure 17: Computed and observed vertically averaged currents at the time of maximum ebb current at the Narrows.

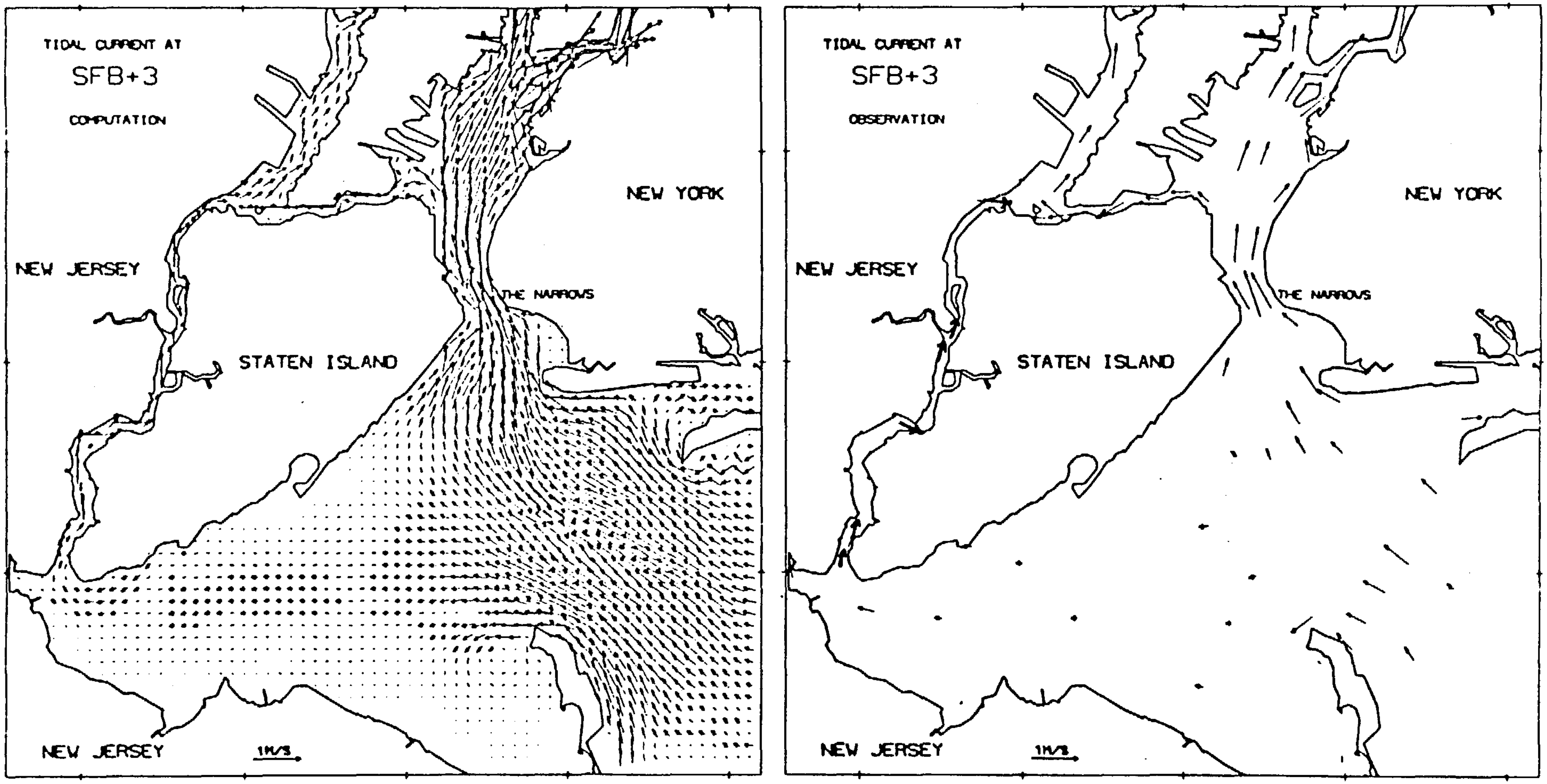

Figure 18: Computed and observed vertically averaged currents at the time of maximum flood currents at the Narrows.

ADDENDUM

The level of significance for current speed difference was taken as 7.5 cm/s (0.15 knot) for the peak ebb or flood speed. For elevation the level of significance was taken as a change in high-or low-water elevations of 2.5 cm (1 inch) or a change in tidal range of more than 3.7 cm ($1\frac{1}{2}$ inches). In Table 1 a comparison of the computed results with and without the deepened channel is presented for six, nearly equally spaced, locations along the ship track from the Sandy Hook-Rockaway Point transect to Upper Bay off Port Jersey. Since the first four locations listed in Table 1, lie along Ambrose Channel we expect that the largest effect of the channel deepening would occur at these locations. No significant differences are found at these four and we conclude that the effects of channel deepening would be negligible on the remainder of the Harbor as well.

Table 1

COMPARISON OF TIDAL CHARACTERISTICS FOR THE PRESENT AMBROSE CHANNEL GEOMETRY AND FOR THE PROPOSED DEEPENED CHANNEL

This comparison has been made for six stations nearly equally spaced along the principal ship channel from the Sandy Hook-Rockaway Point transect to a location in Upper Bay off Port Jersey.

Station Number	1	2	3	4	5	6
Station Location						
Latitude	40° 30.5' N	40° 32' N	40° 33.6' N	40° 35.5' N	40° 37.7' N	40° 39.8' W
Longitude	73° 58.5 W	74° 01' W	74° 01.7' W	74° 02.5' W	74° 03.5' W	74° 02.8' W
Present Channel Depth						
Tidal Range (cm)	146.2	139.1	137.7	134.2	129.7	126.4
Peak Flood Current (cm/s)	88.3	75.5	69.1	82.8	98.4	78.3
Flood Current Direction (°T)	304	318	338	342	355	026
Peak Ebb Current (cm/s)	101.9	65.4	84.4	81.1	97.9	99.6
Ebb Current Direction (°T)	124	144	166	162	184	197
Deepened Channel						
Tidal Range (cm)	146.6	141.5	141.0	137.3	131.2	127.2
Peak Flood Current (cm/s)	89.2	78.9	66.9	83.1	98.8	79.6
Flood Current Direction (°T)	303	318	342	341	355	026
Peak Ebb Current (cm/s)	94.4	71.6	81.5	82.5	99.9	100.2
Ebb Current Direction (°T)	123	140	167	162	183	197

EFFECTS OF CRUDE OIL SPILLS

ON MARINE INVERTEBRATES AND VERTEBRATES--

RELATION TO

PROJECTED ACCIDENTAL CRUDE OIL DISCHARGES

INTO NEW YORK HARBOR

Final Report
To the Port Authority of New York and New Jersey

by

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PREFACE

This report was written at the request of the Port Authority of New York and New Jersey. The objectives were to review the existing literature in order to provide synoptic information and analysis that could be used in planning for the proposed construction of a crude oil facility. The report was to include the following:

(a) Synoptic description of selected large crude oil spills or blowouts in the world.

(b) Qualitative and quantitative assessments of marine vertebrate and invertebrate populations of New York Harbor and possible effects of crude oil on these.

(c) Provide biograms of (b) on maps of the defined harbor.

(d) Overlay profiles of existing and projected spills as provided by the Port Authority on the biological activity depicted in (b) and (c) above.

(e) Provide estimates of possible damage.

(f) Review and propose relevant mitigation measures for New York Harbor.

In the body of the report I have commenced each section by the specifications of the Port Authority as described in the letter of agreement. Each section ends in a selected reference list. The report consists of 49 pages of text inclusive of the references and 46 pages of appended figures and tables which were either directly taken from cited authors or modified after them.

Opinions expressed in this report are those of the author and not Rutgers University or any of its components.

2(a) Provide a synopsis of existing written information on the effects of large crude oil discharges from ship casualties and other sources on marine vertebrates and invertebrates.

Torrey Canyon

Close to 0900 hours on the morning of March 18, 1967 the 970 foot long tanker "Torrey Canyon," carrying within her 18 storage tanks some 117,000 metric tons of Kuwait crude oil, ran aground on the Seven Stones reef 15 miles west of Land's End, Cornwall, England. During the first 24 hours 30,000 tons of oil were discharged and moved southward and eventually upon the coast of Guernsey (Channel Island) and Brittany (France). At sea this oil was treated by some 15,000 gallons of organic nonionic detergents sprayed by small and large British Naval vessels. This pattern of discharge and movement continued till March 21 as attempts at air flotation of the ship failed. On March 24 the wind shifted from the north-west to south-west pushing the thickened oil onto the coast of Cornwall by March 25. Subsequently shores open to the north-west and west received heavy pollution due to the 18,000 tons of oil which deposited on the coast over a 4-5 day period. On March 26 the Torrey Canyon broke her back, releasing 40,000-50,000 tons of oil into the sea. The large slick, after several wind shifts, moved south toward the Bay of Biscay. The French Navy sank most of this thickened oil at sea by treatment with powdered chalk mixed with Na stearate as an emulsifier. A very small portion of this mass of oil landed on the coast of Brittany at Brest on May 19 and 20. Finally, the Torrey Canyon was considered beyond salvage on March 29 and bombed for three days. The oil in the ship and the surrounding water was set aflame. Some oil continued to escape as she gradually submerged by the end of April.

The effects of the oil and oil-detergent-sea water emulsion and the detergent alone were examined from March to August at sea, on the rocky shores, sandy shores, estuaries and the offshore sea bed. Simultaneously physicochemical and toxicological investigations were carried out in the laboratory. The information gathered from the Cornwall area, the coasts of Guernsey and Brittany are summarized below:

At sea, the main damage was to marine birds, thousands of which died as a result of direct contact with the oil. Examination of phytoplankton, zooplankton and fish in the water column showed little damage. Stations were established in clean, thin oil, and oil-detergent areas. Samples were taken at surface, 5, and at 10 m depths at each station during the first week of the spill. During the second week contaminated areas had abnormal phytoplankton and all the pilchard (fish) eggs were dead. Young fish hatchlings were scarce or absent in areas where detergent had been sprayed.

On the rocky and sandy shores, the oil arrived mostly thickened like a "chocolate mousse," was heavily treated with detergent and hosed back into the receding tide with sea water or fresh water hoses. Reinvasion occurred with flood tides and the cycle repeated well into May. Wherever detergent was sprayed high mortalities of algae; anemones and other coelentrates; polychaete worms; crustacea (crabs, lobsters, isopods, amphipods, hermit crabs, and barnacles); echinoderms (sea stars, sea urchins, and heart urchins); molluscs (limpets, snails, oysters, mussels, the sea hare, and whelks) and fish (blenny, sucker, pholis, cottus, sand eels or ammodytes) were recorded. In the absence of detergent, the effect of crude oil was mild during the first few days. However, when the "mousse" was thick (1 inch or more) and covered an area for a long time, limpets, barnacles, anemones, and some algae were "smothered." Effects on fish could not be assessed because fish either swam away or died and were eaten by shore birds. Overall, animals that could shut themselves off from the environment (barnacles, mussels, snails, and some worms) survived best. By August these shores were recovering and being recolonized by algae and some animals. In the absence of detergent, oil weathering and biodegradation may be more swift.

On the sandy beaches the thick oil mixed with sand to form "coffee grounds." Wave action covered this with clean sand. Divers reported some oil-sand mixture sinking on the sea bed near shore. By July erosion of the beaches reexposed the sticky oily layer and oil spread again. Oil alone sank slowly in sand but oil-detergent sank rapidly in the interstitial water. Because of the combination of oil-sand-air particles, temporary quicksand was created on beaches with oil alone. Gray layers of sulfide indicated microbial degradation. By May oil decomposing bacteria were as high as 400 million per ml of wet sediment. Excessive detergent used in certain areas reduced the bacteria greatly. Anaerobic degradation by bacteria was far less efficient than aerobic. The initial destruction of interstitial fauna may have helped bacterial build-up since these small animals feed on bacteria around sand grains. As toxicity was reduced by the bacterial action, interstitial fauna returned. These consisted mainly of small isopods especially *Eurydice pulchra*. Among larger sandy beach animals, crabs, heart urchins and razor clams were killed by spraying. Oligochaete worms survived but nematodes and small crustacea (copepods, cumaceans) perished. On the upper driftline beach, sand hoppers, isopods, and amphipods were killed.

The Hayle Estuary was badly polluted by invading oil but no detergent was used. The worm fauna of the sandy flats remained unharmed by April 10. By mid-August weathering had reduced the oil rim. Lichen and salt-marsh plants were growing over oil residue. Amphipod (*Orchestia*) and wood lice (*Oniscus*) were common and normal. Oil flushed out rapidly from this estuary and bacterial decomposition was very effective, otherwise damage would have left long-term effects.

Offshore diving on April 11 showed great mortality or damage to some algae, crabs, lobster, prawn, starfish, and sea urchins at 2 fathoms. By contrast, at 5-6 fathoms damage was slight because of the laminaria (large algae) canopy protection. In deeper water (8 fathoms), on sandy bottom, many dead or dying heart urchins, bivalves, and starfish were observed.

Laboratory investigations confirmed that the main toxic effects were due to the liquid detergent used in dispersing the oil by the Navy. The immediate acute effect of the crude oil itself was mild (except on birds). Flora and fauna did begin to recover in a few months after weathering and bacterial degradation of oil. (For further details see J.E. Smith, 1970).

Amoco Cadiz

About 11:30 p.m. on March 16, 1978, the supertanker "Amoco Cadiz" (a VLCC) went aground on a rocky area 2.5 km offshore from Portsall on the northwest coast of France. It contained 100,000 tons of light

Arabian and 123,000 tons of light Iranian crude and 4,000 tons of bunker fuel. At 6:00 a.m. March 17, the tanker broke-up and during the next 15 days spilled all the oil into the sea. The oil quickly transformed from sheen oil to a water-in-oil "mousse" (emulsion) of at least 50% water. It severely impacted nearly 140 km of the Brittany coast from Portsall to Ile de Brehat. Overall, contamination (including secondary respreading from primary areas) was observed along 393 km of coastline and 60 km offshore, the areas including recreational beaches, mariculture impoundments, and marine fishery.

Low viscosity and very rough seas dispersed the oil to considerable depths before an appreciable component could evaporate, thus permitting time for solution of the more soluble and toxic aromatic fraction in the water column. Eventually some 40% (about 80,000 tons) of the total spill was lost to the air and presumably largely degraded by photooxidation.

NOAA investigators estimated that 64,000 tons of oil went ashore on beach surfaces during the first two weeks. By mid-April, cleanup activities and natural erosion reduced the beach surface pollution to 11,000 tons. In addition to the surface deposits, a large amount of oil was deposited on rocky shores or trapped in the sediment (50-80 cm deep). The amount which was dispersed naturally or artificially (through the use of chalk and 3000 tons of low toxicity spray dispersants by French and British vessels beyond the 50 m depth contour i.e., five miles offshore) was estimated at 40,000-50,000 tons. The biodegradation of this oil in the sub-tidal sediment has been followed by different methods.

Cleanup procedures were rather successful, if labor intensive, and very expensive. Attempts at lightering by pumping from shore, which required 2.5 km of pipe, or by lightering vessels failed mainly due to severe weather and the rapid break up of the Amoco Cadiz in eight days. Booming was successful at the mouth of protected rivers and bays (e.g., Morlaix) but proved inefficient in areas exposed to severe winds. Pumping of thick oil from bays was carried out by pumps or vacuum trucks from beaches, slips, docks, and roads. The oil from this mix of "mousse," sediment, debris, and algae eventually went to the refineries for oil recovery. This type of work lasted a month during which up to 300 pumping machines, 150 trucks, and 1500 people were involved. The last stages of cleanup began when there was little floating "mousse" left and the surface oil layers became too thin for pumping. Removal of oiled seaweed from beaches was carried out by 7000 soldiers and other men who placed the weeds in plastic bags and had them trucked to a dump site in Brest. "Mousse" on sand was collected by scrapers or shovel or by adsorption to saw dust, shredded paper, straw and other materials. These and the oiled sediment layer were also bagged and sent to the dump site in Brest. Rocks, piers, walls and other installations were cleaned by low, and later, high pressure cold water and hot water fire hoses between the sixth and ninth weeks after the Amoco Cadiz grounding. Mousse from the surface of marshes near oyster beds was manually skimmed. Oil adsorbed to mud and was most difficult to remove from muddy regions of the marsh.

The more fluid part of the debris, some 30,000 tons of mousse, yielded about 10,000 tons of reclaimed oil. The solid residues, about 200,000 m^3, contained on the average 2-11% oil or 15,000 tons of oil equivalent. The residues were treated with quicklime and stored permanently at the special dump sites in Brest and Tregastel.

The cost of cleanup vastly exceeded the total estimated oil reclaimed and the $50 million maximum insurance. Nonetheless, public demand and ecological necessity superseded cost-effective accounting.

The general biota of the region and, in particular, commercially important algae (Laminaria, Chondrus, and Gigartina); crustacea (crabs, Cancer and Maia); molluscs (oyster, clams, and mussel) and many fishes were severely impacted by the fresh oil during the first two weeks. Oil collected from a fresh slick at Portsall was used for toxicity studies and had marked toxic effects on mussel larvae and their settlement. Feeding rates of small mussels were reduced.

When the influx of oil occurred plankton was abundant but, within 20 days, few living plankton could be observed and these were unhealthy. By mid-May some recovery of zooplankton and patchy phytoplankton were observed. Fish larvae were patchy and, due to the cold winter, the effect of the spill on these could not be assessed. Coastal algae (Laminaria and Fucus) and land plants were not seriously harmed although the lichens were smothered. Areas that were denuded by cleanup operations were recolonized by July, 1980.

On March 22 a blanket of oil temporarily covered the sand flats between St. Efflam and St. Michel-en-Greve. A few sensitive animals began to die immediately but a cataclysmic effect was observed on April 2 when razor clams, cockles, surf clams, and heart urchins affected by oil came up from the sand, were washed out of their sublittoral habitat and perished in the millions. A survey in July, 1980 showed a persistent oil layer in the sediment of most of these beaches and recolonization remains uncertain. In other areas, burrowing intertidal species (polychaetes and some bivalves) were not seriously disturbed.

On the rocky shore heavy mortality occurred among herbivorous gastropods (snails) from 160 sites studied (mean loss for the limpet Patella was 20% and that for Littorina, Gibbula, and Monodonta was 50-99%). By July, however, an abundant recruitment of young Littorina (winkles) were seen at Portsall. On the lower part of the shores no mortality was observed among barnacles (Chthamalus and Balanus); mussels (Mytilus) or worms (Sabellaria).

The crustaceans free-living among the intertidal algae suffered high mortality everywhere especially close to the wreck. Amphipods nearly vanished and isopods and crabs were rare. By July, there was a strong recruitment of the shore crab (Carcinus maenas) and an abnormal population explosion of harpacticid copepods which live on the surface of algae. (By comparison, in the nearby oiled sediments interstitial crustacea were absent). These were 20 times as numerous on the algae as in unpolluted areas. The shrimp (Leander serratus) which also lives on algae was 2-2.5 times more abundant than normal. These explosions were due to the great reduction in herbivorous species noted above. The populations of rock overhangs and below boulders also suffered high mortalities at Portsall.

Survival of in-fauna species of 15 beaches which received differing amounts of oil showed that polychaete worms (Arenicola, Opheliidae) were remarkably resistant while certain bivalve molluscs (Solen, Ensis, Pharus, and Cardium) were almost totally killed and others like the clams (Tellina and Mya) completely survived. In the high water zone, nearly all the sandhoppers (Talitrus) were killed and in the low water zone nearly all the Ampeliscid amphipods perished. The isopod Eurydice and other crustacea of lower tidal level showed much less mortality. Among echinoderms nearly all the heart urchins and brittle stars were killed but the worm-like sea cucumber, Leptosynapta survived well. Damage to burrowing macrofauna has been more severe because the level of petroleum hydrocarbon in the sediment remained high well after the disappearance of oil from the surface waters. Mortalities were particularly high in the subtidal populations of burrowing macrofauna since these are less adapted to resist stresses than intertidal animals. Among the mobile fauna high mortalities were noted in the 10 km radius of the wreck. These included several groups of fish (Ammodytidae or sand eels, Labridae, Syngnathidae, Gobiidae, Blenniidae, littoral gadoids and others). By the end of April, specimens of mullet (Mugil), pollack (Gadus) and mackerel (Scomber) were emaciated but not tainted. In August, 50-80% of the grey mullet (Mugil) had ulceration on their skin. Among the mobile crustacea mortalities were mainly of the crabs (Carcinus, Cancer, Portunus) and several shrimps (Crangon, Leander, Galathea). Toward the end of April, when the dilution of oil in water was 0.05 ppm, the commercial crabs (Cancer and Maia) and the lobsters (Palinurus and Homarus) were normal in quantity and quality.

Near Ile Grande, about 90 km to the east of the wreck, a salt marsh received some 7400 tons of oil. The mousse cover was 3-5 cm thick and smothered nearly all the fauna including shore crabs, cockles, and polychaetes (these worms are resistant to more moderate oil pollution). The surface oil was pumped and the sediment bulldozed away. By mid-May green shoots were visible and live fish and crabs were seen in pools. Natural redeposition of sediment is expected to hasten recovery.

Finally some 4500 birds belonging to 30 species perished through direct contact with oil. (For further details see W.N. Hess, 1978; M.F. Spooner, 1978; P. Bellier, 1979; Long et al., 1981; and Gundlack et al., 1981).

Argo Merchant

On December 15, 1976, the "Argo Merchant," a tanker under Liberian registry, carrying approximately 27,000 tons (7.7 million gallons) of Venezuelan No. 6 residual fuel oil, ran aground on Fishing Rip Shoals, about 25 miles southeast of Nantucket Island. Stormy weather and 10-to-15 foot seas prevented towing or lightering and dug the 40-foot draft tanker deeper into the underlying sand. By the morning of the 16th, U.S. Coast Guard reported an oil slick extending two miles north to south and four miles east to west. On the 17th, mappers extended the slick five miles to the northwest toward Nantucket and described the slick as "an asphalt road" with no thin sheen surrounding it. Most of the oil disappeared on the following rough days and reappeared on clear days. By the 19th, it became clear that the "asphalt" was a mixture of "pancakes" surrounded by sheen. On December 21, the Argo Merchant broke in two, releasing 1.5 million gallons of oil. On the 22nd, it split again and released another 1.5 million gallons. The remaining cargo was discharged into the environment during the following few days.

Prevailing easterly winds on December 26 threatened to drive the slick onto Nantucket, but these winds were short-lived and oil never went ashore. Coast Guard burn tests on a 300-foot diameter "pancake" were negative and the "pancake" would not burn. On December 31, a satellite-trackable buoy was dropped in the center of the original large "pancake" of December 21 release. By January 1, the slick had covered "thousands of square miles of sea surface" and was no longer mappable. The path of the buoy was charted till September, 1977 when it stopped transmitting 200 miles off the Azores. The spill had passed over and through the important fishing areas of the Georges Bank.

Several agencies and institutions participated in computer predictions of spill movement; actual mapping, photography of the surface, the sub-surface, and the bottom by divers; and collecting and analysis of water, sediment, and animal samples. These included the U.S. Coast Guard, U.S. Geological Survey, U.S. Navy, NOAA, WHOI, and University of Rhode Island.

Physical analysis showed that the oil fractionated on the surface into bulk oil forming the "pancakes" and lighter components into thin sheen. The surface movement was essentially related to 3.5% of the wind drift in addition to tidal currents. The oil had a high specific gravity of 0.96 and the suspended sediment concentrations in the water column were high, therefore sinking oil droplets with or without sediment were expected and to some extent detected in the water column.

Chemical analyses demonstrated that the lighter aromatic compounds dissolved and entered the water column. Samples taken from December 20-28 in the vicinity of the Argo Merchant showed a petroleum oil concentration of 340 ppb. During January and February, the level dropped to 20 ppb. By August and November, 1977, the range had gone down to 1-20 ppb in samples from the Georges Bank area.

Tar balls, collected on the shores of Rhode Island, Cape Cod, Martha's Vineyard, and Nantucket between 60-90 days after the grounding of the Argo Merchant did not have the same "fingerprint" as the oil from the Argo Merchant and were similar to the oil cargo of the Grand Zenith, a tanker which had disappeared off the New England coast.

Gas Chromatographic analysis of stomach content of fish (cod, windowpane flounder, and silverhake) and sediments collected during December and January near the wreck showed that the saturated hydrocarbons resembled those from the Argo Merchant oil. By July, the sediment hydrocarbon near the wreck no longer resembled that of the original cargo. This was due to the physicochemical and biological weathering as well as the turbulent mixing on the shoals which "probably transported the contaminated sediments out of the area or buried them under clean sand."

Samples of animals were collected from the water column as well as the benthos within 30 days after the spill and on subsequent surveys near the wreck and in the spill area. Comparison of fish, molluscs, crustaceans, sea urchins, and starfish collected from control clean stations with those from stations in the proximity of the wreck showed that the latter had no clear histopathology attributable to the oil spill. A more detailed study of the live as well as fixed macrobenthic animals concluded that the effect of the spilled oil was within their physiological tolerance limits. Studies on the blood of winter flounder, yellowtail flounder, and haddock showed depressed values for serum osmolarity, sodium and potassium when fish from oil impacted areas were compared to those from control stations. Ocean scallops (Placopecten) and horse mussels (Modiolus) from the impacted area had depressed gill-tissue oxygen consumption but were normal on later cruises. Serum sodium and calcium levels in the impacted area were elevated in these species. Certain metabolic enzymes also had abnormal activities.

The trophic pathways of Argo Merchant oil were observed among the zooplankton and benthic organisms leading directly to fish stocks. Samples of zooplankton collected in February, 1977 near the wreck showed a relatively high (1.2-75 ppm) oil concentration. By December, 1977, these levels could not be detected. Fish eggs (cod and pollock) at all stations showed some oil contamination. Overall, 20% of cod eggs and 46% of pollock eggs were dead or moribund. Within the slick 18% of pollock embryos were malformed while in the periphery of the slick only 9% were grossly abnormal.Eggs from the more distant stations were normal. Experimental laboratory toxilogical tests on cod eggs supported the field observations.

Examination of the sediment directly below the wreck in February, 1977 showed a reduced benthic community (copepods and ostracods, crustaceans, polychaete worms, nematodes, and nemertean worms). By July the total number of individuals had increased by 100% at some and several fold at other stations.

Passage of oil to higher trophic levels was clearly established by examination of stomach content of 21 species of fish and squid. These ingested four main prey groups: amphipods, polychaete worms, rock crabs (Cancer), and American sandlance. Even though large quantities of oil were not recovered from fish stomachs, the pathway of oil via contaminated copepod, amphipod, annelidan worms and sand lance to juvenile fish of such species as Atlantic cod, haddock, silver hake, red hake, flounder and plaice is well established.

There was no evidence of large scale juvenile or adult fish mortality during the 12 months following the wreck of the Argo Merchant. However, the long-term effects on the fisheries of the Georges Bank resulting from contamination of food items and damage to eggs mentioned above remain to be assessed.

Finally, bird observations and collections showed that approximately 50% of the gulls in the area were affected by oil. During the period 20 December, 1976 - 24 January, 1977, 69 live and 112 dead birds of 16 species were collected in Nantucket and Martha's Vineyard. It was concluded that the Argo Merchant spill had minimal effect on birds. (For further details see Grose and Mattson, 1977; Milliman, 1977; Center for Ocean Management Studies, 1978; and Hess and Kerr, 1979).

Burmah Agate

On November 1, 1979, the Liberian tanker, "Burmah Agate" collided with the Liberian freighter Mimosa 7 km southeast off the mouth of Galveston Bay, Texas. The Burmah Agate was carrying 46,500 tons of light Nigerian crude and blended crude oil. Explosion and fire followed the collision and the tanker burned out of control for over two months. It is estimated that nearly 250,000 barrels had either burned or were released into the environment. By January 8, the fire burned itself out. About 150,000 barrels were salvaged from the forward tanks before the ship was refloated and towed to Brownsville, Texas for scrap. Although the vessel owners took responsibility for the collision, the U.S. Coast Guard took an active role in the containment and recovery of spilled oil at the collision site and protection of the onshore environment. By November 9, booms, skimmers, and skimming barriers were deployed around the ship and eventually 6,700 barrels of oil and water emulsion were recovered from the water. Booms and skimmers were effectively used at the Galveston entrance and a number of passes in order to minimize the threat to the coastal environment. Fortunately, the offshore winds dispersed the oil toward the gulf. Onshore winds of long enough duration, however, were predominantly responsible for driving a small part of the spill onto a number of beaches. The major problem in protecting tidal inlets was insufficient equipment for booming and skimming. It was estimated that 2,100 barrels (0.5% of the total cargo) went ashore and a major part of this, 500 barrels, impacted a 10 km section of San Jose Island. This oil came from the initial large release caused by the collision for which there was no possibility of prevention. No cleanup measures were used on San Jose and approximately 25% of the impact remained on the beaches or was buried in the sand by November 16. On November 19 to 21, 1,500 barrels beached on Galveston Island. Cleanup measures on these beaches were mainly by front-end loader and manual pooling of the oil followed by vacuum truck pick up. There were several other minor impacts on coastal beaches and tidal inlets.

Little published information has been found on the biological effects of the Burmah Agate spill. This is probably due to the relatively small amount of crude that was discharged into the environment and the fact that a large impact (IXTOC-I, see below) superimposed upon the same areas in August and September, 1979. (For further details see: Anonymous, 1979; Thompson et al., 1981; Thebeau and Kana, 1981; and Kelly et al., 1981).

Santa Barbara

Santa Barbara Channel has been known to have natural small oil seepages since 1792. On January 28, 1969, an uncontrolled flow through a fissure in the sea bed caused by the drilling operations on platform "A" of the Union Oil Company, 10 km off the Montecito coast, began to pollute the sea off Santa Barbara. Allen estimated the flow at 726 metric tons (5000 barrels) per day from January 28 to February 7, 1969. The flow reduced for a few days and resumed at a lower rate. Allen's estimate based on 0.001 inch oil layer thickness for the first 100 days of blowout was 78,000 barrels. Reconsideration of thickness at 0.01 inch places the maximum total close to 780,000 barrels. The slick spread to cover 1,700 square kilometers during the first eight days. The oil went ashore on Santa Barbara beaches within this period. Normally the weak Davidson current which moves up toward Santa Barbara Channel would have been expected to drive the oil onshore. The prevailing wind from the northwest would have counteracted the Davidson current since an oil slick normally moves at 3.4-4% of the relative wind vector. Both of those normal weather elements were nullified by two severe winter storms which blew mainly from the southwest and drove the oil ashore. Estimates derived from aerial photographs and core samples by February 8 gave 87.7 km of coast with a beach area of 1,847 km^2 as impacted. The estimated dosage on the beach ranged from 2.7-118 metric tons/km and for the entire coast as 51.4 metric tons/km. Eventually 160 km of coast, including the channel islands, were affected. By March 5, the well had been brought under control and the leak had been reduced to 3.5 metric tons per day. This leak continued through July 30, 1969. The impact on the beaches would have been greater if the giant kelp (Macrocystis) had not acted as an offshore barrier. No detergents were used and cleanup procedures were limited to soaking up by straw (2,300 metric tons/day) and sinking by talc and diatomaceous earth (18 metric tons). Rocks were washed with hot water hoses. Oiled straw and sand were mechanically removed from the beaches.

In the Santa Barbara incident the sophisticated gas chromatographic methods for analysis and "fingerprinting" of the oil and its "weathered" fractions in the environment were not used. Nearly all quantitation was limited to gravimetric and volumetric measurements or visual observations of gut contents, conditions of various species, and counting individuals in samples. Fortunately, adequate baselines of fauna and flora and fisheries of the impacted area were available from previous ecological and fisheries research and class work. Also, comparable but "nonoiled" areas were available and could be used as "controls" in assessing damage. However, all the initial ecological surveys were complicated by the unusually violent storms and record breaking rainfall in the area which occurred in January and February, 1969, before and during the early phase of the spill.

The initial heavy dose of oil damaged many of the algae and the surf grass in the upper intertidal zone (e.g. Phyllospadix, Enteromorpha, Chaetomorpha, Ulva, etc.). Plant mortalities ranged from 1-100% along a number of transects, but the mean mortality for algae and surf grass was approximately 20% during this initial phase. The majority of the brown algae, which occur in the lower intertidal and subtidal zones were protected from the initial large oil dose (e.g. Egregia, Porphyra). Of the 11 species of common macrofaunal, intertidal animals representing four dominant invertebrate phyla (coelentrates, molluscs, echinoderms, and arthropod crustacea) only the small barnacle Chthamalus fissus had a 20-90% mortality in various transects. This was probably due to "smothering" by the oil layer. In all other species mortality remained at 1-5%. In the offshore kelp beds, no damage or observable changes were recorded at the surface, subsurface, or on the bottom by divers. Divers did not observe any oil below the surface in this area but did report oil on the bottom in the harbor area where talc had been used to sink the oil.

The immediate effects of the Santa Barbara oil pollution on the biota were minimal mainly due to the natural rapid evaporation, dilution, dispersion and offshore movement of the spill due to the ventilation of the basin by offshore winds and severe storms. The cleanup procedures which excluded the use of detergent also minimized damage.

About one month after the initial blowout, midwater trawl collections of small fishes and invertebrates at various depths in the Santa Barbara Channel and the Santa Cruz basin showed no significant decrease in species diversity, evenness of abundance, overall abundance, or increase in patchiness when compared to similar samples from previous years with the exception of an increase in rock fishes and diversity of flat fishes. These could not be directly related to oil damage. Data from seasonal sport and commercial fishing showed lower catch rates but these were traced to reduced fishing effort caused by the news of the oil blowout or the stormy conditions.

Visual examination of gut and tissues of larger fish did not reveal evidence of oil in the above collections.

The rocky intertidal beaches in the general area of the Santa Barbara oil impact were ecologically reinvestigated in June and July of 1972, three and a half years after the initial blowout. Data from ten stations showed no damage or change in species composition that could be traced to oil. Mortalities were mainly due to substrate movement (shifting small rocks and sand) by natural and human factors. (For further details see University of

California, Santa Barbara, 1970; Allan Hancock Foundation, 1971; University of California, Santa Barbara, 1971; and Cimberg et al., 1973).

IXTOC-I and Gulf of Mexico

At 0030 hours on June 3, 1979, the exploratory well IXTOC-I belonging to Pemex (Petroleos Mexicanus) and located approximately 43 nautical miles northwest of Ciudad del Carmen (Bay of Campeche, Gulf of Mexico) suffered a blowout. The initial rate of release was estimated at 30,000 barrels/day. Before the well was capped on March 23, 1980, an estimated 3.3 million barrels (476,000 tons) of oil was released under pressure and mixed with sea water to form a thick "mousse" as it floated into the Gulf of Mexico. Approximately 3,900 tons of this oil impacted the South Texas coast.

There was no predeveloped contingency plan for response to this crisis. At the request of the Mexican Government, the National Response Team (NRT), the U.S. Coast Guard's National Strike Force (NSF) and the EPA became involved in containment, cleanup and damage assessment operations. In addition, an ad hoc interagency damage organization was formed to develop a comprehensive IXTOC-I damage assessment program. The agencies involved included the EPA, the Bureau of Land Management (BLM), the Fish and Wildlife Service (FWS), the U.S. Geological Survey (USGS), the National Park Service (NPS), the Food and Drug Administration (FDA), and NOAA. A number of Texas State agencies also participated.

The USCG National Strike Force directed and carried out most of the operations in booming and skimming oil at the IXTOC-I site. In addition, they were in charge of predicting the oil movement, and reviewing the use of dispersants.

Exxon Chemical Company of Houston and Conair, the world's largest aerial spraying operator, were engaged by PEMEX to supply and carry out dispersant spraying along the offshore Mexican Coast (south and southwest of the Gulf). Selective aerial treatment of oil masses that threatened locations 25 miles (40 km) from shore was carried out along 1,000 miles (1,600 km) of coastline. Oil thickness was variable but was estimated at 50-75 micrometer to 0.15-0.2 mm. The concentration range was from 800-3000 barrels/mi^2 (49-184 m^3/km^2). The planes flew 1000 hours on 493 missions with an average coverage of about 2 mi^2 (5.1 km^2) per spray flight. Dispersant dosage varied from 2-4 gal/acre (18-37 l/ha) over approximately 1000 mi^2 (2,590 km^2) of sea surface. It was concluded that the application of COREXIT-9527 oil dispersant was "extremely effective" during the entire six months of the aerial spray program. This included oil that drifted 500 mi. and that had been on water for four to six months (i.e., after evaporative loss and dissolution of the light fractions). No oil reached the Mexican shore except a small amount at Tampico and when the planes were grounded by the hurricane Henri in late September. While the heavy rains and the resulting water outflow spared the lagoons, the western shores of the Yucatan were impacted by oil.

In terms of cost effectiveness, the cost estimate for per barrel abatement is: \$700-3,000 for shore cleaning; \$400 recovering at sea; and \$40 by dispersant use to prevent oil from coming ashore (see Lindblom et al., 1981). The risk of environmental damage by detergent has not been considered in this study.

Chemical characterization of IXTOC-I oil, its sea water mixtures and its beach and sea bottom weathered components have been undertaken by the University of Texas Marine Science Institute (UTMSI) in an extensive short and long range monitoring program (see Woods and Hannah, 1981). The initial results showed that total concentration of oil accumulated in sea water varied from about 25-35 ppm of which only about 10% was actually water-soluble. Some 4000 samples from the water, sediment, macrobenthic organisms, various species of commercial shrimp, oyster, blue crab, and finfish were collected for analyses before and after the impact. Using remote sensing techniques and ground verification surveys, marshes and estuarine areas around Brazos-Santiago pass and Aransas pass were monitored. During the heaviest period of oil impact from August 29 through September 1, an estimated 3,900 metric tons of oil accumulated over 130 mi. of South Texas beaches. Parts of these beaches had already been impacted by the Burmah Agate incident in November 1979. A tropical storm on September 13, 1979 removed more than 90% of the beached oil. By spring of 1980, surveys showed that only 19% of the original tar mats remained and the quantity of tar balls could not be distinguished from chronic accumulations.

Biological monitoring was concentrated on the seaward sand beaches that received the brunt of the impact. The baseline information before the impact had established the intertidal and benthic infauna of these beaches as consisting of coquina clams (Donas), polychaete worms, mole crabs (Emerita), and haustoriid amphipods with a low-diversity, high density community characteristic.

Pre-spill and post-spill sampling along seven transects on the South Texas Barrier Island sandy beaches in August through September, 1979 produced a total of 5,124 specimens representing 51 species of seven invertebrate phyla and one Cephalochordate. Comparison of the pre-spill to post-spill data showed significant decline in all dominant species in the intertidal and the subtidal zones except for polychaete worms in one area which showed an appreciable increase after the spill. Another area which received the heaviest oil budget showed the highest decline in population density. In the interpretation of the data, factors other than IXTOC-I oil damage were considered. These were the concurrent tropical storms, normal seasonal faunal variations from summer to fall, and beach cleaning techniques that disturbed the substrate.

Finally the studies on shore birds showed that the bird population naturally shifted from the foreshore to the low food backshore to avoid oil. The percentage of total birds with oiled plumage never exceeded 10%. After the tropical storms cleaned the foreshore, the birds returned to their normal feeding grounds but in lower numbers than in the pre-impact period. Bird mortalities were minimal. (For details see a series of articles in Oil Spill Conference, 1981, American Petroleum Institute; and the Proceedings of a Symposium on Preliminary results from the September 1979 Researcher/Pierce IXTOC-I Cruise. 1980. U.S. Dept. of Commerce NOAA-OMPA).

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2(b) Provide a synopsis of existing data on key marine vertebrate and invertebrate populations of New York Harbor. Specifically, consider their distribution, reproduction, growth, feeding habits and other physiological and ecological information relevant to the assessment of crude oil discharge effects on the marine environment.

An extensive survey of the literature was used to assess the diversity and density of the vertebrates and invertebrates of the New York-Raritan Bay complex and adjacent waters. Most of these sources are in the form of unpublished reports which mainly deal with species diversity and distribution. The dearth of published quantitative inventory and the trophic interdependence (food chain) of benthic and pelagic organisms make it difficult to pick out "key" invertebrates and vertebrates of concern in an oil spill situation. Furthermore, the defined area is so heavily impacted by human activity and therefore subject to considerable change, that it is not possible to determine how relevant are the data which were reported 10-20 years ago for current assessments of animal diversity and density. Therefore this section will be devoted to:

2(b)-1- A general treatment of phytoplankton, zooplankton, and benthic invertebrates with specific considerations of species of trophic or fisheries importance.

2(b)-2- A general treatment of pelagic and benthic finfish, ichthyoplankton, and specific consideration of species of commerical and sport fisheries importance.

2(b)-3- A brief statement on birds.

2(b)-1- Phytoplankton-Zooplankton-Benthic Invertebrates

The Raritan-Hudson estuary has a rich nutrient supply from natural and domestic sources. This, plus a sluggish circulation and scarcity of macroscopic algae combine to form an environment capable of supporting dense plankton populations.

The more recent studies of phytoplankton are those of Patten (1962), Hulbert (1963), McCarthy (1965), Lacky (1967), DeFalco (1967), Nuzzi and Perzan (1974), and a Texas Instrument field report (Anonymous, 1976). The best recent review on the subject is the comprehensive report of Malone (1977) which covers over 75 years of literature. The estuary inside the Sandy Hook-Rockaway point transect has a very high level of primary productivity, 700-1050 g carbon/m^2/yr (Duedall et al., 1979). As the distance from the estuary toward the open Atlantic increases, the phytoplankton and zooplankton densities decrease. The nutrient budget of the estuary and its contribution to the New York Bight waters outside of the mentioned transect also indicate that a substantial amount of the available nutrients (ammonium, nitrate, phosphate, etc.) are utilized by the phytoplankton within the estuary. This phytoplankton biomass forms the primary trophic base for the zooplankton and higher animals. Cell densities in the estuary range from 10^6 - 10^9/liter compared with 10^4 - 10^7/liter in the apex waters just outside of the above mentioned transect and 10^3 - 10^5/liter in the open waters of the New York Bight (Malone, 1977). The phytoplankton populations are dominated by diatoms (Bacillariophyceae) in the cold months (Skeletonema costatum, Chaetoceros decipiens, and Gyrosigma acuminatum) and Chlorophytes during the warm months (Nannochloris atomus). Other members of the phytoplankton biomass with high densities are Prorocentrum micans and the three Peridinium species, P. trochoideum, P. breve, and P. divaricatum. In the area of Liberty and Ellis Islands, total phytoplankton was highest in July, reduced to a third of this peak in September and became minimal in December (Anonymous, 1976). Total phytoplankton sampled along seven stations on the Arthur Kill during 1963-64 exceeded 10^5 cells/ml at all stations (DeFalco, 1967).

The major reports on the zooplankton are those of Jeffries (1962, 1964), DeFalco (1967), Sage and Herman (1972), and Malone (1977). The zooplankton densities decrease with the distance from the Raritan-Hudson River estuary. Densities in the estuary range from 10^3 - 10^6 individuals/m^3, in the apex, 10^3 - 10^5, and in the outer Bight, 10^2 - 10^4. The predominant species in the Raritan Bay are the calanoid copepods, Acartia clausi (winter and spring) and Acartia tonsa (summer and fall). These species comprise over 70% of the total zooplankton. Both temperature and salinity regulate the spring replacement of A. clausi by A. tonsa (Jeffries, 1962). The abundance of both species at peak is about 50-62 x 10^3 individuals/m^3. In addition to the above, 14 other copepod species, five cladocerans, three cnidarians, four ctenophores, rotifers, nematodes, an amphipod, and a mysid, all occurring at lower or unknown densities have been reported for the Raritan estuary and Lower Bay. These groups peak mainly during spring, summer and fall.

Planktonic larvae of other invertebrate groups (meroplankton) also appear in substantial numbers mainly in spring and summer. The more common species are the hard-shell clam (Mercenaria mercenaria), soft-shell clam (Mya arenaria), polychaete worms, barnacles (Balanus), snails (Nassarius), shrimp (Crangon) and six crabs (Cancer, Carcinides, Neopanope, Pagurus, Uca and Callinectes). Ichthyoplankton will be discussed below (2(b)-2).

It is important to note that most of the zooplankton mentioned above are either major items in the diet of finfish and birds or themselves may develop into species of fisheries importance (e.g. the hard-shell clam Mercenaria, or the blue crab Callinectes). Furthermore, if soluble aromatic components of crude oil reach 1-20 ppm in the water column for one to several days, high mortality or sublethal damage to zooplankton can be expected (Anderson, 1979).

DeFalco (1967) surveyed the zooplankton along the Arthur Kill. The density of zooplankton determined along seven stations was: over 11,000 individuals/m^3 off Perth Amboy and South Creek; 6,000 below Fresh Kills, about 2,000 at Pralls Island, nearly 4,000 just below the Elizabeth River; 10,000 off Elizabeth Port and about 14,000 off New Brighton in the Kill van Kull. The depression in density near Pralls Island (station 505) and below the Elizabeth River (station 506) may have been due to chronic exposure to toxic components of crude resulting from refinery activity in this area during the period Oct., 1963-Sept., 1964. (See Figure from DeFalco, 1967 in Appendix - page 1 of this report).

Several semiquantitative surveys of the macrobenthic invertebrate in different parts of the Raritan-New York Bay are available. Dean and Haskin (1964) took samples along 19 stations from New Brunswick to the river mouth near Perth Amboy from 1957-1960. This is a 20 km section falling within the tidal effect zone. They noted that after a trunk sewer system began operation in 1958, the number of fresh water and marine species increased considerably from zero fresh water species and 17 marine species in 1957 to eight fresh water species and 28 marine species in 1959. The dominant fresh water groups were oligochaete worms, leeches, and bivalves. Overall density was given as 7,102 organisms/m^2 at a fresh water station in 1960. The dominant marine groups were annelid worms and bivalve molluscs. The density close to the river mouth was 8,696/m^2 with the soft-shell clam (Mya arenaria) accounting for over 95% of this biomass in July, 1959.

In 1962, Haskin reported an abundance of hard-shell clams (Mercenaria mercenaria) in two major areas, one along the Raritan Bay Channel west of the Navy pier (for reference see DeFalco's stations 17-19, 22-29, 45-52 in Appendix - page 2 of this report) and the second in Sandy Hook Bay (DeFalco stations 13-16 in Appendix - page 2 of this report). The standing crop was estimated at 600,000 bushels (250 large individuals or 850 "neck" per bushel; a "neck" is 47-66 mm). The larger "chowder size" were mainly along the channel in mud bottom and the smaller sizes were in the Sandy Hook Bay proper. Areas north of Sandy Hook Point were covered with mussels (probably the blue mussel, Mytilus edulis) and old mussel shells. In the 1967 clam survey, high concentrations or hard- and soft-shell clams (Mercenaria and Mya) were reported from areas closer to shore, the Lower Bay and the Shrewsbury River mouth, near the Sandy Hook Bay (for reference see DeFalco station 702 in Appendix - page 2 of this report and Haskin, 1967).

The most extensive survey of the hard- and soft-shell clam population inside the Raritan-New York Bay complex was reported by Campbell (1967). The station locations are shown on a map taken from Campbell's paper (see Appendix - page 3 of this report). The distribution and density of hard-shell clam (Mercenaria mercenaria) for all sizes above 15 mm are shown on a chart of Campbell (see Appendix - page 4 of this report). The New York sector of the Raritan Bay is by far more widely covered with commercial size hard-shell clam. The "sub-legal" size is approximately equally distributed in the N.Y. and N.J. half of the bay. The distribution pattern is irregular and may be related to "setting" as well as physical conditions. In general, the N.Y. area shows 1.05 individual clams per square foot and and the N.J. side only 0.47. For the commercial size, the N.Y.:N.J. ratio is 3:1. The total standing crop was estimated at 3.4 million bushels for N.Y. and 1.4 million for N.J.

The soft-shell clam (Mya arenaria) distributions are shown on a chart taken from Campbell (see Appendix - page 5 of this report). The distribution is even but scattered for "sub-legal" size (smaller than 50 mm). The legal size is less abundant and confined to specific locations. There was no attempt to measure density or standing crop. Campbell's results generally corroborate those of Haskin cited above.

In his report on the geology of the Raritan Bay, DeFalco (1967, Vol. III, Appendix F) mentions populations of live as well as dead shells of the little surf-clam or coot clam (Mulinia lateralis) distributed on both sides of the state boundary line west of a transect from Sandy Hook Point to Fort Wadsworth at The Narrows. The quantity was not estimated.

DeFalco (1967), in addition to using the numbered stations shown on Appendix - page 2 of this report, divided the area near the mouth of the Raritan River into five sections (see Appendix - page 6 of this report). Section A was designated as "polluted" and sections B, C, D, and E were located at 0.5, 1.0, 2.0, and 5.0 miles from section A. As the distance from section A toward the Bay increased, the number of macrobenthic species and their density increased (see Appendix - page 7 of this report). During his 1964 survey, DeFalco used another series of stations covering the area from Sandy Hook Bay to the mouth of the Raritan as shown on a chart taken from his report (see Appendix - pages 8 and 9 of this report). These results show practically no organisms near the Raritan River during the winter. Polychaete worms and some amphipods were observed in appreciable numbers at station B and in the Sandy Hook Bay during the winter. In spring, large numbers of polychaete worms were recorded at all stations. Amphipods at station B and in Sandy Hook Bay were abundant. During the summer, soft-shell clams became the dominant species near the mouth of the Raritan River. The other stations showed a dominance of polychaetes, amphipods, and soft-shell clams. About 5% of the organisms recorded belonged to other invertebrate groups.

The benthic studies on the Arthur Kill were done at the stations shown on a chart of DeFalco (see Appendix - page 2 of this report). The 11-mile bottom from stations 501 to 509 was devoid of macrobenthic organisms. In the entire area there were only seven species and the density never exceeded 800 individuals per square meter. The dominant species was the polychaete worm Polydora which is highly resistant to pollution (see Appendix - page 10 of this report).

In 1971, the Sandy Hook Laboratory of the National Marine Fisheries Service carried out a benthic survey for the Battelle Institute. They sampled at DeFalco's stations 2, 5, 6, 10, 12, 21, 27, and 38 (see Appendix-page 2 of this report). The results shown in a table from the original report (see Appendix - pages 11 and 12 of this report) demonstrate the relative paucity of invertebrate species and density in the center of the Lower Bay. The exception was station 38 near Swinburne Island where 19 species were observed. The polychaete worm, Sabellaria; the slipper shell, Crepidula; the barnacle, Balanus; and the isopod, Cyathura were the dominant species.

In a preliminary report on the Benthic Macrofaunal Census of Raritan Bay, McGrath (1974) used 78 of DeFalco's stations and added eight of his own as shown on a chart from his report (see Appendix - page 13 of this report). Although four seasonal surveys were planned for 1973, the results presented in the report were based on the Jan.-Feb., 1973 collections. He listed 47 species belonging to major invertebrate groups (see Appendix - pages 14 and 15 of this report).

The average number of species per sample was four and the average number of individuals per sample was 11. No sample contained more than 138 individuals. Analysis of species distribution and percent occurrence showed that the Raritan Bay and Sandy Hook Bay are faunistically similar. Two communities could be delineated. Community "A" in the central portion of the Lower New York Bay was dominated by the deposit-feeding bivalve, Tellina agilis, and the polychaete worms, Streblospio benedicti and Nephtys bucera. These and 13 other species (mainly polychaetes; a nemertean; haustorid, but not ampeliscid, amphipods; and molluscs) of less frequency were presented in a table by McGrath (see Appendix - page 16 of this report). Juveniles of the commercial surf-clam, Spisula, were also observed. Community "B" was more impoverished by comparison to community "A" and generally occupied the Western Raritan Bay muds and Sandy Hook Bay muds. Only ten species of worms, snails and bivalves were observed (see Appendix - page 17 of this report). The dominant species were the opportunistic coot clam, Mulinia lateralis; the snail, Nassarius trivittatus; and the worms, Nephtys incisa and Nephtys picta. The commercial hard-shell clam, Mercenaria mercenaria, was also observed at low frequency. Using computational methods, McGrath estimated the density of the Raritan Bay Benthos at 109 organisms/m^2 and considered this to be strikingly impoverished when compared to 2,420 individuals/m^2 as reported by O'Connor (1972) for Moriches Bay, New York and approximately 50,000/m^2 as reported by Phillips (1970) for Barnegat Bay, New Jersey. In addition, he observed that this impoverishment may be due to pollution and low dissolved oxygen during warm months. The absence of ampeliscid amphipods was attributed to the high sensitivity of this group to "chronic low-level oil pollution."

In the Texas Instrument field survey for the projected Liberty State Park (Anonymous, 1976), benthic samples were taken from August, 1975 to June, 1976 at approximately bimonthly intervals near Ellis Island at stations designated on a chart (see Appendix - page 18 of this report). The complete species list was given on a table (see Appendix - page 19 of this report). Some of these species cannot be considered strictly benthic. The density and diversity were tabulated on two tables (see Appendix - pages 20 and 21 of this report). Although the number of species was as high as 42 in October, 88.3% of this benthic population consisted of two polychaete species, Streblospio benedicti, and an unidentified tubificid worm. Five species of polychaete worms and the barnacle, Balanus together accounted for 97.2% of all the benthic animals collected. Mean annual density (individuals/m^2) was 9806 for Streblospio benedicti, 5,394 for the tubificid worm, and 648 for the barnacle, Balanus. For the next four species in the rank order, the density dropped to a range of 98-322. All four were polychaete worms. The rest of the 71 species listed were of very low density, mostly under ten organisms/m^2. It is obvious that the fauna of this area was dominated by a few opportunistic resistant polychaete worms and the barnacle, Balanus. Even though species of commercial or sport fisheries importance were not observed in any significant numbers, the polychaete worms and the other species recorded are known to be important food items for various fishes and birds.

In a recent report on the Raritan Bay, McCormick (1981) reconfirmed the observations of Haskin and also Campbell on hard-shell, soft-shell and tellin clams (these observations were detailed above). Furthermore, he presented a species list which was nearly identical to the species listed by McGrath but in addition included the rock crab, Cancer irroratus; green crab, Carcinus maenas; and the lady crab, Ovalipes ocellatus. These crabs can be of commercial interest. He concluded that there was an increased diversity of macrofauna greater than 1 cm in size and that this was due to the improvement in the "environment health of the Raritan Bay over the last ten years."

Finally, Pearce et al. (1981) have surveyed the benthic macrofauna of the apex region of the New York Bight. This region is entirely outside the scope of the present report but is only mentioned because any large oil spill in the Lower New York Bay could move out of the

Sandy Hook-Rockaway Point transect and impact the relatively rich coastal waters and sea bed within the 100 meter depth. Two other reports (Dean, 1975 and Kasten, et al., 1978) which are pertinent to the macrobenthic fauna of the New York Harbor area have not been located as yet and therefore have not been considered in this report.

In summary, the Raritan Bay-New York Bay Complex has a rich phytoplankton population which is important in the food chain for macrobenthic invertebrates, finfishes and birds. The zooplankton, particularly larval stages within this estuarine nursery area, are highly susceptible to the toxic effects of the soluble aromatic components of crude oil in the range of 1-20 ppm over one to several days of exposure.

The greatest density of zooplankton in general, and larval plankton in particular, are found during the spring and summer months. This is due to changes in salinity, rise in temperature, availability of particulate food, photoperiodicity and reproductive cycles. One may expect that the effect of any major oil spill on this fragile component of the biota will be greatest from March to November. The damage can be lethal, sublethal, direct, or indirect but a detailed description of it is beyond the scope of this synoptic report.

The macrobenthic invertebrate population in the defined Harbor area is relatively impoverished when compared to similar embayments within the New York Bight. This large estuary has 10-70 species with a density of ten to several hundred of nonopportunistic individuals/m^2; other comparable areas have 300-400 species with densities ranging from thousands to tens of thousands of indivuduals/m^2.

While several species of clams and crabs and one species each of mussel, oyster, and scallop of commercial and sport fisheries importance have been recorded in recent years, the economically and recreationally exploitable species are the hard-shell clam, Mercenaria mercenaria, the soft-shell clam, Mya arenaria, and the blue crab, Callinectes sapidus. Although direct commercial shell-fishing in the Raritan-Hudson estuary and adjacent waters has been banned since the outbreak of hepatitis in the early sixties, it is conceivable that, with reduction in pollution, such a fishery can be restored to its previous prominence. Other commercial species such as lobster, oyster, surf clam, bay scallop and crabs, in addition to the three species mentioned above, could reinvade and reestablish themselves. Realistically speaking, however, the only shellfish species of economic and recreational concern for the immediate future are the three species referred to above. Currently depuration plants for hard-shell and soft-shell clams located in Staten Island, N.Y. and Highlands, N.J. do exploit these two species for commercial purposes after a required depuration (or cleansing) period in clean sea water. There are plans for licensing the overland "relaying" of hard- and soft-shell clams from the contaminated areas of Raritan, New York, and Sandy Hook Bays to clean coastal waters such as the Barnegat Bay for subsequent commercial exploitation (Gale Critchlew, N.J. Dept. of Marine Fisheries, 1981, personal communication). Thus, we may regard the defined harbor area not only as an important area for shellfish nursery but also as a rich "feedlot" for filter feeders such as clams which are then commercially marketed after depuration.

The distribution of the hard- and soft-shell clams can vary due to season, "setting," substrate and human disturbance. The available data indicate a rich but patchy bottom distribution, for the Raritan, New York, Sandy Hook Bay complex. Since no clear geographic pattern exists, one is forced to view the entire bottom as inhabited by one, the other, or both species of these clams when considering the possible effects of a large oil spill. Consequently, the waters inside the Sandy Hook-Rockaway Point transect cannot be regarded as a natural sink for a large oil spill.

Crude oil or its components in the water column and on/in the sediment affect clams (and other bivalves) by virtue of the fact that these organisms are filter feeders and have very low self-mobility. They remove particulate matter by a ciliary mucoid process from the incurrent water maintained through the siphon for oxygen transport over the gills. During active pumping, therefore, these animals are exposed to a continuous flow of the dissolved toxic aromatic components of crude oil after a large spill. In addition, oil which is adsorbed to particulare suspended solids can be taken into the gut by the ciliary-mucoid process mentioned above. A third type of exposure to oil is "smothering" by "mousse" which can cover the opening of the clam burrows for days in sandy intertidal regions. This "smothering" proved to be devastating to large clam populations in the Amoco Cadiz spill. Such effects are less dramatic in the case of the blue crab since it is not a filter feeder, does not live in a sandy-mud burrow, and has an appreciable self-mobility in avoiding oil contamination.

While the direct commercial value of the standing crop of shell-fishes in the Raritan, New York and Sandy Hook Bays is limited, their biological value may be extensive. These protected populations within bays can be a source of "seed" to the relatively pristine waters of the New York Bight outside of the Sandy Hook-Rockaway Point transect. Furthermore, these shellfish species are preyed upon by some large finfishes and therefore form important links in the food chain (see next section below).

It is useful to have a rough estimate of the current maximum value of the hard-shell and soft-shell clams in the defined New York Harbor area. If one accepts Campbell's 1967 estimate of the standing crop of hard-shell clam for N.Y. and N.J. at 4.8 million bushels and sets the current value at $90 per bushel, the total maximum worth of the hard-shell clam would be $432 million. For the soft-shell clam, although no estimate of standing crop is available, Haskin (1967) and Campbell (1967) agree that the population largely consists of smaller sub-legal size (less than 2") individuals and the distribution is more limited than the hard-shell clam (see Appendix, page 5 of this report). Thus, a rough estimate of the upper limit of soft-shell standing crop may be half that of the hard-shell clam or approximately 2.5 million bushels. At the current market price of $20 per bushel, the total value is estimated at $50 million. The price of blue crab is about $20 per bushel, but no estimate of standing crop is available.

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2(b)-2- Ichthyoplankton-Pelagic and Benthic Finfishes

The major reports on fish larvae (ICHTHYOPLANKTON) are those of Croker (1965) for the Sandy Hook Estuary; the Texas Instrument survey for Liberty State Park (Anonymous, 1976); a report for the Werner Generating Station by Lynch and Associates (1977); and Esser (1982). Croker (1965) observed eggs and larvae from 20 species of fish representing 16 families (see Appendix - page 22 of this report). Seven species (American eel, Atlantic herring, American sand lance, winter flounder, bay anchovy, northern pipefish, and Atlantic silverside) made up 98% of the larvae. The eggs of searobin and Atlantic menhaden were the most abundant. Eggs were most abundant during May and June while larvae were predominant from March through July. The winter flounder larvae exhibited diel (24 hour) variation, mainly appearing during the night in surface waters. Of the 20 species identified at least 10 are of commercial or sport fisheries interest (Atlantic menhaden, Atlantic herring, bay anchovy, American eel, pollock, tautog, searobin, butterfish, windowpane, and winter flounder). Three species (mummichog, American sand lance, and Atlantic silverside) are important as bait or food for the larger commercial fish.

In the Texas Instrument field report on the Liberty State Park area (Anonymous, 1976), 23 species of fish were identified by their eggs, larvae, or post-larval life stages (see Appendix - pages 18 and 23 of this report). The prominent species were bay anchovy, sand lance, searobin, winter flounder, and hogchoker. Except for the sand lance whose life stages appeared most abundantly during January and February, all other species were recorded mainly between May and September. Lynch and Associates (1977) collected 19 species of fish eggs, larvae or young near the mouth of the Raritan River during April through October, 1976 and March, 1977 (see Appendix - pages 24 and 25 of this report). The only dominant species was bay anchovy (Anchoa mitchilli), which appeared as eggs and larvae mainly in June and July. Esser (1982) lists 12 brackish water species and 12 freshwater species of fish which are resident nonmigratory in the Hudson-Raritan estuary (see Appendix - page 26 of this report). These resident fish and most of the migratory species shown use the estuary as spawning or nursery areas.

In summary, the Hudson-Raritan estuary is an important nursery area for 20-30 species of fish, a number of which are important from a commercial and sport fishery point of view. Eggs, larval, and post-larval stages mainly appear during the spring and summer months. Fish eggs and larvae are known to be highly sensitive to the aromatic hydrocarbons in crude oil. Benzene, the most abundant of these compounds and polynuclear aromatic hydrocarbons have been shown to dissolve in the membranes of fish eggs and act as carcinogens and mutagens. Such action eventually leads to death or abnormal cell division and development. Aromatic compounds tend to adhere to the outer membranes of eggs and alter their permeability. This results in a loss of integrity and eventually death. Sublethal effects on embryos include lowered heart rate and respiration (Sharp et al., 1979). Mortality and cytogenetic effects in cod and pollock eggs were recorded during the Argo Merchant oil spill (Longwell, 1977). In the present state of the art, it is not possible to quantify and economically evaluate the damage.

The major papers and reports covering the benthic and pelagic finfishes of the defined New York Harbor and the rivers which flow into its estuaries are those of Perlmutter et al. (1967); the Sandy Hook Laboratory Report

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(1971); the Texas Instrument field report (Anonymous, 1976); Wilk and Silverman (1976); the reports of Lynch and Associates on the Werner Generating Station (1977) and the Sayreville Generating Station (1977); and a paper by Esser (1982). In addition to the above, the paper of Briggs and O'Connor (1971) on the Great South Bay; the thesis of Gaw (1972) on the Great South Bay and Connetquot River; the paper by Wilk et al. (1978) on the New York Bight and the MESA monograph of McHugh and Ginter (1978) on the New York Bight Fisheries have been found to be useful sources.

In their survey of the Hudson River between Tarrytown and Catskill, Perlmutter et al. (1967) listed 18 species occurring commonly in their

All these species are of commercial or recreational interest except for the bay anchovy which serves as food for larger species. The area of highest density, by numbers or weight, is around DeFalco's station 13 or 14 (see Appendix - page 35 of this report). This area also contains the highest density of the commercially important winter flounder.

In their studies on the impingement of fish at the Werner Generating Station (1977) and the Sayreville Generating Station (1977), Lynch and Associates collected 46 and 61 species of fish at each site, respectively. Although their sampling stations were close to the mouth of the Raritan, the species composition was similar to that described for the Sandy Hook and Raritan Bay (see Appendix - pages 27-31 of this report). The dominant species at all stations were the bay anchovy, blueback herring, Atlantic menhaden, striped bass, white perch, alewife, bluefish, weakfish, and spot. The highest frequency of capture was between April and October for all species.

Esser (1982) reviewed the long term changes, spawning, nursery growth, feeding, and migration of a number of important finfishes of the Hudson-Raritan estuary. He grouped 12 species as brackish water residents and 12 as freshwater residents. Of the 15 migratory fishes, Atlantic menhaden, bluefish, summer flounder, and the American eel spawn in the ocean but the larvae or the young go to the estuary to feed and grow. Bay anchovy, weakfish, scup, and winter flounder spawn in the spring or early summer in the estuary, and the young remain to feed until fall when they migrate offshore. The winter flounder spawn late in winter. The Atlantic sturgeon, alewife, shad and striped bass are all anadromous fishes which migrate into fresh or low salt water to spawn in spring. The young move down into the more salty estuary as they continue their development and feeding. The young may overwinter but the adults return to the ocean in the summer or fall except for the striped bass which may overwinter in the bay. The rainbow smelt and the Atlantic tomcod enter the estuary in fall, the former spawn in spring and the latter in winter. The adults return to the sea after they spawn while the young feed and develop in the estuary.

The foregoing description shows that the Hudson-Raritan estuary is vital to the spawning, larval development, feeding, migration, and overwintering of 40 or more species of finfishes of commercial, recreational, and food-chain value. This value is not limited to the estuary itself but also to the New York Bight as a whole because of the net movement of young fish from this estuary to the open sea.

Due to the self-mobility of the subadult and adult finfishes, mass mortality which may be traced directly to crude oil spills is not recorded in the literature except when fish are trapped under heavy mousse in shallow marsh channels. There is no doubt that exposure to high concentrations, 10-20 ppm, of aromatic hydrocarbons for several days can result in death for most species.

The carcinogenic and mutagenic effect of oil on the developing egg and larva was discussed above. These biological effects could result in malformed or dysfunctional adults. However, there is no factual data for quantitation and economic evaluation of such probable damage.

Lethal and sublethal damage from crude oil and polycyclic aromatic hydrocarbons to adult or young fish has been well established in field observations and laboratory experiments. The uptake and accumulation of aromatic hydrocarbons and the resulting oily taint and enzymatic changes in fish are firmly documented (Stegeman, 1977 and 1978; Mackie et al., 1978;

Rice et al., 1979; Payne and Maloney, 1979; Korn et al., 1979; and Hawkes, 1980). Toxicity is mainly due to mono-, di-, and tri-aromatic hydrocarbons in oils. Alkylation (adding methyl or ethyl groups) of these compounds increases their toxicity. The four ring (chrysene) and five ring (benzo(a)pyrene) compounds are less water soluble and therefore of lower toxicity (Anderson, 1979). Toxicity to some oils may also result from heavy metal contents in crude (Stegeman, 1977).

The accumulation of total hydrocarbons in winter flounder tissue increased from a range of 0-21 ppm in a clean environment, to 7-662 ppm when exposed to a petroleum hydrocarbon environment (Stegeman, 1977). The route of entry is mainly via food and absorption from the intestine although the gills may contribute as a surface of absorption. High concentrations of naphthalenes in the gall bladder and liver of Fundulus similis (killifish) was reported by Anderson (1979). It is known that levels above 200 ppm in the brain can interfere with regulatory mechanisms. These aromatic compounds can rapidly accumulate in a few hours in fish but they are also rapidly released when fish move to clean water. Depuration of naphthalene can be as high as 79% in 24 hours (Neff et al., 1976).

In sensitivity tests on nine species of fish, the pelagic species such as herring and salmon were shown to be more sensitive than benthic species such as flounder. The 96 hour median tolerance limits (96-h TLm- the concentration that killed 50% of the animals in 96 hours of static exposure) was 1.22 ppm for herring, 1.69 ppm for salmon and greater than 5.34 for flounder (Rice et al., 1979). Concentration of toxicant in oil declines faster at higher temperatures due to rapid evaporation and biodegradation. The 96-h TLm of salmon exposed to Cook Inlet crude and toluene, increased as the temperature was raised from 4°C to 12°C, i.e. fewer fish died at the same concentration when temperature was higher and the toxicant evaporated under static exposure (Korn et al., 1979). This implies that exposure to toxicant increases in the cold seasons because of reduced evaporation.

Growth of fish was appreciably reduced when they were chronically exposed to levels of 0.1-0.6 ppm naphthalenes for days or weeks (Anderson, 1979).

Accumulated hydrocarbons can damage cellular and subcellular membranes in liver, intestine, eye tissue, olfactory mucosa, and gonads. These can affect normal metabolism, absorption of nutrients, visual perception of the environment, the chemical senses and fecundity (Stegeman, 1977; Hawkes, 1980).

At the enzyme level, the polycyclic aromatic hydrocarbons (e.g. benzo(a)-pyrene) can increase the activity of hepatic cytochrome p-450, benzo(a)pyrene hydroxylase and aminopyrine demethylase in fish (Stegeman, 1978; Payne and Maloney, 1979). Such enzyme changes were detectable in Fundulus populations even eight years after an oil spill in a restricted marsh in the Buzzards Bay area. The metabolic byproduct of benzo(a)pyrene can be a potent carcinogen by virtue of binding to cellular DNA. However, there is a question as to whether such carcinogens are significant components of crude oil or mainly result from industrial combustion of polycyclic hydrocarbons (Hodgins et al., 1977; Varanosi and Malins, 1977). Details of other sublethal effects of crude oil components on various species of fish such as on interaction of temperature and oxygen consumption of salmon fry (Thomas and

Rice, 1979); production of antifreeze in sea sculpin (DeVries, 1979); basis for differential sensitivity of fish, embryonic stages (Sharp et al., 1979); behavior of fish (Patten, 1977); trout reproduction (Hodgins et al., 1977); and hepatic aryl hydrocarbon dydroxylases (Gruger et al., 1977) are beyond the scope of this report.

In summary, various lethal and sublethal effects of the aromatic components of different crude oils on finfish have been well documented. Assessment of possible or probable damage of a very large oil spill to the finfishes in the defined New York Harbor area depends upon the season, temperature, wind, location, and human response. These factors are further discussed in a following section of this report.

2(b)-3-Birds

Recent compilations of marine and coastal birds for the specific defined New York Harbor area are those reported in the Texas Instrument survey for the Liberty State Park (Anonymous, 1976) and the MESA Monograph (Howe et al., 1978). From September 1975-June 1976, ground observers at various stations in the vicinity of the Liberty State Park reported 18 species of waterfowl for a total number of 10,783 birds (see Appendix - page 36 of this report). In the MESA report at least 28 species of waterfowl are listed for the New York and New Jersey shores. Nearly all of these are hunted and presumably of recreational and food value (see Appendix - page 37 of this report). Coastal areas of New York and New Jersey are in the migration path of many species and serve as breeding grounds and overwintering areas for others.

Accidental oil spill and particularly beaching of oil where shore birds feed and breed has caused mass mortality in nearly all large oil spills on record (see the first section and Appendix - page 38 of this report); for more details see Holmes and Cronshaw (1977). After a catastrophic spill mortality may continue for weeks. Presently harmless noise cannons are available which automatically fire at a set frequency to drive away birds from a restricted zone of spill. This may prove to be an effective temporary preventive measure in a harbor area. Bird watching societies and bird hospitals have been very effective in cleaning and releasing contaminated birds which have trouble flying.

The causes of death may be physical, such as loss of buoyancy due to loss of air between feathers, inability to move feathers in flight and loss of thermal insulation. All of these can interfere with feeding and metabolism. Preening of contaminated feathers results in substantial ingestion of oil and systemic poisoning. Other deleterious effects of oil on eggs and juvenile have also been reported (Albers, 1977; Szaro and Albers, 1977).

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2(c) Develop a biogram to depict the relevant biological activity on a map of New York Harbor as defined.

It is not possible to develop a single biogram to include all the organisms discussed in 2(b). Instead, a series of biograms have been provided in the Appendix of section 2(b) in which the distribution of the relevant organisms are either directly depicted or related to sampling or observation stations.

2(d) Overlay profiles of the existing and projected crude oil discharges in the waters of the New York Harbor onto the biogram developed in 2(c). Specific factors to be considered shall include, among others, the types and amounts of crude oil spilled, the locations of the spills, whether the spill occurrences are episodic or chronic and interactions of prevailing physical factors such as shore and bottom structure, temperature, wind, current, tides and fresh water runoff.

2(e) Provide estimates of damage, if any, to the marine environment due to episodic and chronic crude oil discharges, based upon 2(a) through 2(d). Specifically elaborate on lethal and sublethal effects on marine life in New York Harbor as defined.

Introduction

In this section the effect of accidentally spilled crude oil in types, amounts, frequencies and places as specified by the Port Authority for existing (situation A) and projected (situation B) facilities and navigation channels will be considered and an estimate of possible lethal and sublethal damage to marine invertebrates and vertebrates will be provided.

In situation A, small spills of 42 gallons at Stapleton anchorage (annual frequency of four) and 336 gallons at each of the refinery piers of Exxon (annual frequency of three) and Chevron (annual frequency of two) and a catastrophic spill of 1,680,000 gallons resulting from an underway incident off Bergen Point will be considered. In situation B, small spills of 42 gallons at Stapleton anchorage (annual frequency of two); 336 gallons at each of Exxon (once per year) and Chevron (once per year); 504 gallons at a projected bulk crude oil facility (once per year) to be built either at the Stapleton or Port Jersey site; and a catastrophic spill of 2,814,000 gallons at the Ambrose Channel Dogleg will be considered.

Computer Model and Calculation

A number of computer models were consulted for this report (see Fraser, 1977; Kollmeyer and Thompson, 1977; Milgram, 1978; Grose, 1978; Lissaur and Welsh, 1978; Wyant and Smith, 1978; Spaulding, 1978; Galt, 1978; Raj and Griffiths, 1979; Bishop, 1980; Aravamundan et al., 1981; and Hires and Mellor, 1981). The essential information for predicting the spill trajectories from the specified locations were found in Fraser (1977); Kollmeyer and Thompson (1977); and Hires and Mellor (1981). These and a series of wind and current based manual calculations were used to estimate possible toxic damage to marine invertebrates and vertebrates. The estimates are at best semiquantitative. For better quantitative assessments more extensive field and literature data are needed to drive a computer model programmed to predict not only the direction and spreading of oil in surface trajectories, as most computer models do, but the fate of oil as affected by evaporation, sinking in the water column, sinking in the shore and sea bed sediments, and biodegradation. While surface trajectories are useful for the open sea and large open embayments, they are of little practical value in such waters as the Arthur Kill, Kill van Kull, the Upper Bay, Hudson, and the East River. In these confined waterways, any appreciable spill will rapidly spread from bank to bank except in rare occasions when 10-20 knot unidirectional winds are sustained for several days. For the New York Harbor, which is dominated by narrow waterways surrounded mainly by commercial and industrial waterfront, there is an urgent need for an expanded quantitative and realistic assessment of fates and effects of petroleum spills as I have briefly discussed above.

Type and Amount of Crude Oil

Nearly 80% of the crude oil handled in the New York Harbor is Saudi Arabian crude oil. Of the total Saudi crude, 70% is Arabian Light and 30% Arabian Heavy. The critical volatile and degradation data listed by Bartha (1981) for these two types of crude differ only by 5%. Since other factors to be considered in the effects of crude oil spills can vary much more than 5%, for practical purposes it will be assumed that all crude oil handled in the New York Harbor is and will continue to be Saudi Arabian Light.

Petroleum is a complex mixture of naturally occurring organic compounds which vary in components and composition not only from region to region but even from well to well. Petroleum contains from 50 to 98% hydrocarbons and most crudes are over 90% hydrocarbons. These hydrocarbons are usually divided into three general classes: aliphatic, alicyclic, and aromatic. Since the toxicity of crude is mainly due to its toxic aromatic components, it is desirable to establish an estimate of the quantity of the aromatic fraction. The values for total aromatics found in the literature in percent by weight (Wt%) of crude are 25.0, 16.6, and 21.9 for Prudhoe Bay, South Louisiana, Kuwait respectively (Clark and Brown, 1977); 35 and 30 for Arabian and Iranian respectively (Spooner, 1978). Exxon data on Arabian Light in Volumes% are 1.2 (18/158° F), 10.1 (158/302°F) and 20.9 (302/401°F) (see Appendix - tables of Bartha, 1981). In my estimations of toxicity I have used the value 20 Volume% total aromatics for Saudi Arabian Light. This is conservative because this crude can often be lower in aromatic components and secondly, not all aromatic compounds in this class are toxic to marine invertebrates and vertebrates.

The amount of oil throughput in New York Harbor under situation A is calculated from a typical 85,000 DWT ship with 550,000 barrels aboard paying 160 port visits per year for a total of 88,000,000 barrels per year. Under situation B the projection is for a typical 212,000 DWT ship with 1,400,000 barrels aboard paying 63 port visits per year for a total of 88,200,000 barrels per year. It is expected, therefore, that the throughput will remain approximately constant under both situations but the frequency of incidents underway and possible spill will decrease from one to 0.4 (or 63/160) in situation B. From this point of view situation B is to be preferred.

Environment

The environment, general geography and the currents of the defined New York Harbor have been summarized by Duedall et al. (1979) and Fraser (1977). The nontidal currents are shown on Appendix - pages 39 and 40 and the tidal currents are shown on Appendix - pages 41 and 42 of this report. The areas of interest are:

(1) The lower Hudson- This river has a swift fresh water discharge of 1200-1800 m^3/sec during spring which drops below 200 m^3/sec during late summer and fall. While the nontidal currents are subject to tidal changes, there is a net downstream surface current towards the Upper Bay and The Narrows. The bottom current is generally the reverse. The maximum tidal currents are over two knots. The waterfront is mostly commercial. The estimated surface area between 40° 47' and the Battery is 11.7 km^2.

(2) The East River- This is a narrow waterway with swift tidal currents up to a maximum of five knots. The waterfront is largely commercial. The surface area between Wards Island and the Brooklyn Bridge was estimated at 8.2 km^2.

(3) Newark Bay is a relatively shallow bay of an average depth of 1-2 m. It received a fresh water discharge from the Passaic River at about 70 m^3/sec during spring and 1.0 m^3/sec during the late summer and fall. The maximum tidal currents are about 1.5 knots. The waterfront is mostly commercial. The surface area was estimated at 15.6 km^2 between Droyers Point and Shooters Island.

(4) Upper New York Bay has an average depth of 10-20 m with a net surface current moving toward the Lower Bay and a net bottom current moving toward the Hudson and the East River. Maximum tidal currents are about two knots. The waterfront is mostly commercial but it does include recreational areas. The surface area between the Battery and The Narrows was estimated at 43.2 km^2.

(5) Kill van Kull is a narrow waterway of 150-400 m width and an average mean low water depth of 5 m from Constable Hook Reach to Elizabeth Port Reach. The maximum tidal current is two knots. The waterfront is mostly industrial. The area was estimated at 3.3 km^2 between Bergen Point and Constable Hook.

(6) The Arthur Kill is a narrow waterway of 150-250 m width and an average mean low water depth of about four m from Outerbridge Reach to north of Shooters Island Reach. The maximum tidal current is 1.5 knots. The waterfront is mostly industrial. Its surface area was estimated at 11.7 km^2 between Elizabeth Reach and Wards Point.

(7) The Lower Bay Complex consists of Lower New York Bay, the Raritan Bay and the Sandy Hook Bay. From a biological resources point of view it is by far the most important part of the defined New York Harbor. It receives an annual mean fresh water discharge of about 800 m^2/sec from the combined Hudson, Raritan and Passaic rivers and

a total of 70-90 m^3/sec of sewage discharge from the surrounding cities and waterways. It has a total surface area of about 300 km^2 and an average depth of 5-20 m. There is a nontidal surface current of approximately 0.3 knots moving from The Narrows toward the Raritan Bay and outward toward the open sea. The bottom current is approximately 0.1 knots and moves in the opposite direction toward The Narrows and Staten Island (see Appendix - pages 39 and 40). These weak nontidal currents are very important from a spill point of view since they generally tend to drive surface slicks toward the ocean and oils deeper in the water column and on the bottom toward the Bay. Maximum tidal currents are less than one knot. The waterfronts are a complex of commercial industrial and considerable park and recreation beaches on the eastern side of Staten Island, northern New Jersey, western Sandy Hook coasts and Rockaway Point. The mean maximum surface water temperature in July and August is about 24°C and falls to a mean minimum range of 0-5°C in December to March. The average air temperatures are between 20-23°C from June to September and 0-8°C from November to March. The mean salinity of surface waters between Sandy Hook and The Narrows is about 24.0 ppt with a range of 17-30 ppt depending upon seasonal freshwater discharge. Near the mouth of the Raritan River the mean salinity is 19.0 with a seasonal range of 6.4-24.2 ppt (Sandy Hook Laboratory, 1971).

The resultant winds are on the average, from the northwest from January through March, from the west in April and from the southwest from May through August, from the south in September, and from west-northwest from October through December. Mean velocities for Newark and Kennedy airports range from 8-12 knots and may vary from 0-30 knots. The mean time to change direction is about 3.5 hours.

Toxicity, Risk and Vulnerability Indices

On the basis of an extensive search of the literature cited in sections 2(a) and 2(b) above, I have evaluated toxicity, risk and vulnerability using the following generalized indices:

a) Concentrations of 1-20 ppm crude in water cause 50% mortality to a wide variety of marine invertebrates and fish when exposed for 96 hours under static conditions at 15-20°C. This is known as the 96 hour LC50. At 4-10°C the 96 hr LC50 is at the lower part of the above concentration range because there is less evaporation of toxic aromatics. Larval and juvenile stages may be 3-4 times more sensitive; the range being 0.3-6 ppm.

b) In flowing systems e.g. fish in currents, the toxicity of crude increases appreciably and may be as much as 10-15 times that of static systems or in the range of 0.1-2 ppm crude in water.

c) Mortality in sediment is not appreciable until contamination reaches 1000-7000 ppm (by dry weight). Exposure time may range from one to several weeks. This is not to be confused with the "smothering" effect in which a thick (1-25 cm) layer of "mousse" overlaying a beach can cause a total mortality of the macroinfauna in a matter of days (see Galt, 1978 and section 2(a) of this report).

d) Sublethal effects, uptake and release phenomena have been observed under various exposure-dose conditions. Such effects are highly variable but very important for nutrition, growth, development, and behavior under chronic pollution. It is difficult to assign a "catch all" range of effective concentrations for sublethal damage, however most of the reported cases fall within 1-10% of the 96 hr LC50 dose i.e. a range of 0.01-2 ppm.

e) It is assumed that 1 ml of crude spreads over 1 m^2 of water surface. Levels of hydrocarbons in the water column reported in the literature range from 0.005 ppb (microgram per liter) in the northern Atlantic to 12,700 ppb in Narragansett Bay sewage (Clark and MacLeod, 1977). In confined waters or turbulent waters with high levels of suspended particles, the level of crude in the water column can reach 48 ppm (mg/l) in the upper meter of water within two hours (Cormack and Nichols, 1977). The evaporative loss of crude from the water surface is about 20% during the first day of spill and increases with temperature and wind (Cormack and Nichols, 1977). Crude can take up water rapidly, as much as 83 Vol% in 7.4 hours and thus form a relatively stable mousse. Dispersion of oil from a 0.5 ton spill at practically no wind and a calm sea state can reach 20,000 m^2 after three hours giving 18 ppm of oil in the top 30 cm water column. This self-dispersion can increase considerably with wind and turbulence of a higher sea state (Cormack and Nichols, 1977).

Specific Risk and Hazard Analysis

Refinery piers, 336 gallons spilled; 1-3 times per year, Arthur Kill

Situations A and B

336 gallons = 1,271,760 ml

At 1 ml/m^2 this spill can cover 1,271,760 m^2 of water and is more than enough to cover 1/10 of the entire 11.7 km^2 surface of the Arthur Kill.

Refinery pier at Woodbridge Creek- Spill can spread from bank to bank from Tufts Point to Ploughshare Point in 8-24 hours. Spills at slack water before flood tide will tend to move north toward Newark Bay within two days and before ebb, south toward Raritan Bay. During most of the year the wind effect will increase the impact risk to the western Staten Island coast. During September the winds from the south would beach the oil mostly near Tufts Point on the New Jersey side.

Refinery pier at Goethals Bridge- Spill can spread from bank to bank from Pralls Island to Elizabethport Reach. Spills at slack before flood tide and ebb tide will tend to move north, pass through the Kill van Kull and south into the Lower Bay and past Sandy Hook into open sea by three to five days. During most of the year the effect of wind will increase the risk to the western Staten Island coast, Brooklyn at The Narrows and possibly the tips of Rockaway Point and Sandy Hook. There is a high risk of most of the spill remaining in areas mentioned rather than moving to the open sea. Complete biodegradation estimated by Bartha will take 27.5 days in the summer and approximately 100 days in the winter. Unless human cleanup measures are used immediately after a spill to reclaim the oil, the frequency of one to three spills/year/refinery will tend to create a chronic pollution problem in the vicinity of the two locations.

Biological hazard- The Arthur Kill has a relatively impoverished zooplankton, benthic invertebrates, and finfish fauna. Most of the benthic invertebrates are opportunistic resistant species because of the existing high load of various types of pollutants. The finfishes will tend to avoid the area under oil. The expected hazard would be mainly to zooplankton and particularly the embryonic stages that may feed on the abundant phytoplankton of the Arthur Kill during spring and summer. The size of the spill is small and the concentration of oil in the 1-2 m water column is not expected to go above 10 ppm except during the first few hours after the spill in a limited area of 100,000 m^2. Therefore, substantial mortality is not expected. If the oil is permitted to persist for days or become chronic, we can expect substantial sublethal effects to nutrition, growth, and development of the zooplankton in the region and the area can become devoid of fish by avoidance throughout the year. The spread of oil to Newark Bay, Kill van Kull, and the Lower Bay Complex is not expected to have any substantial effect because of the small size of the spill, evaporation of the toxic aromatics and dilution in the water column. While toxicity tends to persist longer during the winter, there is little biological activity during the winter months.

Stapleton Anchorage- 42 gallon spills two to four times per year

Situation A and B

42 gallons = 158,970 ml

At 1 ml/m^2 this spill can cover 158,970 m^2 which is a small area of the upper bay. All factors, nontidal surface currents, tidal currents, and winds (Oct.-Apr.) will tend to move oil through The Narrows into the Lower Bay and out to the open sea. The oil can beach on the Brooklyn side from Bay Ridge to Fort Hamilton but in negligible amounts. There is little hazard to the biological resources owing to the small size and relatively swift flushing out tendency. Finfishes will avoid the immediate area of pollution for a few days. Situation B is to be preferred over situation A because the frequency of spill is reduced from four to two and chronic low level pollution around the anchorage is reduced. Bartha sets complete biodegradation at 29.7 days but these small spills will be dissipated by evaporation and dispersion in a few days. Human cleanup measures immediately after the spill will prevent a long term low level chronic pollution in the area.

Stapleton or Port Jersey Bulk Facility- 504 gallons once a year

Situation B

504 gallons = 1,907,640 ml

At 1 ml/m^2 this spill can cover 1,907,640 m^2 which is less than 2% of the total area of 43.2 km^2 of the Upper Bay. From October to April there is a high risk of beaching oil on the Brooklyn side from Governor's Island down to Norton Point and during the summer as far as Manhattan and the East River shores due to prevailing winds. This can occur within 8-24 hours. Nontidal surface currents and tidal currents tend to drive the spill through The Narrows into Lower Bay and out to sea within five days. According to Bartha biodegradation is complete in 29.7 days during the summer and about 100 days during the winter.

Biological hazard- Both sites will impact a zone of very high biological activity, phytoplankton, zooplankton, benthic invertebrates especially hard-shell clam and the migration of finfishes of recreational and commercial value. However, the small spill quantity is not expected to create concentrations above 1 ppm for more than one day because of the excellent flushing and dissipation possibilities by physical forces in the area. Immediate human cleanup measures are strongly advocated to avoid residual affects. The once a year frequency preempts a chronic situation from developing. The Stapleton site is to be preferred over the Port Jersey site because of greater depth and proximity to The Narrows with its good currents driving to open sea.

Situation A

Bergen Point, Catastrophic underway spill of 1,680,000 gallons

1,680,000 gallons = 6,358,800,000 ml

At 1 ml/m^2 this spill can cover 6,358,800,000 m^2. This is 16 times the estimated total area of the defined New York Harbor inside the Sandy Hook-Rockaway Point transect. If evenly spread over the actual area, it will be 16 mm thick (assuming 1 ml/m^2 has a 1 mm thickness). If evenly dispersed through the water column of the entire defined harbor, it will be 16 ppm at 1 m depth, 1.6 ppm at 10 m depth, and 0.8 ppm at 20 m depth. These concentrations are all within the lethal and sublethal range for marine animals. Realistically the spill will impact all the shores of the Arthur Kill, Newark Bay, Kill van Kull and most of the Upper Bay within one to two days regardless of weather or current conditions. From October to April the wind will tend to drive the oil southeast by east from Newark Bay on the Bayonne and Jersey City waterfront. Oil will pass through the Kill van Kull into the Upper Bay and impact the Brooklyn waterfront from Gowanus Bay to Norton Point. It has a high probability of entering Rockaway Inlet, beaching on the northern shores of Rockaway and the tip of Sandy Hook before it goes out to the open sea. From May to September the oil will be driven by prevailing winds in a north by northeast direction deep into Newark and Upper Bays and the respective rivers flowing into them. In the confined shallow bays and waterways mentioned, the entire water column can become contaminated above 10 ppm (2 ppm aromatic equivalent) over several days and oil will enter the bottom sediments and beaches above toxic levels. Since the nontidal bottom currents move salt water inward toward the river mouths in an estuary, the sinking oil will be driven shorewards and will tend to repercolate repeatedly to the surface and threaten various waterfronts and beaches at floodtide for days or weeks. All the confined waters will become anoxic due to oil biodegradation and biodegradation itself will then operate at the very low anaerobic rate, taking more than a year to completely biodegrade most of this oil. Thick "mousse" and "pancake" formation are highly likely from October to April.

Biological hazard- All the zooplankton and finfishes trapped above The Narrows under such a spill will perish from anoxia and oil toxicity within five days. Smothering mousse could cover much of Fresh Kills, Great Kills, Bayonne, Lincoln, Liberty, Breezy Point, and Sandy Hook parks. Jamaica Bay Wildlife Refuge and all the beaches of the Lower Bay complex would be impacted by mousse. During spring and summer high mortality of embryonic and juvenile stages of the migratory fish which use these nursery embayments for feeding and protection would occur (see section 2(b) and Appendix - page 26 of this report). In any period when the northwesterly winds subside and the oil remains in the lower bay for days, 1/3 to 1/2 of the standing crop of the hard-shell and soft-shell clams, especially the younger individuals, will perish. The effects of such a spill can last for years in confined bays, rivers, and waterways. The immediate dockside value of the destroyed finfish and shellfish may run into several hundred million dollars. The total generated and recreational value can run into a billion dollars. Normally, the effect of such a spill would be far more devastating if it occurred from April to October. All possible human measures for prevention and cleanup of such a catastrophe is strongly advocated. Damage outside the Sandy Hook-Rockaway Point transect can occur but is outside the scope of this report.

Situation B

Ambrose Channel Dogleg, Catastrophic underway spill of 2,814,000 gallons

2,814,000 gallons = 10,650,990,000 ml

At 1 ml/m^2 this spill can cover 10,650,990,000 m^2. This is more than 27 times the estimated total area of the defined New York Harbor inside the Sandy Hook-Rockaway Point transect and if evenly spread over the actual area, it will be 27 mm thick. If evenly dispersed through the water column of the entire defined harbor, it will be 27 ppm at 1 m depth, 2.7 ppm at 10 m and 1.35 at 20 m. If evenly dispersed through the water column of the Lower Bay only, the concentration at 1 m depth will be 35.5 ppm, at 10 m, 3.55 ppm, and at 20 m 1.8 ppm. These concentrations are all above the 96 hour lethal range for marine invertebrates and finfishes. Between October and April, such a spill will tend to be driven out to sea by the combined physical forces of prevailing northwest winds, surface currents and tidal excursions. Sandy Hook, Rockaway Point and the Atlantic Coast of northern New Jersey can be severely impacted. Since the winds can diminish or shift, the probability is very high that within one day all the coasts surrounding the Lower Bay Complex will be impacted. There is some probability that oil will move up to the Upper Bay. Between May and October the winds tend to be from the southwest and south and will counter the seaward surface and tidal current. The oil is certain to severely impact all the waterfront of northern New Jersey, eastern Staten Island and move into the Upper Bay to Governor's Island and possibly even into the Hudson and the East Rivers. Anoxia can develop in all or parts of the Lower Bay Complex and the Upper Bay within a day. As the oil sinks, the bottom currents will drive it inward to Staten Island and the mouth of the Raritan and the Upper Bay. This oil will eventually surface as it repercolates. Thick mousse and possibly pancakes will form inside and outside of the Lower Bay and, as they are lifted and deposited on the beaches and marshes by the flood and ebb tides, they will smother all the trapped animals.

Biological hazard- During the winter months the damage will be mainly to the hard-shell and soft-shell clams and other bivalves (see section 2 (b)) which inhabit the bottom of the Lower Bay, Sandy Hook Bay and the Raritan Bay. If the winds move the oil rapidly out to sea before much sinking can take place, this damage will be small. If the oil persists for days or weeks and sinks within the Lower Bay Complex, 50 to 80% of the standing crop of hard-shell and soft-shell clams could perish. The concentrations of the aromatic components can reach 1 ppm throughout the 0-10 m depth area where these animals live (see Appendix - pages 4 and 5 of this report). During the spring and summer there is a high level of biological activity in the Lower Bay Complex. Even though the high temperature favors rapid evaporation of the spill, the winds are not favorable for pushing the spill out to sea. Severe anoxic conditions have a very high probability. The combination of anoxia, toxic aromatics, entrapments within confined waters, and high metabolic demand for food and oxygen will cause mass mortalities of zooplankton, invertebrates, finfishes, and birds. The survivors will be affected sublethally. The oil in sediment and its effects can last a long time and the loss of embryos and juveniles can affect the fisheries stocks in the New York Bight. The economic value can range from several hundred million dollars at dockside prices to several billion dollars of total generated commercial and recreational value. Every human effort should be exerted to prevent and clean up a catastrophic spill such as this.

In terms of the probability of the rapid movement of the spill through the Sandy Hook-Rockaway Point transect and into the open sea for faster evaporation, dispersion, and biodegradation, situation B is to be preferred over situation A.

Ecological values and recovery after spill

In spill analysis, there is a tendency for emphasizing the immediate economic losses and damages because long term effects on the environment are difficult to measure and evaluate. The value of zooplankton and small invertebrates in the pelagic and benthic food chain of valuable fishes and birds of the New York Harbor area is well established (see Appendix - pages 43, 44, and 45 of this report). Damage to these food organisms is often ignored. In many pollution studies, it has been well established that espisodal or chronic pollution can upset the ecological balance and permit opportunistic species to take over an area (Sanders et al., 1980). Recolonization and recovery after an oil spill continues to be a subject for much study and debate (Southward and Southward, 1978; Mann and Clark, 1978). Recovery appears to be related to the extent of entrapment and persistence of oil in an environment after a spill. Recovery from natural crude oil alone has been swift on exposed shores where physical forces rapidly evaporated, dispersed and helped the biodegradation of the spill (see section 2(a) of this report for Torrey Canyon, Amoco Cadiz, and Santa Barbara). In other cases where oil was trapped in marshes and sediments the recovery has been very slow and may take six to ten years (see Mann's estimate in Appendix - page 46 of this report). In addition, lethal and sublethal damage as well as recovery are related to the existing load of hydrocarbons and other pollutants in an environment. The nature of this relationship is not always clear. In some cases, biological resistance develops and in other cases the pollution stresses are additive or synergistic (Searl et al., 1977; Teal et al., 1978; Keizer et al., 1978; Koons and Thomas, 1979; and Multer, 1981). New York Harbor, like so many major harbors, is exposed to a variety of heavy metals, PCBs, and other pollutants besides oil. The interaction of such pollutants, especially under chronic conditions, and the resulting damage is beyond the scope of this report.

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2(f) - Review mitigation measures to counter the effects found in 2(e) and identify those that may be used in New York Harbor.

Mitigation measures in confined bodies of water such as New York Harbor basically consist of well organized and highly sustained efforts of prevention, containment, and cleanup. The use of dispersants in waters inside the 25 mile limit is to be strictly avoided because of the short term and persistent high toxicity of these compounds to biodegraders, invertebrates, finfishes, and birds (see section 2(a) of this report under Torrey Canyon; Kiceniuk et al., 1978; Thompson and Wu, 1981; Rowland et al., 1981). Organic dispersants and powdered chalk which were successfully used to disperse and sink oil in offshore areas covered by the Torrey Canyon, the Amoco Cadiz, and the IXTOC-I oil spills and blowout (see 2(a) above) cannot be recommended for the waters of the New York Harbor as defined in this report. The low average depth, small total size, sluggish circulation, slow water turn-over, and the extant pollutant load in the sediment (insecticides, herbicides, heavy metals, and petroleum hydrocarbons) all further reinforce the view that these bays cannot be treated as sinks for large oil spills (Duedall et al., 1979; McCormick, 1981). Therefore any major spill within the defined harbor would have to be contained by booms and reclaimed by skimmers.

Although every spill is to be cleaned up when prevention fails, the environmental concern should emphasize the large spills which overtax the natural, physical and biological self-cleaning processes in a region. Prevention of large spills is mainly the function of navigation equipment, tanker design, weather and waterway conditions and avoidance of human error. At present, the regulations governing the standards for the above are adequate if they are observed and enforced. New York Harbor has had a good record in this respect (Wirkowski, 1981).

Containment and cleanup in New York Harbor must be swift because dissolution, dispersion and sinking of oil in the water column is directly a function of time and suspended solids. Physical surface, wind, temperature, and sea state will have mixed effects. Excellent methods and equipment for booming and skimming are now available to reclaim spilled oil from water surface (Fraser, 1977; Milgram, 1977; Wirkowski, 1981; Farlow and Griffiths, 1981; and section 2(a) of this report under IXTOC-I).

Specific boom designs and skimmers have been proposed for the conditions of New York Harbor. Strategic points of storage for ready mobilization of such equipment, and sensitive impact areas where the booms would be deployed have been mapped by Fraser (1977). Organizational details and further utilization of equipment and boats at the disposal of the "Clean Harbors Cooperative" have been given by Wirkowski (1981). These proposals and measures are commendable, but do not go far enough. Presently, the maximum sized spill planned for is a 40,000 barrel (1.68 million gallons) incident. Given such a spill, "Clean Harbors Cooperative" would attempt "to clean up the 40,000 barrels of free oil on water in five days, excluding shoreline and bulkhead cleaning." Such a response is insufficient in two respects. Both Frazer (1977) and Kollmeyer and Thompson (1977) have projected high levels of shore impact within one day for large spills in New York Harbor. Bartha, Hires, Mellor, and I currently agree with these projections. Therefore a central agency is needed to coordinate and execute shore and waterfront cleanup and prevent long drawn out tidal cycles of shore to water and water to shore oil contamination. Secondly, in a large spill the damage to biological resources will be 50 to 90% within five days and especially severe during the spring and summer. Every attempt should be made to reclaim the bulk of the oil from a large spill in the defined harbor in three days. This entails more equipment and trained manpower than is available under the "Clean Harbors Cooperative" program. No part of the defined harbor can be treated as a large hydrocarbon sink because the bottom currents are inward and there is little flushing out to sea; biodegradation and recovery will be slow and some areas of these bottoms are already burdened with hydrocarbon loads.

Finally, I strongly recommend regular four season surveys of the biological resources and pollution load of the waters, beaches and the benthic areas of the New York Harbor to be done at least at five-year intervals so that reliable baseline data are available for comparison of the state before and after spill and for realistic assessment of spill damage. During a large spill, funds should be made available to scientists to sample and analyze the progress of cleanup and damage.

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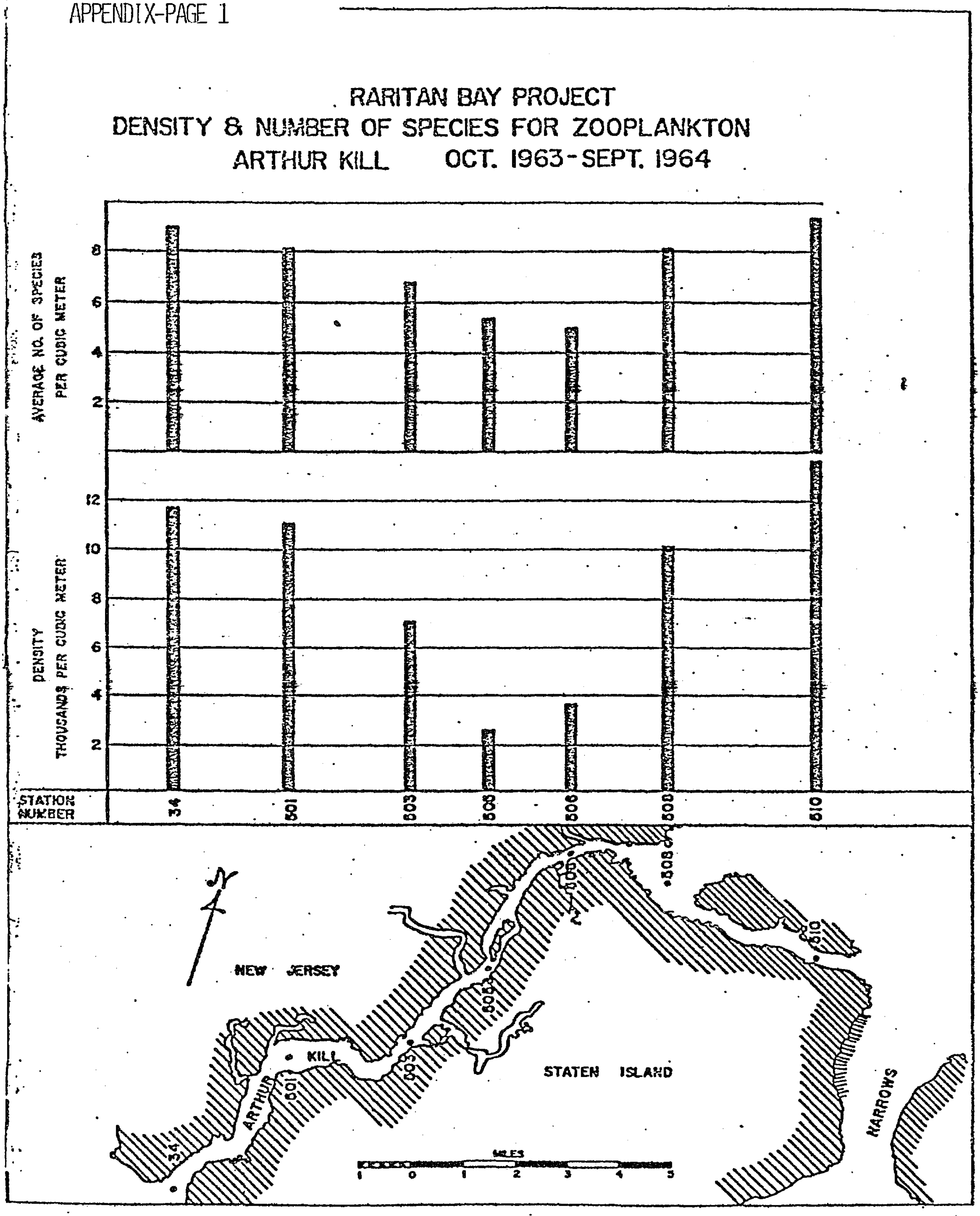
STATEMENT OF QUALIFICATION

The Senior Consultant, A. Farmanfarmaian, was trained in the Physiology of Marine Animals at Hopkins Marine Station of Stanford University where he received his doctorate. He has organized and taught a variety of courses in marine zoology, ecology, and ecological physiology at several well known marine laboratories in the U.S. (MBL, Woods Hole; HMS, Pacific Grove; Santa Catalina Island, Beaufort). He has given seminars and lectures on his research in Europe, Japan, and numerous institutions in the U.S. He has published over 70 papers, reports, presentations, and reviews, most of which are on the physiology, biochemistry, nutrition, aquaculture, and environmental hazards of marine and fresh water animals. These papers and reports have included works on the effects of chlorine, Hg, Cd, oil, and high temperature on aquatic animals, specifically from the Raritan Bay and other U.S. Atlantic coastal waters. Currently (1980-81) he is directing a NOAA research project on the sublethal effects of heavy metals on nutrient absorptions in fish from the New York Bight area. He has acted as a consultant to industry (thermal discharges, oil transshipment, and deep water port), State of New Jersey, and private individuals or groups.



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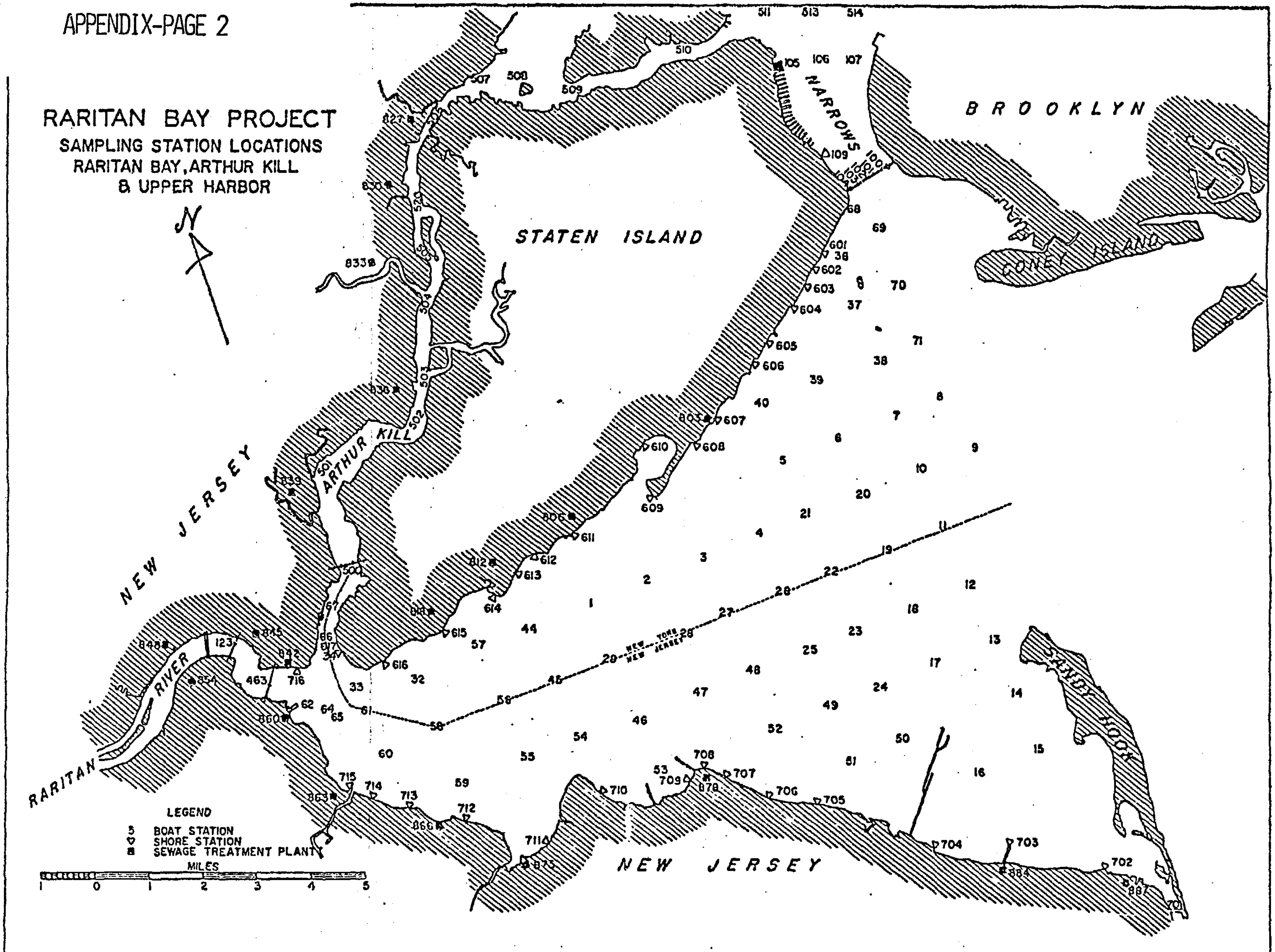
APPENDIX-PAGE 2



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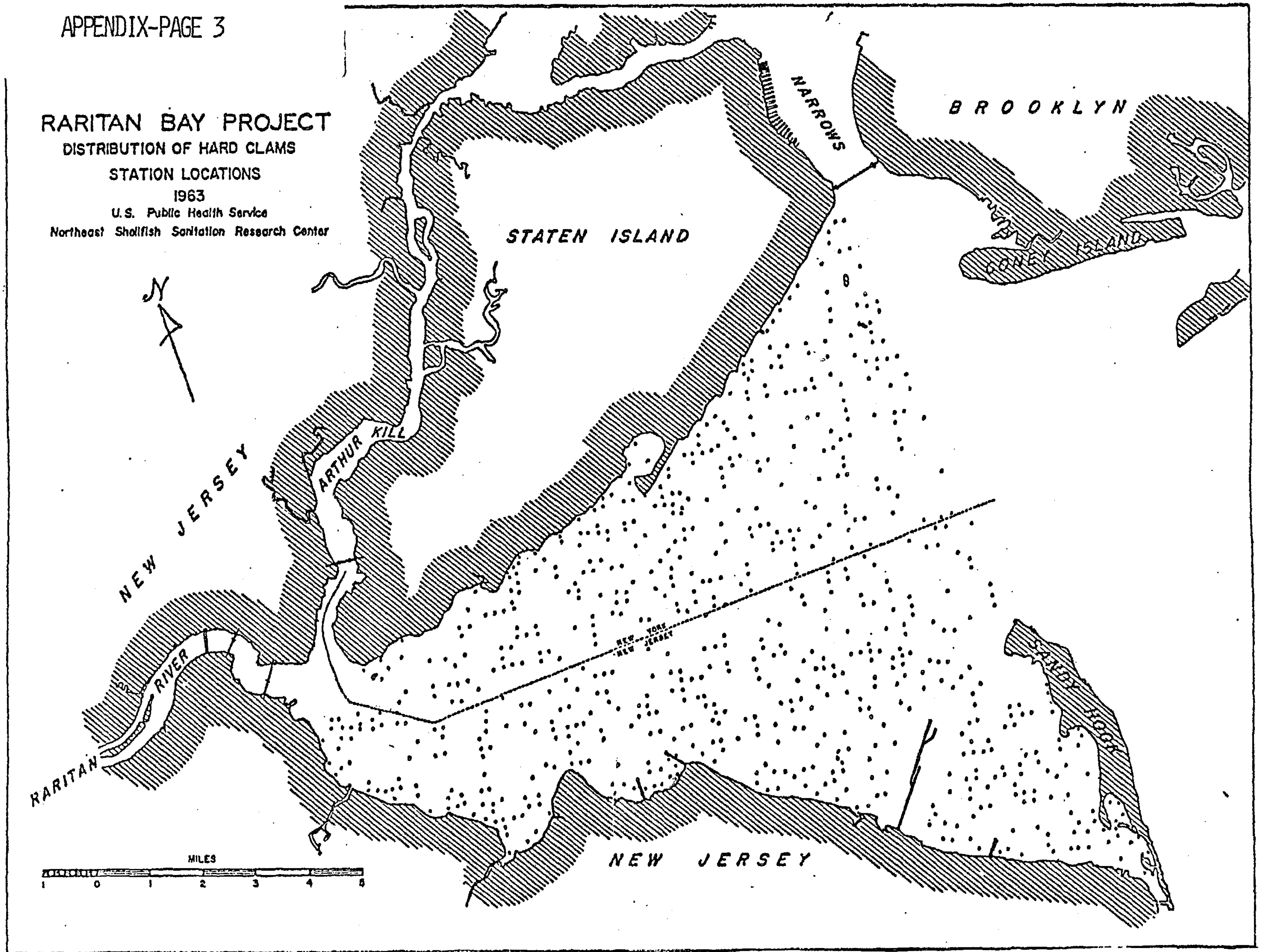

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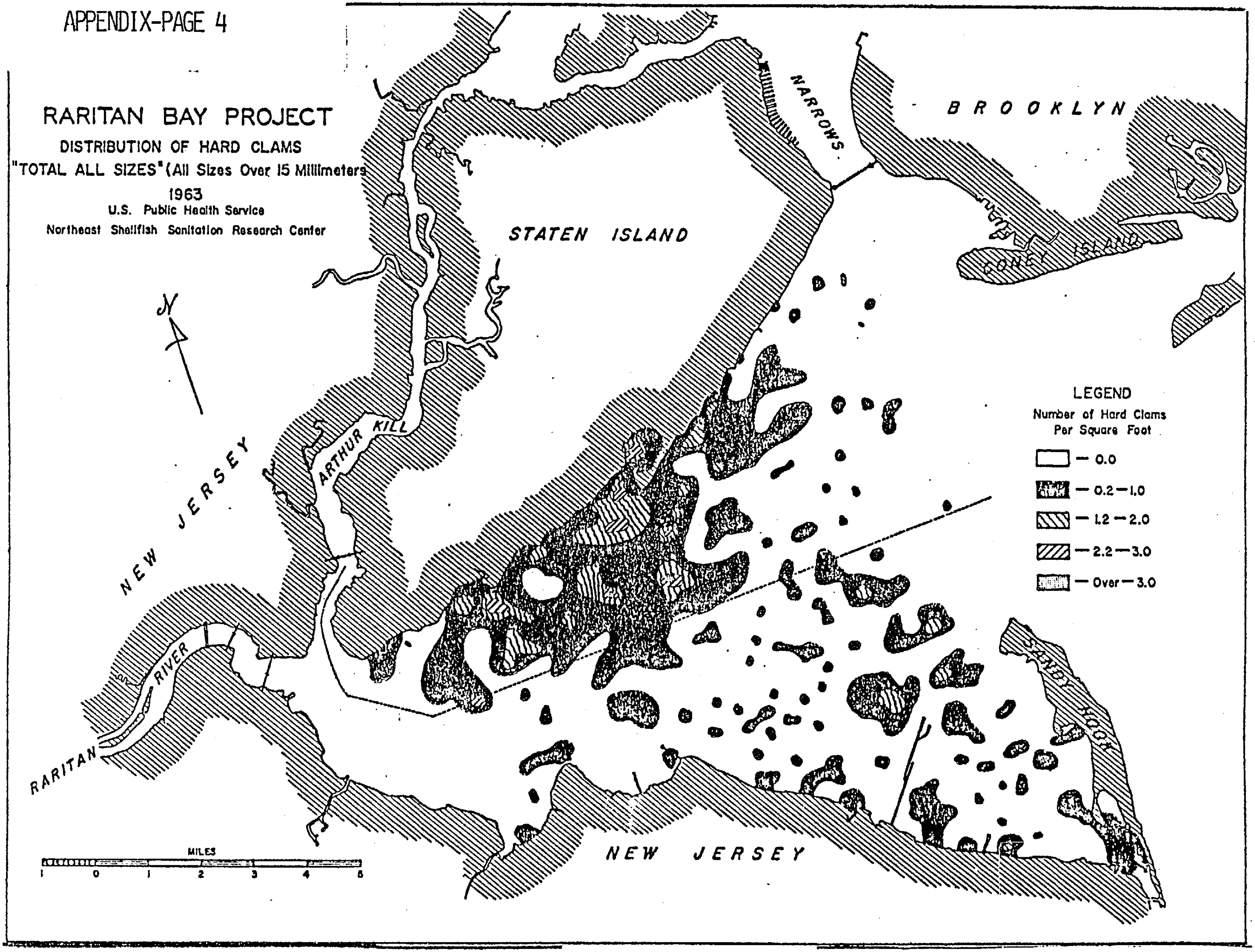

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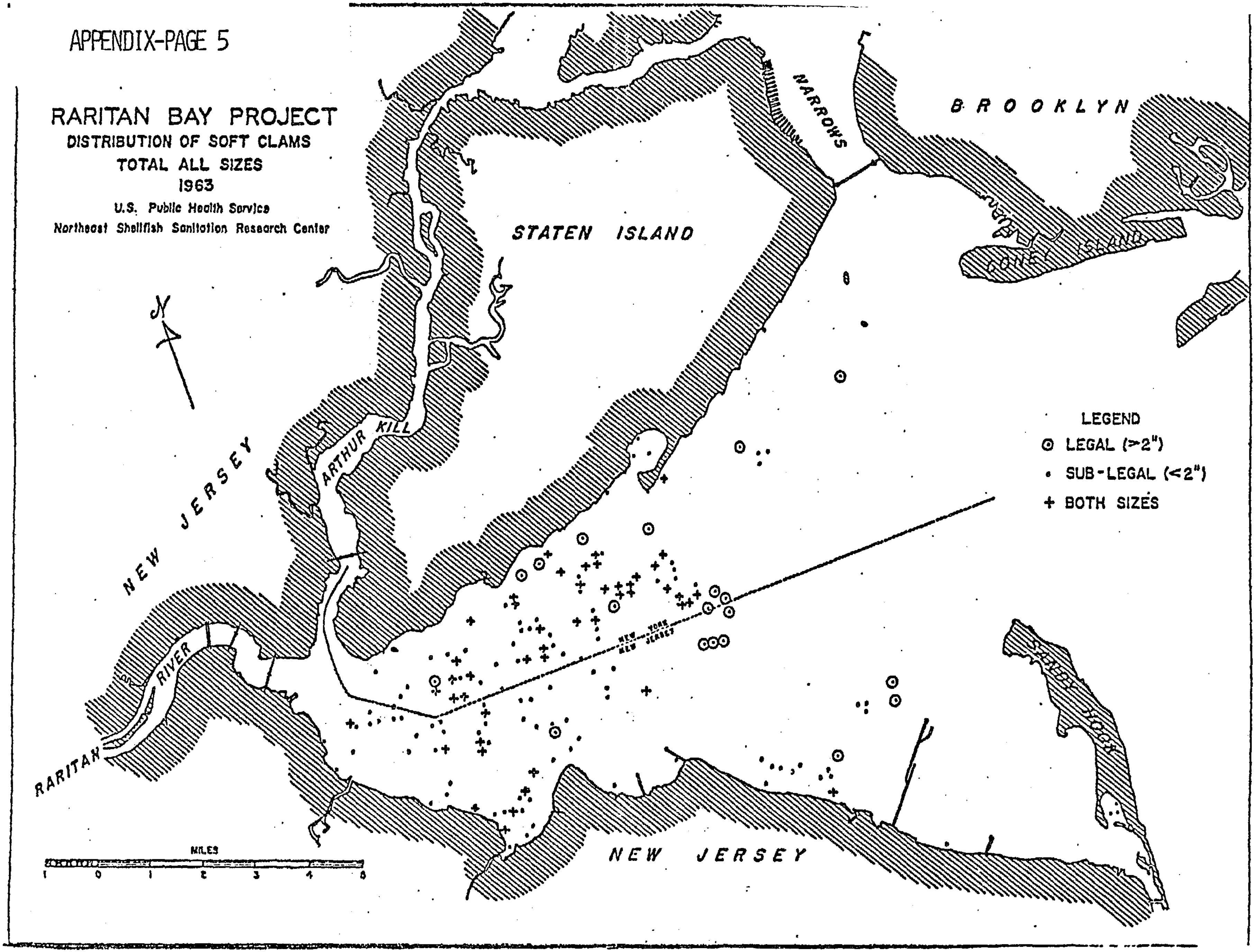

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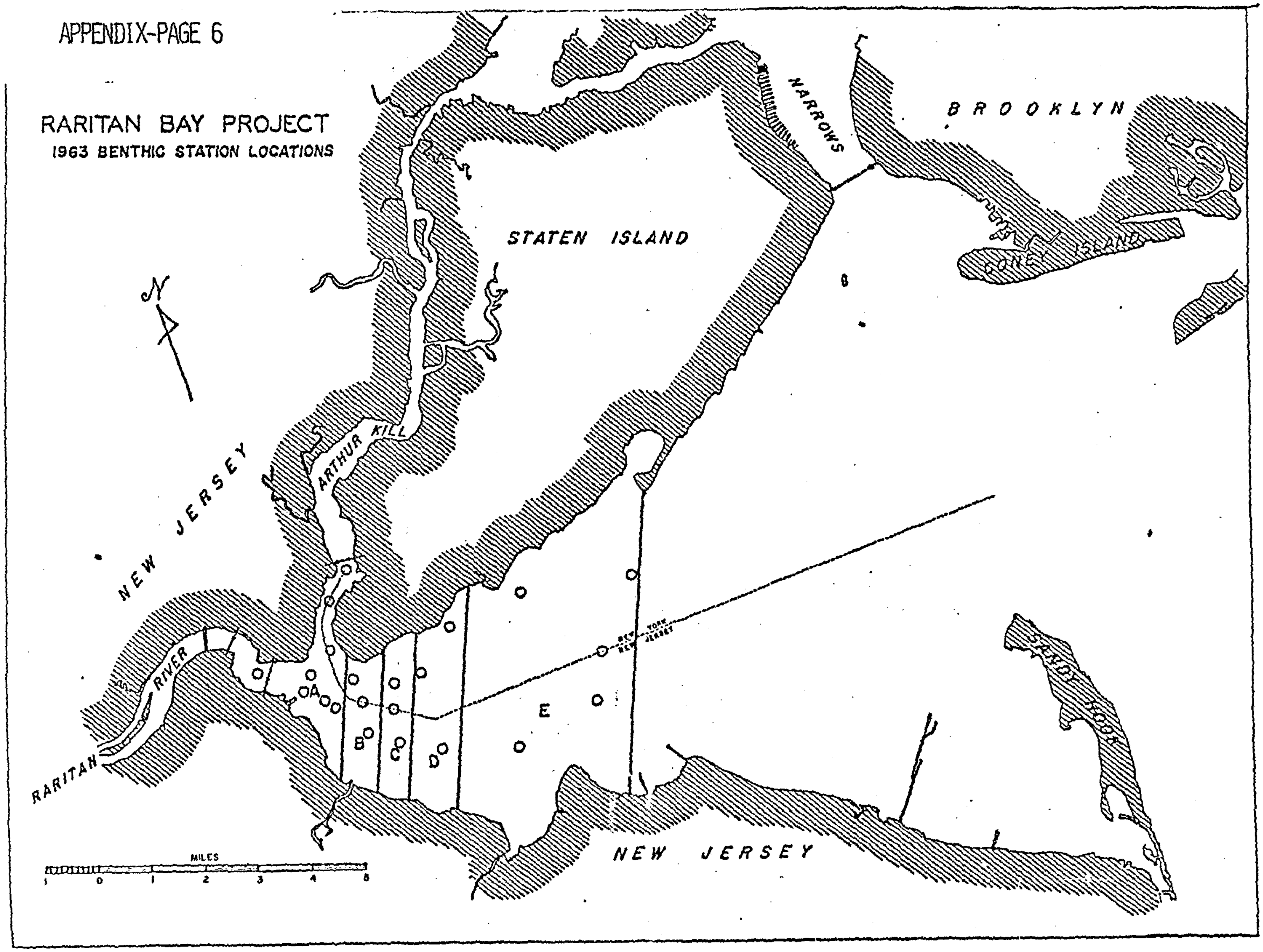

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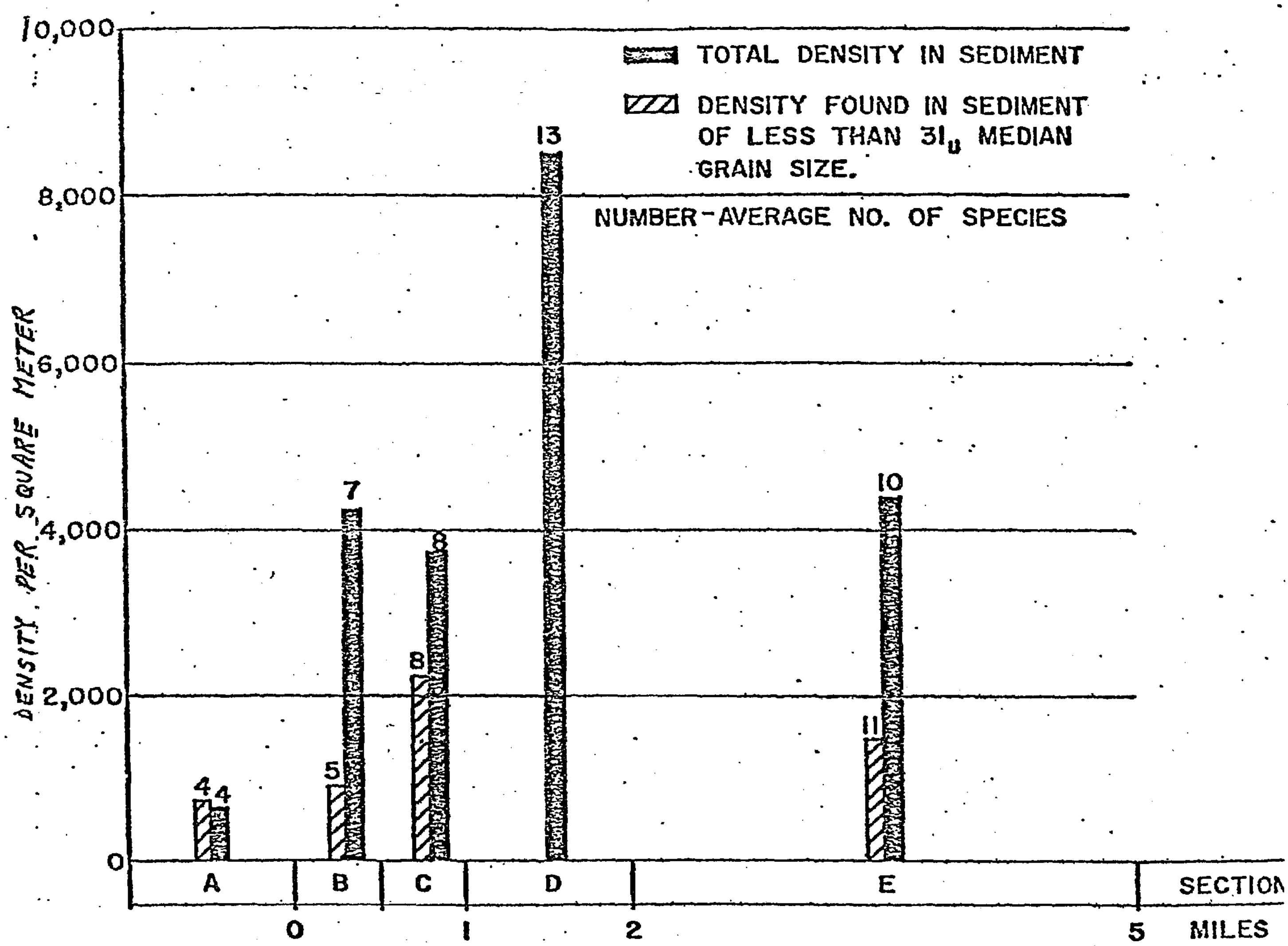
BENTHOS AVERAGE DENSITY & NUMBER OF SPECIES
JUNE-AUG. 1963



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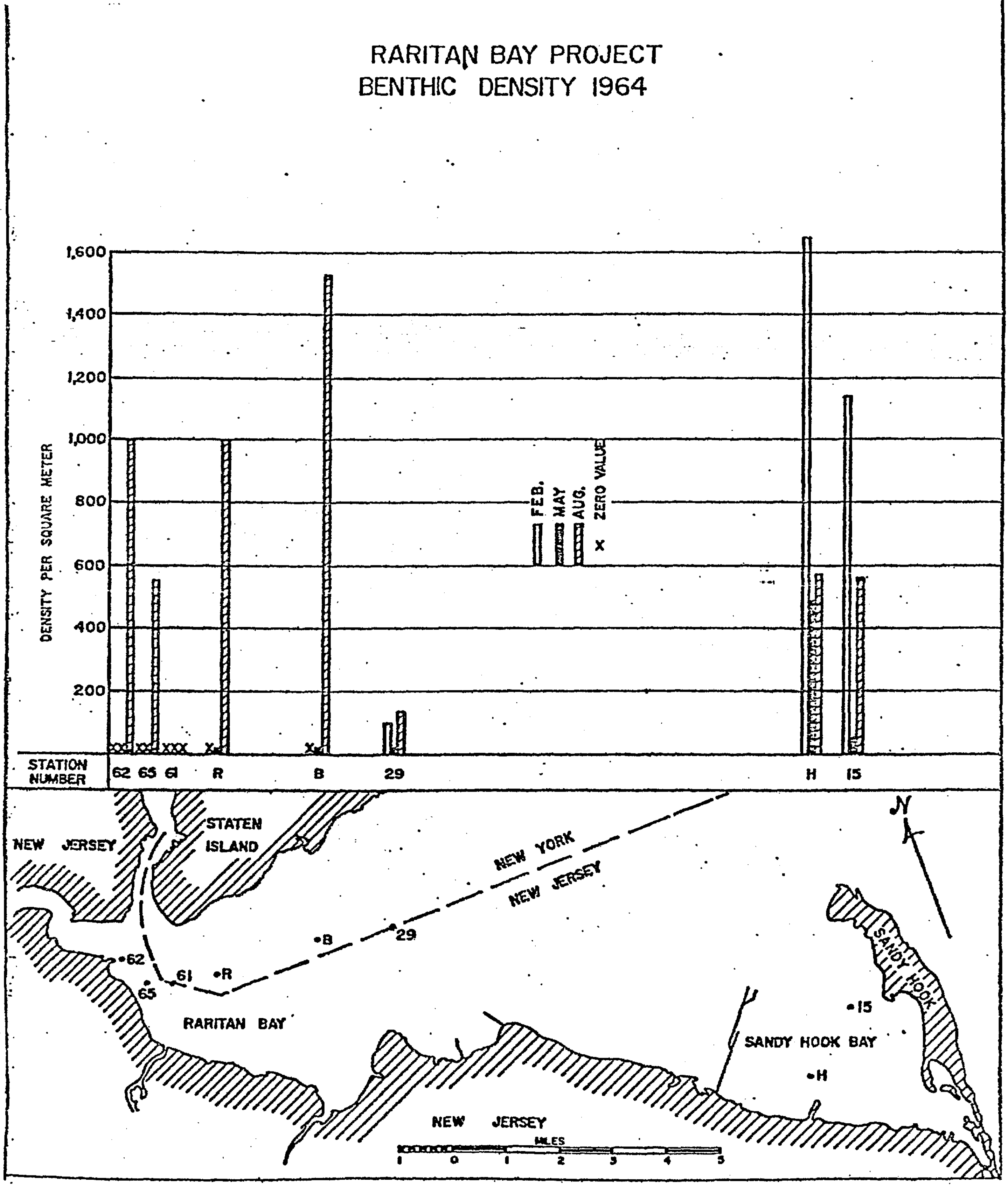


FROM DEFALCO, 1967.

PERCENTAGE OF BENTHOS AT REPRESENTATIVE STATIONS

	Station 62				Station B				Station 29				Station H			
1964	PW	AC	SC	O	PW	AC	SC	O	PW	AC	SC	O	PW	AC	SC	O
Feb.	0	0	0	0	76	6	0	18	67	17	0	16	8	92	0	0
May	100	0	0	0	65	15	0	20	33	66	0	1	15	85	0	0
Aug.	0	0	100	0	35	28	10	27	74	19	7	0	55	38	0	7

PW = Polychaete Worms
AC = Amphipod Crustaceans
SC = Soft Shell Clams
O = Others: All types of organisms that comprised separately less than 5% of the total.

FROM DEFALCO, 1967.

ARTHUR KILL BENTHOS SURVEY

October 1963

Sta.*	Av. No's/M^2	Av. No. Species/M^2	Dominants	Odor	Observations
34	95	1.5	Polychaetes	Slight oil	Small shells (¼"-½"), wood
500	175	5.3	Polychaete	Slight oil	No shells, plant material
501	0		-	Oil	Few Mya SHELLS (¼"), plant material
502	3	0.3		Oil	No shells, plant material
503	0		-	Oil	No shells, little plant material
504	0		-	Oil	No shells, little plant material
505	0		-	Oil	Little plant material
520	0		-	Oil	Nothing
506	0		-	Oil	Little plant material
507	0		-	Oil	Nothing else
508	3	0.3	Polychaetes	Oil, H_2S	Nothing else
509	582	4.0	Polychaetes	Oil, H_2S	2 Mya shells (1"), little plant material
510	594	8.7	Polychaetes	Oil, H_2S	Plant material

FROM DEFALCO, 1967.

*For station locations see APPENDIX-PAGE 2.

SPECIES (31 taxa)	STATION 2	5 a	5 b	6 a	6 b	10	12	21 a	21 b	27	38 a	38 b
Hydractinia echinata											2	
Cerebratulus sp.					1	1		1				
Nematoda							6					1
Aricidea jeffreysii									3			
Cirratulidae			1	1	1		1					2
Glycera sp.	2	2	1		1			1	1	1	1	1
Lumbrineris sp.				1								
Nepthys incisa					1	1		1	2		1	
Nereis sp.		1								4	1	1
Orbiniidae					1	1						
Pectinaria gouldii										2		
Phyllodocia sp.											1	4
Polynoidae			1									
Sabellidae			1									
Sabellaria vulgaris		18	143							73	184	138
Spio setosa					1			1			4	11
Streblospio benedicti		5	3									13
Crepidula fornicata		3	10					1		2	2	1
C. plana			21				2	2	1	4	45	3
Nassarius trivittatus	1		3	1						3	6	6
Epitonium sp.											1	1
Tellina	1			9	10		2	4		4	4	6
Mercenaria mercenaria										1	1	
Spisula solidissima							4					

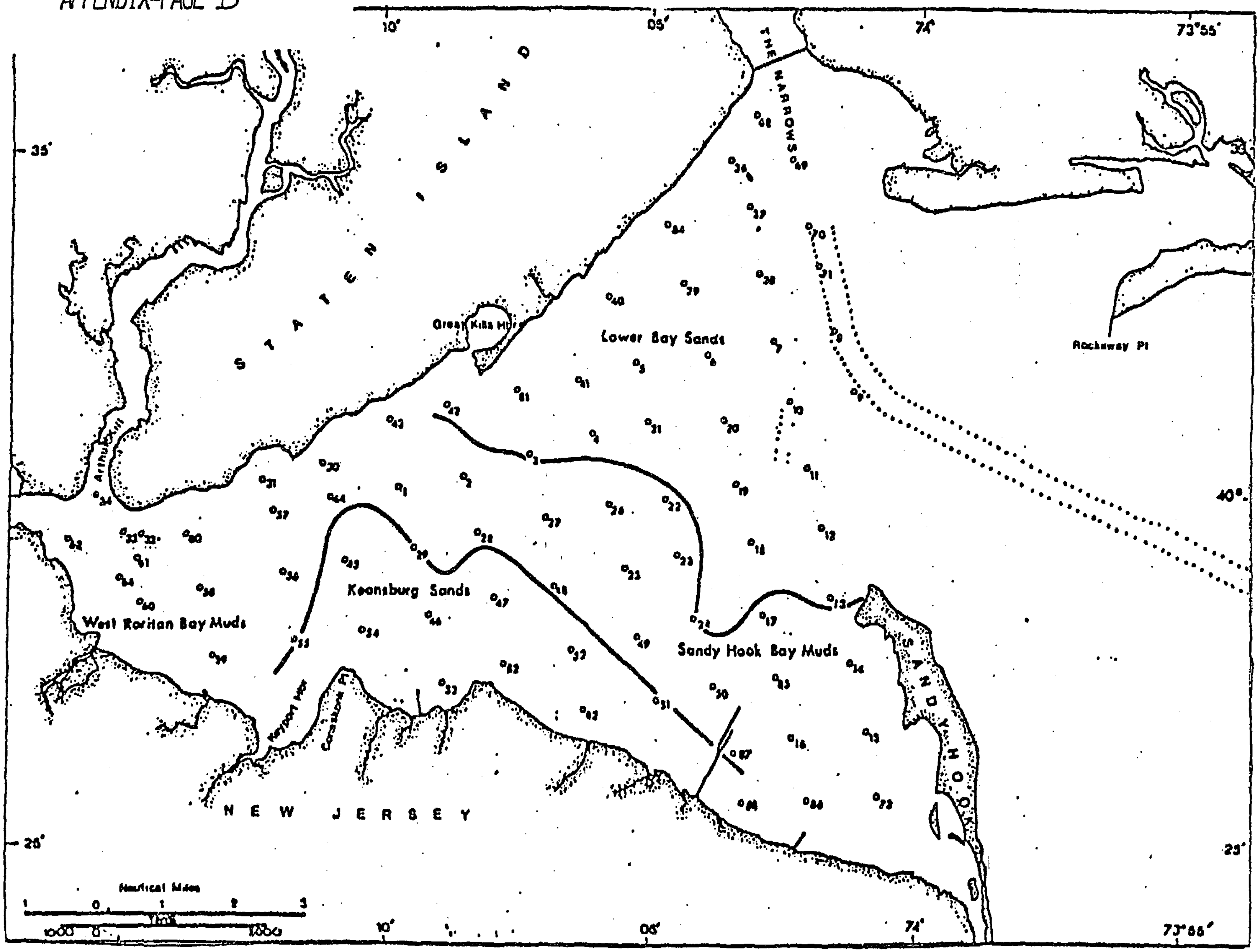
(cont'd on APPENDIX-PAGE 12)

BENTHIC ANIMALS (cont'd)

SPECIES (31 taxa)	STATION 2	5 a	5 b	6 a	6 b	10	12	21 a	21 b	27	38 a	38 b
Balanus improvisus	15	2	3								20	
Cyathura carinata					1							
Unciola serrata			7		1				1	1	17	1
Pagurus longicarpus			1							1		
Cancer irroratus											1	
Rhithropanopeus			3							2	2	
Pseudopleuronectes americanus				1								

FROM SANDY HOOK LABORATORY SURVEY, 1971.

BENTHIC STATIONS



FROM MCGRATH, 1974.

Raritan Bay Species List

Cnidaria
- Hydrozoa spp.
- *Metridium senile*

Nemertea spp.

Nematoda spp.

Ectoprocta spp.

Bivalvia
- *Astarte borealis*
- *Mercenaria mercenaria*
- *Mulinia lateralis*
- *Mya arenaria*
- *Spisula solidissima*
- *Tellina agilis*

Gastropoda
- *Lunatia heros*
- *Nassarius trivittatus*

Oligochaeta spp.

Archiannelida spp.

Polychaeta
- *Aricidea succica*
- *Cirratulis grandis*
- *Eumida sanguinea*
- *Glycera dibranchiata*
- *Lumbrineris* sp.
- *Magelona rosea*
- Maldanidae sp.
- *Nephtys bucera*
- *Nephtys caeca*
- *Nephtys incisa*
- *Nephtys picta*
- *Nereis pelagica*
- *Pectinaria gouldii*
- *Pherusa affinis*
- *Polydora ligni*
- *Sabellaria vulgaris*
- *Scolecolepides viridis*
- *Spio filicornis*
- *Spio setosa*
- *Spiophanes bombyx*
- *Streblospio benedicti*

(cont'd on APPENDIX-PAGE 15)

RARITAN BAY SPECIES LIST
(cont'd)

Cirripedia
Balanus improvisus

Amphipoda
Acanthohaustorius millsi
Jassa falcata
Paraphoxus epistomus
Protohaustorius (?)*deichmannae*
Unciola serrata

Tanaidacea
Leptochelia savignyi

Isopoda
Edotea montosa

Cumacea
Diastylis sculpta
Oxyurostylis smithi

Decapoda
Crangon septemspinosa

FROM MCGRATH, 1974.

Composition of Raritan Bay "sand" community. Percent occurrence as major (>10%) fraction of sample.

Species	% major fraction
Tellina agilis	63.6
Streblospio benedicti	36.4
Nephtys bucera	31.8
Nemertea spp.	22.7
Nassarius trivittatus	22.7
Glycera dibranchiata	22.7
Protohaustorius (?) *deichmannae*	18.2
Spio (?) *setosa*	13.6
Polydora ligni	9.1
Scolecolepides viridis	9.1
Nephtys incisa	9.1
Spisula solidissima	4.5
Mulinia lateralis	4.5
Edotea montosa	4.5
Paraphoxus epistomus	4.5
Acanthohaustorius millsi	4.5

FROM MCGRATH, 1974.

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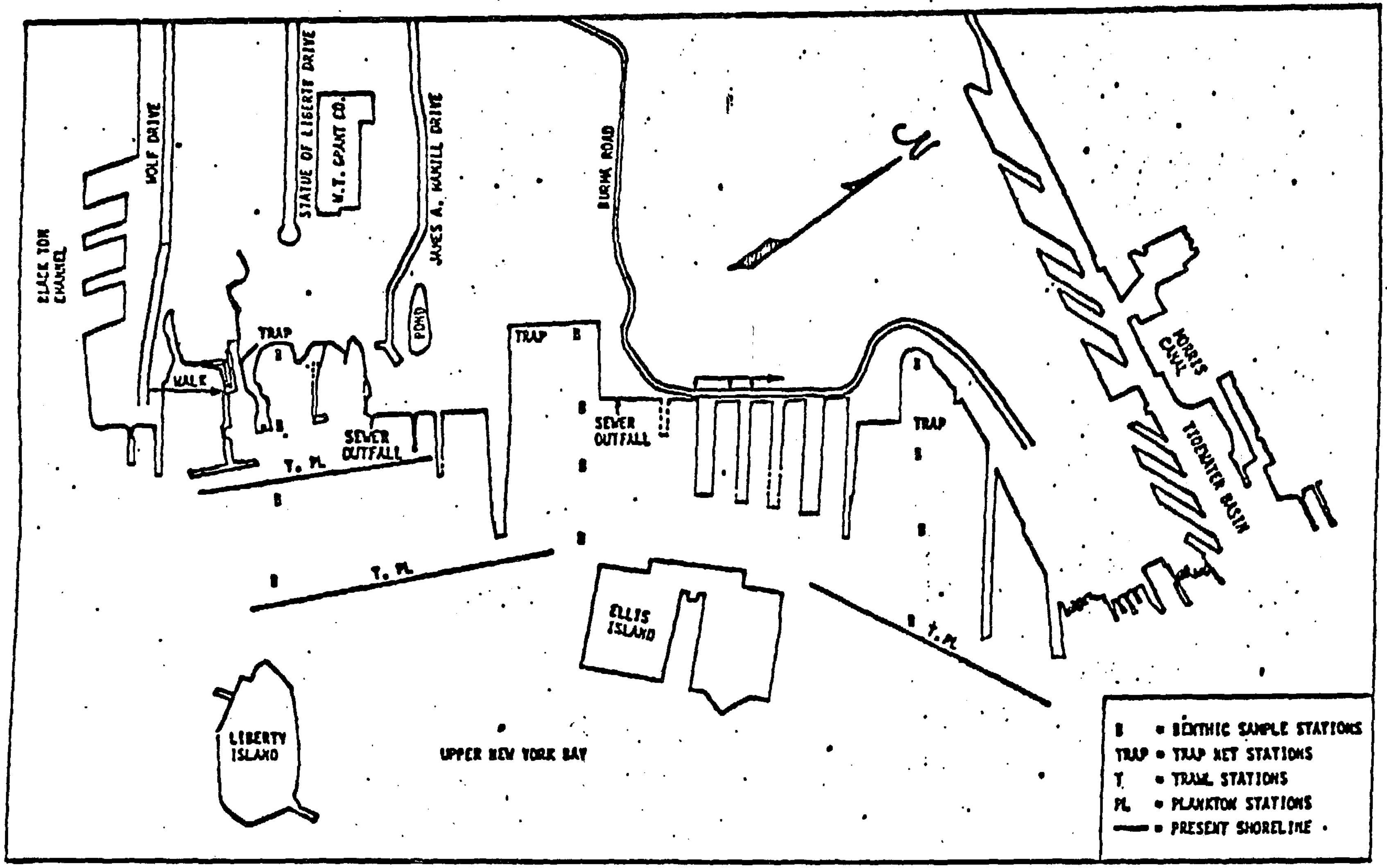
Composition of Raritan Bay "mud" community. Percent occurrence as major (>10%) fraction of sample.

Species	% major fraction
Mulinia lateralis	68.7
Nassarius trivittatus	25.0
Nephtys incisa	18.7
Nephtys picta	12.5
Nephtys caeca	6.3
Nephtys bucera	6.3
Astarte borealis	6.3
Pectinaria gouldii	6.3
Leptochelia savignyi	6.3
Mercenaria mercenaria	6.3

FROM MCGRATH, 1974.

APPENDIX-PAGE 18



(Benthic stations identified by "B" represent transect 1-3 from left to right and stations 1-4 from land to sea.)

Aquatic Sampling Stations in Liberty State Park Study Area

FROM ANONYMOUS, 1976.

Benthos Taxon List

Cnidaria
- Anthozoa

Platyhelminthes
- Turbellaria

Nematoda

Nemertina
- *Cerebratulus* sp.
- Unidentified sp.

Annelida
- Polychaeta
  - Phyllodocidae
    - *Eteona heteropoda*
    - Unidentified sp.
  - Nereidae
    - *Nereis* sp.
  - Glyceridae
    - *Glycera americana*
    - *Glycera* sp.
  - Ariciidae
    - *Scoloplos robustus*
    - *Cirratulidae tharyx* sp.
  - Amphictenidae
    - *Pectinaria gouldi*
  - Opheliidae
  - Sabellidae
    - *Sabellaria vulgaris*
    - Unidentified sp.
  - Serpulidae
    - *Spirorbis* sp.
  - Spionidae
    - *Streblospio benedicti*
    - *Streblospio* sp.
    - *Polydora ligni*
    - Unidentified sp.
- Oligochaeta
  - Tubificidae
    - Unidentified (probably *Limnodrilus* *Nais* sp.)

Arthropoda
- Crustacea
  - Amphipoda
    - *Corophium insidiosum*
    - *Gammarus* sp.
    - *Melita nitida*
    - Gammaridae
  - Isopoda
    - *Edotea montosa*
    - *Chiridotea* sp.
    - *Cyathura* sp.
  - Cirripedia
    - *Balanus* (*Balanus*) sp.
  - Copepoda
    - Calanoida
    - Harpacticoida
    - Cyclopoida
      - *Cyclops* sp.
  - Cumacea
    - *Leucon americana*
    - *Oxyurostylis* sp.
    - *Cyclaspis* sp.
  - Mysidacea
    - *Neomysis americana*
  - Decapoda
    - *Callinectes sapidus*
    - *Crangon septemspinosus*
    - *Neopanope texana*
    - *Palaemonetes pugio*
    - *Rhithropanopeus harrisi*
- Xiphosura
  - *Limulus polyphemus*
- Insecta
  - Ceratopogonidae
  - Chironomidae
    - *Cricotopus* sp.
    - Unidentified sp.
  - Culicidae
    - *Chaoborus* sp.
  - Psychodidae
    - *Psychoda* sp.
    - *Telmatoscopus* sp.
  - Coleoptera
    - *Stenelmis* sp.

Mollusca
- Pelecypoda
  - *Crassostrea virginica*
  - *Macoma balthica*
  - *Mya arenaria*
  - *Mulinia lateralis*
  - *Tellina* sp.
- Gastropoda
  - *Crepidula fornicata*
  - *Corambella* sp.
  - *Calliostoma* sp.
  - Amnicolidae
  - Nudibranchia
  - *Ilyanassa* (Nassarius) *obsolita*

Bryozoa
- Unidentified sp.
- *Electra* sp.
- *Pedicellina* sp.

Chordata-Tunicata
- Ascidiacea
  - *Molgula* sp.
  - Unidentified sp.

FROM ANONYMOUS, 1976, LIBERTY STATE PARK SURVEY.

Liberty State Park Area Mean Monthly Numbers (No./m^2) of Benthic Organisms

Taxon	Aug		Oct		Dec		Feb		Apr		Jun		Annual	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Streblospio benedicti	19119	7860	7777	3717	12143	6162	8120	2130	7618	2736	4063	1430	9806.7	2136.4
Tubificidae	6848	3009	3164	980	5932	1311	3511	1091	8795	2469	4096	1114	5394.3	898.1
Balanus sp.	649	435	808	731	604	494	516	347	147	105	1168	809	648.7	237.4
Nereis succinea	193.0	78.0	189	141	322	150	376	171	350	148	502	152	322.3	48.3
Polydora ligni			253	176	315	246	8	7	23	15	1033	696	275.3	165.1
Ecenna heteropoda	103.0	42.0	152	92	535	243	272	92	365	159	213	55	273.3	64.4
Tharyx sp.			48	38	494	419	39	22	8	7			98.2	79.6
Melita nitida	80.0	50.0	95	92	14	10	27	19	13	11	19	13	41.8	15.2
Harpacticoida					214	204							35.7	35.7
Nematoda	47.0	45.0	26	19					110	64			30.5	17.7
Anthozoa	23.0	14.0	60	59	7	5	7	5	11	8	16	9	20.7	8.2
Chiridotea	83.0	52.0	13	9					12	5			18	13.2
Cyathura polita	10.0	10.0	11	11	11	9	14	10	47	45	6	6	16.5	6.2
Copepoda					93	50							15.5	15.5
Scoloplos robustus			4	4	5	4	7	7	33	44	21	21	13.3	8.5
Calanoida					83	73							13.8	13.8
Amnicolidae	65.0	66.0	1	1									11.2	11.0
Corophium insidiosium	20.0	16.0			9	6	14	7	7	7	10	5	10	2.7
Cyclops sp.					6	4	2	2	31	18			9.8	8.3
Electra sp. (colony)	43.0	29.0	2	1							11	6	9.3	6.9
Sabellaria vulgaris			6	6	38	38	12	9					9.3	6.1
Sabellidae	40.0	37.0	12	12									8.7	6.6
Mulina lateralis	33.0	16.0	11	6	3	3	1	1	<1	<1			<8.2	<5.2
Nais sp.	1.0	1.0	1	1					46	27			8	7.6
Neopanope texana	2.0	1	11	9	17	12	4	3	7	4	5	4	7.7	2.2
Edotea montosa					3	2	22	7	10	9	8	4	7.2	3.4
Tellinia sp.	34.0	26.0									2	2	6	5.6
Ilyanassa obsoleta	7.0	6.0	3	3	1	1	20	18	<1	<1	2	2	5.7	3.0
Mya arenaria	10.0	4.0	13	7	6	3			<1	<1			5	2.3
Crangon septemspinosa	17.0	8.0	3	2	1	1	<1	<1	4	4	4	2	5	2.5
Corambella sp.	1.0	1.0	26	26			1	1					4.7	4.3
Glycera americana			14	22	3	3	3	3	2	2	5	2	4.5	2.0
Neomysis americanus	4.0	3.0	12	6	3	2	1	1	3	2	<1	<1	4	1.7
Macoma balthica	12.0	6.0	2	1	1	1	1	1	1	1	2	1	3.2	1.8
Bryozoa sp.			11	11	4	4							2.5	1.8
Pectinaria gouldii	1.0	1.0	7	4	2	1	1	1	2	1	1	1	2.3	0.9
Gammarus sp.	5.0	3.0	2	2			<1	<1	2	2	2	2	2	0.7
Nudibranchia			10	9					<1	<1			1.8	1.6
Turbellaria			6	5	2	1	1	1	1	1			1.7	0.9
Xanthidae	9.0	6.0											1.5	1.5
Chaoborus sp.	6.0	4.0	2	2									1.3	1.0
Rhithropanopeus harrisii			3	3			2	2	2	1	1	1	1.3	0.5
Calliostoma sp.							7	6					1.2	1.2
Callinectes sapidius	1.0	1.0	1	1			4	4					1	0.6
Crepidula fornicata			2	2	3	2	<1	<1					<1	<0.5
Crassostera virginica			1	1	1	1			3	2	<1	<1	<1	<0.4
Nemertea									4	4	1	1	0.8	0.65
Mogula sp.	3.0	3.0					<1	<1					0.7	0.5
Nereis sp.					4	4							0.7	0.7
Leucon americana					1	1			2	2			0.5	0.3
Cylapsis sp.							3	3					0.5	0.5
Leptodora kindti	2.0	2.0											0.3	0.3
Limulus polyphemus	2.0	2.0											0.3	0.3
Psychoda			2	1									0.3	0.3
Phyllodocidae					2	2							0.3	0.3
Pedicellina sp.					2	2							0.3	0.3
Cerebratulus sp.									2	2			0.3	0.3
Stenelais sp.											2	2	0.3	0.3
Palaemonetes pugio					1	1			<1	<1			<0.3	<0.2
Gammaridae	1.0	1.0											0.2	0.2
Chironomidae	1.0	1.0											0.2	0.2
Cheratopogonidae	1.0	1.0											0.2	0.2
Opheliidae	1.0	1.0											0.2	0.2
Glycera sp.	1.0	1.0											0.2	0.2
Streblospio sp.			1	1									0.2	0.2
Telmatoscopus sp.			1	1									0.2	0.2
Spirorbis sp.			1	1									0.2	0.2
Ascidiacea					1	1							0.2	0.2
Cricotopus sp.							1	1					0.2	0.2
Stenelais sp.											<1	<1	<0.2	<0.2
Mean total density	27476.0		12796.0		20911.0		13132.0		17775.0		11213.0			
No. of taxa	38		42		38		35		38		27			

Percent Composition in Benthic Community in Liberty State Park Vicinity, August 1975–June 1976

(For station locations see APPENDIX-PAGE 18)

	Transect 1 Station				Transect 2 Station				Transect 3 Station				
	1	2	3	4	1	2	3	4	1	2	3	4	Total
Streblospio benedicti	80.9	65.2	51.4	40.1	0.5	6.0	38.1	66.4	53.9	37.6	21.0	31.4	57.0
Tubificidae	13.1	25.1	29.7	29.7	40.5	56.9	15.8	25.5	41.4	56.5	76.4	63.9	31.3
Balanus sp.	<0.1	1.3	10.6	15.9	-	-	3.1	1.6	<0.1	<0.1	-	<0.1	3.8
Nereis succinea	1.0	4.3	3.6	3.6	0.1	-	3.3	0.9	1.3	0.3	0.3	0.5	1.9
Polydora ligni	0.2	0.2	0.2	7.5	-	-	32.1	3.2	0.3	0.3	0.3	0.2	1.6
Eteone heteropoda	1.9	2.1	1.4	1.2	-	-	3.1	0.4	1.3	4.0	0.4	0.5	1.6
Tharyx sp.	1.6	1.0	0.1	0.1	-	-	-	0.1	<0.1	-	<0.1	-	0.6
Melita nitida	<0.1	<0.1	1.1	0.6	-	-	-	<0.1	<0.1	<0.1	-	-	0.2
Harpacticoida	-	<0.1	-	-	42.6	6.0	1.4	-	-	-	-	<0.1	0.2
Nematoda	<0.1	-	0.2	0.1	-	-	-	0.9	<0.1	0.1	<0.1	1.8	0.2
Total No. Species	29	27	36	41	12	7	14	25	32	27	23	22	71
Total No. Specimens	59772.2	17324.8	27467.9	28096.0	963.2	16.7	452.0	18998.4	19564.1	16282.7	14351.3	10169.4	17219.8
Σ%	>98.7	>99.2	98.3	>98.6	83.7	68.9	96.9	>99.0	>98.2	>98.5	>98.4	>98.3	98.4

Species, occurrence, and relative abundance of fish eggs and larvae from the Sandy Hook estuary.

Species	Common Name	Number Eggs	Number Larvae	Occurrence[1]
Brevoortia tyrannus	Atlantic menhaden	258	5	May-June, Nov.-Dec.
Clupea harengus harengus	Atlantic herring	---	292	March-May
Anchoa mitchilli	Bay anchovy	27	158	May-June, June-Sept.
Anguilla rostrata	American eel	---	1100	March-June
Fundulus heteroclitus	Mummichog	11	8	June-July, June
Enchelyopus cimbrius	Fourbeard rockling	---	3	June
Pollochius virens	Pollock	---	3	April
Hippocampus erectus	Spotted seahorse	---	2	June-July
Syngnathus fuscus	Northern pipefish	---	200	May-July
Micropogon undulatus	Atlantic croaker	---	2	Nov.
Tautoga onitis	Tautog	69	1	May-July, July
Gobiosma sp.	Goby	---	2	Aug.
Prionotus sp.	Searobin	281	---	May-June
Myoxecephalus sp.	Sculpin	---	6	March-April
Ammodytes americanus	American sand lance	---	268	March-May
Poronotus triacanthus	Butterfish	---	2	July
Menidia menidia	Atlantic silverside	---	110	May-July
Scophthalmus aquosus	Windowpane	8	14	May-June, June
Pseudopleuronectes americanus	Winter flounder	---	223	April-June
Sphaeroides maculatus	Northern puffer	---	3	June-July
Unidentified	---	---	3	June-July

[1]When both eggs and larvae were collected, the dates for eggs appear first.

FROM CROKER, 1965.

Fishes Collected in Ichthyoplankton Sampling Gear, Liberty State Park Studies

Family	Species	Common Name
Anguillidae	*Anguilla rostrata*	American eel
Clupeidae	*Brevoortia tyrannus*	Atlantic menhaden
	Clupea harengus harengus	Atlantic herring
Engraulidae	*Anchoa mitchilli*	Bay anchovy
Osmeridae	*Osmerus mordax*	Rainbow smelt
Gadidae	*Enchelyopus cimbrius*	Fourbeard rockling
	Gadus morhua	Atlantic cod
	Microgadus tomcod	Atlantic tomcod
Cyprinodontidae	*Fundulus heteroclitus*	Mummichog
Atherinidae	*Menidia menidia*	Atlantic silverside
Syngnathidae	*Syngnathus fuscus*	Northern pipefish
Percichthyidae	*Morone saxatilis*	Striped bass
Sciaenidae	*Bairdiella chrysura*	Silver perch
Labridae	*Tautoga onitis*	Tautog
Pholidae	*Pholis gunnellus*	Rock gunnel
Ammodytidae	*Ammodytes* sp.	Sand lance
Gobiidae	*Gobiosoma bosci*	Naked goby
Scombridae	*Scomber scombrus*	Atlantic mackerel
Triglidae	*Prionotus* sp.	Searobin
Cottidae	*Myxocephalus octodecemspinosus*	Longhorn sculpin
Bothidae	*Scophthalmus aquosus*	Windowpane
Pleuronectidae	*Pseudopleuronectes americanus*	Winter flounder
Soleidae	*Trinectes maculatus*	Hogchoker

FROM ANONYMOUS, 1976.

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Summary by month of fish eggs, larvae, and young taken in 20-cm bongo net collections in the Raritan River and Bay in the vicinity of the Werner Generating Station from April through October 1976 and in March 1977. + indicates less than 0.001/m³.

Month	April		May		June		July		August	
Station *	12-7		12-7		12-7		12-7		12-7	
Volume filtered (m³)	352.9		860.0		1293.8		544.1		661.8	
Species	No.	n/m³	No.	n/m³	No.	n/m³	No.	n/m³	No.	n/m³
Eggs										
Anchoa mitchilli	0	0	0	0	124509	96.235	45872	84.308	92	0.139
Unidentified	1	0.003	0	0	2	0.002	0	0	0	0
Larvae										
Anchoa mitchilli	0	0	0	0	3209	2.480	889	1.634	244	0.369
Microgadus tomcod	0	0	0	0	0	0	0	0	0	0
Fundulus heteroclitus	0	0	0	0	0	0	1	0.002	0	0
Menidia menidia	0	0	9	0.010	1	0.001	1	0.002	0	0
Cynoscion regalis	0	0	0	0	2	0.002	7	0.012	0	0
Micropogon undulatus	0	0	0	0	0	0	0	0	0	0
Tautoga onitis	0	0	0	0	1	0.001	0	0	0	0
Tautogolabrus adspersus	0	0	0	0	1	0.001	0	0	0	0
Pholis gunnellus	0	0	0	0	0	0	0	0	0	0
Ammodytes sp.	0	0	0	0	0	0	0	0	0	0
Hyoxocephalus aenaeus	1	0.003	0	0	0	0	0	0	0	0
Scophthalmus aquosus	0	0	0	0	2	0.002	0	0	0	0
Pseudopleuronectes americanus	29	0.082	24	0.027	0	0	0	0	0	0
Young										
Anguilla rostrata	3	0.009	3	0.003	1	0.001	0	0	0	0
Clupea harengus	2	0.006	0	0	0	0	0	0	0	0
Anchoa mitchilli	0	0	0	0	0	0	0	0	0	0
Syngnathus fuscus	0	0	0	0	11	0.009	11	0.020	9	0.014
Peprilus triacanthus	0	0	0	0	0	0	1	0.002	0	0
Total Eggs	1	0.003	0	0	124511	96.237	45872	84.308	92	0.139
Total Larvae	30	0.085	33	0.038	3216	2.486	898	1.650	244	0.369
Total Young	5	0.015	3	0.003	12	0.009	12	0.022	9	0.014
Taxa	5		3		9		6		2	
Diversity (larvae)	0.15		0.62		0.02		0.06		0.00	
Evenness	0.30		0.89		0.10		0.03		1.00	

[a]Stations 11 and 7 not sampled.

*All the stations are near the mouth of the Raritan River, for detailed description see the original report.

(cont'd on APPENDIX-PAGE 25)

(cont'd from APPENDIX-PAGE 24)

Month	September[a]		October[a]		March[a]		Total	
Station*	12-8		12-8		12-8			
Volume filtered (m^3)	546.4		511.0		538.8		5308.9	
Species	No.	n/m^3	No.	n/m^3	No.	n/m^3	No.	n/m^3
Eggs								
Anchoa mitchilli	0	0	0	0.	0	0	170473	32.111
Unidentified	0	0	1	0.002	0	0	4	0.001
Larvae								
Anchoa mitchilli	83	0.152	1	0.002	0	0	4426	0.834
Microgadus tomcod	0	0	0	0	13	0.024	13	0.002
Fundulus heteroclitus	0	0	0	0	0	0	1	+
Menidia menidia	0	0	0	0	0	0	11	0.002
Cynoscion regalis	1	0.002	0	0	0	0	9	0.002
Micropogon undulatus	0	0	3	0.006	0	0	4	0.001
Tautoga onitis	0	0	0	0	0	0	1	+
Tautogolabrus adspersus	0	0	0	0	0	0	1	+
Pholis gunnellus	0	0	0	0	4	0.007	4	0.001
Ammodytes sp.	0	0	0	0	28	0.052	28	0.005
Hyoxocephalus aenaeus	0	0	0	0	0	0	1	+
Scophthalmus aquosus	0	0	0	0	0	0	2	+
Pseudopleuronectes americanus	0	0	0	0	188	0.349	241	0.045
Young								
Anguilla rostrata	0	0	0	0	7	0.013	14	0.003
Clupea harengus	0	0	0	0	0	0	2	+
Anchoa mitchilli	0	0	4	0.008	0	0	4	0.001
Syngnathus fuscus	1	0.002	1	0.002	0	0	32	0.006
Peprilus triacanthus	0	0	0	0	0	0	1	+
Total Eggs	0	0	1	0.002	0	0	170477	32.112
Total Larvae	84	0.154	4	0.008	233	0.432	4742	0.893
Total Young	1	0.002	5	0.010	7	0.013	53	0.010
Taxa	3		5		5		18	
Diversity (larvae)	0.07		0.56		0.66		0.31	
Evenness	0.10		0.81		0.47		0.27	

[a]Stations 11 and 7 not sampled

FROM LYNCH AND ASSOCIATES, 1977.

Major fish species of the Hudson-River estuary. Diadromous species either migrate into fresh water from the sea (anadromous) or into the sea from fresh water (catadromous) to spawn.

Nonmigratory species

Resident brackish water species

Fundulus heteroclitus	Mummichog
Fundulis majalis	Striped killifish
Fundulis diaphanus	Banded killifish
Apeltes quadracus	Fourspine stickleback
Menidia beryllina	Tidewater silverside
Menidia menidia	Atlantic silverside
Hippocampus erectus	Spotted seahorse
Syngnathus fuscus	Northern pipefish
Roccus americanus	White perch
Perca flavescens	Yellow perch
Scophthalmus aquosus	Wndowpane
Acipenser brevirostrum	Shortnose sturgeon

Resident fresh water species

Carassius auratus	Goldfish
Cyprinus carpio	Carp
Notemigonus crysoleucas	Golden shiner
Notropis atherinoides	Emerald shiner
Notropis hudsonius	Spotted shiner
Catostomus commersoni	White sucker
Ictalurus catus	White catfish
Ictalurus nebulosus	Brown bullhead
Lepomis gibbosus	Pumpkin seed
Lepomis macrochirus	Bluegill
Pomoxis nigroniaculatus	Black crapple
Etheostoma olmstedl	Tessellated darter

Migratory

Nursery species

Brevoortia tyrannus	Atlantic menhaden
Anchoa mitchilli	Bay anchovy
Pomatomus saltatrix	Bluefish
Cynoscion regalis	Weakfish
Stenotomus chrysops	Scup
Paralichthys dentatus	Summer flounder
Pseudopleuronectes americanus	Winter flounder

Diadromous species

Acipenser oxyrhynchus	Atlantic sturgeon
Alosa acstivalis	Blueback herring
Alosa pseudoharengus	Alewife
Alosa sapidissima	Shad
Osmerus mordax	Rainbow smelt
Morone saxatilis	Striped bass
Anguilla rostrata	American eel

FROM ESSER, 1982.

CHECK LIST OF FISHES FROM SANDY HOOK AND RARITAN BAY

SCIENTIFIC NAME	COMMON NAME	OCCURRENCE
Class Agnatha		
Order Petromyzontiformes		
Family Petromyzontidae	Lampreys	
Petromyzon marinus	Sea lamprey	C
Class Chondrichthyes		
Order Squaliformes		
Family Odontaspididae	Sand tigers	
Odontaspis taurus	Sand tiger	C
Family Carcharhinidae	Requiem sharks	
Carcharhinus milberti	Sandbar shark	C
Mustelus canis	Smooth dogfish	C
Family Sphyrnidae	Hammerhead sharks	
Sphyrna zygaena	Smooth hammerhead	R
Family Squalidae	Dogfish sharks	
Squalus acanthias	Spiny dogfish	C
Order Rajiformes		
Family Rajidae	Skates	
Raja eglanteria	Clearnose skate	C
Raja erinacea	Little skate	C
Raja laevis	Barndoor skate	C
Family Dasyatidae	Stingrays	
Dasyatis centroura	Roughtail stingray	C
Gymnura micrura	Smooth butterfly ray	R
Family Myliobatidae	Eagle rays	
Myliobatis freminvillei	Bullnose ray	R
Rhinoptera bonasus	Cownose ray	C
Class Osteichthyes		
Order Acipenseriformes		
Family Acipenseridae	Sturgeons	
Acipenser brevirostrum	Shortnose sturgeon	C
Acipenser oxyrhynchus	Atlantic sturgeon	C
Order Elopiformes		
Family Elopidae	Tarpons	
Elops saurus	Ladyfish	R
Megalops atlantica	Tarpon	R
Order Anguilliformes		
Family Anguillidae	Freshwater eels	
Anguilla rostrata	American eel	A
Order Clupeiformes		
Family Clupeidae	Herrings	
Alosa mediocris	Hickory shad	C
Alosa aestivalis	Blueback herring	C
Alosa pseudoharengus	Alewife	C
Alosa sapidissima	American shad	C
Brevoortia tyrannus	Atlantic menhaden	A
Clupea harengus harengus	Atlantic herring	R

(cont'd on APPENDIX-PAGE 28)

SCIENTIFIC NAME	COMMON NAME	OCCURRENCE*
Class Osteichthyes (cont.)		
Order Clupeiformes		
Family Clupeidae		
Dorosoma cepedianum	Gizzard shad	R
Etrumeus teres	Atlantic round herring	R
Opisthonema oglinum	Atlantic thread herring	R
Family Engraulidae	Anchovies	
Anchoa hepsetus	Striped anchovy	A
Anchoa mitchilli	Bay anchovy	C
Order Salmoniformes		
Family Salmonidae	Trouts	
Salmo gairdneri	Rainbow trout	R
Salmo trutta	Brown trout	R
Order Myctophiformes		
Family Synodontidae	Lizardfishes	
Synodus foetens	Inshore lizardfish	R
Order Batrachoidiformes		
Family Batrachoididae	Toadfishes	
Opsanus tau	Oyster toadfish	C
Order Lophiiformes		
Family Lophiidae	Goosefishes	
Lophius americanus	Goosefish	C
Order Gadiformes		
Family Gadidae	Codfishes	
Gadus morhua	Atlantic cod	R
Merluccius bilinearis	Silver hake	R
Microgadus tomcod	Atlantic tomcod	R
Urophycis chuss	Red hake	C
Urophycis regius	Spotted hake	C
Family Ophidiidae	Cusk-eels and brotulas	
Rissola marginata	Striped cusk-eel	R
Order Atheriniformes		
Family Exocoetidae	Flyingfishes and halfbeaks	
Hyporhamphus unifasciatus	Halfbeak	C
Family Belonidae	Needlefishes	
Strongylura marina	Atlantic needlefish	C
Family Cyprinodontidae	Killifishes	
Cyprinodon variegatus	Sheepshead minnow	C
Fundulus heteroclitus	Mummichog	A
Fundulus majalis	Striped killifish	C
Lucania parva	Rainwater killifish	C
Family Atherinidae	Silversides	
Menidia menidia	Atlantic silverside	A
Membras martinica	Rough silverside	C
Order Gasterosteiformes		
Family Gasterosteidae	Sticklebacks	
Gasterosteus aculeatus	Threespine stickleback	C
Apeltes quadracus	Fourspine stickleback	R
Family Syngnathidae	Pipefishes and seahorses	
Hippocampus erectus	Lined seahorse	R
Syngnathus fuscus	Northern pipefish	C

(cont'd on APPENDIX-PAGE 29)

CHECK LIST OF FISHES (cont'd)

SCIENTIFIC NAME	COMMON NAME	OCCURRENCE*
Class Osteichthyes (cont.)		
Order Perciformes		
Family Percichthyidae	Temperate basses	
Morone americanus	White perch	C
Morone saxatilis	Striped bass	C
Family Serranidae	Sea basses	
Centropristes striata	Black sea bass	C
Family Pomatomidae	Bluefishes	
Pomatomus saltatrix	Bluefish	A
Family Rachycentridae	Cobias	
Rachycentron canadum	Cobia	R
Family Echeneidae	Remoras	
Echeneis naucrates	Sharksucker	R
Family Carangidae	Jacks and pompanos	
Alectis crinitus	African pompano	R
Caranx crysos	Blue runner	C
Caranx hippos	Crevalle jack	C
Chloroscombrus chrysurus	Atlantic bumper	R
Selar crumenophthalmus	Bigeye scad	R
Selene vomer	Lookdown	R
Seriola zonata	Banded rudderfish	R
Trachinotus carolinus	Florida pompano	R
Trachinotus falcatus	Permit	R
Vomer setapinnis	Atlantic moonfish	C
Family Lutjanidae	Snappers	
Lutjanus griseus	Gray snapper	R
Family Lobotidae	Tripletails	
Lobotes surinamensis	Tripletail	R
Family Pomadasyidae	Grunts	
Orthopristis chrysopterus	Pigfish	R
Family Sparidae	Porgies	
Lagodon rhomboides	Pinfish	R
Stenotomus chrysops	Scup	A
Family Sciaenidae	Drums	
Bairdiella chrysura	Silver perch	C
Cynoscion regalis	Weakfish	C
Leiostomus xanthurus	Spot	R
Menticirrhus saxatilis	Northern kingfish	C
Micropogon undulatus	Atlantic croaker	R
Pogonias cromis	Black drum	C
Sciaenops ocellata	Red drum	R
Family Mullidae	Goatfishes	
Mullus auratus	Red goatfish	R
Family Kyphosidae	Sea chubs	
Kyphosus sectatrix	Bermuda chub	R
Family Ephippidae	Spadefishes	
Chaetodipterus faber	Atlantic spadefish	R
Family Chaetodontidae	Butterflyfishes	
Chaetodon ocellatus	Spotfin butterflyfish	R

(cont'd on APPENDIX-PAGE 30)

CHECK LIST OF FISHES (cont'd)

SCIENTIFIC NAME	COMMON NAME	OCCURRENCE*
Class Osteichthyes (cont.)		
Order Perciformes		
Family Labridae	Wrasses	
Tautoga onitis	Tautog	C
Tautogolabrus adspersus	Cunner	C
Family Mugilidae	Mullets	
Mugil curema	White mullet	R
Mugil cephalus	Striped mullet	C
Family Sphyraenidae	Barracudas	
Sphyraena borealis	Northern sennet	R
Family Uranoscopidae	Stargazers	
Astroscopus guttatus	Northern stargazer	R
Family Ammodytidae	Sand lances	
Ammodytes americanus	American sand lance	R
Family Gobiidae	Gobies	
Gobiosoma bosci	Naked goby	R
Family Trichiuridae	Cutlassfishes	
Trichiurus lepturus	Atlantic cutlassfish	R
Family Scombridae	Mackerels and tunas	
Sarda sarda	Atlantic bonito	R
Scomber japonicus	Chub mackerel	R
Scomber scombrus	Atlantic mackerel	C
Scomberomorus maculatus	Spanish mackerel	R
Family Stromateidas	Butterfishes	
Peprilus alepidotus	Harvestfish	R
Peprilus triacanthus	Butterfish	C
Family Triglidae	Searobins	
Prionotus carolinus	Northern searobin	A
Prionotus evolans	Striped searobin	A
Family Cottidae	Sculpins	
Myoxocephalus aeneus	Grubby	R
Myoxocephalus octodecemspinosus	Longhorn sculpin	C
Order Pleuronectiformes		
Family Bothidae	Lefteye flounders	
Citharichthys arctifrons	Gulfstream flounder	R
Etropus microstomus	Smallmouth flounder	R
Paralichthys dentatus	Summer flounder	C
Paralichthys oblongus	Fourspot flounder	R
Scophthalmus aquosus	Windowpane	A
Family Pleuronectidae	Righteye flounders	
Pseudopleuronectes americanus	Winter flounder	A
Family Soleidae	Soles	
Trinectes maculatus	Hogchoker	C
Order Tetraodontiformes		
Family Balistidae	Triggerfishes and filefishes	
Aluterus schoepfi	Orange filefish	R
Monacanthus hispidus	Planehead filefish	R
Balistes capriscus	Gray triggerfish	R
Family Tetraodontidae	Puffers	
Lagocephalus laevigatus	Smooth puffer	R
Sphoeroides maculatus	Northern puffer	C

(cont'd on APPENDIX-PAGE 31)

CHECK LIST OF FISHES (cont'd)

SCIENTIFIC NAME	COMMON NAME	OCCURRENCE*
Class Osteichthyes (cont.)		
Order Tetraodontiformes		
Family Diodontidae	Porcupinefishes	
Chilomycterus schoepfi	Striped burrfish	R
Family Molidae	Molas	
Mola mola	Ocean sunfish	R

* A - abundant
C - common
R - rare

FROM SANDY HOOK LABORATORY SURVEY, 1971.

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NEW JERSEY LANDINGS BY COUNTIES, 1979

SPECIES	COUNTY					
	MONMOUTH		OCEAN		BURLINGTON	
FISH	POUNDS	DOLLARS	POUNDS	DOLLARS	POUNDS	DOLLARS
ANGLERFISH.	6,614	1,552	371,455	82,098	-	-
BLUEFISH.	205,736	52,782	482,242	85,117	-	-
BONITO.	301	104	1,072	360	-	-
BUTTERFISH, LARGE	-	-	100	42	-	-
BUTTERFISH, MEDIUM.	-	-	12,921	4,721	-	-
BUTTERFISH, SMALL	15	5	1,955	458	-	-
BUTTERFISH, UNCLASSIFIED. . . .	64,097	13,841	266,530	96,757	-	-
COD, LARGE.	-	-	38,267	17,521	-	-
COD, MARKET	-	-	8,214	3,842	-	-
COD	588	276	11,566	6,587	-	-
CREVALLE.	48	5	-	-	-	-
CROAKER, UNCLASSIFIED	4,223	1,178	6,330	2,795	-	-
CUNNER.	68	9	-	-	-	-
DOLPHIN	-	-	33	20	-	-
DRUM, BLACK	71	8	4,501	87	-	-
EELS, COMMON.	39,144	20,497	33,655	18,120	-	-
EELS, CONGER.	538	94	8,791	2,052	-	-
FLOUNDERS, BLACKBACK.	103,004	28,497	60,995	17,814	-	-
FLOUNDERS, FLUKE, JUMBO	3,161	2,925	230,697	164,123	-	-
FLOUNDERS, FLUKE, LARGE	12,574	12,008	775,983	549,141	-	-
FLOUNDERS, FLUKE.	18,733	15,703	14,537	8,577	-	-
FLOUNDERS, FLUKE, MEDIUM. . . .	14,926	13,085	331,121	222,753	-	-
FLOUNDERS, FLUKE, SMALL	4,332	2,136	31,435	13,681	-	-
FLOUNDERS, GRAY SOLE, UNCL. . .	-	-	4,187	1,247	-	-
FLOUNDERS, SAND	38	12	-	-	-	-
FLOUNDERS, YELLOWTAIL, UNCL . .	-	-	25,174	8,092	-	-
HADDOCK, LARGE.	-	-	220	22	-	-
HAKE, RED	738,633	87,762	981,019	136,566	-	-
HAKE, WHITE, UNCLASSIFIED . . .	25	7	1,139	287	-	-
HALIBUT	-	-	185	370	-	-
HERRING, SEA.	41,039	4,703	14,720	2,200	-	-
HICKORY SHAD.	-	-	84	12	-	-
KING WHITING OR "KINGFISH". . .	-	-	10	2	-	-
MACKEREL, ATLANTIC.	1,069	369	66,475	13,798	-	-
MARLIN, UNCLASSIFIED.	38	8	47	14	-	-
MENHADEN.	1,719,037	85,576	33,661	1,683	-	-
POLLOCK	176	44	1,104	207	-	-
SCUP OR PORGY, LARGE.	16,660	9,934	49,691	22,532	-	-
SCUP OR PORGY, MEDIUM	-	-	678,794	276,157	-	-
SCUP OR PORGY, SMALL.	306	49	88,260	23,265	-	-
SCUP OR PORGY, UNCLASSIFIED . .	10,325	3,689	5,052	763	-	-
SEA BASS, LARGE	-	-	7,250	7,161	-	-
SEA BASS, MEDIUM.	48	29	9,607	6,041	-	-
SEA BASS, SMALL	-	-	465	237	-	-
SEA BASS, UNCLASSIFIED.	6,100	4,110	3,603	3,236	-	-
SEA ROBIN	-	-	412	41	-	-
SEA TROUT, GREY	148,210	44,457	372,250	110,465	-	-
SHAD, BUCK.	44	14	-	-	-	-
SHAD.	23,249	4,277	29,298	6,036	-	-
SHARKS, GRAYFISH.	833	133	5,114	606	-	-
SHARKS, UNCLASSIFIED.	-	-	15,185	3,631	-	-
SKATES.	1,423	222	10	2	-	-
SPOT.	757	91	157	26	-	-
STRIPED BASS.	1,046	1,360	9,913	11,569	-	-
STURGEON.	1,205	307	792	271	-	-
SWORDFISH	-	-	215,863	333,107	-	-
TAUTOG.	34,480	6,305	2,163	437	-	-
TILEFISH.	61,714	43,200	3,956,542	2,299,722	-	-
TUNA, ALBACORE.	652	98	120	48	-	-
TUNA, BLUEFIN	3,203	3,080	-	-	-	-
TUNA, LITTLE.	42	9	908	197	-	-
TUNA, YELLOWFIN	653	229	9,548	3,931	-	-
TUNA, UNCLASSIFIED.	-	-	1,842	810	-	-
WHITE PERCH	187	63	16,780	5,096	-	-
WHITING	3,477,747	478,549	7,276,744	1,122,113	-	-
WOLFFISH.	-	-	37	14	-	-
UNCLASSIFIED FOR FOOD	101,337,574	3,193,546	5,094	1,707	-	-
TOTAL FISH	108,126,709	4,137,157	16,581,919	5,698,371		
SHELLFISH						
CRABS, BLUE, HARD	1,083	368	193,221	77,373	-	-
CRABS, BLUE, PEELER	-	-	3,510	1,839	-	-
CRABS, ROCK	33,216	5,560	588	84	-	-
LOBSTERS, AMERICAN, UNCL. . . .	509,317	1,100,174	132,163	301,223	-	-
CLAMS, HARD (MEATS)	-	-	491,380	836,322	-	-
CLAMS, SOFT, PUBLIC (MEATS) . .	179,160	194,434	-	-	-	-
CLAMS, SURF (MEATS)	147,815	34,768	239,893	108,260	-	-
CONCHS (MEATS).	113	34	200	117	-	-
OYSTERS (MEATS)	-	-	10,880	29,920	-	-
SCALLOPS, SEA (MEATS)	24,279	70,416	1,113,242	3,578,474	-	-
SQUID, UNCL	709	298	32,026	13,323	-	-
SQUID, LONG-FINNED.	15,490	6,748	98,325	48,653	-	-
TURTLES, UNCLASSIFIED	100	3	-	-	-	-
TOTAL SHELLFISH	911,282	1,412,805	2,335,228	5,013,938		
GRAND TOTAL	109,037,991	5,549,962	18,917,147	10,714,329		

FROM NATIONAL MARINE FISHERIES SERVICES, 1979.

NEW YORK LANDINGS BY COUNTIES, 1979

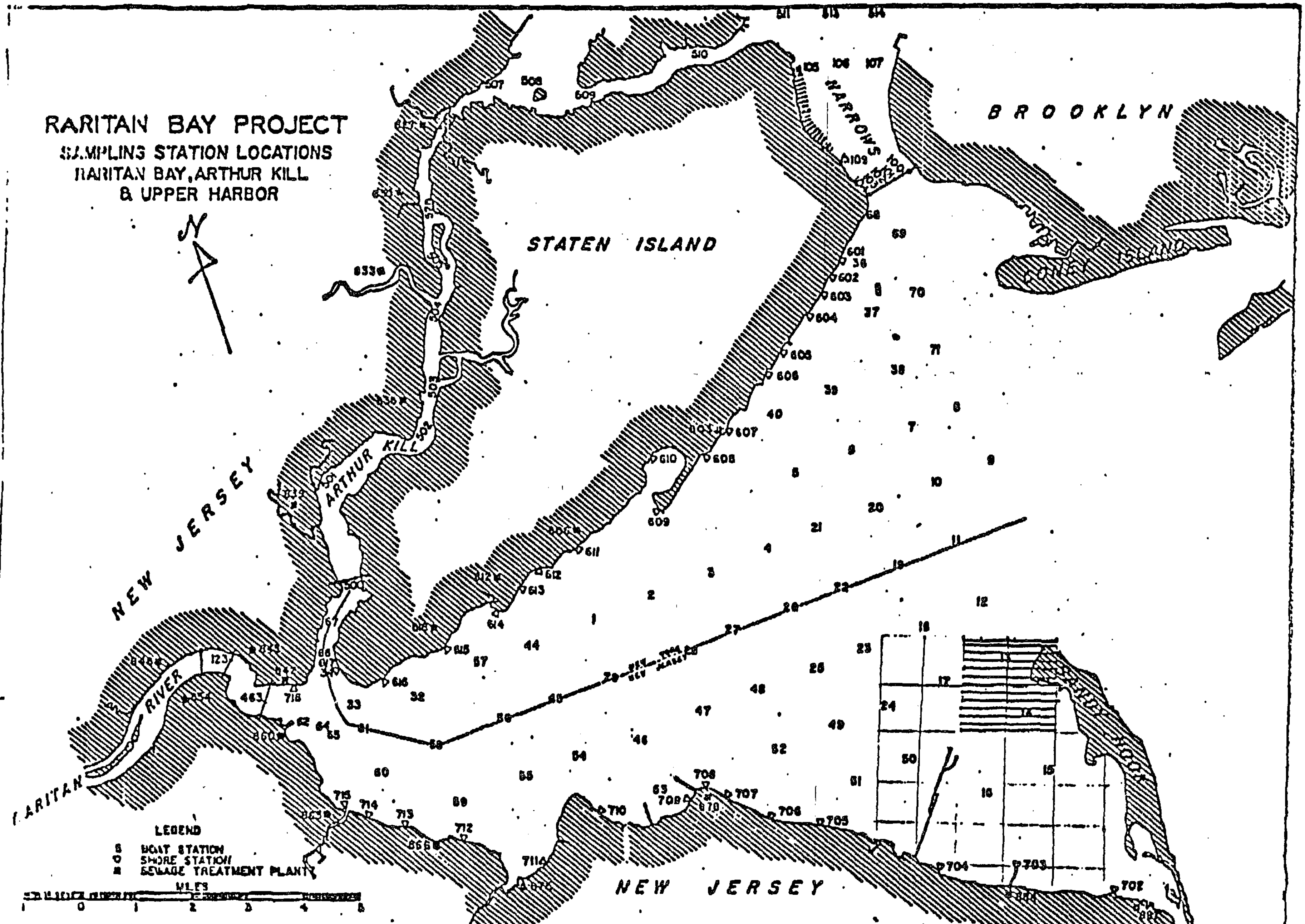
SPECIES	COUNTY					
	NEW YORK		KINGS		NASSAU	
FISH	POUNDS	DOLLARS	POUNDS	DOLLARS	POUNDS	DOLLARS
ANGLERFISH	1,800	630	2,725	951	7,469	2,570
BLUEFISH	-	-	55,391	13,580	57,077	14,542
BONITO	-	-	10,175	3,426	8,200	2,755
BUTTERFISH, UNCLASSIFIED	-	-	15,242	8,675	28,277	14,607
COD	-	-	5,576	2,381	53,775	28,345
EELS, COMMON	-	-	15,776	15,999	9,005	9,681
EELS, CONGER	-	-	-	-	200	20
FLOUNDERS, BLACKBACK	-	-	37,394	12,738	24,356	8,162
FLOUNDERS, FLUKE	2,200	1,660	62,166	51,823	101,942	87,763
FLOUNDERS, GRAY SOLE, UNCL.	-	-	-	-	480	192
FLOUNDERS, UNCLASSIFIED	-	-	300	100	902	92
HAKE, RED	-	-	67,406	11,428	330,441	38,710
HERRING, SEA	-	-	325	57	810	89
KING WHITING OR "KINGFISH"	-	-	60	20	2,460	369
MACKEREL, ATLANTIC	-	-	20,948	6,834	57,732	17,649
POLLOCK	-	-	-	-	110	17
SCUP OR PORGY, UNCLASSIFIED	-	-	48,715	22,263	90,295	35,192
SEA BASS, UNCLASSIFIED	-	-	13,607	14,575	18,260	18,988
SEA ROBIN	-	-	995	157	230	49
SEA TROUT, GREY	-	-	34,154	13,579	33,297	12,577
SHARKS, DOGFISH	-	-	14,125	2,318	20,549	3,809
SHARKS, UNCLASSIFIED	-	-	1,205	613	-	-
SKATES	-	-	3,150	563	7,999	1,515
SPOT	-	-	250	100	-	-
STRIPED BASS	-	-	47,492	77,068	9,393	16,291
STURGEON	-	-	137	29	923	206
SWELLFISH	-	-	265	436	80	130
TAUTOG	-	-	5,846	1,150	5,186	973
TILEFISH	-	-	-	-	337	174
TUNA, LITTLE	-	-	3,550	2,455	1,600	1,600
WHITING	-	-	821,326	147,969	2,033,283	351,073
TOTAL FISH	4,000	2,290	1,288,901	411,287	2,924,868	688,120
SHELLFISH						
LOBSTERS, AMERICAN, UNCL.	-	-	26,500	82,075	35,300	86,860
CLAMS, HARD (MEATS)	-	-	-	-	36,900	113,948
CLAMS, HARD, PRIVATE (MEATS)	-	-	-	-	17,900	59,727
CLAMS, OCEAN QUAHOG (MEATS)	-	-	-	-	43,100	12,981
CLAMS, SOFT, PUBLIC (MEATS)	-	-	-	-	300	418
CLAMS, SURF (MEATS)	-	-	61,100	27,967	1,483,400	666,697
MUSSELS, SEA (MEATS)	-	-	-	-	800	467
OYSTERS (MEATS)	-	-	-	-	215,400	686,892
SCALLOPS, SEA (MEATS)	196,300	657,241	-	-	91,600	313,292
SQUID, SHORT-FINNED	-	-	1,483	119	4,659	373
SQUID, LONG-FINNED	-	-	28,639	14,204	89,132	35,637
TOTAL SHELLFISH	196,300	657,241	117,742	124,365	2,018,691	1,955,292
GRAND TOTAL	200,300	659,531	1,406,643	535,652	4,943,559	2,643,412

FROM NATIONAL MARINE FISHERIES SERVICES, 1979.

Fishes Collected in Fisheries Sampling Gear during
Liberty State Park Studies

Family	Species: Scientific Name	Species: Common Name
Anguillidae	Anguilla rostrata	American eel
Clupeidae	Alosa aestivalis	Blueback herring
	Alosa pseudoharengus	Alewife
	Alosa sapidissima	American shad
	Brevoortia tyrannus	Atlantic menhaden
	Clupea harengus harengus	Atlantic herring
Engraulidae	Anchoa mitchilli	Bay anchovy
Osmeridae	Osmerus mordax	Rainbow smelt
Gadidae	Merluccius bilinearis	Silver hake
	Microgadus tomcod	Atlantic tomcod
Belonidae	Strongylura marina	Atlantic needlefish
Cyprinodontidae	Fundulus heteroclitus	Mummichog
	Fundulus majalis	Striped killifish
Atherinidae	Membras martinica	Rough silverside
	Menidia beryllina	Tidewater silverside
	Menidia menidia	Atlantic silverside
Gasterosteidae	Apeltes quadracus	Fourspine stickleback
	Gasterosteus aculeatus	Threespine stickleback
Syngnathidae	Syngnathus fuscus	Northern pipefish
Percichthyidae	Morone americana	White perch
	Morone saxatilis	Striped bass
Pomatomidae	Pomatomus saltatrix	Bluefish
Carangidae	Caranx hippo	Crevalle jack
Sciaenidae	Cynoscion regalis	Weakfish
	Leiostomous xanthurus	Spot
	Menticirrhus saxatilis	Northern kingfish
Mugilidae	Mugil curema	White mullet
Uranoscopidae	Astroscopus guttatus	Northern stargazer
Gobiidae	Gobiosoma bosci	Naked goby
Triglidae	Prionotus carolinus	Northern searobin
Cottidae	Myoxocephalus aenaeus	Grubby
Pleuronectidae	Pseudopleuronectes americanus	Winter flounder

FROM ANONYMOUS, 1976.



The large squares represent the area of highest fish density in Sandy Hook Bay; the stippled squares near stations 13 and 14 (of DeFalco, 1967) represent areas of highest density of winter flounder.

REDRAWN AFTER WILK AND SILVERMAN, 1976.

Number of Individuals of 18 Waterfowl Species Observed during 34 Ground Surveys in Vicinity of Liberty State Park, September 1975-June 1976

Species	Number
Canada Goose	3
Brant	2
Mallard	90
Black Duck	573
Gadwall	646
Pintail	98
Green-winged Teal	3
Blue-winged Teal	2
American Wigeon	679
Redhead	1
Canvasback	5530
Greater Scaup	2334
Lesser Scaup	9
American Goldeneye	9
Bufflehead	714
Ruddy Duck	1
Hooded Merganser	10
Red-breasted Merganser	6
Unidentified	73
Total	10,783

FROM ANONYMOUS, 1976.

Estimated waterfowl shot annually by hunters, 1961-70

Species	Long Island South Shore	New Jersey East Shore	Total for Bight	Composition by Species	Total for Atlantic Flyway	Bight/Atlantic Flyway
Mallard	3,408	6,901	10,309	9.2%	261,006	4.0%
Black Duck	9,391	21,465	30,856	27.5	318,682	9.7
Gadwall	215	189	404	0.4	22,972	1.8
American Widgeon	534	2,325	2,859	2.5	66,224	4.3
Green-winged Teal	1,918	3,983	5,901	5.3	119,362	4.9
Blue-winged Teal	76	161	237	0.2	38,418	0.6
Northern Shoveler	35	245	280	0.3	11,762	2.4
Pintail	335	584	919	0.8	34,293	2.7
Wood Duck	173	286	459	0.4	234,482	0.2
Redhead	57	116	173	0.2	11,256	1.5
Canvasback	86	1,076	1,162	1.0	24,187	4.8
Greater Scaup	8,019	4,514	12,533	11.2	48,822	25.7
Lesser Scaup	1,041	1,442	2,483	2.2	54,882	4.5
Ring-necked Duck	5	26	31	0.03	99,640	0.03
Common Goldeneye	896	475	1,371	1.2	24,047	6.7
Bufflehead	1,671	3,240	4,911	4.4	38,216	12.9
Ruddy Duck	204	61	265	0.2	7,909	3.4
Oldsquaw	475	668	1,143	1.0	7,354	15.5
Black Scoter	51	704	755	0.7	7,808	9.7
White-winged Scoter	561	372	933	0.8	22,363	4.2
Surf Scoter	152	718	870	0.8	15,417	5.6
Hooded Merganser	120	327	447	0.4	50,200	0.9
Red-breasted Merganser	873	547	1,420	1.3	14,244	10.0
Common Merganser	42	39	81	0.1	8,680	0.9
All ducks[a]	30,714	51,967	82,681	73.6	1,546,968	5.3
Canada Goose	893	3,950	4,843	4.3	185,826	2.6
Brant	5,337	19,547	24,884	22.1	29,288	85.0
All geese[a]	6,230	23,497	29,727	26.4	215,316	13.8
All waterfowl	36,944	75,464	112,408	100.0	1,762,284	6.4

[a]Totals do not equal sum of data in columns because hybrids and domestic releases are not included. Atlantic Flyway data include species not listed here

Sources: Crissey 1961; Glover and Smith 1963; Hansen 1964, 1967; Hansen and Hudgins 1965, 1966; Martinson et al 1968, 1969; Chamberlain et al 1971, 1972; Carney et al 1975.

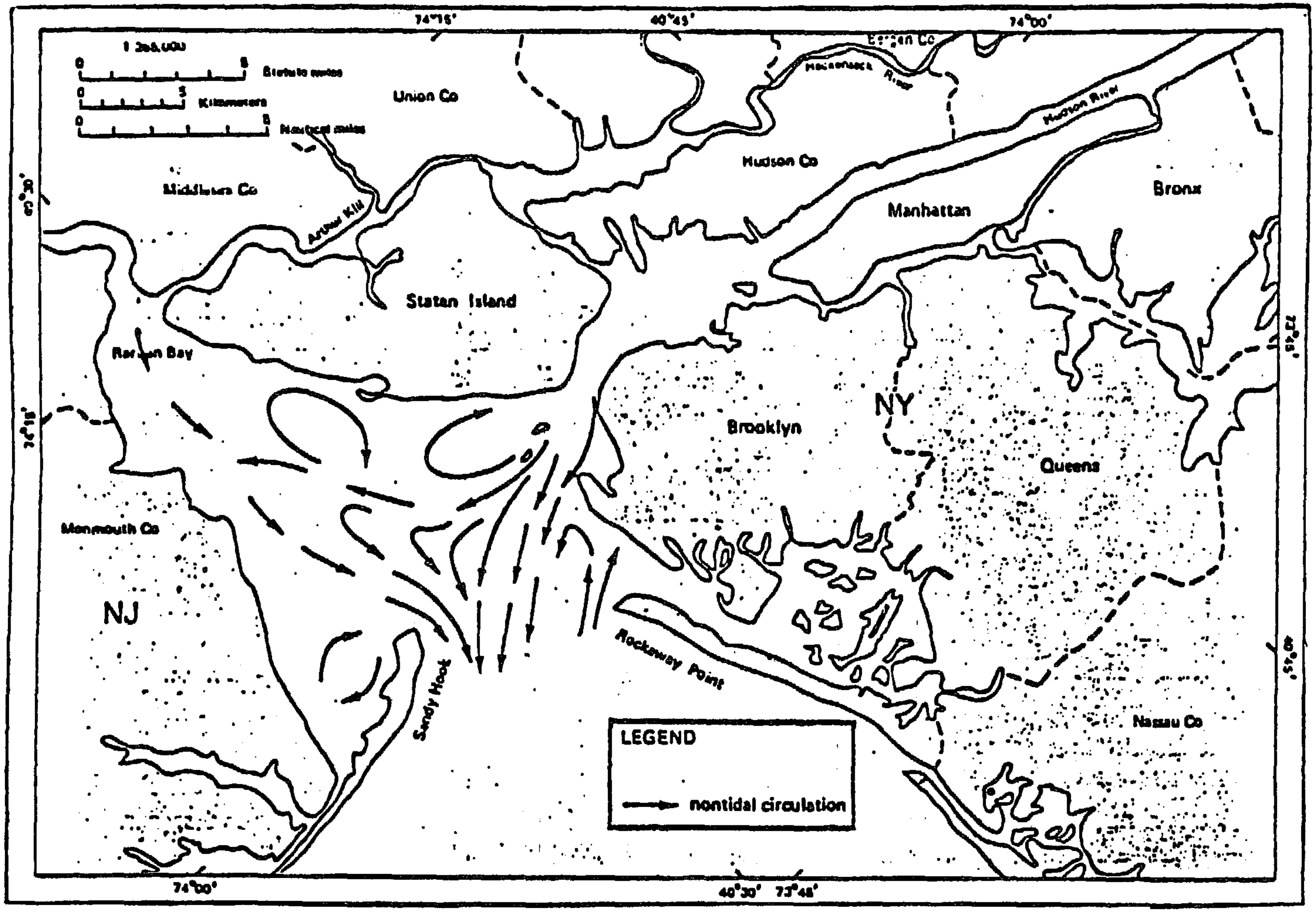
FROM HOWE ET AL., 1978.

The estimated mortalities sustained by seabird populations following some of the major oil spills that have occurred since 1937

Incident	Spillage	Mortality	Species	Reference*
March 1937 San Francisco Bay USA	Crude oil 9,000 tons	10,000 (1.1 birds/ton)	Murre, grebe, scoter	5
Jan. 1953 Howacht Bay Baltic Sea	Oil residues 500 tons	10,000 (20 birds/ton)	Eider, merganser, scoter	6
Jan. 1955 Gerd Maersk Elbe River, Germany	Crude oil 8,000 tons	275,000 (34.4 birds/ton)	Scoter	6
Sept. 1956 Seagate, Washington, USA	Bunker C fuel oil	6,000	Scoter, guillemot	7
1962 Gotland, Sweden	No record	30,000	Long-tail duck	8
March 1967 Torrey Canyon, SW England	Crude oil 117,000 tons	30,000 (0.26 birds/ton)	Guillemot, razorbill	9
Feb. 1969 N. Zeeland, Denmark	No record	10,000	Eider, common scoter	10
Feb. 1969 Terschelling, Holland	Crude oil	30-35,000	Eider, common scoter	11
March 1969 Santa Barbara, Calif., USA	Crude oil 11,000 tons	3,600 (0.3 birds/ton)	Western grebe, loon, scoter, cormorant	12,13
April 1969 Hamilton Trader, Irish Sea	Heavy fuel oil 600-700 tons	6,000 (9.2 birds/ton)	Guillemot, razorbill	14
May 1969 Palva, Kökar, Finland	Crude oil 150 tons	3,000-3,500 (21.7 birds/ton)	Eider, long-tail duck	15
Jan. 1970 NE Britain	Fuel oil 1,000 tons	50,000 (50 birds/ton)	Sea duck, auk	16
Feb. 1970 East Jutland, Denmark	No record	12,000	Eider, common scoter, velvet scoter	10
Feb. 1970 Delian Apollon Tampa, Florida, USA	Bunker C fuel oil 80-100 tons	9,000 (90 birds/ton)	No record	17
Feb.-April 1970 Arrow & Irving Whale Newfoundland & Nova Scotia	Bunker C fuel oil 10,000 tons	12,800 (0.8 birds/ton)	Sea duck, auk, alcid, eider, ducks	18
Feb.-March 1970 Kodiak Oil Spill Alaska	Tanker ballast	10,000	Alcid, sea duck, gull, kittiwakes	19
Dec. 1970-Jan. 1971 South Kattegat	No record	15,000	Eider, scoter	10
Jan. 1971 San Francisco Bay, Calif. USA	Bunker C fuel oil 300-350 tons	7,000 (21.5 birds/ton)	Grebe, guillemot, scoter	20
March 1972 Jutland	No record	30,000	Eider, scoter	21
Dec. 1972 Danish Waddenzee	No record	30,000	Eider, common scoter	21

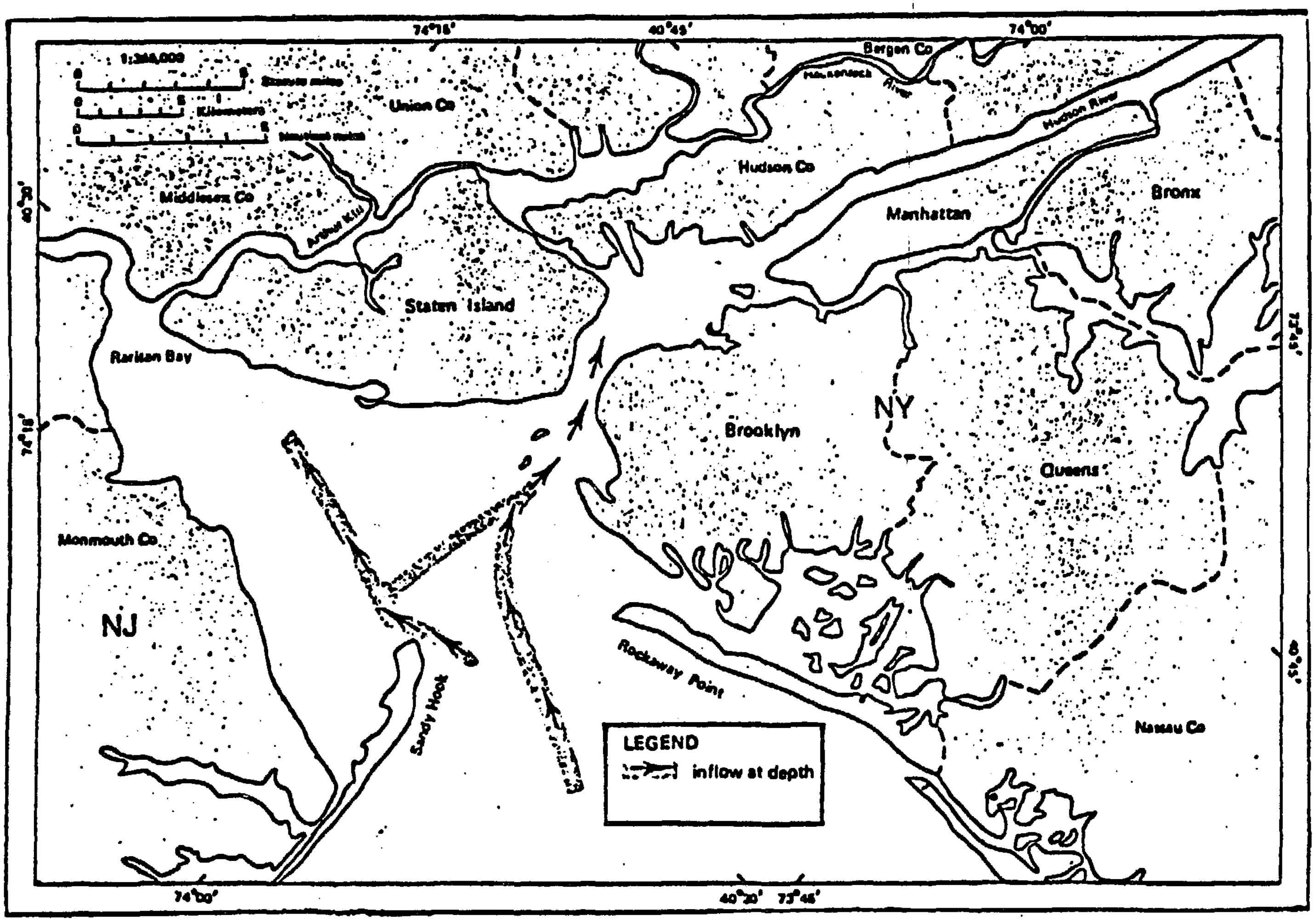
*For references see the original report.

FROM HOWE ET AL., 1978



FROM DUEDALL ET AL., 1979.

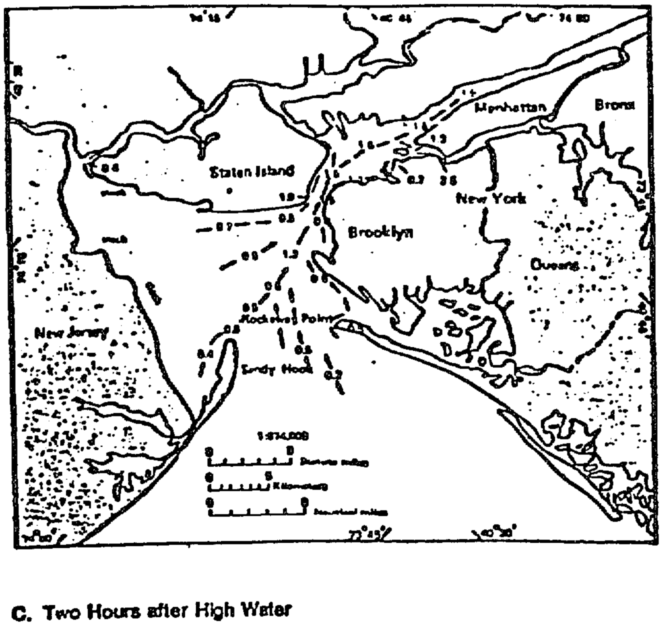
APPENDIX-PAGE 40



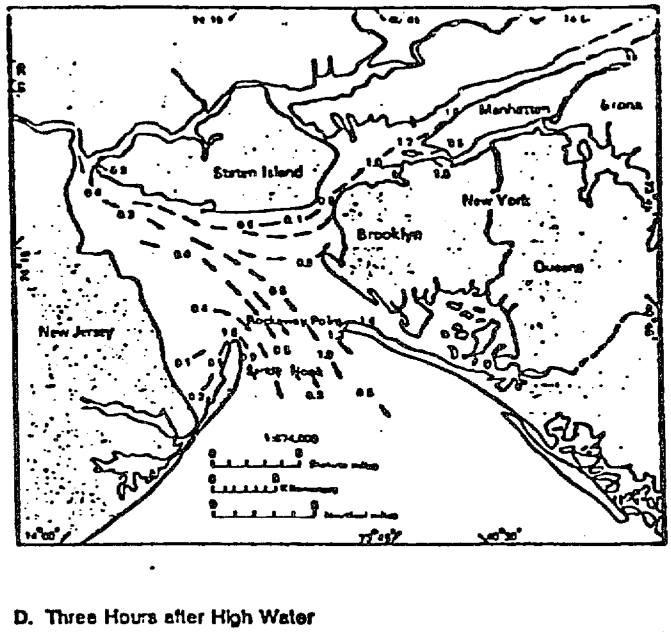
FROM DUEDALL ET AL., 1979.

Tidal currents (knots)

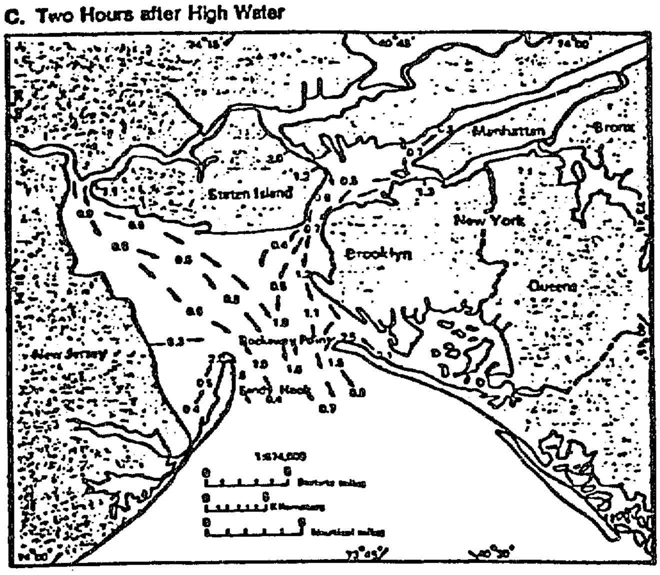
A. High Water



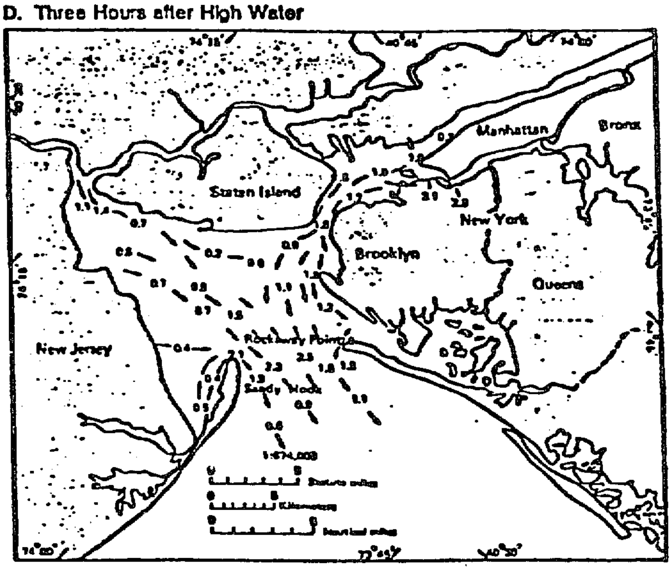
B. One Hour after High Water



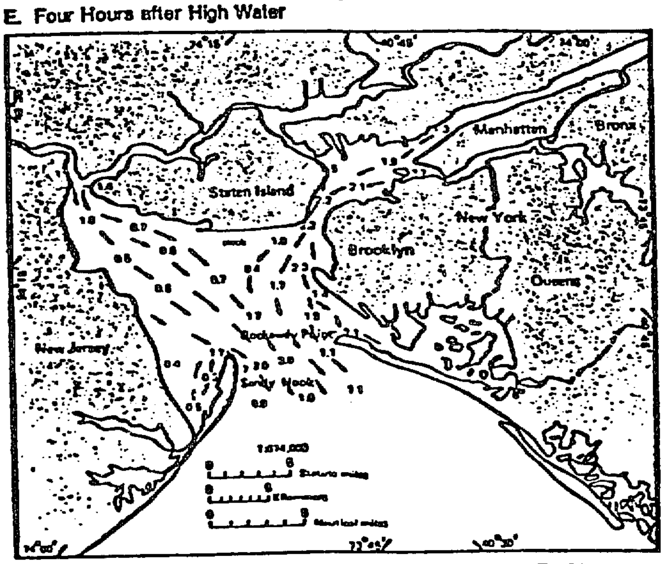
C. Two Hours after High Water



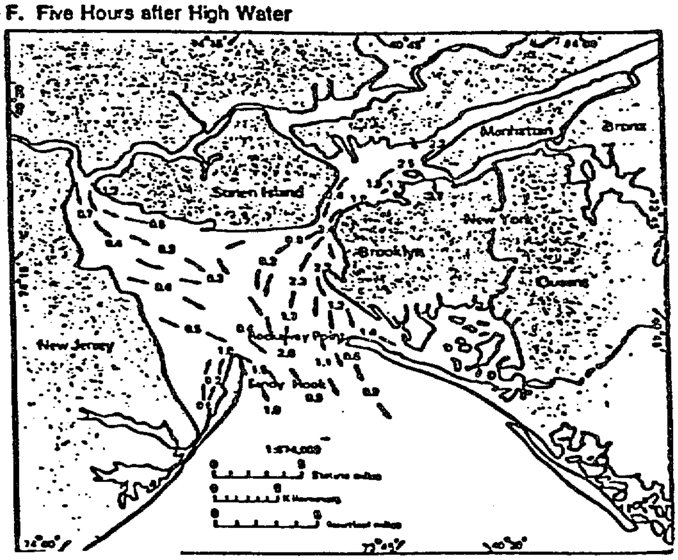
D. Three Hours after High Water



E. Four Hours after High Water



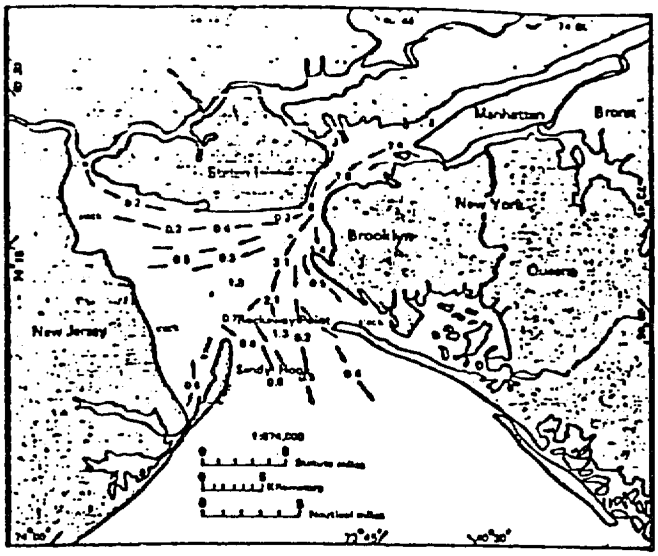
F. Five Hours after High Water



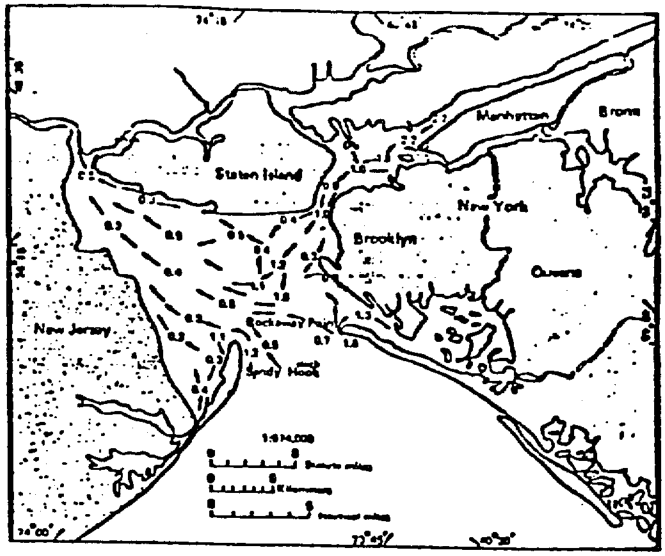
FROM DUEDALL ET AL., 1979

Tidal currents (knots)

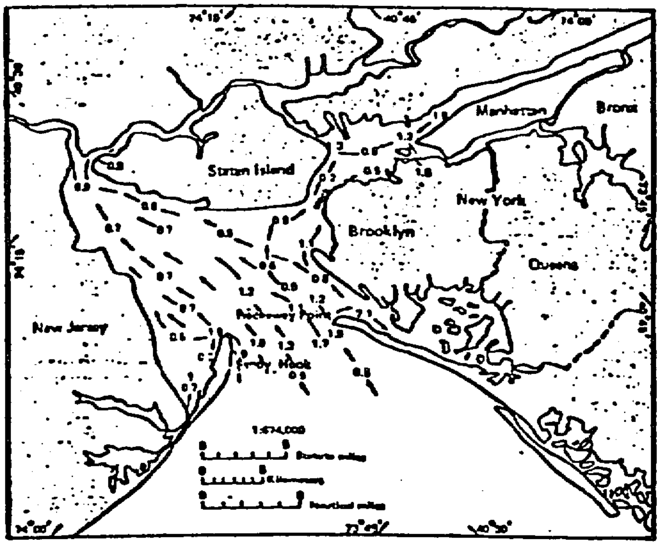
G. Low Water



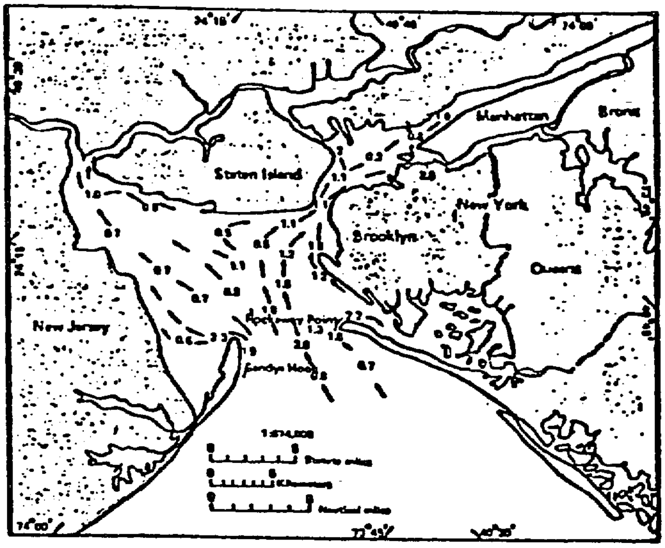
H. One Hour after Low Water



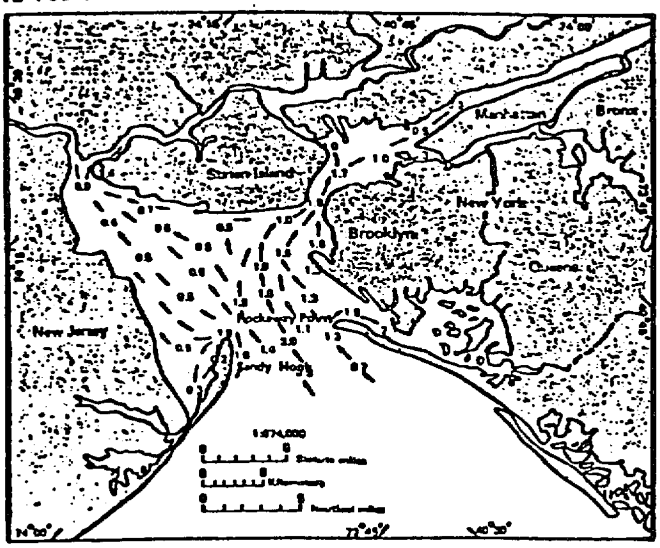
I. Two Hours after Low Water



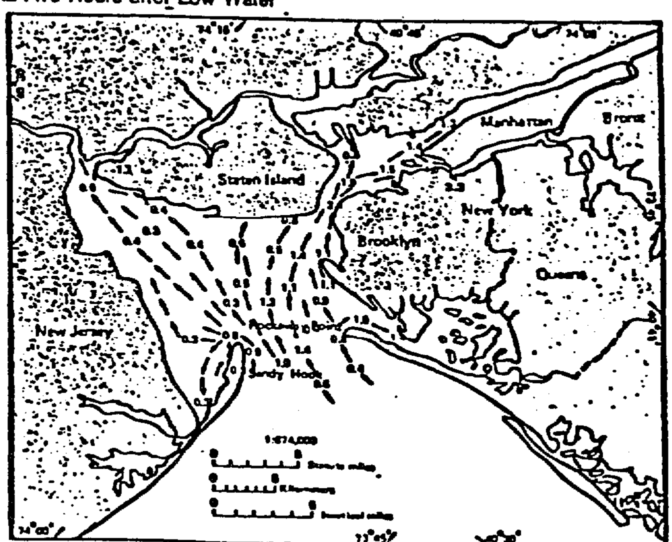
J. Three Hours after Low Water



K. Four Hours after Low Water



L. Five Hours after Low Water



FROM DUEDALL ET AL., 1979

.-Fish species from New York Bight (Jones Inlet and three miles south of Manasquan Inlet) containing *Cancer irroratus* and *C. borealis* in their digestive tract.

Species	Total specimen of each species	No. specimens containing Cancer in digestive tract	Percent of each finfish species containing Cancer
Urophycis chuss/tenuis	30	10	33.3%
Tautogolabrus adspersus	78	6	7.7%
Raja erinacea	3	1	33.3%
Tautoga onitis	52	20	38.4%
Centropristes striatus	9	3	33.3%
Gadus morhua	39	26	67.1%
Myoxocephalus octodecemspinosus	5	4	80.0%
Squalus acanthias	3	3	100 %
Menticirrhus saxatilis	23	3	13.0%

FROM SANDY HOOK LABORATORY SURVEY, 1971.

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Taxa Occurrence in Stomach Contents

	Spot	Atlantic tomcod	White perch	Bluefish	Atlantic silverside	Striped bass	Mummichog	Winter flounder	Threespine stickleback	Silver hake	Striped killifish	Number of fish species/taxa occurrence
Polychaeta	●	●	●		●			●				5
Harpacticoida	●											1
Nematoda	●											1
Annelida	●	●										2
Detrital matter	●	●										2
Empty stomach	●		●		●	●	●	●				6
Copepoda	●		●	●			●					4
Isopoda		●										1
Edotea		●										1
Amphipoda		●		●	●	●	●				●	6
Gammarus		●										1
Decapoda		●										1
Amphipod-Gammaridean		●										1
Digested matter			●	●	●	●	●		●			6
Invertebrate eggs			●			●						2
Anchovy				●								1
Crustacean appendages				●								1
Fish				●								1
Neomysis americana				●		●						2
Mysidacea				●		●				●		3
Fish eggs				●	●		●					3
Brachiura				●								1
Decapod larvae				●								1
Algae (filamentous)				●								1
Calanoida				●								1
Hirudinea						●						1
Undetermined matter							●					1
Number of taxa/fish species	5	8	3	12	3	5		4	1	1	1	

FROM ANONYMOUS, 1976, LIBERTY STATE PARK STUDY.

Foods in 24 Canvasback Ducks from Upper New York Bay in Vicinity of Liberty State Park, Winter 1975-76

		Gullet			Gizzard		
		Aggregate		%	Aggregate		%
	Foods	Vol.	%	Occurrence	Vol.	%	Occurrence
Animal	Sand worm (*Nereis* sp.)	20	31	25	Tr*	Tr	25
	Soft-shelled clam (*Mya arenaria*)	52	42	29	88	84	83
	Eastern mud snail (*Illyanassa obsoleta*)	0	0	0	1	3	4
	Unidentified crab (claw fragment)	Tr	Tr	4	Tr	Tr	4
	Unidentified fish (scales)	Tr	Tr	4	0	0	0
	Total	72	73	42	89	87	83
Plant	Beans (*Phaseolus* spp.)	27	26	17	11	13	17
	Rice (*Oryza sativa*)	1	1	4	0	0	0
	Corn (*Zea mays*)	Tr	Tr	4	Tr	Tr	4
	Grape (*Vitis* sp.)	Tr	Tr	4	Tr	Tr	13
	Wheat (*Triticum* sp.)	Tr	Tr	4	Tr	Tr	4
	Total	28	27	17	11	13	17
	Total Food Volume	100	100		100	100	

*Less than 0.5%

FROM ANONYMOUS, 1976.

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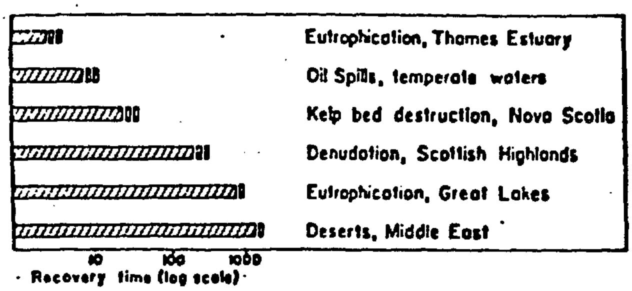

Estimates of possible recovery times (on a log scale) for various environmental perturbations. Estimates are of the time taken for the system to recover after the cessation of the activity causing the perturbation.

FROM MANN AND CLARK, 1978.

DEEPWATER OIL PORT

AIR QUALITY STUDY

FOR

THE PORT AUTHORITY

OF

NEW YORK AND NEW JERSEY

ENVIRO-SCIENCES, INC.
DENVILLE, NEW JERSEY

TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of the Deepwater Oil Port Study was to evaluate the economic and environmental feasibility of alternatives to the current practices of marine crude oil delivery to refineries located in New York Harbor and along the Delaware River. One such alternative concept investigated by the Port Authority of New York and New Jersey for the New Jersey Department of Energy, consists of a crude oil receiving facility capable of handling large tankers to be located either in the New York Harbor area or in the Delaware Bay/Delaware River/Port of Philadelphia area or both (Figure 1.0-1).

The object of this report is to compare the atmospheric impacts of the proposed facilities to those associated with existing operations. Specifically, Enviro-Sciences, Inc. (ESI) has been retained to:

* Provide an air quality characterization with respect to Federal and States' existing and proposed ambient air quality standards based upon the identification, collection and compilation of existing baseline air quality data.

* Prepare a meteorological and dispersion characterization based upon the examination of historical data such as averages and extremes of temperature and humidity, wind characteristics, precipitation types and levels, the frequency and effects of storms accompanied by high winds and pertinent climatological or topographical features.

* Prepare a comparison between air emissions associated with marine crude oil delivery for existing facilities and operations and for proposed facilities and operations in order to determine subsequent ambient air quality impacts, if a facility were to be built.

* Prepare an analysis of the positive and negative impacts of the proposed facilities as they pertain to ambient air quality standards.

By its very nature, this type of report must be based upon many assumptions. Key among those assumptions are the following:

1. An increase in refinery throughput capacity will not be stimulated by either of these two facilities.

2. As provided to ESI by the Port Authority, the project scenarios for the New York Harbor facility and the Delaware Bay facility are representative of the real world.

Preparation of this type of report requires the use of many sources--Federal and State agencies, private and public organizations and individuals from the private sector. Their contributions are gratefully acknowledged.

GENERAL LOCATION MAP

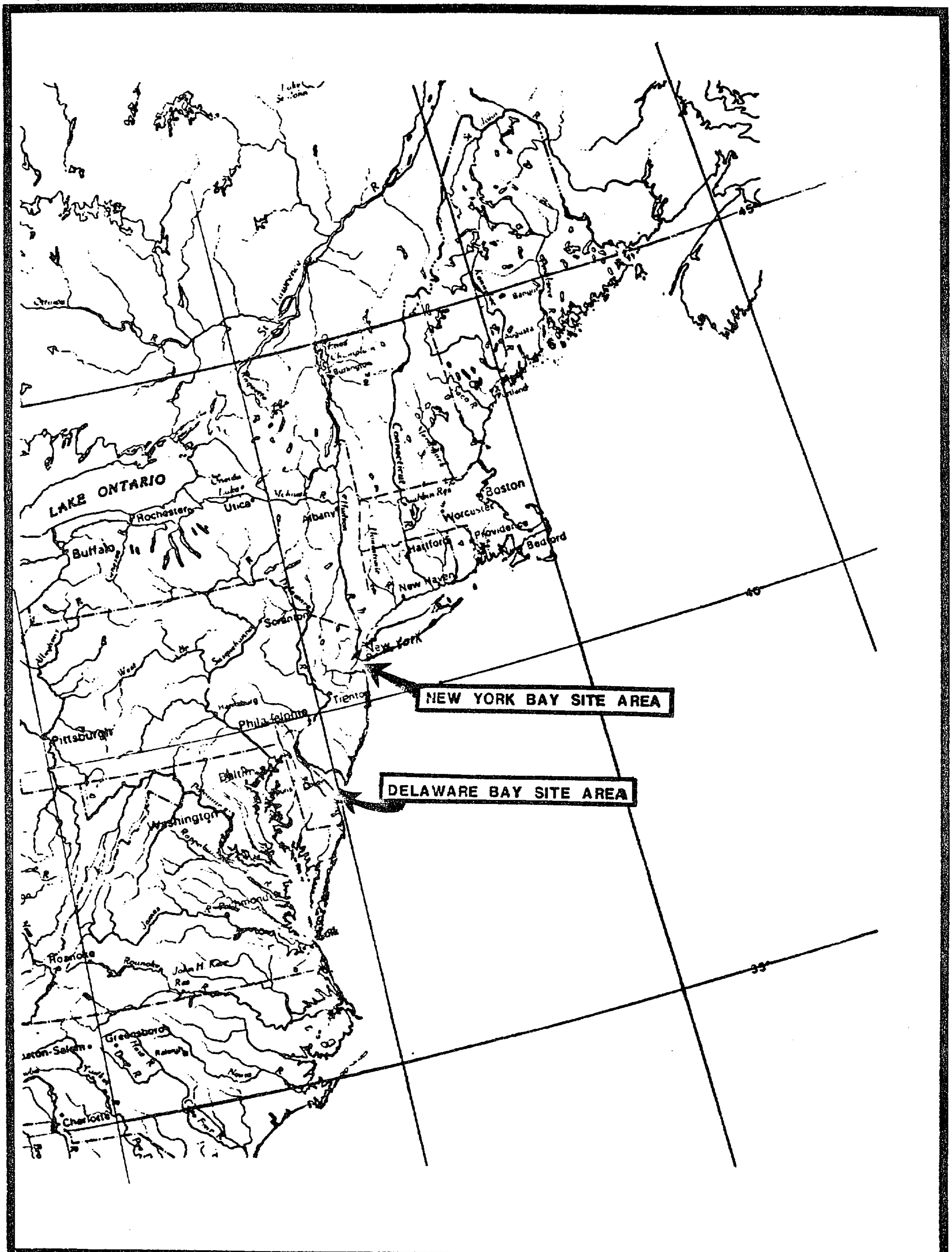

FIGURE 1.0-1

2.0 DESCRIPTION OF THE PROPOSED ACTION

The proposed action represents a modification to the present crude oil delivery system which replaces the currently used 85 to 120 Thousand Dead Weight Ton (MDWT) Tankers and the associated barges involved in lightering these vessels with Very Large Crude Carriers (VLCC's) carrying volumes of crude oil commensurate with a draft of 60 feet. These vessels would do no in-shore lightering. For either of the two areas of study (New York Bay and Delaware Bay), offloading facilities and a storage tank farm with associated pipelines and pumping stations would have to be constructed (the facility).

New York Bay--In the New York Bay study area, two refineries (Exxon, Linden and Chevron, Perth Amboy) would be the recipients of the crude oil delivered through the proposed project. Presently, the annual requirements for the two refineries are 142.4 million barrels per year (MMBPY) of which 87.6 MMBPY are delivered by 85 MDWT vessels, carrying 500,000 BBLS per visit; this necessitates 175 annual visits by this class of tanker, the remainder being delivered by a variety of smaller tanker classes. The proposed project is designed to deliver the 87.6 MMBPY to the area via VLCC's (up to 260 MDWT partially laden carrying 1.25 MMBBLS per visit); this reduces the annual number of tanker visits for this volume from 175 to 70.

New York Harbor, the supply artery for the two refineries, is accessed via the twelve-mile long, 45-foot deep Ambrose Channel. The access channels to the refineries for tankers (Arthur Kill, Kill van Kull, Sandy Hook and Raritan Bay)are all limited to a 35-foot depth. Typically, an 85 MDWT tanker requires a draft of nearly 45 feet when loaded. Because of the water depth limitations these vessels require 20-30% offloading to barges (lightering) before traversing the approach channels to the refineries. This operation requires the vessel to be at one of the principal anchorages in New York Bay--Stapleton, Bayridge or Gravesend; Stapleton anchorage is used for short-term lightering while Bayridge and

Gravesend are used for longer term operations. Presently it is estimated that 600 barge movements annually are required to lighter the crude supply to the two refineries; using the proposed supply system will result in 155 barge movements to the two refineries.

Tanker duration in the harbor area is dependent upon extant traffic, availability of tugs, assignment of anchorage, government inspections, tide and weather conditions. The range of time an 85 MDWT tanker spends in port is 2.5-5 days, spending 3 days on the average. Of this, lightering operations require approximately 12 hours, anchorage time up to an additional 36 hours, pier time 24-48 hours (out of which 20-24 hours are required for unloading), the balance being spent transiting the channels. Utilization of VLCC's would eliminate the need for the use of the anchorages for lightering and can reduce port time to a total of 36 hours.

Comparisons of the vessel movements involved in crude oil delivery with and without the facility are show below:

	Extant Operations (Annual)	Proposed Facility (Annual)
Total Tanker Visits:	336	231
Large Tankers:	85 MDWT	260 MDWT
	175 Tankers to Ambrose Channel to Stapleton Anchorage to lighter.	70 Tankers to Facility
	Tankers after lightering.	No lightering.
	96 - Stapleton to Kill Van Kull to Arthur Kill and Exxon Refinery Pier.	No vessel movement to refinery piers.
	79 - Stapleton to Ambrose Channel to Sandy Hook Channel to Raritan Channel to Arthur Kill and Chevron Refinery Pier.	

	Extant Operations (Annual)	Proposed Facility (Annual)
Small Tankers	: 137 Tankers	No change
	110 - Ambrose Channel to Stapleton then to Kill Van Kull to Arthur Kill to Exxon Refinery Pier.	
	27 - Direct to Chevron Refinery Pier via Sandy Hook Channel and Raritan Channel to Arthur Kill.	
Crude Destined for other points	: 24 Tankers to Ambrose Channel, Hudson River to Albany.	No change.
Barges	: 400 Anchorage to Kill Van Kull/Arthur Kill to to Exxon.	155 Anchorage to Kill Van Kull/ Arthur Kill to Exxon.
	200 Anchorage to Arthur Kill to Chevron.	
	25 Anchorage to Hudson River to Albany.	No change.
Total Barge Movements	: 625 Movements	180 movements

The following activities would be required to allow VLCC's to service the area:

1. Ambrose Channel and an access channel to the facility would be deepened to at least 60 feet.

2. An offloading facility would be constructed, either in Stapleton area of Staten Island, or at Port Jersey in New Jersey.

3. Twin 36" pipelines would be installed from the offloading facility to the east bank of the Arthur Kill, south of the Goethals Bridge.

4. A small tank farm would be constructed on either the west or east shore of the Arthur Kill.

   ... East Shore Farm 4 200,000 Barrel & 2 150,000 Barrel
   ... West Shore Farm 2 400,000 Barrel & 2 150,000 Barrel

   Should the tank farm be on the west shore, then twin 36" pipelines would be extended across the Arthur Kill.

Delaware Bay/River--The Delaware study area involves the region extending from Big Stone Anchorage in lower Delaware Bay up to the Port of Philadelphia; refineries to be served include Getty--Delaware City, Delaware; BP and Sun--Marcus Hook, Pennsylvania; Mobil and Seaview--Paulsboro, New Jersey; Gulf and Arco--Philadelphia, Pennsylvania; and Texaco--Westville, New Jersey. The existing crude oil consumption for the refineries is approximately 339.5 MMBPY of which 60% is delivered in 120 MDWT tankers; 273 trips carrying a load of 750,000 BBLS each are made annually by these vessels. The remaining crude (139.5 MMBPY) is delivered in a variety of vessel types averaging 450,000 BBLS per visit (300 port calls, yearly). The proposed project will replace the former delivery tanker types with VLCC's carrying 1.1 MMBBLS per visit thereby reducing the number of annual visits for this portion of the crude oil to 186.

The main anchorage for vessels entering Delaware Bay is Big Stone Anchorage (60+ foot water depth), 10 miles northwest of Cape Henlopen. Although some vessels are completely offloaded at anchorage, the majority of lightering ranges between 20%-50% of the vessel's cargo. This requires approximately 1087 barges or about 473 "barge string movements" annually; the proposed delivery system would reduce these movements to 150 strings (300 barges), yearly.

Following is a summary of the vessel movements associated with existing and proposed operations:

	Extant Operations (Annual)	Proposed Facility (Annual)
Tanker Visits Total :	573	486
Tankers to Facility : (VLCC's)	0	186
Tankers Lightered : and then Upriver	473	200
Tankers Upriver : Directly	100	100
Barges :	1087 (473 barge strings)	300 (150 barge strings)

The facilities to be constructed for the proposed project are:

1. Existing approaches into Big Stone Anchorage would be used with dredging performed as required to achieve a 60-foot depth in the area of the facility.

2. Two single point mooring buoys capable of offloading crude oil would be installed north of the northern end of Big Stone Anchorage, approximately five miles east of Big Stone Beach, Delaware.

3. Unloading would be accomplished via a 48" submarine pipeline from each buoy to shore. A small pumping station would be located approximately one mile inland from the landfall.

4. A 48" pipeline would be installed running about 30 miles north of the pumping station to a point near Delaware City, Delaware. There, a second pumping station would be located along with a small storage tank farm consisting of two tanks of 250,000 barrel capacity, each.

5. From Delaware City, Delaware, a 48" pipeline would run in a generally northerly direction approximately twenty miles to Marcus Hook, Pennsylvania where a third pumping station would be located. A major tank farm of some 6,100,000 barrels consisting of 9 tanks of 400,000 barrels each, and 10 tanks of 250,000 barrels each, would be built in this area. The refineries would be responsible for connecting spur lines at this point, with at least one line crossing the Delaware River to the vicinity of Paulsboro, New Jersey.

2.1 Sources of Emissions

The sources of emissions from the existing and proposed crude oil delivery systems can be categorized as mobile point sources (tankers, barges, tugs) in transit through the access channels and stationary sources (storage tanks--breathing; tankers in hotel mode; and tankers and barges in pumping mode during lightering or offloading). Any other sources, e.g. refinery operations, will remain unchanged by this proposed action. In addition, other sources such as personnel associated with the facilities are assumed to be local hire and hence no increase in job related emissions would be anticipated.

The following table summarizes the calculations developed in Appendix 'A' for the net decrease in emissions associated with the proposed facility at each location. The calculated net emissions were based upon the decrease effectuated by the replacement of existing sources with VLCC's, combined with the additional storage tank emissions associated with the proposed action.

NET REDUCTION OF EMISSIONS-POUNDS PER YEAR

	New York Bay	Delaware Bay
Particulates	35,774	42,581
Sulfur Oxides	924,659	1,346,581
Hydrocarbons	587,403	(19,147)*
Nitrogen Oxides	132,672	168,115
Carbon Monoxide	6,060	7,935

The data used to calculate the emissions for ship operations have been supplied to ESI by marine operators of typical vessels and are compiled in Figure A-1; emission factors published in AP-42 are used to determine emission rates. These data are shown in Appendix 'A'.

* net increase

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3.0 ATMOSPHERIC ENVIRONMENT

3.1 Meteorology

New York Bay

The project area's climate is predominantly influenced by air masses and prevailing winds from an inland direction. The weather is highly variable, characterized by a succession of alternate high and low pressure systems moving, in general, from west to east with average velocities of 30 to 35 mph in winter and 20 to 25 mph in summer.

About 40 percent of the low pressure centers pass very close to the site and most of the others approach closely enough to exert some influence on its weather, resulting in a regular change in weather patterns without any consistent periods of stagnation. The movement of high pressure centers is slowest in summer and early fall and sometimes becomes stationary for periods of several days; the result is increasing atmospheric stability. This condition is frequently broken up diurnally in the summer because of the length and intensity of the sun's heating during the day, however, strongly stable conditions may persist for a number of successive days in almost any month. Nonetheless, persistent stability, lasting 7 days or more, occurs infrequently; on the average, perhaps once in 10 years. Stagnating high pressure systems which result in winds of less than 7 mph for a period of 7 or more days occurred just once in 21 years (Mochta, et al). Over the same 21 year period, stagnation lasting four or more days occurred much more frequently and reached a maximum occurrence in the fall. For example, no such cases were observed in January, there was 1 in April, 2 in August and 7 in October for an average of once every three years. More recent studies by Korshover (1967) and Holzworth (1972) verify the relative infrequency of stagnation periods and their concentration of occurrence in the fall.

During the spring, fall and winter, the weather is dominated by cold air masses of continental Arctic or continental

Polar types. These air masses, although extremely stable at their source, are subjected to heating from below as they move across the land and are thus generally unstable in the lower few thousand feet by the time they reach the New Jersey area.

In the summer, the maritime tropical air mass and continental air masses both play strong roles in the region's weather. Nocturnal cooling from below, which causes temperature inversions during the summer, are most often broken up or weakened by heating during the day with ensuing turbulence and mixing in the atmosphere.

Prevailing winds in the area are generally from the westerly semicircle. More specifically, they blow from north of west in the months January through April, and south of west in the months May through December. The period of lightest winds is summer and fall, particularly late summer and early fall. This coincides with periods of maximum frequency of clear skies at night. The latter condition contributes to low level cooling at night and the possible formation of inversions. Thus, the large scale weather observations would indicate that poorest diffusion conditions occur about one third of the days of the year and in the late summer and early fall, and are associated, in general, with winds from a south westerly direction. Figures 3.1-1 to 3.1-6 show the percentage frequencies of wind direction and speed on a monthly and annual basis for the period of 1951-1960 for the area. The meteorological and topographical features of the area are such as to make atmospheric diffusion moderately good most of the time.

The climate of the area can best be described as humid and temperate, with warm summers and moderate winters. Temperatures rarely exceed 100°F in the summer and seldom drop as low as 0°F in the winter. Extreme temperatures of 107°F and -15°F have been recorded. The annual mean temperature ranges from 60.6 to 63.6, depending upon the station (Tables 3.1-1 to 3.1-4).

Precipitation (Tables 3.1-5 to 3.1-8) is fairly evenly distributed throughout the year. The annual average ranges from

40.2 to 45.5 inches, with the highest monthly average in August. A maximum 24-hour rainfall of 11.17 inches occurred in October, 1903. Measurable precipitation falls approxiamtely 120 days a year with thunderstorms recorded on an average of 25 days a year. Generally, thunderstorms occur five days a month throughout the summer, however, thunderstorms with hail and damaging winds are rare.

Snowfall averages 35.2 inches a year, with February generally having the highest monthly average. The average annual relative humidity varies from 54 percent in the afternoon to 73 percent in the early morning, generally with the highest values occurring in the early morning and the lowest in the afternoon. Seasonally, highest values occur during the fall months, and lowest values occur in the spring. Heavy fog (restricting visibility to 0.25 miles or less) occurs approximately two days a month except during the summer, when it is recorded on the average of once a month. Annually, heavy fog is recorded about 20 days a year.

Delaware Bay

The climate of the area can be classified as humid-temperate with warm and humid summers and relatively mild winters. The relative humidity is higher during the summer months when early morning readings are in the mid 80's versus the mid 70's during the winter. Precipitation is fairly evenly distributed throughout the year with maximum amounts occurring during the summer months (June through August).

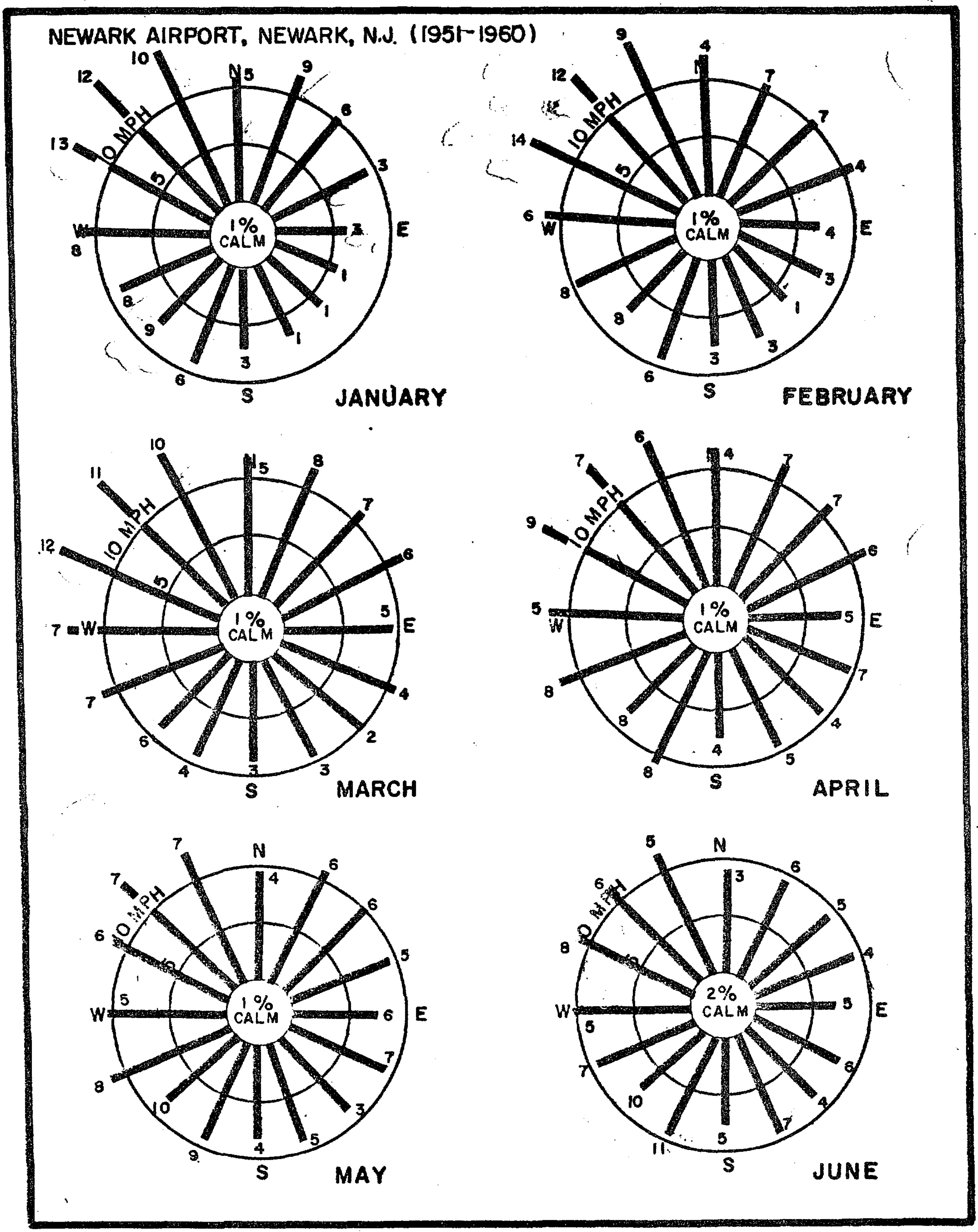
The monthly percentage frequencies and wind speed and direction are show in Figures 3.1-7 to 3.1-10. During the winter (December - February) and early spring, winds are predominantly west northwesterly through northerly. From late spring to early fall the predominant direction switches to a southwesterly and west-south-westerly direction. Average monthly wind speeds are greatest from January through April and least from July through September.

Temperature statistics are presented in Tables 3.1- 9 and 3.1-10. The coldest month is January with an average minimum of 23.8°F and the warmest month is July with an average maximum of 66.7°F; the mean monthly averages for the aforementioned months are 32°F and 76.8°F, respectively. The mean annual monthly temperature is approximately 54°F. The highest temperature of this record period was 104°F (1966), while the lowest was -6°F (1979).

Precipitation is fairly evenly distributed throughout the year with the summer months having the maximum rainfall. During the summer, local showers and thundershowers contribute to this rainfall. Infrequent hurricanes and tropical storms occasionally cause heavy rainfall and flash flooding in the late summer and early fall. Tables 3.1-11 and 3.1-12 summarize the precipitation statistics for the 1941-1970 record.

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JANUARY-JUNE)

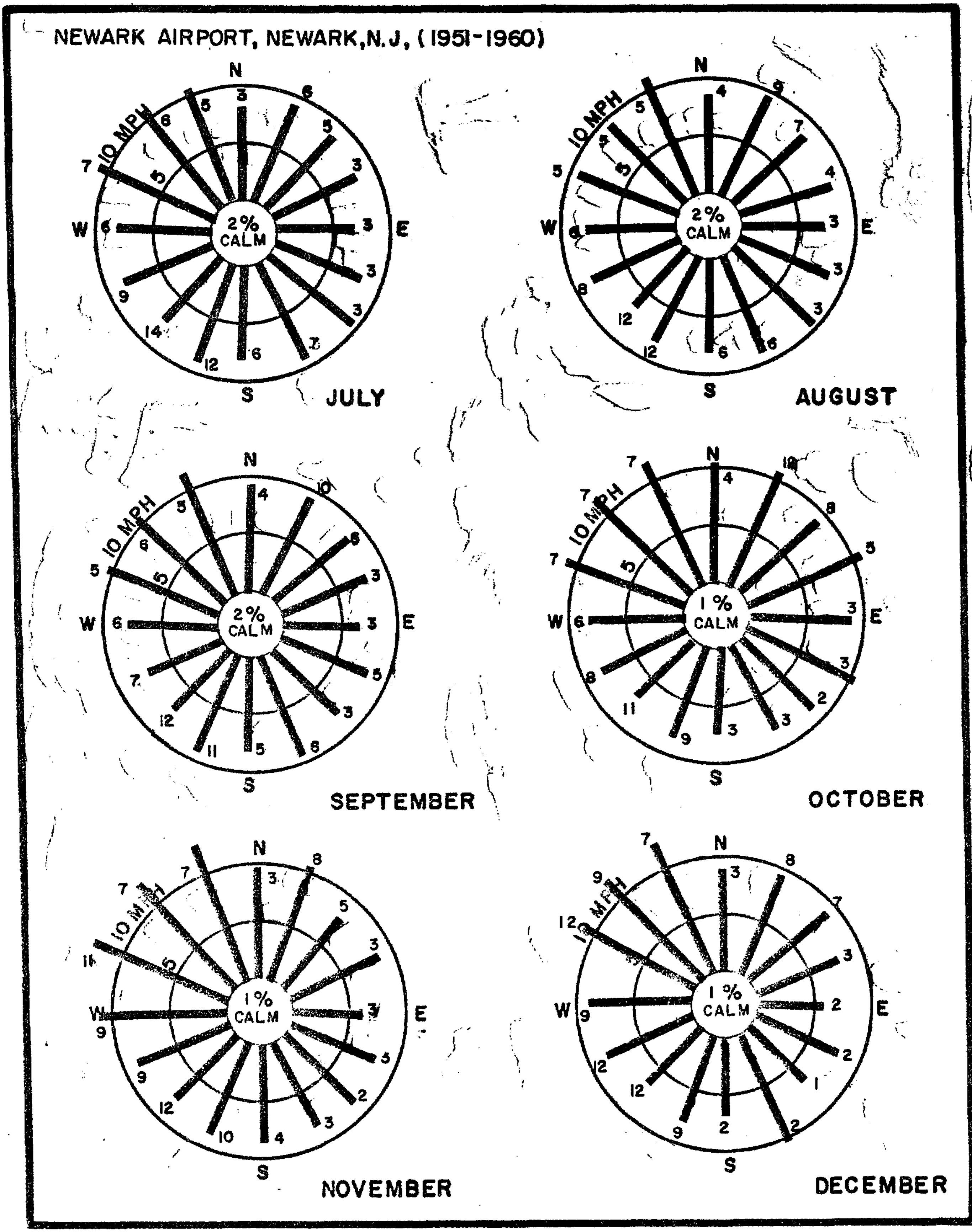


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-1

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JULY-DECEMBER)

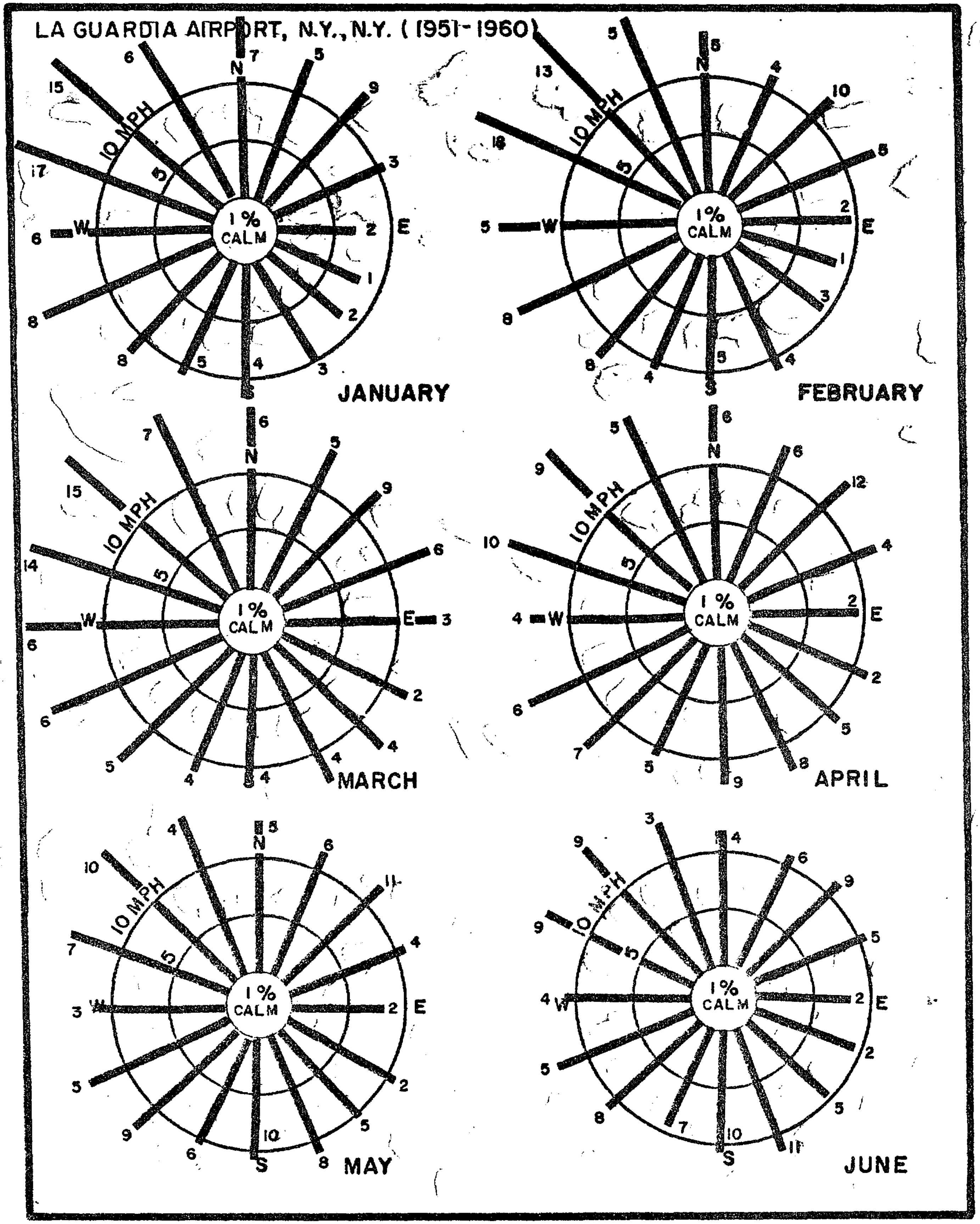


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-2

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JANUARY-JUNE)

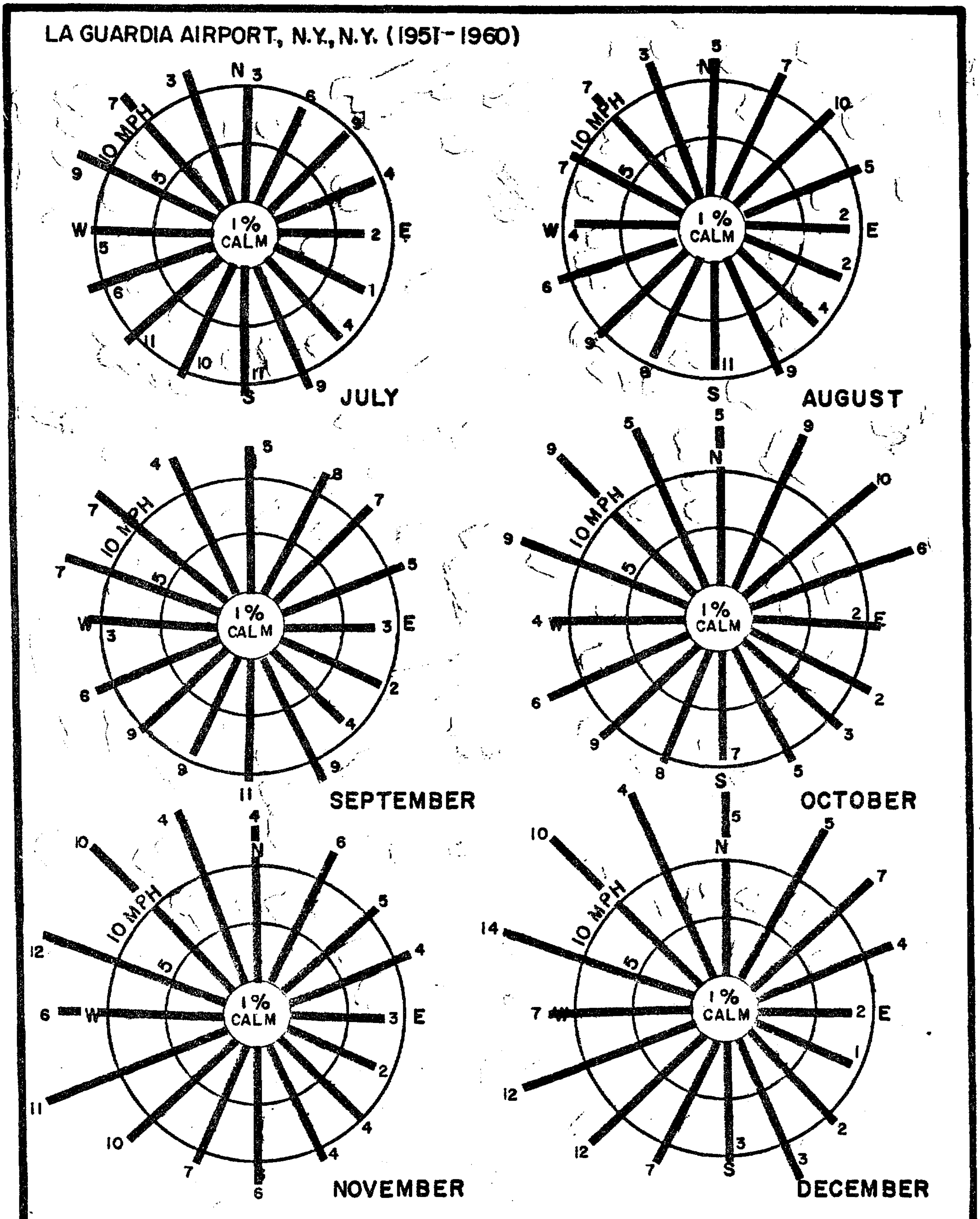


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-3

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JULY - DECEMBER)

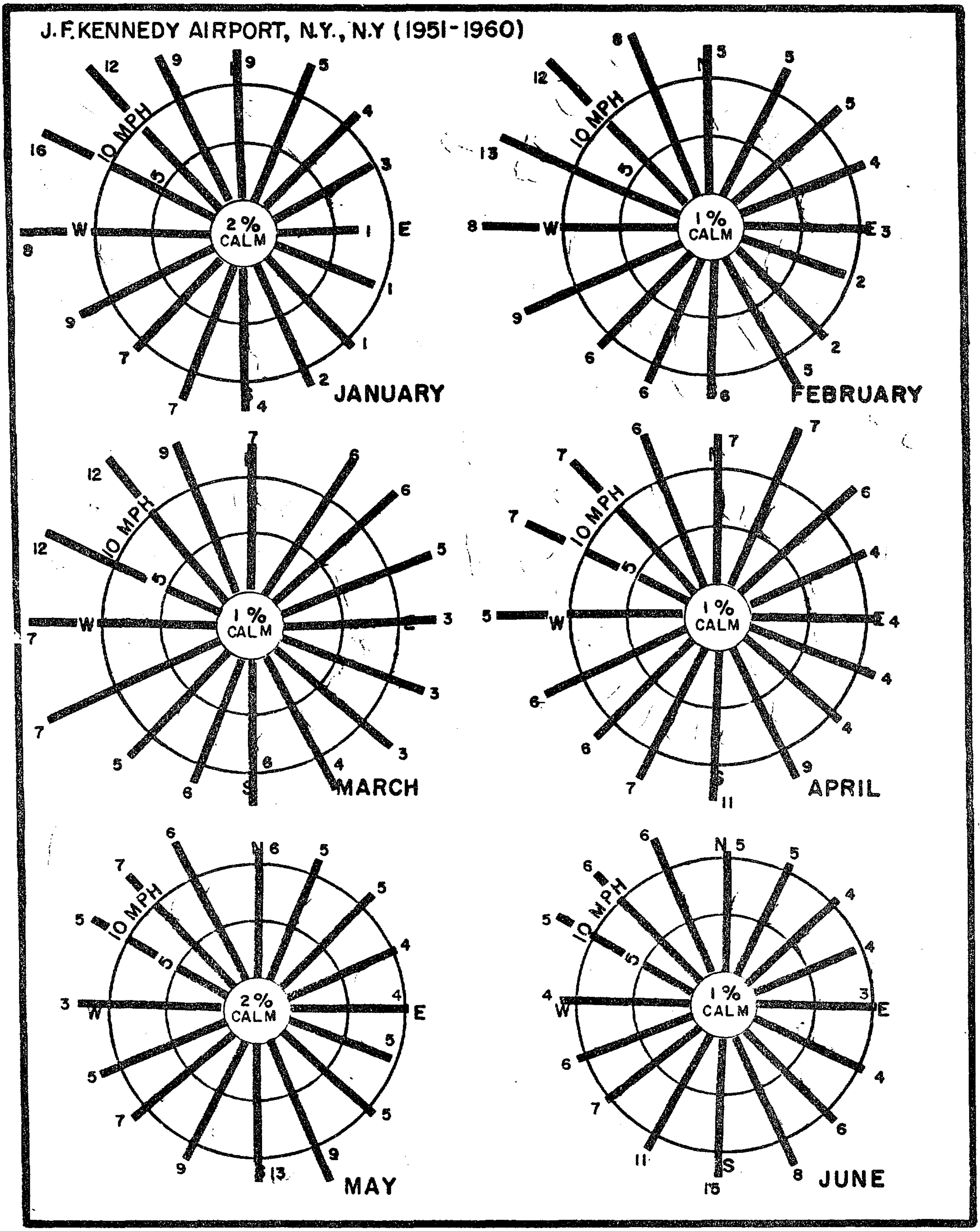


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-4

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JANUARY-JUNE)

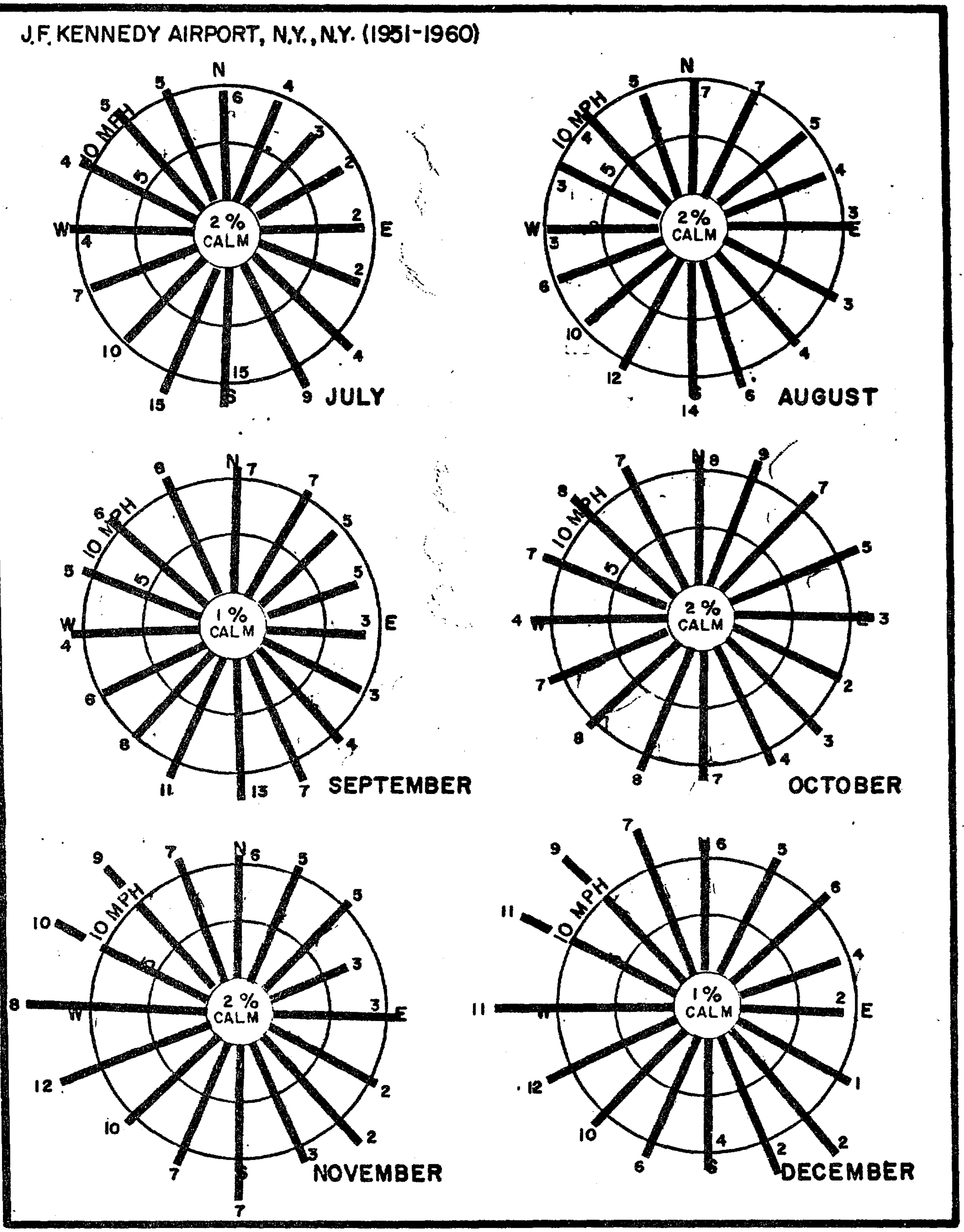


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-5

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JULY-DECEMBER)

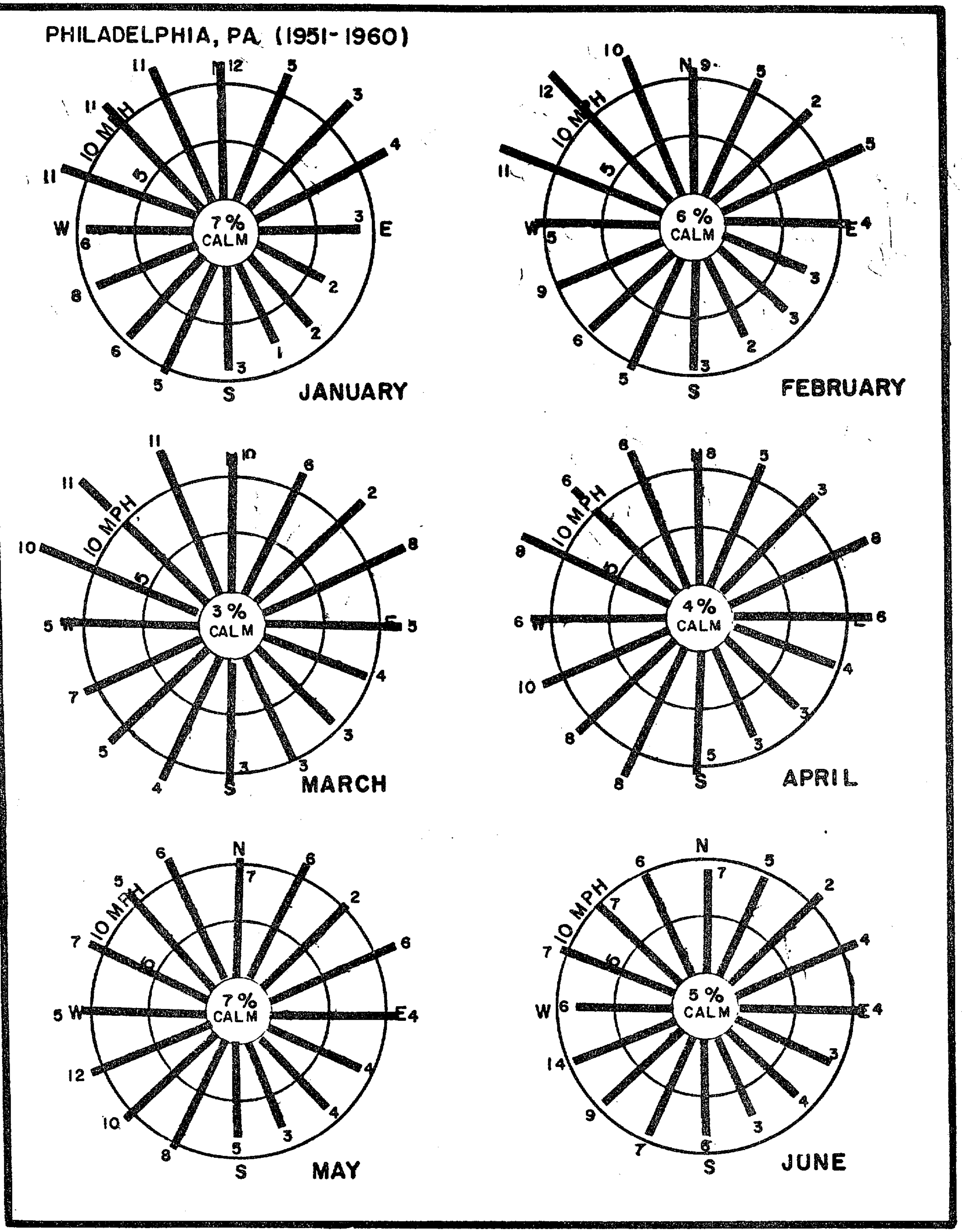


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-6

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JANUARY-JUNE)

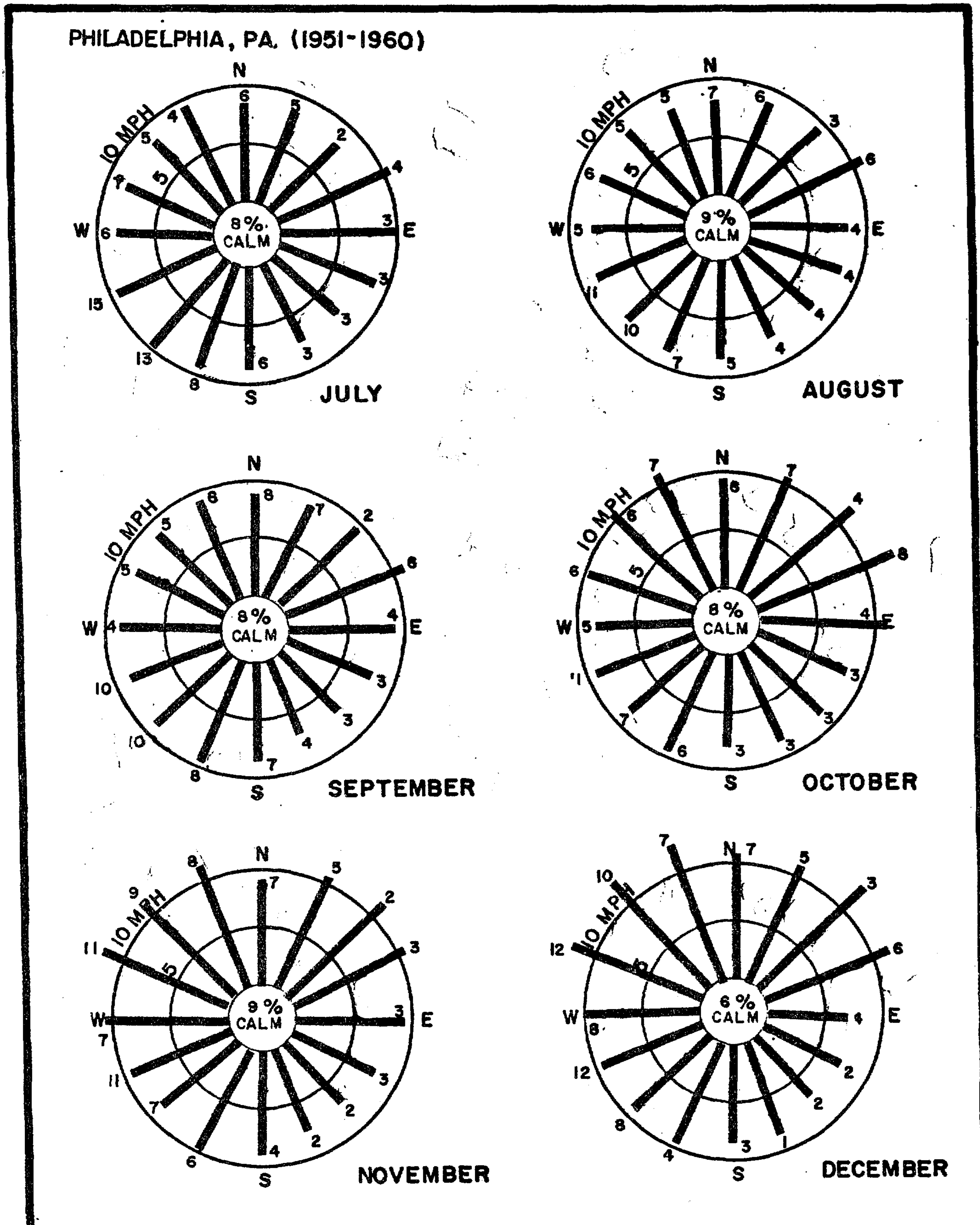


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-7

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JULY - DECEMBER)

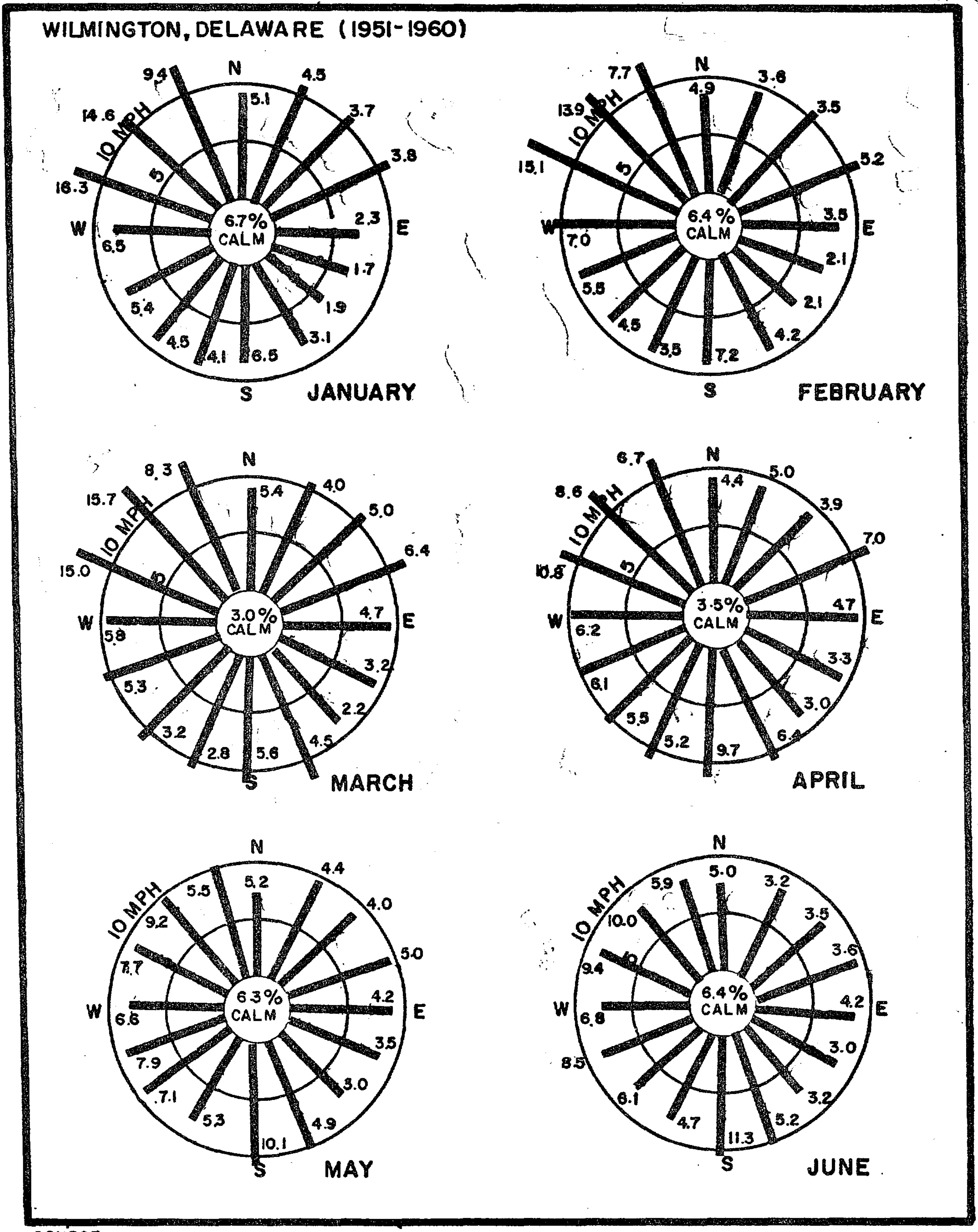


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-8

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JANUARY-JUNE)

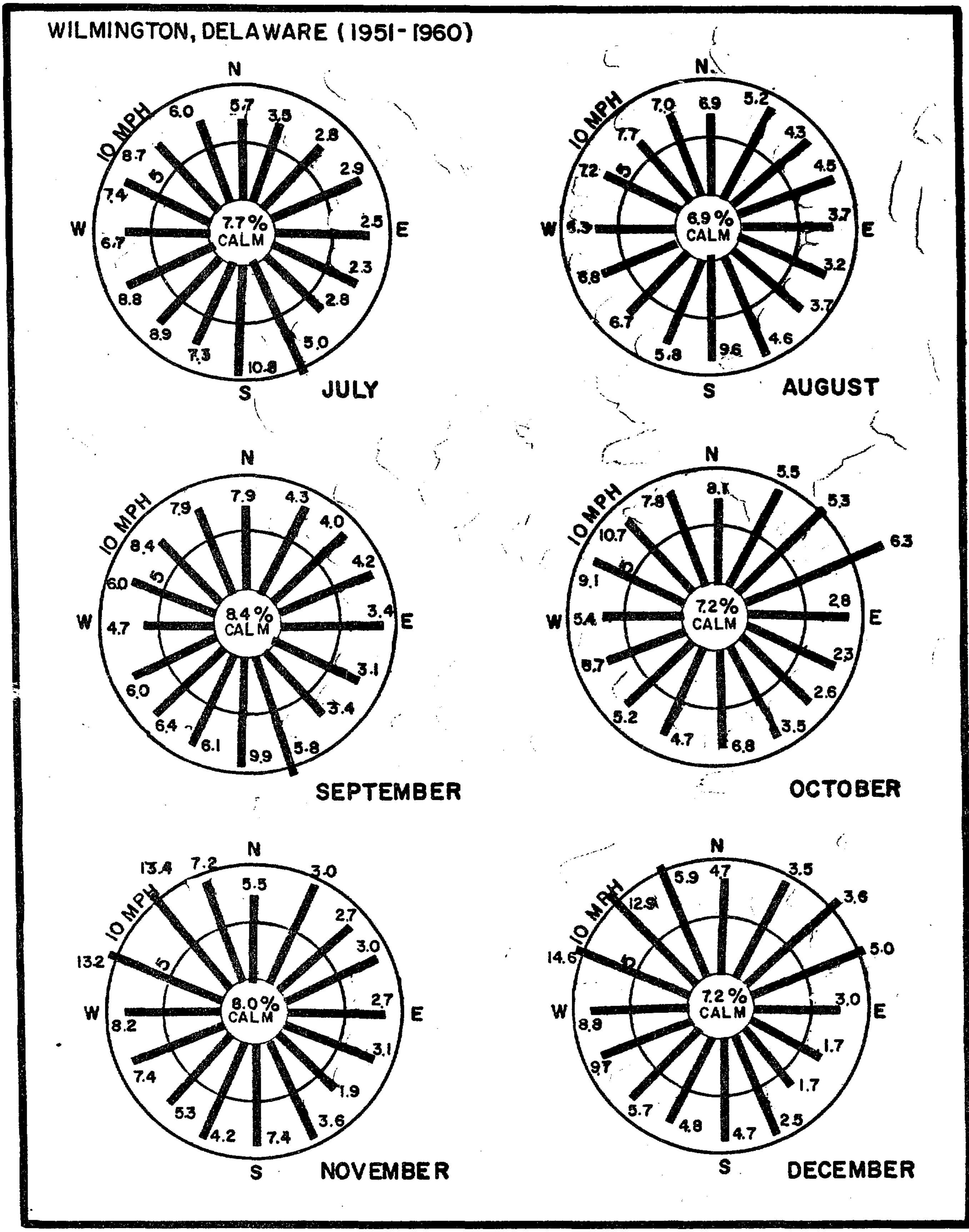


SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-9

WIND ROSE

MEAN WIND SPEED VS. PERCENTAGE OF TIME (JULY-DECEMBER)



SOURCE:
U.S. DEPARTMENT OF COMMERCE

FIGURE 3.1-10

TABLE 3.1-1

TEMPERATURE MEANS (1941-1970) AND EXTREMES 1/

CENTRAL PARK, NEW YORK, NEW YORK

Month	Mean Daily Maximum	Mean Daily Minimum	Mean Monthly	Record Maximum	Year	Record Minimum	Year
January	38.5	25.9	32.2	72	1950	-6	1882
February	40.2	26.5	33.4	75	1930	-15	1934
March	48.4	33.7	41.1	86	1945	3	1872
April	60.7	43.5	52.1	96	1976	12	1923
May	71.4	53.1	62.3	99	1962	32	1891
June	80.5	62.6	71.6	101	1966	44	1945
July	85.2	68.0	76.6	106	1936	52	1943
August	83.4	66.4	74.9	104	1918	50	1976
September	76.8	59.9	68.4	102	1953	39	1912
October	66.8	50.6	58.7	94	1941	28	1936
November	54.0	40.8	47.4	84	1950	5	1875
December	41.4	29.5	35.5	70	1946	-13	1917
Annual:	62.3	46.7	54.5	106	July 1936	-15	Feb. 1934

1/ Temperature in ^{o}F

Source: U.S. Department of Commerce, NOAA, 1980 Local Climatological Data, Central Park, New York, New York.

TABLE 3.1-2

TEMPERATURE MEANS (1941-1970) AND EXTREMES [1/]

LA GUARDIA AIRPORT, NEW YORK, NEW YORK

Month	Mean Daily Maximum	Mean Daily Minimum	Mean Monthly	Record Maximum	Year	Record Minimum	Year
January	37.7	26.4	32.1	68	1967	-1	1977
February	39.2	27.0	33.1	68	1967	-2	1963
March	47.1	34.1	40.6	78	1977	8	1980
April	59.3	44.0	51.7	91	1976	25	1972
May	69.8	53.7	61.8	95	1962	38	1978
June	79.4	63.6	71.5	97	1964	46	1972
July	84.1	69.3	76.7	107	1966	56	1979
August	82.1	67.6	74.9	97	1973	52	1976
September	75.2	60.9	68.1	94	1965	44	1974
October	65.1	51.0	58.1	85	1967	30	1969
November	53.2	41.3	47.3	79	1974	18	1976
December	41.0	30.1	35.6	67	1978	-1	1980
Annual:	61.1	47.4	54.3	107	July 1966	-2	Feb. 1963

1/ Temperature in ^{o}F.

Source: U.S. Department of Commerce, NOAA, 1980 Local Climatological Data, La Guardia Airport, New York, New York.

TABLE 3.1-3

TEMPERATURE MEANS (1941-1970) AND EXTREMES 1/

J.F. KENNEDY INTERNATIONAL AIRPORT
NEW YORK, NEW YORK

Month	Mean Daily Maximum	Mean Daily Minimum	Mean Monthly	Record Maximum	Year	Record Minimum	Year
January	38.0	24.8	31.4	65	1974	-1	1977
February	39.1	25.2	32.2	67	1976	-2	1963
March	46.5	32.1	39.3	72	1979	7	1967
April	58.1	41.7	49.9	90	1977	26	1977
May	68.4	51.1	59.8	99	1969	34	1966
June	78.0	60.9	69.5	99	1964	45	1967
July	83.2	66.9	75.1	104	1966	55	1979
August	81.7	65.4	73.6	98	1975	46	1965
September	75.4	58.6	67.0	94	1961	40	1963
October	65.8	48.7	57.3	84	1967	25	1961
November	53.7	39.3	46.5	77	1975	19	1976
December	41.3	28.4	34.9	68	1962	3	1980
Annual:	60.8	45.3	53.1	104	July 1966	-2	Feb. 1963

1/ Temperature in °F

Source: U.S. Department of Commerce, NOAA, 1980 Local Climatological Data, J.F. Kennedy International Airport, New York, New York.

TABLE 3.1-4

TEMPERATURE MEANS (1941-1970) AND EXTREMES 1/

NEWARK INTERNATIONAL AIRPORT, NEWARK, NEW JERSEY

Month	Mean Daily Maximum	Mean Daily Minimum	Mean Monthly	Record Maximum	Year	Record Minimum	Year
January	38.5	24.3	31.4	74	1950	-2	1977
February	40.2	24.9	32.6	76	1949	-7	1943
March	48.8	32.4	40.6	89	1945	6	1943
April	61.2	42.2	51.7	93	1976	23	1954
May	71.6	52.1	61.9	98	1962	33	1947
June	81.1	61.6	71.4	102	1952	43	1945
July	85.6	67.2	76.4	105	1966	52	1945
August	83.7	65.5	74.6	103	1948	48	1976
September	77.0	58.6	67.8	105	1953	35	1947
October	66.9	48.5	57.5	92	1949	28	1969
November	54.2	38.2	46.2	85	1950	15	1955
December	41.5	27.4	34.5	72	1946	-1	1980
Annual:	62.5	45.2	53.9	105	July 1966	-7	Feb. 1943

1/ Temperature in ^{o}F.

Source: U.S. Department of Commerce, NOAA, 1980 Local Climatological Data, Newark International Airport, Newark, N.J.

TABLE 3.1-5

MONTHLY MEAN AND EXTREME AND DAILY MAXIMUM PRECIPITATION 1/

CENTRAL PARK, NEW YORK, NEW YORK (1941-1970)

Month	Mean Monthly (inches)	Maximum Monthly (inches)	Minimum Monthly (inches)	Maximum 24 Hour Amounts (inches)	Maximum Monthly Snowfall (inches)
January	2.71	10.52	0.66	3.91	27.4
February	2.92	6.87	0.46	3.04	27.9
March	3.73	10.41	0.90	4.25	30.5
April	3.30	8.77	0.95	3.46	13.5
May	3.47	9.15	0.30	4.88	T
June	2.96	9.78	0.02	4.74	0.0
July	3.68	11.89	0.49	3.60	0.0
August	4.01	10.86	0.24	5.78	0.0
September	3.27	16.85	0.21	8.30	0.0
October	2.85	13.31	0.14	11.17	0.8
November	3.76	12.41	0.34	8.09	19.0
December	3.53	9.98	0.25	3.21	29.6
Annual:	40.19	16.85	0.02	11.17	30.5

1/ Inches

Source: U.S. Department of Commerce, NOAA, 1980
Local Climatological Data, Central Park,
New York, New York.

TABLE 3.1-6

MONTHLY MEAN AND EXTREME AND DAILY MAXIMUM PRECIPITATION 1/

LA GUARDIA AIRPORT, NEW YORK, NEW YORK (1941-1970)

Month	Mean Monthly (inches)	Maximum Monthly (inches)	Minimum Monthly (inches)	Maximum 24 Hour Amounts (inches)	Maximum Monthly Snowfall (inches)
January	2.88	8.68	0.76	3.55	18.3
February	3.10	5.76	0.92	2.90	21.5
March	3.98	8.73	0.87	3.25	18.9
April	3.56	7.36	1.21	2.69	6.4
May	3.36	8.15	0.43	3.02	T
June	2.89	8.15	0.03	3.67	0.0
July	3.85	12.33	0.69	3.82	0.0
August	4.48	16.05	0.24	7.11	0.0
September	3.15	9.63	0.62	4.52	0.0
October	2.96	9.09	0.06	3.58	1.2
November	3.77	9.92	0.31	4.46	4.0
December	3.63	7.70	0.31	3.44	26.8
Annual:	41.61	16.05	0.03	7.11	26.8

1/ Inches

Source: U.S. Department of Commerce, NOAA, 1980 Local Climatological Data, La Guardia Airport, New York, New York.

TABLE 3.1-7

MONTHLY MEAN AND EXTREME AND DAILY MAXIMUM PRECIPITATION [1/]

J.F. KENNEDY INTERNATIONAL AIRPORT, NEW YORK, NEW YORK

(1941-1970)

Month	Mean Monthly (inches)	Maximum Monthly (inches)	Minimum Monthly (inches)	Maximum 24 Hour Amounts (inches)	Maximum Monthly Snowfall (inches)
January	2.69	8.33	0.21	3.25	20.1
February	3.05	5.48	1.60	2.87	25.3
March	3.79	8.17	1.35	2.40	21.1
April	3.59	7.53	1.12	3.31	3.2
May	3.54	6.44	0.38	2.88	T
June	2.98	7.06	T	2.75	0.0
July	4.04	8.48	0.46	3.21	0.0
August	4.30	17.41	0.42	6.59	0.0
September	3.31	9.65	0.70	5.83	0.0
October	2.76	6.41	0.09	3.42	0.5
November	3.90	9.51	0.32	4.09	2.1
December	3.60	6.16	0.90	2.46	16.4
Annual:	41.53	17.41	T	6.59	25.3

1/ Inches

Source: U.S. Department of Commerce, NOAA, 1980
Local Climatological Data, J.F. Kennedy
International Airport, New York, New York

TABLE 3.1-8

MONTHLY MEAN AND EXTREME AND DAILY MAXIMUM PRECIPITATION 1/

NEWARK INTERNATIONAL AIRPORT, NEWARK, NEW JERSEY (1941-1970)

Month	Mean Monthly (inches)	Maximum Monthly (inches)	Minimum Monthly (inches)	Maximum 24 Hour Amounts (inches)	Maximum Monthly Snowfall (inches)
January	2.91	10.10	0.81	3.59	27.4
February	2.95	4.94	1.22	2.45	26.1
March	3.93	9.13	1.12	2.66	26.0
April	3.44	7.28	0.90	2.96	4.1
May	3.60	8.12	0.52	4.22	T
June	2.99	6.40	0.07	2.31	0.0
July	4.03	8.02	0.89	3.40	0.0
August	4.27	11.84	0.50	7.84	0.0
September	3.44	10.28	0.95	5.27	0.0
October	2.82	8.20	0.21	3.04	0.3
November	3.61	11.53	0.51	7.22	3.1
December	3.46	7.24	0.27	2.14	29.1
Annual:	41.45	11.84	0.07	7.84	27.4

1/ Inches

Source: U.S. Department of Commerce, NOAA, 1980 Local Climatological Data, Newark International Airport, Newark, N.J.

TABLE 3.1-9

TEMPERATURE MEANS (1941-1970) AND EXTREMES 1/

PHILADELPHIA INTERNATIONAL AIRPORT
PHILADELPHIA, PENNSYLVANIA

Month	Mean Daily Maximum	Mean Daily Minimum	Mean Monthly	Record Maximum	Year	Record Minimum	Year
January	40.1	24.4	32.3	74	1950	-5	1963
February	42.2	25.5	33.9	74	1949	-4	1961
March	51.2	32.5	41.9	87	1945	7	1943
April	63.5	42.3	52.9	94	1976	24	1969
May	74.1	52.3	63.2	96	1962	28	1966
June	83.0	61.6	72.3	100	1964	44	1977
July	86.8	66.7	76.8	104	1966	51	1966
August	84.8	64.7	74.8	101	1955	45	1965
September	78.4	57.8	68.1	100	1953	35	1963
October	67.9	46.9	57.4	96	1941	25	1969
November	55.5	36.9	46.2	81	1974	15	1976
December	43.2	27.2	35.2	72	1951	1	1980
Annual:	64.2	44.9	54.6	104	July 1966	-5	Jan. 1963

1/ Temperature in ^{o}F.

Source: U.S. Department of Commerce, NOAA, 1980, Local Climatological Data, Philadelphia International Airport, Philadelphia, Pennsylvania.

TABLE 3.1-10

TEMPERATURE MEANS (1941-1970) AND EXTREMES 1/

WILMINGTON AIRPORT, WILMINGTON, DELAWARE

Month	Mean Daily Maximum	Mean Daily Minimum	Mean Monthly	Record Maximum	Year	Record Minimum	Year
January	40.2	23.8	32.0	75	1950	-4	1957
February	42.2	24.9	33.6	74	1954	-6	1979
March	51.1	32.0	41.6	86	1948	6	1980
April	63.0	41.5	52.3	91	1974	22	1965
May	73.1	51.6	62.4	95	1962	30	1978
June	81.6	61.1	71.4	99	1952	41	1972
July	85.5	66.1	75.8	102	1966	50	1979
August	83.9	64.3	74.1	101	1955	46	1965
September	78.2	57.6	67.9	100	1953	36	1974
October	67.8	46.5	57.2	91	1951	24	1976
November	55.2	36.2	45.7	85	1950	14	1955
December	43.0	26.3	34.7	72	1966	2	1980
Annual:	63.7	44.3	54.0	102	July 1966	-6	Jan. 1979

1/ Temperature in °F

Source: U.S. Department of Commerce, 1980. Local Climatological Data, Wilmington Airport, Wilmington, Delaware.

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TABLE 3.1-11

MONTHLY MEAN AND EXTREME AND DAILY MAXIMUM PRECIPITATION [1/]

PHILADELPHIA INTERNATIONAL AIRPORT
PHILADELPHIA, PENNSYLVANIA (1941-1970)

Month	Mean Monthly (inches)	Maximum Monthly (inches)	Minimum Monthly (inches)	Maximum 24 Hour Amounts (inches)	Maximum Monthly Snowfall (inches)
January	2.81	8.86	0.45	2.70	23.4
February	2.62	6.44	0.96	1.96	27.6
March	3.69	7.01	0.68	2.39	13.4
April	3.29	6.68	1.13	2.76	4.3
May	3.35	7.41	0.47	2.48	T
June	3.70	7.88	0.11	4.62	0.0
July	4.09	8.33	0.64	4.26	0.0
August	4.11	9.70	0.49	5.68	0.0
September	3.03	8.78	0.44	5.45	0.0
October	2.53	5.21	0.09	3.85	2.1
November	3.39	9.06	0.32	3.99	8.8
December	3.32	7.23	0.25	2.04	18.8
Annual:	39.93	9.70	0.09	5.68	27.6

1/ Inches

Source: U.S. Department of Commerce, NOAA, 1980 Local Climatological Data, Philadelphia International Airport, Philadelphia, Pennsylvania.

TABLE 3.1-12

MONTHLY MEAN AND EXTREME AND DAILY MAXIMUM PRECIPITATION 1/

WILMINGTON AIRPORT, WILMINGTON, DELAWARE (1941-1970)

Month	Mean Monthly (inches)	Maximum Monthly (inches)	Minimum Monthly (inches)	Maximum 24 Hour Amounts (inches)	Maximum Monthly Snowfall (inches)
January	2.85	8.41	0.59	2.12	17.2
February	2.75	7.02	0.83	2.29	27.5
March	3.74	6.22	0.81	3.11	20.3
April	3.20	6.57	1.12	2.56	1.1
May	3.35	7.35	0.22	2.35	T
June	3.34	7.49	0.44	4.35	0.0
July	4.31	7.51	0.16	6.24	0.0
August	3.98	12.09	0.25	4.11	0.0
September	3.42	9.53	0.82	5.62	0.0
October	2.60	6.41	0.21	3.88	2.5
November	3.49	7.84	0.49	3.83	11.9
December	3.32	7.90	0.19	2.22	21.5
Annual:	40.25	12.09	0.16	6.24	27.5

1/ Inches

Source: U.S. Department of Commerce, NOAA, 1980. Local Climatological Data, Wilmington Airport, Wilmington, Delaware.

3.2 AIR QUALITY

Ambient Air Quality

National primary and secondary air quality standards for five major pollutants were established by the Environmental Protection Agency under the Clean Air Act Amendments of 1970 and amended by Public Law 95-95 on August 7, 1977. To comply with the new Federal standards, each state has adopted its own ambient air quality standards for the protection of public health and welfare. (Table 3.2-1).

In addition to meeting the ambient air quality standards as defined in Table 3.2-1, the United States Environmental Protection Agency has stipulated that an additional requirement be met, namely, that there be "no significant degradation of air quality". In order to achieve this goal, each state classified specific areas into air quality control regions (AQCR) based upon the priorities outlined in Table 3.2-2.

Non-degradation provisions range from Class I (pristine) to Class III (industrialized). All AQCR's in the U.S. have been designated Class II except for national parks, wildlife areas, etc., listed in the Clear Air Act Amendments of 1977; reclassification must be accomplished by public hearing and technical analyses. In order to maintain ambient levels, new sources may not increase existing concentrations within an AQCR by more than the following:

	Allowable Increases (ug/m^3)
Particulate Matter	
Annual Geometric Mean	19
Max. 24-Hour Average	37
Sulfur Oxides	
Annual Arithmetic Mean	20
Max. 24-Hour Average	91
Max. 3-Hour Average	512

Note: $u = 1 \times 10^{-6}$ units

Tables 3.2-3 and 3.2-4 identify the AQCR priority classifications for New York Bay and Delaware Bay, respectively.

New York Bay

The air quality of metropolitan New York area has been classified as a non-attainment area for all pollutants. As shown in Table 3.2-5, monitoring stations are showing trends for improvement of particulates, carbon monoxide, sulfur dioxide and nitrogen oxides; however, hydrocarbons (correlated to ozone) show many violations.

Delaware Bay

The air quality of the Delaware Bay site is shown in Table 3.2-6. Other than the Philadelphia area, the air quality is good and generally meets air quality standards.

3.3 ATMOSPHERIC DIFFUSION

Atmospheric dispersion (diffusion) is important when considering the dispersion of gaseous effluents. Certain meteorological parameters are required to determine atmospheric dispersion potential. These are:

1. Atmospheric stability and corresponding mean wind speed and direction.
2. Atmospheric temperature and pressure.
3. Mean mixing heights (morning and afternoon), and
4. Horizontal and vertical dispersion coefficients for each stability class.

Generally, six stability classes are used which are based upon wind speed, and the amount of incoming solar radiation (determined by the amount of cloud cover and the azimuth of the sun). Basically, stability is determined by comparing the actual temperature gradient (assumed to be uniform) of an atmospheric

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layer with a dry adiabatic temperature gradient which is about -5.41°F/1000 feet, the temperature change a parcel of air would undergo if moved upward adiabatically (without exchange of heat with the surroundings). This is generally referred to as a "lapse rate" indicating the decrease in temperature with height. For practical applications, the adiabatic lapse rate applies well to moist air, provided that it is not saturated.

If the "lapse rate" is superadiabatic (temperature decreasing with height at a greater rate than adiabatic conditions) the air mass will be warmer than its surroundings and continue to rise. Similarly, a parcel of air moving downward will be cooler than its surroundings and will continue to fall. This favors good mixing and is classified as "unstable" air. Should the converse conditions prevail, that is, air either cooler but moving upward, or warmer but moving downward, than the surroundings, mixing is inhibited and the air is classified "stable".

There are variations in assessment criteria for stability classes, but the classification system used in the Day-Night STAR program will be used for most of the atmospheric dispersion calculations presented. This is a modification of Pasquill-Gifford stability classes with stability Class 1 being extremely unstable, Class 2 is very unstable, Class 3 is unstable, Class 4 is neutral (dry adiabatic lapse rate), Class 5 is stable and Class 6 is stable to extremely stable. Wind speed and turbulence modify the vertical temperature structure significantly; therefore, stability classes are temperature dependent.

The effect of stability on atmospheric dispersion varies from excellent mixing and dispersion (Class 1) to poor mixing, inversions and stagnant conditions (Class 6).

Winds are caused by pressure (density) differences, which result from temperature differences, and the velocity of the wind generally increases with height because of decreasing surface friction. Winds carry and dilute emissions from a source;

however, if the wind persists for an extended period of time from one direction, then the pollutant concentration may build up downwind of the source.

Mixing height is the height to which mixing is expected during the day due to the warm-up of the earth's surface. Morning mixing height is calculated as the height above the ground at which the dry adiabatic (neutral stability) extension of the morning minimum surface temperature increased by 9°F intersects the vertical temperature profile observed at 1200 Greenwich Median Time; the afternoon mixing height is calculated in the same manner, except the 9°F is not added and the surface temperature is the maximum observed between 1200 and 1600 Local Time.

Barometric pressure and temperature are required to determine the density of the ambient air and the resultant buoyant effect of the atmosphere on a plume being released from an exhaust stack.

Based upon the existing data at the airports in both project areas, conditions for favorable diffusion account for the majority of time.

3.3 DIFFUSION MODELING

Model Description

Air quality modeling study was attempted in order to compare, in a preliminary fashion, the impact of the proposed facilities to the present facilities for the New York Harbor Area and the Delaware Bay Area. The general technique involved running first a simple model (PTMAX) to establish preliminary indications of such things as pollution concentration levels, plume heights, and downwind distances, then a more specific model (PTMTP) to establish highest level short term concentrations and finally, a more sophisticated model (CDM) to give a picture of the long term area distribution of pollutants.

A brief description of the models follows:

(1) DBT52 (PTMAX). Produces an analysis of maximum hourly concentrations as a function of wind speed and stability for a single stack.

(2) DBT51 (PTMTP). Calculates hourly concentrations from up to 25 point sources and specified meteorological conditions for up to 30 receptors, and average concentrations over the total time period. This model has been modified to allow for user options to include an exponential increase of wind speed with height, and a plane displacement method for elevated receptors. The revised program is called PTMTPA(DBT51A).

(3) CDM. Determines annual concentrations at any ground level receptor using average emission rates from point and area sources and a joint frequency distribution of wind direction, wind speed, and stability for the same period.

Modeling Results

A simplistic approach was used for the short-term models, in determining the ground level effects of the emission sources of the existing and proposed marine operations. Each source was modeled independently as a stationary source rather than a mobile one since:

(1) the goal of this study is to examine comparatively existing and proposed emissions associated with crude oil handling;

(2) the interaction of mobile sources are dependent upon their own timing, location and meteorology at the precise moment; and

(3) other activities are occurring within the site areas.

Although the results for the short-term (maximum concentrations) shows changes with the reductions of emissions per source, the area of influence is within 1.5 KM of the source and is dependent upon location and physical stack parameters (diameter, height, temperature, velocity). Since the results are sensitive to these factors, without an intensive analysis of each vessel configuration and source movement, the results would be questionable in an absolute sense. The annual average concentration results (CDM) show little change between existing and proposed facilities and practices. Moreover, the major influence to the air quality in this area is not associated with this specific operation of crude oil handling but rather with all industry and mobile sources of transportation. Since the modeling results are based upon the foregoing as well as the reactivity of the major constituent--hydrocarbons, they were judged to be insufficiently conclusive at this level of analysis and, hence, are not presented herein. However, the results of the modeling demonstrated the general impact area associated with the facility to be quite local and provided necessary data for the design of a future air quality monitoring/modeling program should the facility be built in either location.

TABLE 3.2-1

AIR QUALITY STANDARDS

	USEPA Standards			State Standards			
	Primary (ug/m^3)	Secondary (ug/m^3)	Non-Degrad. Allowance 1/ (ug/m^3)	New York	New Jersey	Pennsylvania	Delaware
Particulate Matter (ug/m^3)							
Annual Geometric Mean	75	60	19	75	75	75	75
Max. 24-hour average	260		37	250	260	260	260
Sulfur Dioxide (ug/m^3)							
Annual Arithmetic Mean	80	--	20	80	80	80	80
Max. 24-hour average	365	--	91	365	365	365	365
Max. 3-hour average	--	1,300	512	1,300	1,300	1,300	1,300
Carbon Monoxide (mg/m^3)							
Max. 8-hour average	10	10	--	10	10	10	10
Max. 1-hour average	40	40	--	40	40	40	40
Photochemical Oxidants (ug/m^3)							
Max. 1-hour average	235	235	--	235	235	235	235
Hydrocarbons 2/ (ug/m^3)							
Max. 3-hour (6AM to 9AM)	160	160	--	160	160	160	160
Nitrogen Dioxide (ug/m^3)							
Annual Arithmetic Mean	100	100	--	100	100	100	100

1/ Non-degradation provision allows these additional concentrations over existing ambient concentrations.

2/ Excluding methane.

Sources: 40 CFR 50; 30 FR 22384 November 25, 1971 with latest revision June 29, 1979. Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards.

TABLE 3.2-2

AIR QUALITY CONTROL REGION PRIORITY CRITERIA

Pollutant 1/	Priority I 2/ Greater than	Priority II From - to	Priority III Less than
Sulfur Oxides:			
Annual arithmetic mean	100 (0.04)	60-100	60 (0.02)
24-hour maximum	455 (0.17)	260-455 (0.10-0.17)	260 (0.10)
3-hour maximum	NA	1,300 (0.50)	1,300 (0.50)
Particulate Matter:			
Annual geometric mean	95	60-95	60
24-hour maximum	325	150-325	150
Carbon Monoxide:			
1-hour max. (mg/m^3)	55 (48)	NA	55 (48)
8-hour max. (mg/m^3)	14 (12)	NA	14 (12)
Nitrogen Dioxide:			
Annual arithmetic mean	110 (0.06)	NA	110 (0.06)
Photochemical Oxidants:			
1-hour maximum	195 (0.10)	NA	195 (0.10)

NA indicates None Applicable

1/ All units in $\mu g/m^3$ and (ppm) except for carbon monoxide as noted.

2/ Priority determined by ambient air quality of region--Priority #I--Poorest Quality; Priority #III Highest Quality.

Source: 40 CFR 51; 36 FR 22398, Environmental Protection Agency Regulations on Preparation of Implementation Plans, November 25, 1971, last revised December 2, 1980.

TABLE 3.2-3

AIR QUALITY CONTROL REGION CLASSIFICATIONS

DELAWARE RIVER SITE
PRIORITY CLASSIFICATIONS

AQCR	AQCR Number	Particulate Matter	Sulfur Oxides	Nitrogen Dioxide	Carbon Monoxide	Photochemical Oxidants & Hydrocarbons
Metropolitan Philadelphia Interstate	45	I	I	III	I	I
Southern Delaware Intrastate	46	III	III	III	III	III
New Jersey, New York, Connecticut Interstate	43	I	I	I	I	I

Source: 40 CFR 52, Subpart I, Delaware; and 40 CFR 52, Subpart NN, Pennsylvania and 40 CFR 52, Subpart HH, New York. Environment Reporter, May 1, 1981.
Priority I--poorest quality; Priority III-- best quality.

TABLE 3.2-4

AIR QUALITY CONTROL REGION CLASSIFICATIONS

NEW YORK BAY SITE

PRIORITY CLASSIFICATION

AQCR	AQCR Number	Particulate Matter	Sulfur Oxides	Nitrogen Dioxide	Carbon Monoxide	Photochemical Oxidants & Hydrocarbons
New Jersey, New York, Connecticut Interstate	43	I	I	I	I	I

Source: 40 CFR 52, Subpart HH - New York; and 40 CFR 52, Subpart FF - New Jersey.
Environment Reporter May 1, 1981.
Priority I--poorest quality; Priority III- best quality.

TABLE 3.2-5

NEW YORK BAY SITE

AIR QUALITY OF THE PROJECT AREA

1980 DATA

Monitoring Station	Particulates (ug/m^3)		Carbon Monoxide (mg/m^3)		Sulfur Dioxide (ug/m^3)			Nitrogen Dioxide (ug/m^3)		Total Hydro-carbons (ppm)	Ozone (ppm)	
	Max. 24 hr. Avg.	Ann. Geo. Mean	Max. 1 hr. Avg.	Max. 8 hr. Avg.	Max. 3 hr. Avg.	Max. 24 hr. Avg.	Ann. Arith. Mean	Max. 24 hr. Avg.	Ann. Arith. Mean	Max. 3 hr. Avg.	Max. 1 hr. Avg.	Ann. Arith. Mean
PERTH AMBOY, N.J.	146	73	16.7	11.3	676	451	42	-	-	-	-	-
ELIZABETH CITY, N.J.	102	57	19.8	12.9	414	223	26	-	-	-	-	-
BAYONNE, N.J.	206	71	10.5	7.4	249	179	46	-	56	-	.162	173[a]
JERSEY CITY, N.J.	115	68	23.1	14.3	286	189	34	-	-	-	-	-
NEWARK, N.J.	148	64	18.2	9.9	388	197	47	-	73	-	.161	82[a]
ELIZABETH, N.J. (LAB.)	-	-	18.8	7.7	322	210	34	-	73	-	-	-
LINDEN, N.J.	148	84	-	-	-	-	-	-	-	-	-	-
SHEEPSHEAD BAY, H.S., NYC	107	58	-	-	393	254	50	-	-	-	.184	44[a]
SUSAN WAGNER H.S., NYC	102	52	-	-	383	199	39	-	-	-	.174	20
MABEL DEAN BACON H.S., NYC	123	61	9.1	6.2	500	312	76	-	-	-	.155	19
GREENPOINT WPC PLANT, NYC	124	63	-	-	348	244	52	-	-	-	-	-

a. Number of hours above standard.

Sources: New Jersey Department of Environmental Protection, Department of Environmental Quality 1979 and 1980 Annual Air Quality Monitoring Summaries.

New York State Department of Environmental Conservation, New York State Air Quality Report, Annual 1979 and 1980. Continuous and Manual Air Monitoring Systems.

TABLE 3.2-6

DELAWARE BAY SITE

AIR QUALITY OF THE PROJECT AREA

1980 DATA

Monitoring Station	Particulates (ug/m^3)		Carbon Monoxide (mg/m^3)		Sulfur Dioxide (ug/m^3)			Nitrogen Dioxide (ug/m^3)		Total Hydro-carbons (ppm)	Ozone (ppm)		
	Max. 24 hr. Avg.	Ann. Geo. Mean	Max. 1 hr. Avg.	Max. 8 hr. Avg.	Max. 3 hr. Avg.	Max. 24 hr. Avg.	Ann. Arith. Mean	Max. 24 hr. Avg.	Ann. Arith. Mean	Max. 3 hr. Avg.	Max. 1 hr. Avg.	Ann. Arith. Mean	
CAMDEN, N.J.	141	73	9.3	7.4	414	233[a]	52	-	-	-	.174	-	
CAMDEN LAB., N.J.	126	66	17.0	6.6	396	246	39	-	56.4	-	-	-	
CAPE MAY COUNTY, N.J.	142	32	-	-	139	52	16	-	-	-	.140	-	
PENNS GROVE, N.J.	-	-	16.2	8.3	375	134	29	-	-	-	-	-	
PILESGROVE TWP., N.J.	76	43	-	-	-	-	-	-	-	-	-	-	
P-1 CLAYMONT, DE.[c]	122	63	d	d	-	139	18	-	56.2	-	8[e]	-	
P-2 WILMINGTON, DE.[c]	222	d	d	d	-	157	31	-	68.8	-	-	-	
P-4 NEW CASTLE, DE.[c]	169	47	-	-	-	121	10	-	-	-	-	-	
S-3 LINDAMERE, DE.[c]	164	60	-	-	-	100	13	-	-	-	5[e]	-	
MEDIA, PA.	159	50	-	-	-	-	-	-	-	-	-	-	
CHESTER, PA.	113	46	8.4	4.3	671	244	37	320	51	3.6	.194	.028	28[e]
FOLCROFT, PA.	126	56	-	-	403	144	37	-	-	-	.349	.018	5[e]
PHILADELPHIA, PA. (INT)	-	-	15.6[a]	9.1[a]	359[a]	149[a]	34[a]	-	-	-	.130[a]	.013[a]	
PHILADELPHIA, PA. (PEP)	114	67	-	-	-	-	-	-	-	-	-	-	
PHILADELPHIA, PA. (MTH)	122	67	-	-	-	-	-	-	-	-	-	-	

a. 1979 Data (1980 Data insufficient)
b. Data Not Available (April-December)
c. Data for the period May, 1980 through April, 1981
d. Standard values not exceeded.
e. Number of hours exceeding the ozone standard.

Sources: New Jersey Department of Environmental Protection, Department of Environmental Quality - 1979 and 1980 Annual Air Quality Monitoring Summaries.
City of Philadelphia, Department of Health, Air Management Services, Emissions Inventory and Air Quality Data Report to the Air Pollution Control Board, Annual Summaries 1979 and 1980.
Commonwealth of Pennsylvania, Department of Environmental Resources, Air Quality Reports 1979 and 1980.
State of Delaware, Department of Natural Resources and Environmental Control, Division of Environmental Control. Annual Air Quality Data Summary 1979 and 1980.

4.0 POLLUTANT EFFECTS

4.1 INTRODUCTION

The earth is surrounded by a flowing energy system which is in continual contact with flora and fauna upon its surface. This energy system or air absorbs materials continually produced by natural and man-made processes. In turn, the system deposits these materials or converted forms back to the earth's surface. The effects of interactions between these materials and biological systems are important, not only to man but to his use of other animals and plants which exhibit susceptibility. Essentially, the concern for air pollution involves the excess of airborne materials and their potentially deleterious effects upon man and his environment.

A pollutant can be classified as anything that is added to the existing environment that causes some amount of negative change from the norm which can be perceived. Pollutants originate from man-made (e.g. combustion of fossil fuels) and natural sources (fires, biological decay, etc.). They combine to form an air pollution pool which is the sum total of all primary pollutants and their products through atmospheric reactions. This pool then settles to earth coming in contact with all things (plants, animals, water, etc.) where it may directly cause effects depending upon concentrations. Often adverse effects do not occur until the causative agent is formed through reactions with substrate chemicals.

Research evidence indicates that most major pollutants do not accumulate in the atmosphere but are rather rapidly removed. The removal involves photochemical reactions in the atmosphere and adsorption and breakdown by living organisms and their physical and chemical surroundings (soil, water, etc.). Vegetation may act as an atmospheric cleaner by removing many pollutants. However, in most cases pollutants do not accumulate in plant tissue but are rapidly converted to less harmful compounds which probably do not accumulate in the food chain. An exception is hydrogen fluoride (HF) which is accumulated by plants causing injury to sensitive species over time or resulting in fluorosis of grazing animals.

Some investigators consider vegetation to be a sink for many air pollutants, including HF, SO_2, NO_2, O_3, Cl_2, and Peroxyacetyl Nitrate (PAN). However, the role of vegetation as a regulator of pollutants is questionable. It is known that plants do not readily take up CO and NO. Soil microorganisms take up CO while NO is first converted to other compounds in the atmosphere and then absorbed.

4.2 Overview of Selected Pollutants

4.2.1 Sulfur Dioxide (SO_2)

The predominant source of SO_2 emitted to the atmosphere is the combustion of fossil fuels--coals and oil. Estimates (1965) of emitted SO_2 worldwide was 72 metric tons; coal combustion--51, petroleum refining--3, petroleum combustion--11, and smelting--8. Atmospheric SO_2 can be oxidized to SO_3 which can be further hydrated to H_2SO_4 and deposited by dry (SO_4) or wet deposition (acid rain).

4.2.2 Nitrogen Oxides (NO_x)

Nitrogen oxides include a number of nitrogen containing compounds. Several oxides such as nitric oxide (NO) and nitrogen dioxide (NO_2) are the major contributors to air pollution. From a total of 103.8×10^{10} kg/yr production (estimate 1970) of the above nitrogen oxides less than 5% (primarily NO_x) was produced by man-made sources. The remaining 95% (NO and N_2O) resulted from normal biological action.

Man related NO_x sources are the consequence of high temperature combustion of fossil fuels, from mobile sources (motorized vehicles) and stationary sources (electric utilities and industrial plants).

4.2.3 Ozone (O_3) and PAN

Ozone (O_3) and PAN are produced from a complex series of atmospheric reactions between oxides of nitrogen and hydrocarbons in the presence of sunlight. Sources of oxides of nitrogen (NO_x) include high heat combustion and naturally occurring NO_2 which comprises about 78% of the earth's lower atmosphere. Hydrocarbons are released to the atmosphere as by-products of incomplete fossil fuel combustion. These exhaust gases contain varying amounts of original fuel and partially oxidized fuel depending upon the systems' efficiency.

4.2.4 Organics

Other man-made sources include petroleum storage tank fields and petroleum processing plants. Hydrocarbons are also emitted from natural sources. Besides water vapor, oxygen and carbon dioxide, forests are known to emit metabolically-related, photochemically reactive hydrocarbons. They are emitted by both hardwoods and softwoods. Both eastern and western conifer forests (softwoods) emit mainly the organics alpha pinene (α-pinene), but also a varied assortment of monoterpene organics. Release rate for these compounds is related to both temperature and light. Estimates (1972) of reactive hydrocarbon release worldwide to the atmosphere from foliage is 175×10^6 tons. This compares to 27×10^6 tons from man-made sources. Thus about 75% of the worldwide atmospheric hydrocarbon pollutant is emitted from natural sources. It has been postulated that these naturally released hydrocarbons are precursors to the blue haze which is visible in still, hot weather over deserts and forests.

4.2.5 Summary

In summary, man is responsible for varying amounts of different pollutants: almost all SO_2, 5% of nitrogen oxides and 25% of hydrocarbons. It should be noted, that a comparison of man-made production with naturally occurring emissions shows the former to be confined to a very small portion of the earth's surface thus causing significant increases above normal background levels. Details on the physiological effects of pollution are shown in Appendix 'B'.

5.0 CONCLUSION

The construction of the proposed facilities in either location (New York or Delaware Bays) will result in a decrease in the amount of criteria pollutants emitted to the atmosphere (see Section 2.1). In generalized terms, this trend will help achieve the goals of attaining primary and secondary air quality standards. Although not developed within this report, the less fuel burned will result in fewer trace elements (i.e., heavy metals) being discharged to the atmosphere and subsequently inhaled by the populace. The results of the study basically show:

* that the ships' (both 85-120 MDWT and VLCC's) emissions are predominantly particulates, sulfur oxides, and nitrogen oxides;
* that the tug boat contribution is small and is not considered significant;
* that the hydrocarbon losses are predominantly from barge loading;
* that carbon monoxide emissions are negligible when compared to urban emissions from other sources;
* that the immediate impact of the reduction of pollutants is to the local area (within 1.5 KM); and
* that the long-term benefit will be to aid in achieving the national goal of attainment of air quality standards.

Although all emissions are reduced to a large extent in the Delaware Bay area, the majority of the reductions will occur in a location that is sparsely populated and already meeting air quality standards. Should the facility be built in Delaware Bay, additional hydrocarbon sources (storage tanks) will be placed in a more populated area at the expense of a reduction at Big Stone Anchorage (lightering reduction). However, in the New York Bay scenario, both the reduction from lightering as well as the addition caused by the storage tanks (still resulting in a net decrease) will occur in the same vicinity, thereby not trading off one area versus another. The New York Area is a non-attainment area for all the criteria pollutants whereas the Big Stone Anchorage is attainment for the aforementioned pollutants; the Philadelphia area is only attainment for Nitrogen Oxides.

In order to discuss the effects of the reduction of pollutants, information is presented in Appendix B giving an esoteric analysis of each pollutant and what effects occur on living species (predominantly botanical). The pollutants' interactions are extremely important, i.e., the formation of photochemical oxidants (PAN) from hydrocarbons, nitrogen oxides, the formation of NO_2 from NO, etc., when analyzing their impact upon the human environment. The reduction of 200 + Tons/year of hydrocarbons is significant to the point that if it were an addition of the same amount, Federal Prevention of Significant Deterioration of Air Quality (PSD) regulations would apply. Similarly sulfur oxides and nitrogen oxides reductions are considered to be of equal consequence. It is known that both latter compounds are significant in acid rain formation. The actual location of major effect is within the immediate area of the sources since the height of the discharge sources is low, resulting in maximum concentrations close to the emission point.

The impact upon the environment from the proposed action at either site is the discharge of less pollutant material into the atmosphere. It is known that the proposed action will: 1) cause no increase of pollutants but rather a significant pollutant load reduction; 2) aid the New York Bay location which is heavily polluted; and 3) reduce emissions of trace elements and reaction products. The aforementioned consequences of the proposed project will positively impact upon the human environment. Therefore, it is our conclusion that this type of facility would be environmentally beneficial, especially in the New York Bay area.

INTRODUCTION TO APPENDIX "A"

The intent of this section is to provide a basis for the comparison of emissions between existing modes of operation and proposed modes of operation . The foundations of the calculations and assumptions used are presented herein. To summarize the format of this section, all assumptions and data used for general procedures are outlined prior to applying them to each source of emissions and associated scenario.

A.1 Basic Assumptions for Emissions' Calculations

1. All in-harbor and in-bay marine movements, other than those to be altered by the proposed project, are disregarded.

2. Three percent (3%) Sulfur Residual Fuel is used for tankers. Diesel Fuel is used for tug boats.

3. Transit losses for hydrocarbons (HC) are not altered by a change in delivery system since the same annual crude oil volume will be delivered with or without the proposed facility.

4. The proposed facility located in New York Harbor would be capable of handling 240 MBPD. The assumption is that 25% of this volume would be lightered, if there were no facility (21.9 MMBPY).

5. The proposed facility located in Delaware Bay would be capable of handling 560 MBPD. It is assumed that 35% of this volume would be lightered, if there were no facility (71.5 MMBPY).

6. As used in assumption 11 below, the "port-of-call hours" for ships and support facilities (tugs) are based upon an average of reported operating times, as well as data accessed by the Deepwater Port Study Team from sources such as Marine Fleet Operators, Sandy Hook Pilots and Docking Pilots operating in the appropriate areas. It is acknowledged that these times may vary according to the refinery serviced, weather conditions, existing traffic and pier availability.

7. For the Delaware Bay Site, since Big Stone Anchorage is far removed from the refinery locations and the mono-buoys will be located proximate to this anchorage, sea to anchorage times have not been added

since they are relatively equal for both cases. It is recognized that slight variations may occur, but are deemed to be inconsequential.

8. Fuel consumption is based upon data developed by TRC Corporation for EPA as well as upon data acquired from marine fleet operators. It is assumed that tankers in the 85,000 to 120,000 DWT range will have approximately the same fuel consumption as a 93,000 DWT tanker.

9. Information on tug operations indicates that:
   a) For the most part, tugs spend little, if any, time standing by waiting to bring tankers to anchorages but generally meet them en route.
   b) Tugs make as few special trips as possible for the purpose of shifting empty barges. Such shifting is accomplished in conjunction with the inbound or outbound portion of another movement. Therefore, house- 404
   keeping movements of this nature have not been included.

10. There are no particulate or SO_2 emission factors given by EPA for marine diesel engines. However, other data for this type of engine show SO_2 to be 27#/1000 gallons (based upon 0.20%S fuel) and particulates average about 25#/1000 gallons.

11. For purposes of calculation, the time segments for the various movements of marine vessels involved in the delivery of crude oil in New York Harbor and in the Delaware Bay/River have been normalized for operations without the facility and for operations with the facility. These representative time segments are displayed in the following tables.

A. NEW YORK BAY - Existing 85,000 DWT

Port-of-Call Hours

Mode	Transit (Maneuvering)	Hotel	Pumping
Sea to Anchorage	2.5		
Federal Inspection		1.5	
At Anchorage		31.5	6
Anchorage to Pier	3.75		
At Pier		28	19
Preparations to Leave		1.5	
Pier to Sea	3.25		
Total:	9.5	62.5	25

Total In-Port Time: 72

B. NEW YORK BAY - Existing Tugs

Port-of-Call Hours (Total Tug Hours)

Mode	Idle	Half Power	Full Power
Anchorage to Pier	4	1	
Pier to Sea	1.5	1	
Barge Transport		2.5	0.5
Total:	5.5	4.5	0.5

C. NEW YORK BAY - Proposed Facilities, VLCC

Port-of-Call Hours

Mode	Transit (Maneuvering)	Hotel	Pumping
Sea to Pier	4		
Federal Inspection		1.5	
At Pier		26.5	25
Preparations to Leave		1.5	
Pier to Sea	2.5		
Total:	6.5	29.5	25

Total In-Port Time 36

D. NEW YORK BAY - Proposed Facilities, Tugs

Port-of-Call Hours (Total Tug Hours)

Mode	Idle	Half Power	Full Power
Anchorage to Pier	2	2	2
Pier to Sea		3.5	
Total	2	5.5	2

E. DELAWARE BAY - Existing Ships

Port-of-Call Hours

Mode	Transit (Maneuvering)	Hotel	Pumping
Sea to Anchorage	See (7)		
Federal Inspection		1.5	
At Anchorage		30	12
Anchorage to Pier	13.5		
At Pier		37	18
Preparations to Leave		1.5	
Pier to Sea	12.5		
Total:	26	70	30
Total In-Port Time	96		

F. DELAWARE BAY - Existing Tugs

Port-of-Call Hours (Total Tug Hours)

Mode	Idle	Half Power	Full Power
Berthing & Deberthing	0.5	1.5	0.5
Barge String Transport	2	8	
Total:	2.5	9.5	0.5

G. DELAWARE BAY - Proposed Facilities, VLCC

Port-of-Call Hours

Mode	Transit (Maneuvering)	Hotel	Pumping
Sea to Anchorage	See (7)		
Federal Inspection		1.5	
At Buoy		26.5	25
Preparations to Leave		1.5	
Buoy to Sea	See (7)		
Total:		29.5	25

H. DELAWARE BAY - Proposed Facilities, Support Boats

Mode	Idle	Half Power	Full Power
Assist VLCC to Secure to Monobuoy		1.5	
Total:		1.5	

A.2 MARINE VESSELS' FUEL USE (GENERAL)

The data for fuel consumption have been compiled from a study by TRC Corporation for a PSD review of a VLCC terminal and associated refinery, as well as data compiled from marine operators, Exxon and Chevron sources. These data are subsequently used to establish an average fuel consumption to allow calculation of source emissions.

TABLE A-1

FUEL CONSUMPTION (IN LBS* PER HOUR)

Ship Speed (Knots)	93,000 DWT	VLCC
0	910	1256
2	950	1300
4	1050	1575
6	1360	2320
8	1910	3750
10	2800	6110

* LBS = # for balance of report.

Source: ESI, 1982

Adapted from PSD Permit Application Review
Pittston Refinery - USEPA Region I
TRC Report, June, 1978 & Exxon Data

A.3 MARINE VESSELS' EMISSIONS (GENERAL)

Emission Factors below are based upon data presented in USEPA Reference AP-42 "Compilation of Air Pollutant Emission Factors".

A. MARINE VESSELS

There are two (2) contributions from marine vessels:

1. Emissions due to power requirements;
2. Emissions due to losses of cargo.

These emission factors are excerpted below from Tables 3.2.3-2 and 3, and Table 4.4-3, of AP-42, respectively:

POWER REQUIREMENTS
SHIPS USING RESIDUAL OIL

Pollutant	Hoteling		Cruise		Full	
	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal
Particulates	1.20	10.0	2.40	20.0	6.78	56.5
Sulfur oxides (SO_x as SO_2)	19.1S	159S	19.1S	159S	19.1S	159S
Carbon monoxide	Neg.	Neg.	0.414	3.45	0.872	7.27
Hydrocarbons	0.38	3.2	0.082	0.682	0.206	1.72
Nitrogen oxides (NO_x as NO_2)	4.37	36.4	6.70	55.8	7.63	63.6

Source: Compilation of Air Pollutant Emission Factors AP-42, USEPA, Third Edition, August 1977; Table 3.2.3-2.

Where S = percent sulfur in fuel.

Table 3.2.3-3. DIESEL VESSEL EMISSION FACTORS BY OPERATING MODE
EMISSION FACTOR RATING: C

Horsepower	Mode	Emissions					
		Carbon monoxide		Hydrocarbons		Nitrogen oxides (NO_x as NO_2)	
		lb/10³ gal	kg/10³ liter	lb/10³ gal	kg/10³ liter	lb/10³ gal	kg/10³ liter
200	Idle	210.3	25.2	391.2	46.9	6.4	0.8
	Slow	145.4	17.4	103.2	12.4	207.8	25.0
	Cruise	126.3	15.1	170.2	20.4	422.9	50.7
	Full	142.1	17.0	60.0	7.2	255.0	30.6
300	Slow	59.0	7.1	56.7	6.8	337.5	40.4
	Cruise	47.3	5.7	51.1	6.1	389.3	46.7
	Full	58.5	7.0	21.0	2.5	275.1	33.0
500	Idle	282.5	33.8	118.1	14.1	99.4	11.9
	Cruise	99.7	11.9	44.5	5.3	338.6	40.6
	Full	84.2	10.1	22.8	2.7	269.2	32.3
600	Idle	171.7	20.6	68.0	8.2	307.1	36.8
	Slow	50.8	6.1	16.6	2.0	251.5	30.1
	Cruise	77.6	9.3	24.1	2.9	349.2	41.8
700	Idle	293.2	35.1	95.8	11.5	246.0	29.5
	Cruise	36.0	4.3	8.8	1.1	452.8	54.2
900	Idle	223.7	26.8	249.1	29.8	107.5	12.9
	2/3	62.2	7.5	16.8	2.0	167.2	20.0
	Cruise	80.9	9.7	17.1	2.1	360.0	43.1
1550	Idle	12.2	1.5	–	–	39.9	4.8
	Cruise	3.3	0.4	0.64	0.1	36.2	4.3
	Full	7.0	0.8	1.64	0.2	37.4	4.5
1580	Slow	122.4	14.7	–	–	371.3	44.5
	Cruise	44.6	5.3	–	–	623.1	74.6
	Full	237.7	28.5	16.8	2.0	472.0	5.7
2500	Slow	59.8	7.2	22.6	2.7	419.6	50.3
	2/3	126.5	15.2	14.7	1.8	326.2	39.1
	Cruise	78.3	9.4	16.8	2.0	391.7	46.9
	Full	95.9	11.5	21.3	2.6	399.6	47.9
3600	Slow	148.5	17.8	60.0	7.2	367.0	44.0
	2/3	28.1	3.4	25.4	3.0	358.6	43.0
	Cruise	41.4	5.0	32.8	4.0	339.6	40.7
	Full	62.4	7.5	29.5	3.5	307.0	36.8

Source: Compilation of Air Pollutant Emission Factors AP-42, USEPA, Third Edition, August 1977; Table 3.2.3

CRUDE OIL HYDROCARBON LOSSES FOR MARINE OPERATIONS (LOADING AND EVAPORATIVE)

Loading barges	
$lb/10^3$ gal transferred	1.7
$kg/10^3$ liters transferred	0.20
Tanker ballasting	
$lb/10^3$ gal cargo capacity	0.6
$kg/10^3$ liters carbo capacity	0.07
Transit	
$lb/week-10^3$ gal transported	1.0
$kg/week-10^3$ liters transported	0.1

Source: Excerpted from Compilation of Air Pollutant Emission Factors AP-42, USEPA, Third Edition, August 1977, Table 4.4-3.

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A.4 TANK FARM EMISSIONS (GENERAL)

For floating roof tanks, the losses are only associated with seal losses, therefore:

From Sect. 4.3.2.2. EQ (3) AP-42

$$L_s = 9.21 \times 10^{-3} M \left[\frac{P}{14.7-P}\right]^{0.7} D^{1.5} V^{0.7} K_t K_s K_p K_c$$

L_s = Standing Loss #/day.

From Table 4.3-1

M = 50

P = 5.7 @ 100°F

$D_2 \emptyset$= Diam.

V_w = Avg. Wind Velocity 15 mph

K_t = Tank Type Factor = 0.13

K_s = 1.0 seal factor

K^p = Paint factor = white = 0.9

K_c = Crude Oil Factor = 0.84

For $D \geqq 150$ $D^{1.5}$ is replaced by $D\sqrt{150}$

A.5 MARINE VESSELS' FUEL USE (EACH SCENARIO)

I. NEW YORK BAY. EXISTING SCENARIO

A. 85,000 DWT Ships

1. Transit Mode

Sea to Anchorage

1 hour @ 10 knots	......	2,800 #/hr x 1	=	2,800
1 hour @ 6 knots	......	1,360 #/hr x 1	=	1,360
½ hour @ hotel	......	910 #/hr x ½	=	455
Total Fuel Consumed	....		=	4,615

Avg. Fuel/hr = 4,615/2.5 = 1,846 #/hr ≃ 1,850 #/hr.

Anchorage to Pier

2.25 hr @ 10 knots	.....	2,800 #/hr x 2.25	=	6,300
1.5 hr @ 0 knots	.....	910 #/hr x 1.5	=	1,365
Total Fuel Consumed	....		=	7,665

Avg. Fuel/hr = 7,665/3.75 = 2,044 #/hr ≃ 2,050 #/hr.

Pier to Sea

0.25 hr @ 0 knots	.....	910 #/hr x 0.25	=	230
3 hours @ 10 knots	.....	2,800 #/hr x 3	=	8,400
Total Fuel Consumed	....		=	8,630

Avg. Fuel/hr = 8,630/3.25 = 2,655 #/hr ≃ 2,660 #/hr.

Total Fuel Consumed in Transit =

4,615 + 7,665 + 8,630 = 20,910 #/visit

= 20,910 #/visit ÷ 8 #/gal = 2,615 gal./visit

2. Hotel Mode

910 #/hr x 62.5 hr/visit = 56,875 #/visit

= 7,110 gal/visit

3. Pumping Mode

5,800 #/hr x 25 hr/visit = 145,000 #/visit

= 18,125 gal/visit

B. Tug Boats -- 2,500 HP

For Ship Operations -- 5.5 Hrs. @ idle
2 Hrs. @ ½ power

From Item B. on page

Idle : 5.5 Hr. x 140 #/hr. = 770 #/7#/gal = 110 gal.

Half Power : 2 Hr. x 455 #/hr. = 910 #/7#/gal = 130 gal.

For Barge Operations -- 2.5 Hrs. @ ½ power
0.5 Hrs. @ full power

Half Power: 2.5 Hr. x 455 #/hr. = 1,137.5#/7#/gal = 162.5 - 165 gal.
Full Power: 0.5 Hr. x 700 #/hr. = 350 #/7#/gal = 50 gal.

II. NEW YORK BAY PROPOSED SCENARIO

A. 260,000 DWT SHIPS

1. Transit Mode

Sea to Pier

1 hour @ 10 knots	6,110 #/hr x 1	=	6,110
3 hours @ 0 knots	1,256 #/hr x 3	=	3,768
Total Fuel Consumed		=	9,878 #

Avg. Fuel/hr = 9,878/4 = 2,470 #/hr.

Pier to Sea

0.5 hour @ 4 knots	1,575 #/hr x ½	=	788
2 hours @ 10 knots	6,110 #/hr x 2	=	12,220
Total Fuel Consumed		=	13,008 #

Avg. Fuel/hr = 13,008/2.5 = 5,205 #/hr.

Total Fuel Consumed in Transit =

9,878 + 13,008 = 22,886 #/trip ÷ 8 #/gal
≃ 2,865 gal/visit.

2. Hotel Mode

1,256 #/hr. x 29.5 hrs/visit ÷ 8 #/gal = 4,631.5 gal
≃ 4,635 gal/visit

3. Pumping

10,000 #/hr. x 25 hrs/visit ÷ 8#/gal =
31,250 gal/visit.

B. Tugs

Idle	140 #/hr. x 2 hrs. ÷ 7#/gal = 40	gal/trip
Half Power	455 #/hr. x 5.5 hrs. ÷ 7#/gal = 357.5	gal/trip
Full Power	700 #/hr. x 2 hrs. ÷ 7#/gal = 200	gal/trip

III. DELAWARE BAY EXISTING SCENARIO

A. 120,000 DWT SHIPS

1. Transit Mode

Anchorage to Pier

12 hrs @ 6 knots	......	1,360 #/hr x 12	=	16,320
1.5 hrs @ hotel	......	910 #/hr x 1.5	=	1,365
Total Fuel Consumed		....	=	17,685

Avg. Fuel/hr = 17,685/13.5 = 1,310 #/hr.

Pier to Sea

12 hrs @ 6 knots	......	1,360 #/hr x 12	=	16,320
0.5 hrs @ hotel	......	910 #/hr x 0.5	=	455
Total Fuel Consumed		....	=	16,775

Avg. Fuel/hr = 16,775/12.5 = 1,342 #/hr ≈ 1,350 #/hr.

Total Fuel Consumed in Transit =
17,685 + 16,775 = 34,460 ÷ 8#/gal =
4,310 gal/trip.

2. Hotel Mode

910 #/hr x 70 hrs/trip ÷ 8#/gal = 7,965 gal/trip.

3. Pumping Mode

5,800 #/hr x 30 hrs/trip ÷ 8#/gal = 21,750 gal/trip

B. Tug Boats -- 2,500 HP

Ship Operations

Idle	0.5 hr x 140 #/hr =	70	#/7 =	10 gal.
Half Power	1.5 hr x 455 #/hr =	682.5	#/7 =	100 gal.
Full Power	0.5 hr x 700 #/hr =	350	#/7 =	50 gal.

Barge Operations

Idle	2 hr x 140 #/hr =	280/7 =	40 gal.
Half Power	8 hr x 455 #/hr =	3,640/7 =	520 gal.

IV. DELAWARE BAY PROPOSED SCENARIO

A. 260,000 DWT SHIPS

1. Transit Mode

No net emissions

2. Hotel Mode

1,256 #/hr x 29.5 hrs ÷ 8 #/gal = 4,635 gal/visit.

3. Pumping Mode

10,000 #/hr x 25 hrs ÷ 8#/gal = 31,250 gal/visit.

B. SUPPORT BOATS (ASSUMED TO BE SAME AS TUG) @ HALF SPEED

455 #/hr x 1.5 hrs + 7#/gal = 100 gal/visit.

A.6 MARINE VESSELS' EMISSIONS (EACH SCENARIO)

I. NEW YORK BAY EXISTING SCENARIO

A. 85,000 DWT TANKERS

From Table 3.2.3-2 on page A-

Emissions (# Per Trip)

	Transit	Hotel	Pumping
Particulates	20 #/1,000 gal x 2.615 = 52.3#	10 x 7,110 = 71.1#	20 x 18.13 = 362.6#
Sulfur Oxides	159S # x 3 x 2.615 = 415.8#	159S # x 3 x 7.110 = 3,391.5#	159 x 3 x 18.15 = 8,648 #
Hydrocarbons	0.682 x 2.615 = 1.8#	3.2 x 7.110 = 22.8#	0.682 x 18.13 = 12.4#
Nitrogen Oxides	55.8 x 2.615 = 145.9#	36.4 x 7.110 = 258.8#	55.8 x 18.13 = 1,011.7#
Carbon Monoxide	3.45 x 2.615 = 9.0#	Negl.	3.45 x 18.13 = 62.5#

Therefore total 85,000 DWT emissions in # per trip.

Particulates	:	52.3 + 71.1 + 326.6	= 486 #
Sulfur Oxides	:	415.8 + 3,391.5 + 8,648	= 12,455.3#
Hydrocarbons	:	1.8 + 22.8 + 12.4	= 37 #
Nitrogen Oxides	:	145.9 + 258.8 + 1,011.7	= 1,416.4#
Carbon Monoxide	:	9.0 + 62.5	= 71.5#

B. TUGS & BARGES

From Table 3.2.3-3 on page A- , assuming 2/3 and half power to be equal in emission factors and using average SO_2 and particulate factors of 27 x 3/.2* = 405 #/1,000 gal and 25 #/1,000 gal (full power) respectively. The average idle/slow relationship is 2.4 for HC.

* The ratio of 3% to 0.2% sulfur in fuel.

Tug Emissions # Per Vessel Trip

	Idle	Half Power
Particulates	25 x .11 = 2.8#	15 x .130 = 2.0#
Sulfur Oxides	405 x .11 = 44.6#	405 x .130 = 52.7#
Hydrocarbons	35.3 x .11 = 3.9#	14.7 x .130 = 1.9#
Nitrogen Oxides	204.5 x .11 = 22.5#	326.2 x .130 = 42.4#
Carbon Monoxide	36.5 x .11 = 4.0#	15.2 x .130 = 2.0#

Therefore total tug emissions in # per ship trip.

Particulates	:	2,8 + 2.0	=	4.8#
Sulfur Oxides	:	44.6 + 52.7	=	97.3#
Hydrocarbons	:	3.9 + 1.9	=	5.8#
Nitrogen Oxides	:	22.5 + 42.4	=	64.9
Carbon Monoxide	:	4.0 + 2.0	=	6.0#

Tug Emissions # Per Barge Movement

	Half Power	Full Power
Particulates :	15 x .165 = 2.5#	25 x .05 = 1.3#
Sulfur Oxides :	405 x .165 = 66.8#	405 x .05 = 20.3#
Hydrocarbons :	14.7 x .165 = 2.4#	21.3 x .05 = 1.1#
Nitrogen Oxides:	326.2 x .165 = 53.8#	399.6 x .05 = 20.0#
Carbon Monoxide:	15.2 x .165 = 2.5#	11.5 x .05 = 0.6#

Therefore total tug emissions per barge movement

Particulates	:	2.5 + 1.3	=	3.8#
Sulfur Oxides	:	66.8 + 20.3	=	87.1#
Hydrocarbons	:	2.4 + 1.1	=	3.5#
Nitrogen Oxides	:	53.8 + 20.0	=	73.8#
Carbon Monoxide	:	2.5 + 0.6	=	3.1#

Barge HC (Loading Losses) =

$$1.7\ \#/1{,}000\ \text{gal trans} \times 42\ \text{gal/BBL} \times 21.9 \times 10^3\ (10^3\ \frac{\text{BBLS}}{\text{yr}}) =$$

1.56 MM #/year

II. NEW YORK BAY PROPOSED SCENARIO

The change in vessel movements if the proposed facility were to be built would be an elimination of 175 tankers of the 85 MDWT class, annually.

A. 85, DWT TANKERS

175-85 MDWT Vessels Reduced:

Particulates	:	486	x	175	=	85,050#
Sulfur Oxides	:	12,455.3	x	175	=	2,179,678#
Hydrocarbons	:	37	x	175	=	6,475#
Nitrogen Oxides	:	1,416.4	x	175	=	247,870#
Carbon Monoxide	:	71.5	x	175	=	12,513#

B. **TUG & BARGE MOVEMENTS REDUCED:**

175 Tug movements per ship reduced

445 Tug barge movements reduced

Particulates ;	175	x	4.8 +	445	x	3.8	=	2,531#
Sulfur Oxides ;	175	x	97.3 +	445	x	87.1	=	55,787#
Hydrocarbons ;	175	x	5.8 +	445	x	3.5	=	2,573#
Nitrogen Oxides;	175	x	64.9 +	445	x	73.8	=	44,199#
Carbon Monoxide:	175	x	6.0 +	445	x	3.1	=	2,430#

Barge HC losses:

1.56 MM #/year

Total Marine Emission Reduction Due To Proposed Facility

Particulates :	85,050 + 2,531	=	87,581
Sulfur Oxides :	2,179,678 + 55,787	=	2,235,465
Hydrocarbons :	6,475 + 2,573 + 1,560,000	=	1,569,048
Nitrogen Oxides:	247,870 + 44,199	=	292,069
Carbon Monoxide:	12,513 + 2,430	=	14,943

C. **260,000 DWT TANKERS**

Emissions in # Per Trip

	Transit		Hotel		Pumping	
Particulates	20 x 2.865 =	57.3#	10 x 4.635 =	46.4#	20 x 31.25 =	625 #
Sulfur Oxides	159 x 3 x 2.865 =	1,366.6#	159 x 3 x 4.635 =	2,210.9#	159 x 3 x 31.25 =	14,906.3#
Hydrocarbons	.682 x 2.865 =	2.0#	3.2 x 4.635 =	14.8#	.682 x 31.25 =	21.3#
Nitrogen Oxides	55.8 x 2.865 =	159.9#	36.4 x 4.635 =	168.7#	55.8 x 31.25 =	1,743.8#
Carbon Monoxide	3.45 x 2.865 =	9.9#	Negl.		3.45 x 31.25 =	107.8#

Therefore Total 260,000 DWT Emissions in # per trip.

Particulates :	57.3 + 46.4 + 625 = 728.7#
Sulfur Oxides :	1,366.6 + 2,210.9 + 14,906.3 = 18,483.8#
Hydrocarbons :	2.0 + 14.8 + 21.3 = 38.1#
Nitrogen Oxides:	59.9 + 168.7 + 1,743.8 = 2,072.4#
Carbon Monoxide:	9.9 + 107.8 = 117.7#

70 - VLCC's:

Particulates	:	728.7#	x	70	= 51,009#
Sulfur Oxides	:	18,483.8#	x	70	= 1,293,866#
Hydrocarbons	:	38.1#	x	70	= 2,667#
Nitrogen Oxides	:	2,072.4#	x	70	= 145,068#
Carbon Monoxide	:	117.7#	x	70	= 8,239#

D. TUG BOATS

Tug Emissions # Per Vessel Trip

	Idle	Half Power	Full Power
Particulates	25 x .04 = 1.0#	15 x .3575 = 5.4#	25 x .2 = 5.0#
Sulfur Oxides	405 x .04 = 16.2#	405 x .3575 = 144.8#	405 x .2 = 81.0#
Hydrocarbons	35.3 x .04 = 1.4#	14.7 x .3575 = 5.3#	21.3 x .2 = 4.3#
Nitrogen Oxides	204.5 x .04 = 8.2#	326.2 x .3575 = 16.6#	399.6 x .2 = 79.9#
Carbon Monoxide	365 x .04 = 1.5#	15.2 x .3575 = 5.4#	11.5 x .2 = 2.3#

Total Tug Boat Emissions in # per VLCC trip.

Particulates	:	1 + 5.4 + 5	= 11.4#
Sulfur Oxides	:	16.2 + 144.8 + 81	= 242 #
Hydrocarbons	:	1.4 + 5.3 + 4.3	= 11.0#
Nitrogen Oxides	:	8.2 + 116.6 + 79.9	= 204.7#
Carbon Monoxide	:	1.5 + 5.4 + 2.3	= 9.2#

Total Tugs For 70 VLCC Visits:

Particulates	:	11.4	x	70	= 798#
Sulfur Oxides	:	242	x	70	= 16,940#
Hydrocarbons	:	11.0	x	70	= 770#
Nitrogen Oxides	:	204.7	x	70	= 14,329#
Carbon Monoxide	:	9.2	x	70	= 644#

Total Marine Losses Associated with Proposed Facilities

	Ships	Tugs	Total
Particulates :	51,009#	798#	51,807#
Sulfur Oxides :	1,293,866#	16,940#	1,310,806#
Hydrocarbons :	2,667#	770#	3,437#
Nitrogen Oxides:	145,068#	14,329#	159,397#
Carbon Monoxide:	8,239#	644#	8,883#

III. DELAWARE BAY EXISTING SCENARIO

A. 120,000 DWT TANKERS

Emissions in # Per Trip

	Transit	Hotel	Pumping
Particulates	20 x 4.31 = 86.2#	10 x 7.965 = 79.7#	20 x 21.75 = 435 #
Sulfur Oxides	159 x 3 x 4.31 = 2055.9#	159 x3 x 7.965 = 3799.3#	159 x 3 x 21.75 = 10,374.8#
Hydrocarbons	.682 x 4.31 = 2.9#	3.2 x 7.965 = 25.5#	.682 x 21.75 = 14.8#
Nitrogen Oxides	55.8 x 4.31 = 240.5#	36.4 x 7.965 = 289.9#	55.8 x 21.75 = 1,213.7#
Carbon Monoxide	3.45 x 4.31 = 14.9#	Negl	3.45 x 21.75 = 75.0#

Total 120 MDWT Emissions in # Per Trip

Particulates :	86.2 + 79.9 + 435	= 600.9#
Sulfur Oxides :	2,055.9 + 3,799.3 + 10,374.8	= 16,230#
Hydrocarbons :	2.9 + 25.5 + 14.8	= 43.2#
Nitrogen Oxides:	240.5 + 289.9 + 1213.7	= 1,744.1#
Carbon Monoxide:	14.9 + 75	= 89.9#

B. TUG BOATS AND BARGES

Tug Emissions # Per Vessel Trip

	Idle	Half Power	Full Power
Particulates	25 x .01 = .3#	15 x .1 = 1.5	25 x .05 = 1.3#
Sulfur Oxides	405 x .01 = 4.1#	405 x .1 = 40.5	405 x .05 = 20.3#
Hydrocarbons	35.3 x .01 = .4#	14.7 x .1 = 1.5#	21.3 x .05 = 1.1#
Nitrogen Oxides	204.5 x .01 = 2.1#	326.2 x .1 = 32.6#	399.6 x .05 = 20.0#
Carbon Monoxide	36.5 x .01 = .4#	15.2 x .1 = 1.5#	11.5 x .05 = 0.6#

Therefore Total Tug Emissions Per Vessel Trip

Particulates	:	.3	+	1.5	+	1.3	=	3.1#
Sulfur Oxides	:	4.1	+	40.5	+	20.3	=	64.9#
Hydrocarbons	:	.4	+	1.5	+	1.1	=	3.0#
Nitrogen Oxides	:	2.1	+	32.6	+	20	=	54.7#
Carbon Monoxide	:	.4	+	1.5	+	.6	=	2.5#

Tug Emissions # Per Barge Movement

	Idle	Half Power
Particulates	25 x .04 = 1.0#	15 x .52 = 7.8#
Sulfur Oxides	405 x .04 = 16.2#	405 x .52 = 210.6#
Hydrocarbons	35.3 x .04 = 1.4#	14.7 x .52 = 7.6#
Nitrogen Oxides	204.5 x .04 = 8.2#	326.2 x .52 = 169.6#
Carbon Monoxide	36.5 x .04 = 1.5#	15.2 x .52 = 7.9#

Therefore Total Tug Emissions Per Barge String Movement

Particulates	:	1.0	+	7.8	=	8.8#
Sulfur Oxides	:	16.2	+	210.6	=	276.8#
Hydrocarbons	:	1.4	+	7.6	=	9.0#
Nitrogen Oxides	:	8.2	+	169.6	=	177.8#
Carbon Monoxide	:	1.5	+	7.9	=	9.4#

Barge HC (Loading Losses) =

$$1.7 \times 42 \times 204.4 \times 10^3 \times .35 = 5{,}107{,}956\#$$

IV. DELAWARE BAY PROPOSED SCENARIO

The change in emissions will be the elimination of 273-120 MDWT tankers and 323 barge string movements.

A. 120,000 DWT TANKERS

273-120 MDWT Tankers:

Particulates	:	600.9	x	273	=	164,050#
Sulfur Oxides	:	16,230	x	273	=	4,430,790#
Hydrocarbons	:	43.2	x	273	=	11,795#
Nitrogen Oxides	:	1,744.1	x	273	=	476,140#
Carbon Monoxide	:	89.9	x	273	=	24,545#

B. TUG EMISSIONS

Total Tug Emissions

Particulates	:	3.1	x	273	+	8.8	x	323	=	3,690#
Sulfur Oxides	:	64.9	x	273	+	276.8	x	323	=	107,125#
Hydrocarbons	:	3.0	x	273	+	9.0	x	323	=	3,726#
Nitrogen Oxides	:	54.7	x	273	+	177.8	x	323	=	72,365#
Carbon Monoxide	:	2.5	x	273	+	9.4	x	323	=	3,720#

Barge HC Losses: 5,107,956#

Total Marine Losses That Would Be Eliminated By Proposed Facility

	Ships	Tugs	Barges	Total
Particulates	164,050#	3,690#	-	167,740#
Sulfur Oxides	4,430,790#	107,125#	-	4,537,915#
Hydrocarbons	11,795#	3,726#	5,107,956#	5,123,477#
Nitrogen Oxides	476,140#	72,365#	-	548,505#
Carbon Monoxide	24,545#	3,720#	-	28,265

C. 260,000 DWT TANKERS

Emissions in # Per Trip

	Transit	Hotel		Pumping	
Particulates		10 x 4.635 =	46.4#	20 x 31.25 =	625 #
Sulfur Oxides	No	159 x 3 x 4.635 =	2,210.9#	159 x 3 x 31.25 =	14,906.3#
Hydrocarbons	Net	3.2 x 4.635 =	14.8#	.682 x 31.25 =	21.3#
Nitrogen Oxides	Emissions	36.4 x 4.635 =	168.7#	55.8 x 31.25 =	1,743.8#
Carbon Monoxide		Negl.		3.45 x 31.25 =	107.8#

Therefore Total 260,000 DWT Emissions in # per trip

Particulates	:	46.4	+	625	=	671.4#
Sulfur Oxides	:	2,210.9	+	14,906.3	=	17,117.2#
Hydrocarbons	:	14.8	+	21.3	=	36.1#
Nitrogen Oxides	:	168.7	+	1,743.8	=	2,012.5#
Carbon Monoxide	:	107.8				

186 - VLCC's:

Particulates	:	671.4#	x	186	=	124,880#
Sulfur Oxides	:	17,117.2#	x	186	=	3,183,799#
Hydrocarbons	:	36.1#	x	186	=	6,715#
Nitrogen Oxides	:	2,012.5#	x	186	=	374,325#
Carbon Monoxide	:	107.8#	x	186	=	20,051#

D. TUG BOATS

Particulates	:	15 #	x	.1	=	1.5#
Sulfur Oxides	:	405 #	x	.1	=	40.5#
Hydrocarbons	:	14.7#	x	.1	=	1.5#
Nitrogen Oxides	:	326.2#	x	.1	=	32.6#
Carbon Monoxide	:	15.2#	x	.1	=	1.5#

For 186 Tug/Vessel movements

Particulates	:	124,880	+	279	=	125,159#
Sulfur Oxides	:	3,183,799	+	7,535	=	3,191,334#
Hydrocarbons	:	6,715	+	279	=	6,994#
Nitrogen Oxides	:	374,325	+	6,065	=	380,390#
Carbon Monoxide	:	20,051	+	279	=	20,330#

A.7 TANK FARM EMISSIONS (EACH SCENARIO)

A. NEW YORK BAY PROPOSED FACILITIES

If east shore then:

4--200,000 Barrel Tanks and 2--150,000 BBL Tanks
175'Ø x 48' HT 150'Ø x 48' HT

150'Ø Tank

$$L_s = (9.21 \times 10^{-3})(50)\left[\frac{5.7}{14.7-5.7}\right]^{0.7}(150)\sqrt{150}\,(15)^{0.7}(0.13)(1)(.9)(0.84)$$

= 402#/day x 365 days/year = 146,734#/year.

175'Ø Tank

$$L_s = 402 \times \frac{175\sqrt{150}}{150\sqrt{150}} = 469\text{#/day} \times 365 = 171,185$$

Total standing losses from east shore tank farm

4(171,185) + 2(146,734) = 978,208#/year.

If tank farm were west shore then:

2--400,000 BBL Tanks and 2--150,000 BBL Tanks
250Ø 150Ø

The standing losses for 150Ø same as above.

$$L_s = 402 \times \frac{250}{150} = 670\text{#/day} \times 365 = 244,550\text{#/year}$$

Total standing losses from west shore tank farm

2(244,550) + 2(146,734) = 782,568#/year

Using more conservative case assume east shore tank farm.

B. DELAWARE BAY PROPOSED FACILITIES

Tank Farms Emissions

9--400,000 BBL Tanks 20--250,000 BBL Tanks
250'Ø 150'Ø

Total Standing Losses

9(244,550) + 20(146,734) = 5,135,630 #/year.

A.8 NET EMISSIONS SUMMARY (IN POUNDS PER YEAR)

A. NEW YORK BAY

Particulates :	51,807 -	87,581		= -35,774#
Sulfur Oxides :	1,310,806 -	2,235,465		= -924,659#
Hydrocarbons :	3,437 -	1,569,048	+ 978,208	= -587,403#
Nitrogen Oxides:	159,397 -	292,069		= -132,672#
Carbon Monoxide:	8,883 -	14,943		= -6,060#

B. DELAWARE BAY

Particulates :	125,159	-167,740		= -42,581#
Sulfur Oxides :	3,191,334	-4,537,915		=-1,346,581#
Hydrocarbons :	6,994	-5,123,477	+5,123,477	= +19,147#
Nitrogen Oxides:	380,390	-548,505		= -168,115#
Carbon Monoxide:	20,330	-28,265		= -7,935#

<u>APPENDIX B</u>

Physiological Effects of Pollution

APPENDIX 'B'

Physiological Effects of Pollution

Factors Affecting Response of Organisms To Air Pollutants

Environmental and organismal factors influence the effect which an air pollutant can have upon a living organism. Once pollutants are emitted to the atmosphere, several environmental factors influence the amount of secondary pollutants (oxidants) produced. In turn, the concentration of all pollutants coming in contact with organisms is also influences. Strong and/or high winds will distribute pollutants over a much greater area, thereby reducing concentrations due to dilution of ambient air. These same winds influence the rate of emittance from many natural sources (e.g., hydrocarbons from forests). Winds affect all pollutants. They are responsible for the movement and mixing of primary pollutants to facilitate the production of secondary pollutants or oxidants. This phenomenon is referred to as transport and often occurs along the east coast of the United States.

Sunlight induces chemical processes which are important factors in some areas' pollution problems. In highly urban communities NO production increases from early morning vehicular traffic and quickly converts to NO_2. The rate of conversion is sunlight dependent. Thus, under conditions of low wind and high irradiation, maximum concentrations are produced. Other chemical reactions within the nitrogen dioxide--photolytic cycle produce O_3. However, the major factor in O_3 production is the entrance of hydrocarbons into the photolytic process. Daily maximum concentrations show, 1) NO buildup early and tapering off by mid-morning and, 2) NO_2 and O_3 buildup in late morning as NO concentrations decline. PAN is also produced by the photolytic cycle in the presence of hydrocarbons.

Temperatures of polluted air masses influence the rate of production of oxidants. Higher temperatures increase the oxidant production rate; thus, possibly increasing concentrations.

The response which plants have to a given pollutant represents the sum total of many environmental factors present in the micro-habitat where the plant is growing. The interrelationship of factors has often been demonstrated by researchers. Generally the plant's response to these factors is the same for primary and secondary pollutants. Resistance decreases as temperaturn increases. This is probably related to a decrease in the physiological activity. Experimentation shows that spruce trees show a marked increase in sensitivity during spring and fall when physiological activity is greater. At no temperature do plants show resistance. Sensitivity at a constant low temperature (40°F) can be increased when water is available.

As humidity increases the sensitivity to SO_2 increases. Although the same appears to hold true for oxidants, research is still inconclusive. A critical relative humidity level for SO_2 may be around 70%. However, a threshold injury level is probably dependent on species and interrelation of many other factors.

Variable responses by pollutants to light have been reported. Ozone exposed plants are more sensitive to low light intensities, whereas, the opposite is true for PAN. SO_2 injury is reduced when light intensity is also reduced. Injury reduction for PAN and SO_2 may be correlated to the stomata (plant leaf structure functioning for gas exchange) of most plants which are closed during darkness. However, closure is dependent on several factors, including spacing, leaf resistance and water potential. These factors may account for the reverse activity of O_3 tested plant species.

Some researchers have shown that plant's SO_2 sensitivity decreases when, 1) water content approaches wilting; 2) the plants are adequately fertilized and 3) proper nutrient levels are present. These same general conditions and responses are true for nitrogen oxides.

Researchers have shown that contradictory results can occur when subjecting a species to a given pollutant under the same conditions. These contradictory results show that the plant's genetic make-up plays a very important role in the sensitivity of any given species. These innate biochemical and morphological characteristics are probably responsible for some species showing variable responses--especially on a geographical basis. These pollutants also act as a selective pressure mechanism in a given species. The more sensitive individuals within a species are damaged and may not survive, or if they survive, may not reproduce; the more resistant species survive. Under these conditions entire communities may change either in species composition or populations (densities) of each species.

The developmental phase of a plant species is closely associated with its sensitivity to a given pollutant. There is probably a time during the growth of a plant where it is most sensitive. Generally, plant leaves are more susceptible to SO_2 when they reach maximum expansion. The same holds true for O_3. PAN injury occurs on the leaf when the youngest mature cells are present.

Varying environmental factors also regulate the degree to which pollutants affect human health and other animals. These have not been investigated as thoroughly as the effects on vegetation. Most investigations on non-human forms have been limited to rats, guinea pigs, rabbits, and to a lesser extent, monkeys. Human investigations have been primarily limited to case histories and not to an abundance of controlled tests. However, all animals are sensitive at some level and as with plants, the degree of sensitivity is probably related to the quality of health, prior exposure to both low and high level concentrations, prior diseases (primarily pulmonary), genetic makeup and general habits (e.g., smoking).

The interrelationship of factors as well as the presence of several pollutants at one time (under ambient or field conditions) complicate interpretations as to the cause and effect of a given pollutant on a particular species. Also, the ability to predict what will happen under given conditons is difficult. The researchers subjectivity in interpretation of damage is very important. What is interpreted as damage by one scientist may not be reported as damage by another.

Pollutant Metabolism

The fate of a pollutant once it reaches living tissue deserves attention. All organisms require sulfur, nitrogen, oxygen and carbon, together with other elements for maintenance. These elements are found in various chemical compounds within tissues and cells. Sulfate is taken up by plants for formation of proteins, nucleic acids, enzymes, etc. Under controlled experimentation SO_2 is oxidized to sulfate and further reactions use the sulfur in formation of compounds. The excess sulfur derived from SO_2 exposure functions to cause enzyme inactivation, photosynthesis inhibition, acidification of cellular fluid and possible interruption of biochemical pathways.

The fate of O_3 after entrance into plant tissue is unclear. Oxygen is probably a product of the reaction. It is thought that cell permeability is changed, thus causing the interruption of normal metabolic processes. Water balance within the cell may also be impaired.

Plant metabolism of PAN is complicated and inadequately understood. At the cellular level it enters into carbonhydrate metabolism, inhibits growth hormones and disrupts normal photosynthetic processes. Upon contact with wet surfaces inside the leaf, NO_2 reacts to form nitrous and nitric acids. Damage occurs when excess amounts persist. These products cause various abnormalities in metabolic pathways stimulating excess production of some compounds and insufficient production of others.

As in plants, pollutants are incorporated into animal metabolic pathways causing inhibition through substrate modification or enzyme inhibition. In some cases, excess products have been found.

Test results indicate that many effects incurred by organisms are reversible once pollutants are removed or lowered to concentrations below the species' specific threshold. The reversibility of organism response is important, especially in considering worst case concentrations (short-term maximums) versus annual average concentrations.

Symptomatology of Pollutant Effects

The effects of pollutants can be categorized into two areas: visible and subtle. Visible effects are readily perceived and result in such aspects as pigmentation changes in plant leaves or eye irritation in animals. Subtle effects cannot be readily identifiable until some measurement of the suspected damage is made; such as decreased yield in plants or decreased respiratory volume in animals. Both subtle and visible effects cause changes in biochemical pathways which may result in morphological abberations; thus, they are physiological effects.

Visible effects are subcategorized into acute and chronic injury. Acute injury occurs within a few hours of exposure. In plants this involves collapse of cells and development of necrotic areas on leaves. Animal responses include immediate eye irritation or pulmonary dysfunction. Acute problems are generally associated with high short-term concentrations. Chronic injury develops over a longer time period and is not as severe. The green color of leaves is temporarily enhanced followed by chlorosis and eventual leaf drop. This type of injury to humans involves pulmonary disorders in smog-prone locations. The acute form of injury can often be associated with a particular pollutant, whereby the causative agent for chronic injury is not as readily identifiable.

In many cases these injury symptoms are mimicked by various entities completely separated from pollutants. Insects and diseases cause similar leaf injury in plants. Asthma and other lung disorders show similar symptoms in animals.

Although the above are actual physiological effects, a third category for injury or effects exists. These are subtle or physiological effects and are not perceived by investigators except during extensive measurements or long term investigations. They may in time produce visible effects such as population density reduction of affected species within a forest.

In attempting to determine acceptable limits for a known pollutant, one may define acceptable as a pollutant concentration level which does not cause acute, chronic or physiological injury. This becomes extremely difficult when considering all variables which influence pollutants and their effects.

Pollutants In The Northeastern United States

In presenting and understanding the effects of pollutants on organisms in a particular geographical area one must take into account the information discussed in previous sections. Just because a species exhibits an injury response to a specific pollutant does not mean it will occur under other geographic conditions. Investigators have interpreted results differently and many reports of injury involve laboratory conditions with one pollutant. Often dosage levels have been extremely high. Under ambient conditions these concentrations do not prevail and, more often than not, more than one pollutant is present.

The synergistic action of several pollutants is an area that requires further investigation. Present study indicates that the combined action of SO_2 and NO_2 produces a greater injury than the separate NO_2 and SO_2 injury combined.

The following discussion of pollutant (SO_2, O_3, NO_x, PAN) effects on plants and animals is relevant to species which occur or may occur in the northeastern United States. Tabular information and discussions have been abstracted from general presentations.

A. Sulfur Dioxide

Acid Mists

The processes by which atmospheric SO_2 could become H_2SO_4 may be many and complex. Research in the field is incomplete, and no Federal guidelines or standards are available. Nevertheless, the possibility of an interaction of SO_2 with fog or water vapor to form an acid mist is one of concern.

A number of studies (Johnstone and Coughanawr, 1958; Johnstone and Moll, 1960; Foster, 1969; Milelr and Pena, 1972) show that the solution oxidation of SO_2 involves both water and dissolved oxygen and requires the presence of a catalyst to take place at an appreciable rate.

$$2SO_2 + 2\ H_2O + O_2 \xrightarrow{\text{catalyst}} 2H_2\ SO_4$$

Known catalysts are sulfates and chlorides of manganese and iron.

Johnstone and Coughanawr (1958) found a rate of oxidation of 1% per minute in the presence of manganese, nearly 500 times the rate of photochemical reaction from intense sunlight. Johnstone and Moll (1960) found that when sodium chloride particles were the only nuclei present, no acid was formed in expansion fogs. When manganese sulfate or ferrous sulfate nuclei were present, significant concentrations of H_2SO_4 were formed in fogs within a few minutes. A small but definite amount of acid formed when NaCl nuclei only were present.

Effects on Flora

The earliest study of air pollutants centered around the effect of smoke upon forests. Early research pointed out that damage to trees was the result of smoke containing SO_2. Since that time, SO_2 effects have been studied worldwide.

Linzon *et al*. (1973) assessed vegetation injury due to SO_2 emission, from a sulfite pulp and paper mill in Ontario, Canada. Investigations occurred after damage was recognized and injury patterns were typical of those for SO_2. A total of 75 species were listed according to the effects of SO_2: sensitive, intermediate or resistant; however, definition of each category was not delineated. Monitoring stations were located nearby durin the emission periods and concentration levels were recorded as follows:

SO Concentrations (ppm) Exceeded For A Six Hour Average

Date July (1971)	Continuous Hours (6) Hour	Peak
7	0.46	0.96
9	-	1.35
12	0.56	0.72

Sidhu and Singh (1977) investigated vegetation damage near a linerboard mill in Newfoundland, Canada. They found several species exhibiting SO_2 damage; however, SO_2 concentrations were not known and damage was not categorized. Species showing damage are listed below:

Trees	
Balsam Fir	*Abies balsamea*
Black spruce	*Picea mariana*
Speckled alder	*Alnus rugosa*
White birch	*Betula papyrifera*
Red maple	*Acer rubrum*
Shrubs	
Raspberry	*Rubus idaeus*
Elderberry	*Sambucus pubens*
Mexican bamboo	*Polygonum cuspidatum*

Van Sickle (1973) reported on damage to forest species around Bathurst, New Brunswick, Canada. Sulfur dioxide was being vented to the atmosphere from mines containing sulfide material waste from heavy metal mining. Over a period of about two years, concentrations of more than 1.0 ppm were recorded. Death or damage was noted for several species depending on distance from point source.

Effects on Fauna

Recent investigations show that under laboratory conditions sulfur dioxide and nitrogen oxides can have a deleterious effect on health. They can cause various pulmonary disorders as well as eye and nasal irritation.

It should be noted that most information relating air pollutant effects are controlled experiments on non-human forms. Therefore, the direct relation of these results to cause and effect ambient conditions is limited due to the following: 1) under environmental or ambient conditions pullutants are in vombination with other pollutants and, 2) morphological characteristics of test animals (i.e., rats, dogs, mice) are much different than those of man.

Several factors are influential in determining the toxicity of pollutants on animals--dosage, length of exposure, fate (biological breakdown), age, ambient temperature, preexisting physical condition (e.g., respiratory infections) and presence of reducing agents.

Most works dealing with SO_2 toxicity to animals (i.e., non-humans) and humans involve concentrations far in excess of that which would be expected in polluted atmospheres. As with other pollutants, SO_2 exposures cause pathological and physiological abnormalities. These responses are briefly described.

Animals

1) Concentrations 430 mg/m^3 (150 ppm) for 847 hr - 50% mortality in mice; concentration 370 mg/m^3 (130 ppm) for 154 hr - 50% mortality in guinea pigs.

2) Concentration 94 mg/m^3 (33 ppm) - no mortality or observed stress in healthy animals.

3) Concentrations above 94 mg/m^3 (33 ppm) in guinea pigs and mice - physiological changes (coughing, dyspnea, rhinitis, lachrymation, conjunctivitis, abdominal distention, lethargy, partial paralysis) and pathological changes (visceral congestion, pulmonary edema and distention of gall bladder and stomach).

4) Concentrations 460 - 2,390 mg/m^3 (0.16 SIC * - 835 ppm) in guinea pigs - pulmonary dysfunction (increased flow resistance, decreased tidal volume, respiratory frequency and minute volume.

<u>Humans</u>

1) Concentrations 3 - 230 mg/m^3 (1 - 23 ppm) and short-term exposures (10-60 min.):

Below 800 $mg\text{-}min/m^3$ (mg-min = concentration X time) - little effect on resistance to air flow; above 1330 $mg/min.m^3$ increased resistance to air flow. Other symptoms include rhinorrhea and lachrymation.

2) Concentrations above 4.6 mg/m^3 (91.6 ppm) cause some broncho-constriction.

3) Concentration about 2.3 mg/m^3 (1.0 ppm) - threshold for odor highly variable due to subjects used (age) and experimental design.

4) Concentration 0.96 - 19.2 mg/m^3 - increase in light sensitivity up to 4.8 mg/m^3; sensitivity decreased with further increase in concentration.

It is very difficult to determine a level at which significant health effects will not occur. However, results to date

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(*) reported as such; should probably be 160 ppm.

indicate that an annual concentration of 8-100 $\mu g/m^3$ for particulates and SO_2, or a daily 24 hour-average of 250 $\mu g/m^3$ for particulates and 500 $\mu g/m^3$ for SO_2 should not be exceeded.

Nitrogen Oxides

The important oxides of nitrogen found in the atmosphere are NO and NO_2, both naturally and anthropogenically produced. According to Robinson and Robbins (1970), NO produced by bacteria amounts to 50 x 107 tons/year compared to 5 x 107 tons/year man-made production. Although natural sources are much greater, the importance of man-made production concerns itself with its concentrated distribution. Tables B -1 and B -2 show 1970 annual emmisions and 30-year trends, respectively.

Visibility

Visibility reduction or impairment is basically due to scattering and absorption of light by particles and gases and is related not only to concentration but also gaseous properties. The degree to which NO_2 causes visibility reduction and coloration of the horizon sky is directly related to concentrations, the viewing distance and the presence of photochemical aerosols. The emission constituents contain no visible emissions that would directly affect atmospheric light transmission. Studies have shown that concentrations of 0.15-0.20 ppm NO_x cause a 15-20% reduction in light transmission.

Reactivity

The major impact associated with NO_x emissions is the potential to react with hydrocarbons to form ozone. The basic reactions are:

$$2NO + O_2 = 2\,NO_2 \text{ (slow)}$$
$$NO_2 + hv = NO + O \text{ (rapid)}$$
$$O + O_2 + M^* = O_3 + M^* \text{ (rapid Production}$$
$$O_3 + NO = NO_2 + O_2 \text{ (rapid) Destruction}$$

* M is a species capable of removing the energy of bond formation. The equilibrium, dependent upon given sunlight intensity can be approximated by:

$$K = \frac{(NO)(O_3)}{(NO_2)}$$

hv = ultraviolet light

Effects on Flora and Fauna

Summarizing, the determination of acceptable limits for NO and NO_2 concentrations is difficult due to a multitude of factors including the surrounding environment (i.e., soils, rainfall, temperature, topography) the species in the vicinity, innate species characteristics (i.e., state of growth, variety), exposure time and the subjectivity of data interpretation by researchers. Further complications stem from comparisons of data between laboratory and ambient investigations.

Another major complicating factor is the determination of acceptable dosage. Dosage is expressed as a function of exposure time and concentration of pollutant. However, recent research (Ferris) has concluded that the present annual standard is sufficient to protect the health and welfare of the public; a short-term NO_2 standard (24-hour) is suggested and is presently being contemplated by EPA.

Mudd and Lozlowski (1975) stated that acceptable limits of NO_2 "...may be defined as levels which fail to meet these criteria. These criteria are to induce the following:

1) Acute responses which are manifested after 1-2 hours exposure and result in intercostal bifacial necrotic collapse of leaf tissue similar to the effects of SO_2. These foliage markings first appear as water-soaked lesions and later turn white, tan, or bronze in color. Lesions may also be marginal and tend to be near the

apex. An overall waxy appearance is shown by some weeds.

2) Chronic effects which may be an enhancement of green color followed by chlorosis and extensive leaf drop.

3) Physiological effects which result in altered photosynthesis, stunting, spindly growth, reduced fruit set, or reduced yield."

This same approach is applicable for determination of acceptable limits for NO.

In many cases the visual effects (i.e., leaf drop, chlorosis, necrosis) are reversible depending upon the time of exposure (plant chronology) or use of the plant. The value of ornamentals and Christmas trees are drastically reduced if damage to leaves occur.

Under laboratory conditions, rats exposed to 100 ug/m_3 (0.05 ppm) for 90 days showed no effects on blood hemoglobin or erythrocytes or the central nervous system. Other laboratory test animals were tested at much higher concentrations and longer periods of exposure.

Under controlled experimentation with human thresholds, dark adaptation was impaired by NO_2 at concentrations as low as 140 ug/m^3 (0.075 ppm), and within study groups, most individuals could detect odor at 230 ug/m^3 (0.12 ppm). These physiologic responses are reversible immediately upon cessation of exposure.

Reversible pulmonary dysfunctions in humans are evident at NO_2 concentrations as low as 2.8 to 3.8 mg/m^3 (1.5 to 2.0 ppm). These concentrations may be potentially adverse for hypersensitive asthmatics or people with advance chronic pulmonary disorders.

Nitrogen Dioxide

Of all the nitrogen oxides (i.e., nitric oxide, nitrous oxide, nitrogen dioxide) present in the atmosphere, nitrogen dioxide is the most important biologically; researchers have indicated that exposures to NO_2 cause pulmonary dysfunction and visual and olfactory disturbances. Results of investigations are summarized below:

<u>Effects on Animals</u>

1) Concentration 75 - 94 mg/m^3 (40 - 50 ppm) for 1 hour - mortality threshold for mice; non-human primates are more susceptible.

2) Concentration 122 mg/m^3 (65 ppm) for 2 hours (guinea pigs) and 28 mg/m^3 (15 ppm) for 2 hours (monkeys) - increase in respiratory rate and decrease in tidal volume which are reversible.

3) Concentration 13.16 mg/m^3 (7.0 ppm) for less than 24 hours - pathological change in lungs (vascular congestion, edema, bronchiolotis, consolidation, exudative plugging of bronchi, tissue destruction, abscess formation and pneumonitis) of all tested species.

4) Concentration 9.4 mg/m^3 (5.0 ppm) for 169 days (squirrel monkeys) and 0.94 - 1.5 mg/m^3 (0.5 - 0.8 ppm) for 30 - 45 days (mice) - pathio-physiologic changes (vascular permeability and edema formation).

5) Concentration 23 mg/m^3 (12.0 ppm) rats and 2.4 and 5.6 mg/m^3 (1.3 and 3.0 ppm) (rabbits - weight loss.

<u>Effects on Humans</u>

Precise descriptions of NO_2 effects on humans have come from volunteers. Accidental exposures have given information on acute exposures which are well above ambient conditions. A summary of human responses to various short-term concentrations of NO_2 are presented in Table B-3.

An estimate for mortality originated from an accidental exposure to high levels of NO_2. This concentration is 282 mg/m^3 (150 ppm) or above. Other high level concentrations of 47 and 140 mg/m^3 (25 and 75 ppm) produce reversible pneumonia and bronchi-olotis. Airway resistance increases at exposure to 2.8 - 3.8 mg/m^3 (1.5 - 2.0 ppm) for 15 - 45 minutes.

C. Ozone

Reactivity

Ozone is classified as a secondary pollutant. It is formed naturally through electrical storms and through the reaction of ultraviolet light on oxygen in the upper atmosphere. However, the primary source of ozone in the lower atmosphere comes from the photochemical reaction of oxides of nitrogen and certain hydrocarbons; the gaseous precursors of O^3 being in many cases exhaust from automobiles. There are many theories concerning the formation of oxone in the troposphere. The basic reactions are:

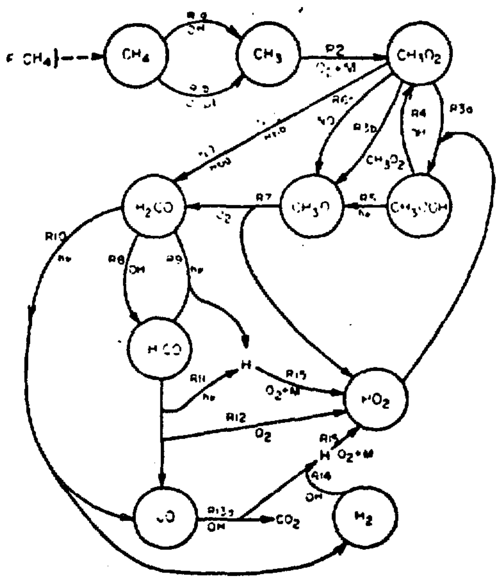
$$2NO + O_2 = NO_2 \quad \text{(slow)}$$
$$NO_2 + hv = NO + O \quad \text{(rapid)}$$
$$O + O_2 + M^* = O_3 + M^* \quad \text{(rapid) Production}$$
$$O_3 + NO = NO_2 + O_2 \quad \text{(rapid) Destruction}$$

* M is species capable of removing the energy of bond formation. The equilibrium, dependent upon given sunlight intensity can be approximated by:

$$K = \frac{(NO)(O_3)}{(NO_2}$$

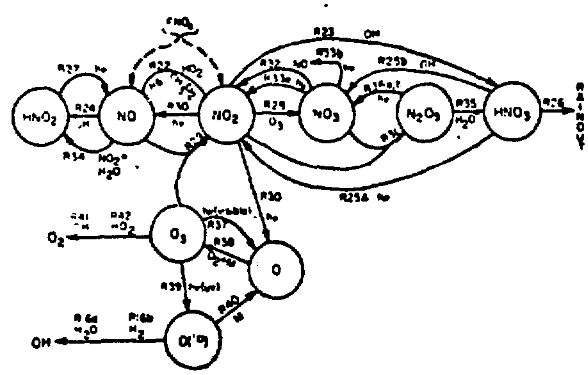
The complexity of the formation of ozone is shown in the following reaction nets based upon the photochemical methane oxidation chain (Figure B -1). Although the figure shows the reactions to be a major source of tropospheric formaldehyde, molecular hydrogen and carbon monoxide, four hydroperoxyl radicals are produced which react with nitric oxide (Figure B-2) for form ozone:

(R22)	$HO_2 + NO$	=	$NO_2 + OH$
(R30)	$NO_2 + hv$	=	$NO + O$
(R38)	$O + O_2 + M$	=	$O_3 + M$



. Methane oxidation chain. FCH_4 represents the production of methane at the ground

Figure B-1



Reactions of the odd nitrogen and odd oxygen gases. FNO_x represents the production of odd nitrogen at the ground

Figure B-2

The importance of ozone lies in the reactions with hydrocarbons to form photochemical smog and other oxidants that have direct effect on vegetation and the human health. Reactions of ozone with hydrocarbons can produce aldehydes, ketone, alkyl and acyl free radicals, acids, epoxides and alcohols. A general reaction scheme is noted below:

$$NO_2 + hv = NO + O$$
$$O + O_2 \ (+M) = O_3 \ (+M)$$
$$NO + O_3 = NO_2 + O_2$$
$$RR + O = R + RO$$
$$RR + O_3 = RO + RO_2$$
$$RO_2 + NO = NO_2 + RO$$
$$R + O_2 \ (+M) = RO_2 \ (+M)$$
$$RO + O_2 \ (+M) = RO_3 \ (+M)$$
$$RO_3 + NO = NO_2 + RO_2$$
$$RO_2 + NO_2 = RO_2 \ NO_2$$
$$RO_3 + NO_2 = RO_3 \ NO_2$$
$$NO_2 + O_3 = NO_3 + O_2$$
$$NO_3 + NO_2 = N_2O_5$$
$$N_2O_5 + H_2O = 2HNO_3$$

Where RR represents an average hydrocarbon type in a polluted atmosphere, interrelationship between compounds are shown in the Figure B-3.

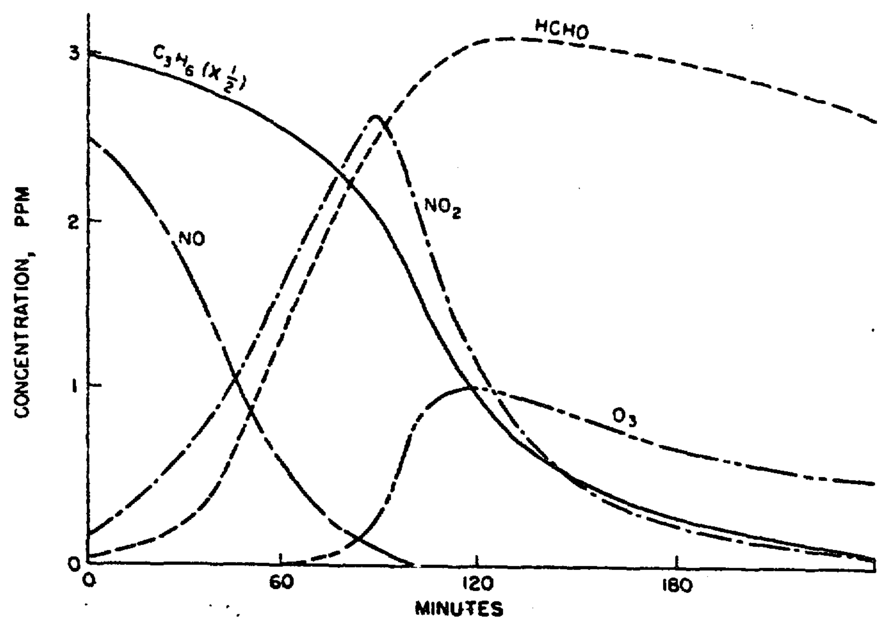


Figure B-3 Photochemical reaction pattern propylene - nitric oxide

The key photochemical oxidant related to photochemical smog is Peroxyacetyl nitrate (PAN) and is formed by the following reactions:

$$O_3 + RH = R'CHO + R'COO$$
$$R'COO + NO = R'CO + NO_2$$
$$R'CO + O_2 = R'COOO+$$
$$R'COOO + NO_2 = R'COONO_2 \text{ (PAN)}$$

where RH is a hydrocarbon and R is an aromatic or aliphatic radical.

Effects on Flora and Fauna

Injury to vegetation caused by photochemical smog has been found in many areas. Ozone produces stipple on grape and fleck on tobacco. PAN is considered to be a major phytotoxicant causing under-surface silvering or bronzing of leaves. Field exposures of 0.02 to 0.05 ppm of oxidants cause damage to vegetation in 4 to 6 hours.

Ozone and oxidants cause major damage to the respiratory tract in animals. Oxidants reduce the respiratory function in animals directly after exposure, and chronic injury to lungs is produced by exposure to a 1 ppm concentration. Also, ozone denatures protein, and oxidants affect visual acuity.

Oxidants and ozone are easily detectable in the 0.02 to 0.05 ppm range by their odor. Even at 0.05 ppm, irritation of nose and throat are reported. Over 0.2 ppm, visual acuity is seriously impaired. At levels of 0.8 ppm onward, pulmonary congestion is reported. PAN has been shown to be a major factor in eye irritation caused by photochemical smog.

Naturally produced ozone is most prevalent in the area of 20 to 50 km above the earth's surface. However, this ozone diffuses very slowly and is destroyed so rapidly that normal concentrations are in the order of 0.02 ppm. However, studies have shown that rural areas, containing no major point sources and no major traffic sources, have exceeded the national standard. The sources of these violations are direct transport and may be associated with the interaction of antropogenic nitrogen oxides from urban areas with the natural photochemical methane oxidation chain. (Figures B-1 and B-2)

Data supporting long distance transport have been documented in many cases. Two cases in particular are notable to mention. Measurements were made in 1972 at Garrett County Airport in western Maryland under a contract with EMSL, EPA. In this rural area O_3 concentrations frequently exceeded the then 0.08 ppm standard. Moreover, during a 26 hour period of September 2-3, 1972, the concentration was greater than the standard. An analysis of meteorological data traced the source to air travelling from New York City, Philadelphia, Baltimore, and Washington, D.C. areas through Virginia to Huntington, West Virginia through Ohio and finally across the Wheeling, Pittsburgh area. The apparent path covered a 4 to 5 day period.

An unusual haze with low visibility in the southern Florida area was reported by the Metropolitan Dade County Pollution Control in May, 1972. Analysis of weather maps showed that an atmospheric system of a stagnant "high" and a slow moving "low" produced transport of air from an area extending between Chicago and Pittsburgh. Other studies in upstate New York substantiate high ozone readings in rural areas correlating with high readings in urban areas.

The proposed mechanism for transport seems to have validity. That part of the air mass from the ground up, in which vigorous vertical mixing occurs is characterized by its mixing depth. These depths are influenced by temperature and are greatest in the afternoon.

In addition to the mixing process, wind speed increases with height. Momentum is transferred downward toward the surface by eddies of air. The coefficient of eddy viscosity varies with the lapse rate. During the day, as the surface temperature increases, the lapse rate and coefficient of eddy viscosity increases so that the high momentum aloft is transported downward by the eddies. The wind at the ground tends to reach its maximum value in the afternoon when the lapse rates are usually the greatest. At night the lapse rate becomes stable, the coefficient of eddy viscosity decreases and there is little exchange of momentum. Thus, surface winds die down.

Therefore, in general, the greatest horizontal movement into the vertical mixing of the air above an urban area will occur in the afternoon when the surface temperature reaches its maximum.

When this air mass, containing ozone and precursors of ozone are transported by a weather system, ozone is synthesized and the precursors which could function as ozone destruction agents at night are consumed. Thus a large local abundance of ozone that exhibits little or no decay at night can be found in a rural area.

<u>Effects on Animals</u>

Ozone toxicity tests have been conducted on non-humans since the turn of the century. Post mortem examinations revealed inflammation of respiratory tracts including hemorrhages and edemas. Continuation of investigations has revealed a variety of effects by ozone. These are summarized in Table B-4 and in the following:

1) Concentration 160 $\mu g/m^3$ (0.08 ppm for 3 hours - decreased resistance (i.e., bacterial infactions).

2) Concentration 390 - 1,960 $\mu g/m^3$ (0.2 - 1.0 ppm) prolonged - pathological changes (bronchitis, bronchiolitis, emphysema, fibrosis).

3) Concentration 590 $\mu g/m^3$ (0.3 ppm) up to 2 hours - pulmonary changes (decreased tidal volume, increased frequency of breathing, increased flow resistance).

4) Concentration 1,960 $\mu g/m^3$ (1.0 ppm) for 1 hour - chemical change especially proteins.

5) Concentrations 1,960 - 9,800 $\mu g/m^3$ (1.0 - 5.0 ppm) for 2-6 hours - increased mortality due to histamine, bacterial infection, age, exercise.

6) Concentration 5,900-11,800 $\mu g/m^3$ (3.0 - 6.0 ppm) for more than 4 hours - biochemical changes in the lungs and other organs.

Effects on Humans

By far, more investigations of O_3 have occurred under experimental rather than ambient conditions. Table B-5 summarizes the findings of occupational exposures, whereas, experimental O_3 exposure results are presented in Table B-6. Both exposure conditions and their effects are briefly summarized.

Prolonged Exposure (Occupational and Experimental)

1) Concentrations below 390 $\mu g/m^3$ (0.2 ppm) - no effects apparent.

2) Concentrations 590 $\mu g/m^3$ (o.3 ppm) - threshold for nasal and throat irritation.

3) Concentration 980 $\mu g/m^3$ (0.5 ppm) intermittent exposure (8 weeks, 3 hr/day for 6 days) - decrease in expiratory volume.

Short-term Exposure Experimental)

1) Concentration below 200 $\mu g/m^3$ (0.1 ppm) for 1 hour - no effects apparent.

2) Concentrations 200 - 780 $\mu g/m^3$ (0.1 - 0.4 ppm) for 1 hour - no effects demonstrated; however, more research heeded.

3) Concentrations 980 - 1,960 $\mu g/m^3$ (0.5 - 1.0 ppm) for 1-2 hours - changes in pulmonary functions (increased airway resistance, decreased vital capacity, decreased CO diffusing capacity and decreased forced expiratory volume.

4) Concentrations 1,960 - 5,900 $\mu g/m^3$ (91.0 - 3.0 ppm) for 2 hours - extreme fatigue, lack of co-ordination in some subjects.

5) Concentrations 17,600 $\mu g/m^3$ (9.0 ppm) - severe pulmonary edema and acute bronchiolitis.

D. Oxidants

Experimental exposures of animals to photochemical smog or oxidants have involved the use of ambient air or processed automobile exhaust; thus, ozone has been a major constituent in the oxidant mixture. Most work has been limited to non-humans. Very few studies applicable to human exposure are available and these mostly relate to eye irritation. A summary of animal research is presented in Table B -7 and briefly outlined below:

1) Concentrations above 980 $\mu g/m^3$ (0.5 ppm) long-term exposure under ambient conditions - increased flow resistance in guinea pigs.

2) Concentrations 390 - 1,900 $\mu g/m^3$ (0.2 - 1.0 ppm) long-term exposure to processed automobile exhaust - decreased fertility, increased neonatal mortality and stress adaptation response in mice.

3) Concentration up to 1,570 $\mu g/m^3$ (0.8 ppm) short-term exposure up to 8 hour - pulmonary disorders in guinea pigs which are reversible (increased tidal volume, minute volume and flow resistance); irreversible disorders include alveolar tissue change and increased susceptibility to bacterial infections (pulmonary) in mice.

E. Peroxytacetyl Nitrate (PAN)

Effect on Plants

Drummond (1971) exposed various woody plant species to 20-30 parts per hundred million (pphm) PAN for 8 hours at 24°C and

70% relative humidity in growth chambers. Several species showed some signs of sensitivity, generally to young leaves.

Effects on Animals

Data for animal and human exposure to PAN are relatively sparse. It's lethality to mice is less than O_3, the same as NO_2 and more than SO_2. At concentrations above 540 ug/m^3 (110 ppm) most mice die. Human experimentation indicates that PAN exposures (1,485 ug/m^3) for 5 minutes will increase oxygen uptake during exercise.

F. Particulate Pollution

Introduction

Particulates constitute a rather heterogeneous category of air pollutants which chemically have nothing in common except that they are not gaseous. The extreme range of particle diameters is 1 nm* to 10 nm, or seven orders of magnitude, although the most siginificant, "lung-damaging" particles lie in the 0.25 to 10 um range.

Types of Particulates

Typical particulates are fly ash, carbon, iron oxide, a wide variety of organics, especially hydrocarbons obtained from incomplete combustion of fossil fuels, and also asbestos. Some of these materials, such as iron oxide may be biologically innocuous, while others are known carcinogens.

Their specific biological interactions aside, particulates in general constitute a health hazard for two reasons:

1. Due to their high specific surface, they can adsorb significant airborne pollutants, and thereby concentrate them.

2. They can serve as sites for secondary nucleation producing additional pollution problems; e.g.,

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* nanometers = 10^{-9} meters

water vapor can condense out on these particles, then react with SO_2, and produce acid mists.

Heavy Metals

Fly ash is known to be particularly effective in adsorbing heavy metals, especially zinc, lead, arsenic, chromium, nickel, tellurium, antimony, sellenium, and cadmium, listed in descending order of typical concentration ranging from about 1% for zinc to 20 ppm for cadmium. This is clearly much higher than the concentration of these metals, for example, in crude oil, as shown on Table B -8, and demonstrates the ability of particulates to concentrate these pollutants. The effect of these metals on plant and animal life is summarized in Table B-9.

Organic Particulates

The various organics in particulates can be categorized as follows:

1) Neutral Pollutants

A. Aliphatic hydrocarbons, both saturates and unsaturates.

B. Aromatics, both low molecular weight and P.A.H. (Polynuclear Aromatic Hydrocarbons).

C. Pesticides

D. Oxygenates

E. Nitrosamines

2) Acidic Pollutants

A. Fatty acids

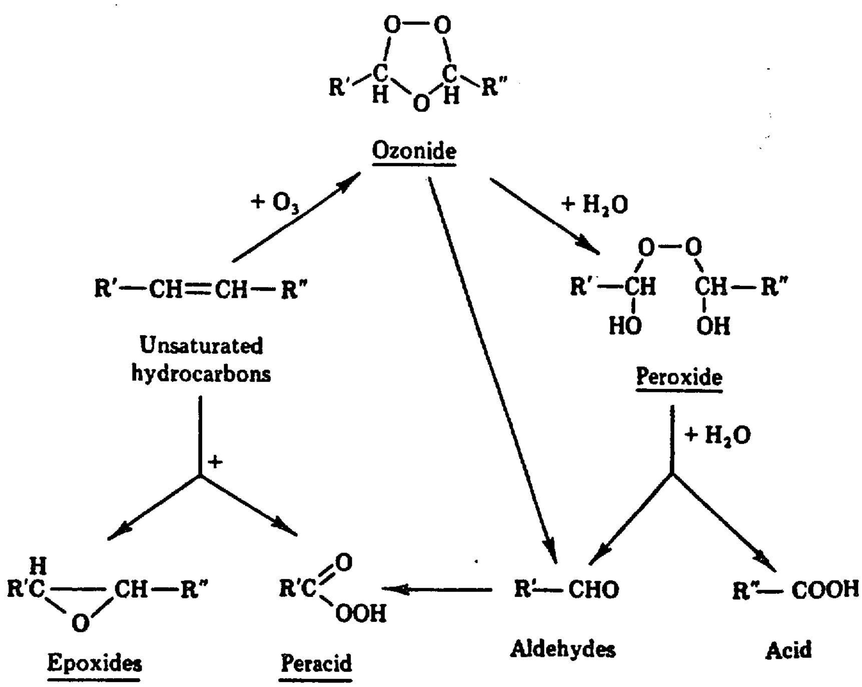
B. Phenolics

3) Basic Pollutants

A. Amines

B. Azaarenes

In addition to being irritants to the eyes, respiratory system, and skin, these hydrocarbons are subject to oxidation, especially the unsaturates, to form oxygenated materials, many of which are known or suspected carcinogens. A summary of these reactions is shown in Figure B-4. The epoxides and peracids shown on this diagram include known and suspected carcinogens.



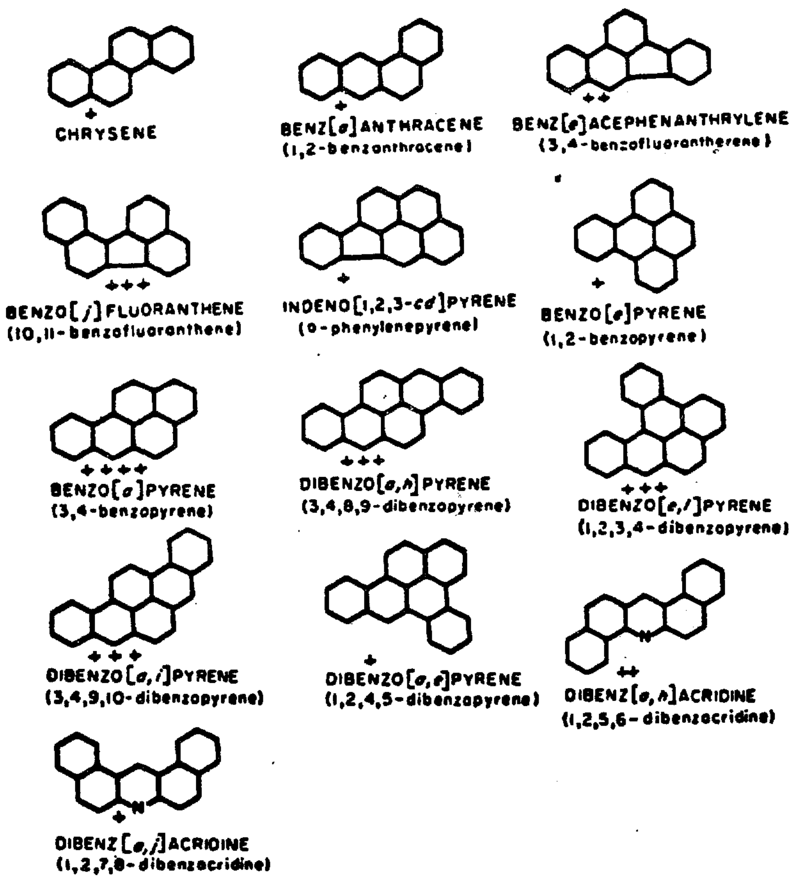
Photochemical reactions of carcinogenic significance in polluted air as postulated by Kotin and Falk (199).

Figure B-4

Aromatic hydrocarbons generally pose a significant carcinogenic hazard. This is especially true of the polynuclear aromatic hydrocarbons (PAH). A number of known carcinogenic PAH have been identified in urban air, as shown in Figure B-5.

Another group of neutral particulate pollutants in the nitrosamine group. Formed by the reaction of amines and NO_x, this group of chemicals, besides containing known and suspected carcinogens, has also been shown to induce cirrhosis of the liver.

The acidic particulate pollutants consist largely of fatty acids and phenolic compounds. Thus far fatty acids do not appear to be biologically active. This family of compounds, which may be formed by partial oxidation of polysaccharides and aromatic hydrocarbons. They are found in plants. Tobacco leaves, for example, contain 0.5 to 7% phenolics, which upon burning are released to the air. Studies have shown that tobacco smoke contains many polyphenols; these compounds may be biologically active, possibly carcinogenic.



Carcinogenic PAH identified in urban air.

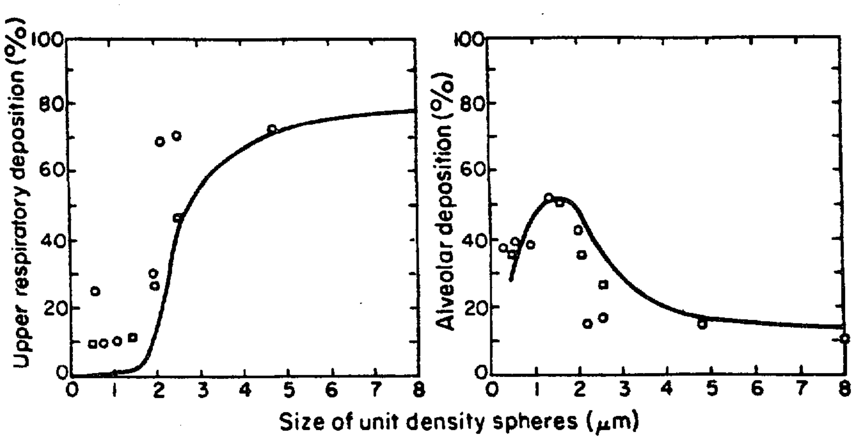
Figure B-5

Both categories of basic pollutants are potentially dangerous. Amines tend to be reactive forming nitrosamines and various oxygenate compounds, while many azaarenes, such as dibenzacridine are known animal carcinogens.

Uptake of Particulate Pollution

The principal modes of uptake of suspended particulates is via the skin, digestive tract, and especially, the respiratory system. Particulate matter can be retained either by the aveoli, thus increasing the residence of pollutants in the lungs and impeding mass transfer of oxygen and CO_{22}, or by the upper respiratory system causing tissue imflammation, impeding the free flow of air to the lungs.

Aveolar retention is greatest for 0.5 to 3 um diameter particles, and tapers off to less than 5% for particles which tend to be trapped in the upper respiratory system, as shown in Figure B-6.



Deposition versus particle size of inhaled particles in the upper respiratory tract and in the lungs of the guinea pig (○) and monkey (□) compared with man (curve) (*324*).

Figure B-6

In summary, particulate matter poses a rather unique hazard to the environment. While other pollutants pose biochemical problems only, particulates in addition, through such mechanisms as adsorption and catalysis can increase the danger of other pollutants. Furthermore, since they are less easily purged, they can significantly increase the residence time of other pollutants in the body as well as acting as a resistance to the normal mass transfer within living organisms.

Present knowledge of the wide variety on "non"-volatile organics present in particulates must still be viewed as limited, especially as regarding carcinogens and mutogens, such as oxygenated compounds, azaarenes, aromatic amines and nitrosamines.

SUMMARY

The combination of intrinsic and extrinsic factors which influence an organism's response to an air pollutant complicates the determination of pollutant dosages which are acceptable for emittance from a point source. Further complications arise from the nature of the pollutant and meteorological factors which may alter its chemical make-up and eventual dispersal throughout the environment.

The use of affected organisms, especially plants, has to be considered since damage, in many cases, is reversible. Forest products may generate new growth; thus, immediate effects are recoverable. However, long-term exposures may reduce growth (as much as aesthetic considerations. Under short-term exposures, new growth will alleviate the problem. Leaf damage to crops (i.e., potatoes, tomatoes) may or may not reduce yield. Long-term (year after year) exposures should not be considered in crop evaluations since they are planted annually.

Human related exposures decrease the general health of the population and may result in loss of workers' efficiency and eventual decrease in the local economy. However, short-term exposures are often recoverable.

TABLE B-1

ESTIMATED ANNUAL NO_x EMISSIONS IN THE UNITED STATES IN 1970[a]

Source	Estimated Emission 10^8 kg/yr[b]			Total %		
Mobile	106.1			51.4		
Motor vehicles		82.5			40.0	
Gasoline			70.7			34.3
Diesel			11.8			5.7
Aircraft		3.3			1.6	
Railroads		1.3			0.6	
Marine use		1.5			0.7	
Non highway use		17.5			8.5	
Stationary	90.9			44.1		
Electric utilities		42.7			20.7	
Industrial combustion		41.1			19.9	
Commercial		2.0			1.0	
Residential		5.1			2.5	
Solid waste disposal	3.6			1.7		
Agricultural burning	2.5			1.2		
Industrial process losses	1.8			1.2		
Miscellaneous	1.3			0.6		
TOTAL:	206.2					

a From Cavender, et al. [80]

b Expressed as nitrogen dioxide

Source: Nitrogen Oxides, National Academy of Sciences, 1977.

TABLE B-2

ESTIMATED ANNUAL NO_x EMISSIONS IN THE UNITED STATES IN 1970[a]

Source	Emission 10^8 kg/yr[b] 1940	1950	1960	1970
Mobile	29.2	47.2	72.5	106.1
Motor vehicles	26.6	40.8	66.0	82.5
Aircraft	Neg.[c]	0.1	0.1	3.3
Railroads	0.1	1.9	1.4	1.3
Marine use	0.9	1.1	0.7	1.5
Non highway use	1.6	3.3	4.3	17.5
Stationary	32.1	39.3	46.8	90.9
Electric utilities	5.4	11.1	20.8	42.7
Industrial combustion	17.6	18.4	16.2	41.1
Commercial	0.6	1.0	1.8	2.0
Residential	8.6	8.8	8.0	5.1
Solid waste disposal	1.2	1.7	2.2	3.6
Agricultural burning	1.8	2.0	2.4	2.5
Industrial process losses	0.3	0.5	0.7	1.8
Miscellaneous	6.8	3.6	2.3	1.3
TOTAL	71.4	94.3	126.9	206.2

a From Cavender, et al.[80]

b Expressed as nitrogen dioxide

c Negligible: 0.1 x 10 kg/yr

Source: Nitrogen Oxides, National Academy of Sciences, 1977.

TABLE B-3

EFFECTS OF SHORT-TERM NO_2 EXPOSURE - HUMANS

Effect	NO_2 Concentration: mg/m^3	ppm	Time to Effect
Odor threshold	0.23	0.12	Immediate
	0.23	0.12	Immediate
Threshold for	0.14	0.075	Not reported
dark adaptation	0.50	0.26	Not reported
Increased airway	1.3-3.8	0.7-2.0	20 min.
resistance	3.0-3.8	1.6-2.0	15 min.
	2.8	1.5	45 min.
	3.8	2.0	45 min.
	5.6	3.0	45 min.
	7.5-9.4	4.0-5.0	40 min.
	9.4	5.0	15 min.
	11.3-75.2	6.0-40.0	5 min.
	13.2-31.8	7.0-17.0	10 min.
Decreased pulmonary diffusing capacity	7.5-9.4	4.0-5.0	15 min.
Increased alveolar-arterial pO_2 difference	9.4	5.0	25 min.
No change in sputum histamine concentration	0.9-6.6	0.5-3.0	45 min.

Source: National Academy of Science, 1970[a]

TABLE B-4

EFFECTS OF OZONE EXPOSURE-ANIMALS 1/

Ozone,[a] $\mu g/m^3$	Ozone,[a] ppm	Length of exposure	Observed effect(s)	Species
			Local effects	
			Short-term exposures	
160	0.08	3 hours	Increased susceptibility to streptoccoccus (Group C)	Mice
670	0.34	2 hours	30% increase in frequency of breathing; 20% decrease in tidal volume	Guinea pigs
1,330	0.68	2 hours	No significant increase in flow resistance	Guinea pigs
1,960	1.00	1 hour	Chemical changes in ground substance and lung protein	Rabbits
1,960	1.00	4 hours	Engorged blood vessels and excess leucocytes in lung capillaries	Mice
2,120	1.08	2 hours	Increased flow resistance	Guinea pigs
2,550	1.30	3 hours	Increased susceptibility to *Klebsiella pneumoniae*	Mice, hamsters
3,900	2.00	3 hours	Increased lung weight, decreased tidal volume, decreased minute ventilation	Rats
6,290	3.20	4 hours	Gross pulmonary edema	Mice
9,800	5.00	2 hours	Increased lung compliance, increased susceptibility to histamine	Guinea pigs
9,800	5.00	3 hours	Decreased activity of bacteriocidal lysozyme	Mice, rabbits
11,800	6.00	4 hours	Gross pulmonary edema, increased lung serotonin	Rats
20,000	15.00	30 min.	Decreased tidal volume, decreased O_2 consumption	Rabbits
41,000	21.00	3 hours	50% mortality	Mice
41,000	21.80	3 hours	50% mortality	Rats
67,980	34.50	3 hours	50% mortality	Cats
71,000	36.00	3 hours	50% mortality	Rabbits
101,370	51.70	3 hours	50% mortality	Guinea pigs
			Long-term exposures	
1,650	0.84	4 hours/ 5 days/2 wk	Increased susceptibility to *Klebsiella pneumoniae*	Mice, hamsters

TABLE B-4

EFFECTS OF OZONE EXPOSURE-ANIMALS (Continued)

Ozone,[1] $\mu g/m^3$	Ozone,[a] ppm	Length of exposure	Observed effect(s)	Species
1,960	1.00	continuous	Bronchitis, bronchiolitis, emphysematous and fibrotic changes; acceleration of lung tumor development	Mice
15,700 to 88,000	8 to 45	1 hr/wk up to 49 wk	Damage to epithelium of the lower trachea and bronchioles; fibrosis	Rabbits
			Systemic effects Short-term exposures	
390	0.20	30 min.	Increased sphering of red blood cells when irradiated	Rabbits, rats, mice
390	0.20	6 hours	Decreased voluntary running activity	Mice
1960	1.00	6 hours	60% increase in mortality as a result of exercise for 15 min/hr	Rats
6100	3.10	20 hours	Increased liver weight; increased liver alkaline phosphatase	Rats
7800	4.00	4 hours	Decreased mortality with age: young 50% mortality, old 10% mortality	Mice
11800	6.00	4 hours	Decreased brain serotonin Long-term exposures	Rats
390	0.20	5 hr/day/ 3 wk	Structural changes in heart myocardial fibers	Mice

(1) Concentration lowest for observed effects

Source: National Air Pollution Control Administration. 1970.

TABLE B-5

EFFECTS OF OCCUPATIONAL EXPOSURE TO OZONE - HUMANS

Ozone, µg/m³	Ozone, ppm	Subjective complaints	Clinical findings attributed to ozone	Measurements of pulmonary function	Other comments
490	0.25	None	None	None	–
590 to 1,570	0.3 to 0.8	Chest constriction and throat irritation in 2 to 4 subjects	None	None	–
17,990 (peak concentration)	9.2 (peak concentration)	Severe headaches, throat irritation, and lassitude in 7 or 8 subjects		None	Negligible nickel carbonyl and oxides of nitrogen. Trichloroethylene degreaser located 50 ft from welding area. Tests for phosgene negative.
		Cough, choking, dyspnea, and substernal oppression in 3 of 8 subjects	By X-ray, molted densities in both lungs, clearing after 9 days	None	
		Very severe headache; dyspnea, substernal oppression in 1 of 8 subjects	Severe pulmonary edema. By X-ray, peribronchial infiltration consistent with peribronchial pneumonia	None	
390	0.2	–	None	None	–
1,570 to 3,330	0.8 to 1.7	Dry mouth and throat, irritation of nose and eyes, disagreeable smell in 11 of 14 subjects	None	None	Concentration of trichloroethylene up to 238 ppm found
390 to 590	0.2 to 0.3	Irritating odor, soreness of eyes, and dryness of mouth, throat, and trachea in 1 of 7 subjects	None	*VC decreased in 3 of 7 subjects. *FRC decreased in 2 of 7 subjects. *DL_{CO} decreased 1 of 7 subjects.	All decreases in pulmonary function measurements were small. All subjects were smokers.
780	0.4	Discomfort and irritation in about 30 minutes	None	None	–
920	0.47	Distinct irritation of mucous membranes	None	None	–
1,840	0.94	Coughing, irritation, and exhaustion, within 1-1/2 hours	None	None	–
5,900	3.0	Sleepiness within 1 hour	None	None	–

(*) VC = Vital Capacity
FRC = Functional Residual Capacity
DLCO = Carbon Monoxide Diffusion

Source: National Air Pollution Control Administration - 1970

TABLE B-6

EFFECTS OF OZONE EXPOSURE - HUMANS

Ozone, $\mu g/m^3$	Ozone, ppm	Length of exposure	No. of subjects	Subjective complaints	Measurements of pulmonary function	Other comments
9,800 to 19,600	5 to 10	Not available	3 male	Drowsiness, headache	None	Measurement of O_3 probably inaccurate
2,940 to 3,920	1.5 to 2	2 hours	1 male	C.N.S. depression, lack of coordination, chest pain, cough for 2 days, tiredness for 2 weeks	VC: decreased 13%, returned to normal in 22 hours, $FEV_{3.0}$: decreased 16.8%, slightly below normal after 22 hours;	—
390	0.2	3 hr/day, 6 days/wk, for 12 wk	6 male	None	VC: no change $FEV_{1.0}$ no change	0.66 upper respiratory infections/person in 12 weeks - Cf. control group had 0.95 in the same period
980	0.5	3 hr/day, 6 days/wk, for 12 wk	6 male	No irritating symptoms but could detect ozone by smell	VC: slight decrease but not significant; $FEV_{1.0}$: significant decrease toward end of 12 weeks. Returned to normal during 6 weeks after exposure.	0.80 upper respiratory infections/person in 12 weeks
1,180 to 1,570	0.6-0.8	2 hours	11: 10 male, 1 female.	Substernal [illegible] and tracheal irritation 6-12 hours after exposure, disappearing within 12-24 hours in 10/11 subjects	DL_{CO}: mean decrease of 25% (11/11 subjects); VC: mean decrease of 10% which was significant (10/10 subjects); $FEV_{0.75} \times 40$: mean decrease of [illegible]% which was significant (10/10 subjects); MMFR: mean decrease of 15% which was not significant; Mixing efficiency: no change (2/2 subjects); Airway resistance: slight increase but within normal limits; Dynamic compliance: no change (2/2 subjects).	
up to 7,800	up to 4.0	10-30 minutes	11	Headache, shortness of breath, lasting more than 1 hour	VC: mean decrease 16.5% (4/8 subjects showed decrease >10%). $FEV_{1.0}$: mean decrease 20% (5/8 subjects showed decrease >10%); MMFR: mean decrease 10.5% (5/6 subjects showed a decrease); MBC: mean decrease 12% (5/8 subjects showed a decrease); DL_{CO}: decreased 20-50% in 7/11 subjects, increased 10-50% in 4/11 subjects.	Only 5/11 tolerated dose for full 30 mins. Wide variation in DL_{CO}.
200	0.1	1 hour	4 male		Airway resistance: mean increase 3.3% at 0 hours after exposure (1/4 subjects showed an increase of 45%);	One subject had history of asthma, and experienced hemoptysis 2 days after 1 ppm.
780	0.4	1 hour	4 male	Odor	Airway resistance: mean increase 3.5% at 0 hours after exposure (1/4 subjects showed an increase of 60%), mean increase 12.6% 1 hour after exposure;	
1,180	0.6	1 hour	4 male	Odor	Airway resistance: mean increase 5.8% at 0 hours after exposure (1/4 subjects showed an increase of 75%), mean increase 5% 1 hour after exposure;	
1,960	1.0	1 hour	4 male	Throat irritation and cough	Airway resistance: mean increase 19.3% at 0 hours after exposure (3/4 subjects showed an increase of > 20%); mean increase 9% 1 hour after exposure.	

TABLE B-6 (Continued)

EFFECTS OF SHORT-TERM NO_2 EXPOSURE - HUMANS

Effect	NO_2 Concentration mg/m^3	ppm	Time to Effect
Odor threshold	0.23	0.12	Immediate
	0.23	0.12	Immediate
Threshold for dark adaptation	0.14	0.075	Not reported
	0.50	0.26	Not reported
Increased airway resistance	1.3-3.8	0.7-2.0	20 min
	3.0-3.8	1.6-2.0	15 min
	2.8	1.5	45 min
	3.8	2.0	45 min
	5.6	3.0	45 min
	7.5-9.4	4.0-5.0	40 min
	9.4	5.0	15 min
	11.3-75.2	6.0-40.0	5 min
	13.2-31.8	7.0-17.0	10 min
Decreased pulmonary diffusing capacity	7.5-9.4	4.0-5.0	15 min
Increased alveolar-arterial pO_2 difference	9.4	5.0	25 min
No change in sputum histamine concentration	0.9-6.6	0.5-3.0	45 min

Source: National Academy of Science, 1970a.

TABLE B-7

EFFECT OF PHOTOCHEMICAL OXIDANT EXPOSURE - ANIMALS

Oxidant, $\mu g/m^3$	Oxidant, ppm	Source	Length of exposure	Observed effect(s)	Species
				Local effects	
				Short-term exposures	
> 240	> 0.12	Irr. auto exhaust	4 hours	Increased mortality from streptococcal pneumonia.	Mice
650 to 1,610	0.33-0.82	Irr. auto exhaust	4 hours	Increased expiratory flow resistance~20 to 120%, increased inspiratory flow resistance - 40%. Decreased respiratory frequency - 15-35%.	Guinea pigs
> 780	> 0.4	Smog	2-3 hours	Alveolar tissue changes in animals aged 9 months or over. Increased severity with age. Damage at 9 months reversible, at 21 months irreversible. Disruption of epithelial walls; cytoplasmic fragments and proteinaceous material in alveoli.	Mice
				Long-term exposures	
> 980	> 0.5	Smog	Continuous	Increase in flow resistance (increase also occurred at lower oxidant levels).	Guinea pigs
1,960 to 7,470	1.0-3.8	Ozonized gasoline	Continuous	Increased frequency of lung tumors seen after 24 weeks	Mice
				Systemic effects	
				Short-term exposures	
650 to 1,610	0.33-0.82	Irr. auto exhaust	6 hours	8 to 80% decrease in spontaneous running activity.	Mice
				Long-term exposures	
200 to 980	0.1 - 0.5	Irr. auto exhaust	16 hour day/46 days	Decrease in fertility. Doubling of non-pregnancy average.	Mice
390 to 1,960	0.2-1.0 (inlet)	Auto exhaust	Continuous	Stress adaptation response, i.e. reduction in spontaneous running activity returning to pre-exposure levels.	Mice
590 to 1,960	0.3 - 1.0	Irr. auto exhaust	16 hour day/46 days	Increased neonatal mortality due to preconditioning of males.	Mice

Source: National Air Pollution Control Administration, 1970.

TABLE B-8

METAL CONTENT IN CRUDE OILS

	Concentration Range (ppm)	*Mean or Median Concentration (ppm)*
Antimony	0.030-0.107	0.055 ± 0.003
Arsenic	0.046-1.11	0.263 ± 0.007
Barium	Small amounts in Texas crudes	--
Cadmium	--	0.03
Chromium	0.0016-0.017	0.008 ± 0.003
Cobalt	0.032-12.751	1.71 ± 0.11
Copper	0.13-6.33	1.32 ± 0.01
Iron	3.365-120.84	40.67 ± 2.48
Lead	0.17-0.31	0.24
Manganese	0.63-2.54	1.17 ± 0.04
Mercury	0.023-30	3.24 ± 0.01
Molybdenum	0.008-0.053	0.031
Nickel	49.1-344.5	165.8 ± 7.1
Selenium	0.026-1.396	0.53 ± 0.044
Silver	Traces in many crudes	--
Tin	Identified in Mexican crudes	--
Vanadium	4.0-298.5	88.55 ± 0.42
Zinc	3.571-85.80	29.80 ± 1.27

References: Shah, K.R., R.H. Filby, and W.A. Haller, J. Radioanal. Chem., 6, 185, 4B (1970).

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TABLE B-9

Physiological Effects of Metals Found in Petroleum Products

Metal	Human Effects	Animal Effects	Plant Effects	Toxicity Data
Antimony	Dermatitis, keratitis, conjunctivitis, and nasal septum ulceration by contact fumes or dust.	Shortens lifespan when fed to rats and mice. Sb oxide caused pneumonitis and heart and liver damage.	--	$\geq$0.1 g lethal oral dose in humans.
Arsenic	Dermatitis, bronchitis, skin cancer. Damages the heart, kidney, nerves, and possibly the liver. GI symptoms in acute systemic poisoning.	Counteracts the toxic effects of Se in rats and chickens. As (V) is nontoxic. Morphol. changes in blood; kidney damage.	0.1 ppm AsO_2 reduces heterotrophic activity of freshwater microflora.	Normal ingestion 0.1 mg/day. Toxic level 5-50 mg/day. Smallest fatal dose recorded 130 mg.
Barium	Baritosis, a benign pneumoconiosis. Soluble salts highly toxic orally. Soluble salts are skin and mucous membrane irritants.	Full strength Ba lubricant dispersant is a mild eye irritant. BaO and $BaCO_3$ caused paralysis.	Poisonous to most plants. 0.1 ppm Ba^{2+} reduces heterotrophic activity of freshwater micro-flora.	LD_{50} diesel exhaust solids 10 g/kg (animals). LD_{50} (oral) Ba sulfonates, 3-10 g/kg. LD_{50} (oral) Ba phenolates 4-5 g/kg. Fatal dose in humans $\geq$0.55 g $BaCL_2$.
Boron	Therapeutic use of H_3BO_3 and borax has caused fatalities. CNS depressant and GI irritant. Boranes highly toxic. Cumulative poison.	2,500 mg/liter in drinking water inhibited animal growth.	0.5-1.0 ppm in soil required for growth of fruit trees. 2.0 ppm possibly toxic. Prevents pitting of apples. Most B fertilizer used on alfalfa.	H_3BO_3 fatal dose in adults 15-20 g and in infants 5-6 g.

TABLE B-9 (Continued)

Metal	Human Effects	Animal Effects	Plant Effects	Toxicity Data
Cadmium	Cumulative poison. Pulmonary emphesema, hypertension, kidney damage. Cardiovascular disease. Interferes with Zn and Cu metabolism. Inhalation of 0.03-35 mg/m³ significantly reduced children's weight. GI symptoms.	1 ppm present in many plant and animal tissues. Caries, anemia, and retarded growth in rats. Maximum concentration in earthworms near a highway, 115 ppm.	Stunts growth of lettuce, radish, bean and turnip plants. Tomatoes, barley and cabbage more tolerant. Leaves accumulative excessive amounts when solutions contain a few tenths μg/ml.	LD (oral) for rabbits 200-600 mg. LD_{50} CdO fume 500 mg/m³ for rats to 1,500 mg/m³ for monkeys.
Chromium	Dermatitis, ulceration of skin, perforation of nasal septum, chronic catarrh, emphysema, carcinogenesis when inhaled. Cr(VI) extremely toxic Not cumulative. Apparently essential in glucose metabolism.	100 ppm recommended limit for fisheries.	5 ppm recommended limit for irrigation water. Soils containing 0.2-0.4% Cr are infertile. Toxic to some aerobic microbes at ppb level A micronutrient.	Normal ingestion 0.05 mg/day. Toxic level 200 mg/day. No ill effects from well water with 1.0-25.0 mg/liter. LD (oral) K chromate in rabbits 1.9 g within 2 hr.
Cobalt	Goitrogenic. Lung effects disputed. Dermatitis. No injury from $Co_2(CO)_8$. Affects heart and GI tract. ~7μg/day beneficial. Liver and kidney damage.	Essential nutrient. Polycythemia. Bone hyperplasia. Meta plasia in spleen, liver and kidneys. Hyperglycemia due to reversible pancreatic damage.	Essentiality not established.	Normal ingestion 0.002 mg/day; toxic level 500 mg/day. Co metal dust more toxic than salts in lung irritation; lethal dose of either relatively high. LD $Co_2(CO)_8$ in animals by inhalation 100 ppm.

TABLE B-9 (Continued)

Metal	Human Effects	Animal Effects	Plant Effects	Toxicity Data
Copper	Antagonistic to Zn toxicity. Not cumulative. Require 1-2 mg/day. Inhalation of Cu-contg. dust causes lung and GI disturbances. Affects erythrocytes and liver. Skin and mucous membrane irritants.	Ingestion or inhalation caused hemochromatosis and lung and liver injury. Limits: irrigation water, saltwater organisms, and freshwater organisms, 0.1, 0.05, and 0.02 ppm, respectively.	A micronutrient. Toxic to some aerobic microbes at ppb level. 0.05 M Cu^{2+} inhibits root growth and 0.1 M stops germination of lettuce.	Normal ingestion 2-5 mg/day; 65-130 mg CuSO4 dangerous and 648-972 mg highly toxic. 27 g $CuSO_4$ fatal.
Iron	Siderosis (a pneumoconiosis due to Fe inhalation).	--	A micronutrient.	--
Lead	Brain damage, convulsions, behavioral disorders, death.	Pb naphthenate kills rabbits by skin absorption (death due to pneumonia). Cumulative poison in vertebrates. Renal and vascular poison.	0.1 ppm Pb^{2+} reduces heterotrophic activity in microflora.	Oral toxicity of Pb naphthenate 3.5-5.1 g/kg. Normal Pb ingestion 0.4 mg/day.
Manganese	Chronic Mn poisoning and/or Mn pneumonitis. Reduces Fe absorption. Requirement 3-9 mg/day. Primarily a nerve toxin. CNS symptoms often result in permanent disability.	Pathological effects on nerve cells and the liver. 1.9-9.9 mg is thyroid inhibitor in rats.	A key role in photosynthesis.	

TABLE B-9 (Continued)

Metal	Human Effects	Animal Effects	Plant Effects	Toxicity Data
Mercury	Nerve damage and death.	Detrimental to aquatic ecosystems at 0.005 ppm.	0.1 ppm Hg^{2+} reduces heterotrophic activity of microflora.	Normal ingestion 0.005-0.2 mg/day; toxic level 10 mg/day.
Molybdenum	No indication of even an industrial hazard. Not cumulative.	Appears to have a reciprocal antagonism with Cu. Requirement in rats <0.5 mg/day. Low order of toxicity. No fatalities from molybdic oxide fumes for 25 one-hour exposures at 1.5 mg/ft^3 air. Toxic to ruminants when fed in excess.	Essential to higher plants. Possible role in photosynthesis.	Ingestion of <500 mg/day MoS_2 nontoxic to animals. 8.1 mg MoS_2/ft^3 nontoxic to guinea pigs. MoO_3 at 5.8 mg/ft^3 very irritating with high mortality. MoO_3 dust more toxic than fume.
Nickel	Rarely gives systemic toxic effects even from therapeutic doses (65-195 mg $NiSO_4$ and 324-454 mg $NiBr_2$). Dermatitis, respiratory disorder, carcinogenesis (nose and lung).	Moderately toxic to aquatic organisms. Maximum Ni concentration in earthworms near a highway 38 ppm Inhibits enzyme systems. Kidney damage (calf). 1-3 mg/kg Ni compound causes intestinal disorders, convulsions, and asphyxia in dogs.	Can be very toxic depending on its chemical form. A micronutrient. 0.01 ppm reduces the heterotrophic activity of freshwater microflora.	Normal ingestion 0.3-0.5 mg/day. 30-73 mg $NiSO_4$ $6H_2O$ toxic in humans.

TABLE B-9 (Continued)

Metal	Human Effects	Animal Effects	Plant Effects	Toxicity Data
Selenium	May cause caries. Prevents teratogenic effects of Cd and As. Affects kidneys, liver, marrow, and CNS. Se compounds are potent skin and mucous membrane irritants.	Carcinogenic in large doses in rats. Essential to mammals and chicks in low doses. Teratogenic in chicks. "Blind staggers" and "alkali disease" in cattle and "white muscle disease" in sheep.	2.5 mg/liter Se inhibits the BOD and growth of aquatic saprophytic microflora.	Industrial selenosis symptoms when Se in air <0.2 ppm. Liver damage in humans from 5-7 mg/liter in food. Liver cancer in animals from food containing 10 ppm Se. H_2Se and SeO_2 more toxic than S analogs. LD by inhalation of SeO_2 10 ppm for 2 hrs. Normal ingestion 0.2 mg/day; toxic level 5 mg/day. Extreme tolerance limit in food (dry weight) 20 ppm.
Silver	Argyria (impregnation of the tissues with Ag) following absorption from the GI tract or lung. I.V. injections of colloidal Ag fatal.	Affects immunological capacity. Histopathological changes in tissues of encephalon and medulla of rabbits.	0.0001 ppm Ag^+ reduces the heterotrophic activity of microflora.	
Tin	Little absorbed when ingested. Affects GI tract and CNS. Sn oxide dust produces benign pneumoconiosis. Ingestion of organotin compounds causes acute cerebral edema and often death.	Decreases longevity slightly when fed to rats and mice for life.	Toxic to some aerobic microbes at ppb levels.	500 mg/kg/day of $SnCl_2$ for 14 months paralyzed a dog. LD_{50} (i.v.) R_2SnCl_2 (where $R=<C_8$ alkyl) 5-40 mg/kg rats. Trialkyltin salts are more toxic.

TABLE B-9 (Continued)

Metal	Human Effects	Animal Effects	Plant Effects	Toxicity Data
Vanadium	Cardiovascular disease, carcinogenesis. Main toxic effects on respiratory system. V_2O_5 residues from fuels irritating to those who clean oil-fired burners, renew firebrick linings, and clean heat-exchanger tubes (dusts contain 6-20% V).	Feeding 5 mg/liter V^{4+} for life to rats gave no significant reduction in growth or longevity. Not carcinogenic in rats and mice.	Essential for green algae. Stimulates higher green plants in small amounts.	10 mg/kg fatal to rat. Sublethal doses 92-368 ppm. 49 μg/ml drinking water highly toxic. 0.205 mg/liter causes lung changes in animals. LD (i.v.) in humans 30 mg V_2O_5 as tetravanadate.
Zinc	Dermatitis, hypertension, arteriosclerotic and heart diseases. 675-2,280 mg/liter is emetic. Causes mineral loss from bones. Most Zn compounds not particularly toxic at moderate concentrations orally. Zn inhibits the teratogenic, embryocidal, and neo-plastic effects of Cd. Essential.	Zn dithiophosphates are severe eye irritants. 0.1-1.0 ppm lethal to fish and other aquatic animals.	Essential. 0.1 ppm Zn^{2+} reduces heterotrophic activity of microflora.	LD_{50} (oral) Zn dithiophosphates 2.13-3.7 g/kg. LD_{50} (skin) 11.3 g/kg for rabbits (24-hr contact). Mixed Mg-Zn phenolate LD_{50} (oral) 9.5 mg/kg. LD_{50} (oral) $ZnCl_2$ in guinea pigs, rats, and mice 200-350 mg/ kg. Normal ingestion Zn 10-15 mg/day.

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Pier End Platform Study

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Pier End Platform Study

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INTRODUCTION

Tankers are being built increasingly larger in recent years. They require more room to maneuver and supply greater cargo capacities than ever before. This places increasing demands on waterways and adjacent structures such as offshore mooring facilities, bridges, docks, harbors, piers, marinas, lock and port entrances.

Tankers built during the early part of this century had an overall length of about 90 to 150 meters and displacements as light as 5,000 long tons. Currently, tankers are being built longer than 300 meters with displacements of more than 400,000 long tons. In addition, the velocities these vessels can attain also have increased. Because of these increases in size and speed, the forces which can be delivered to structures adjacent to the waterway have increased substantially.

Coast Guard casualty statistics show that vessel collisions with fixed objects have been on the uprise. Further, with the decontrol of domestic oil and gas pricing, the demand for offshore oil and gas rigs as well as offshore mooring facilities will rise. Obviously, such factors indicate that a need exists to assure that proper design practices are used for fendering system installation on any bulk oil handling facility. Thus, the proper protective system not only safeguards the facility but the vessel and the marine environment at the same time.

In carrying out our investigation, we sought to design the offloading facility in such a way as to mitigate the risk of oil spills caused by impact between the approaching tanker and the facility.

FACTORS CONSIDERED IN THE DESIGN

The function of fendering systems is to protect marine structures (whether they be mooring facilities, bridge elements or whatever) from damage by waterborne traffic. There are many factors to be considered in the design of protective systems including the size, contours, speed and direction of approach of the vessel using the facility; the wind and tidal current conditions expected during the vessel's maneuvers and while tied up to the mooring facility; and the rigidity and energy absorbing characteristics of the fender system and vessel. The final design selected for the fender system will generally evolve after reviewing the relative costs of initial construction of the fendering systems versus the cost of fender maintenance and of ship repair. In other words, it will become necessary to decide upon the most severe docking or approach conditions to protect against and design accordingly. Hence, any situation which imposes conditions which are more critical than the established maximum would be considered in the realm of accidents and probably result in damage to the facility, fendering system or the vessel.

In this study, an additional factor considered was the vessel's cargo of crude oil. Every effort was made to insure that crude oil would not enter the marine environment as a result of the mooring operation. All design decisions were made on the conservative side to decrease the potential for a spill.

COMPUTER PROGRAM

Based upon the theoretical considerations as described in Appendix A, a computer program was written on the UNIVAC 1108 computer in the Fortran IV language. The program has the capability of designing or analyzing any given protective system and/or device. These include fenders, dolphins, cells, platform structures, and a variety of associated devices.

The basic theory utilized in a protective device system consists of several sub-systems. One sub-system consists of complete interaction of the supporting piling systems, which includes any number of piles (one on up), pile types (pipe, H-piles, wide flanges, or timber), and soil characteristics. The other sub-system is the system, supports, fenders (if applicable) and any applicable connecting beams. The entire system then is examined under the impact of the vessel, at any attack angle. At any instant, the piling is examined for a failure mode. When a given pile fails, the system is automatically modified and the dynamic analysis is continued. This process is continued until the vessel stops or all the energy is consumed; i.e., failure of the pile or piles. At each instant of a pile failure, the resulting forces and stresses on this failed pile are listed.

Inputs consist of the size (tonnage), contours, speed and direction of approach of the vessel, rigidity and energy absorbing characteristics of the protective system and of the vessel, the soil parameters, and finally the geometry and size of the protective system and the materials used.

Output includes the velocity of the vessel at any instant and the load deformation of the protection. Further, it gives the energy absorbed by the protective system and the vessel at any distance.

The results then are interpreted as to whether the protective system is adequate for a given condition or whether it is over or under designed. The given condition in the case of an oil handling facility is to prevent spills caused by an impact between a tanker and the facility.

PIER-END PLATFORM PROTECTIVE SYSTEM

Introduction:

An innovative dock fendering system, "the floating donut" is a new approach to the design of mooring (breasting) dolphins which can provide for the safe and economical berthing of vessels.

Energy of a vessel's berthing is absorbed both by deflection of the steel piling and compression of the closed-cell foam fendering material of the donut. This design permits a large amount of energy to be absorbed with low reaction forces. In some cases, 75 percent of the energy is absorbed by the combination of the steel pile and floating donut while 25 percent is absorbed by the vessel upon impact.

Prior to this innovative design, it was common practice to accept the idea that fendering systems provided little contact area. Thus, the reactive force was one of a point load effect easily puncturing the hull of a vessel. The floating donut system deflects approximately 75 percent of its diameter allowing tremendous contact area to distribute the pressure evenly over the hull of the vessel thus avoiding punctures.

The simplicity of the pile donut system gives it several specific advantages. Since the system only requires the driving of piles and installing the fenders over the pilings, terminal installations can be completed quickly, even in remote areas where construction equipment is limited. Because the fender is free to rotate about the pile, it reduces shear forces on both the ship and pile. Further, the floating donut can rise and fall with the water level, making it ideally suited for use on rivers and in areas of large tidal variations.

In addition, the large cushion area of the donut keeps vessel hull pressures less than 6 $kips/ft^2$ which large vessels typically can withstand. Thus, this advantage prevents oil spills as punctured hulls are unlikely.

A typical end of pier protection device is shown in Figure 1.

General:

The purpose of a pier-end platform fendering system is to decelerate the mass of a berthing vessel without damaging the vessel's hull or the platform. The fendering system therefore must distribute the reaction force acting on the vessel over a suitable area and either store or dissipate the vessel's energy by deflecting in some way. Therefore, a fendering system must consist of several elements.

The first element is a fixed reference upon which the fender system is mounted. A riverbed or the seafloor may constitute this element. All forces exerted on the system are transmitted to this point of fixture.

The second element is a spring which can store the energy of a vessel as it deflects the fendering system. A flexible steel pile which acts as a cantilever spring is used as this element in the floating donut fender system.

One more element must exist to complete a fendering system. That element is a damper, or means for dissipating the energy stored by the fendering system. Fortunately, hydrodynamics ultimately takes care of this task. A vessel moving sideways rapidly dissipates the energy associated with its motion. After a berthing vessel has stopped and the fenders are deflected, they exert a force on the

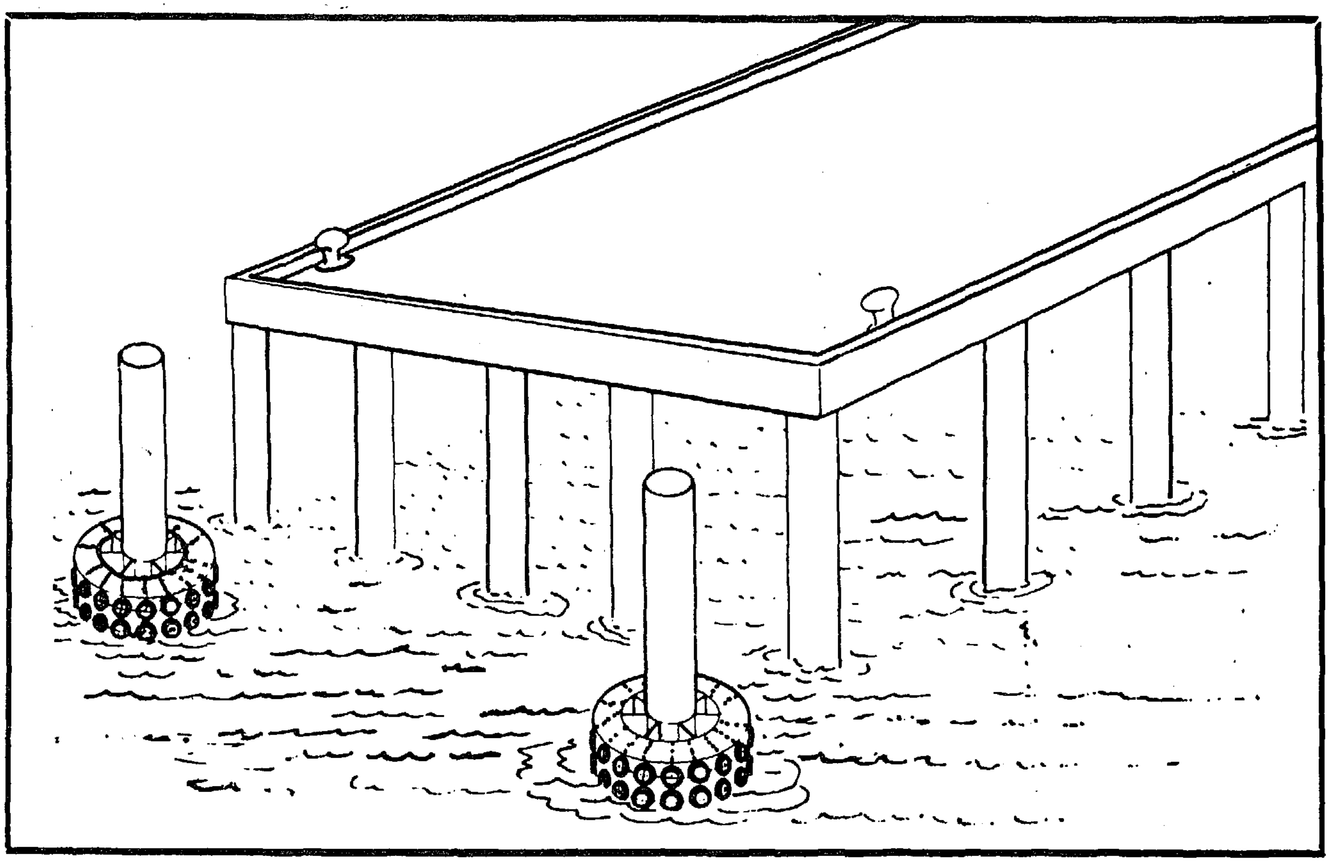


Fig. 1: Typical Protective Set up for Pier

vessel which begins to accelerate it away from the dock. Viscous drag prevents the ship from reaching a velocity equal to that of its initial berthing, and the vessel will ultimately come to rest. It is possible to add additional damping as a part of a fendering system. For example, a fender constructed of closed-cell foam, such as the donut, acts as both a spring and a damper which dissipates energy with each compression cycle, thus lessening risk of hull puncture.

When considering the design of a berth, the dolphin concept has some appeal over a more rigid pier or dock. Dolphins are simpler and generally more economical. Still more important, the dolphins act as both a fixed element (at their bottom end) and a spring element, but the pile must be equipped with a fendering means. The requirements of this fendering means are:

1. To protect the pile-donut and the vessel's hull by : distributing the load on the hull, preventing shock loads on the system, and maintaining standoff so the pile and hull do not contact.
2. Ideally, to share the energy absorption with the pile.
3. To protect the pile over its working length (a function of the change in water level).

A typical detail schematic of the floating donut is shown in Figure 2 and the fender donut design criteria are shown in Appendix B. The results are shown in Table 1: Comparison of Fendering Donuts.

It should be pointed out further that in utilizing the above mentioned design (Appendix B) the average hull pressure would be 5.74 kips/ft^2. This value is well below the pressure values a

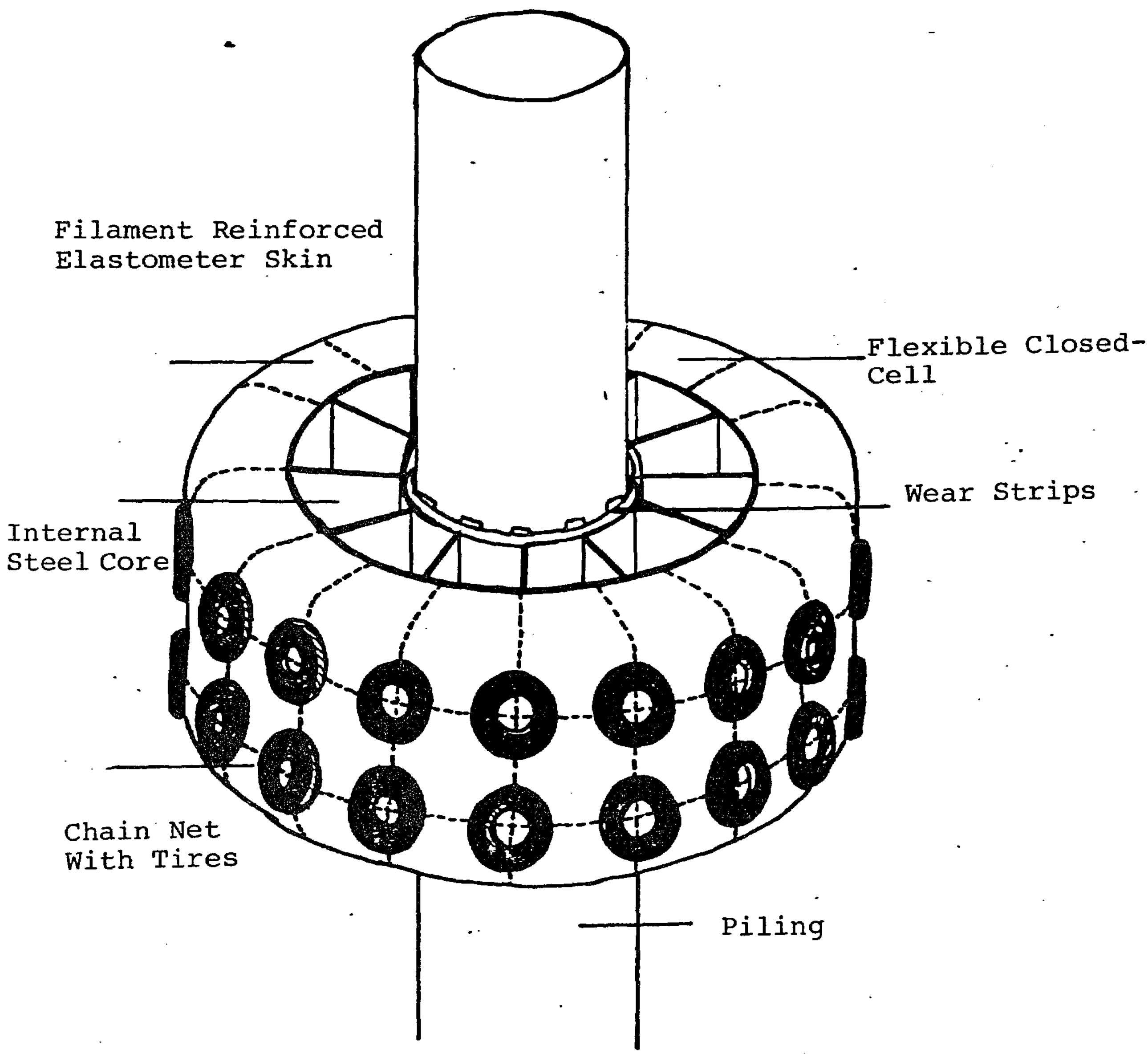


Fig. 2: Donut Details

TABLE 1: Comparison of Fendering Donuts

Item	Cantilever Length			
	75'	80'	85'	90'
F_f (reaction force)	249.82 K	234.00 K	220.00 K	208.00 K
E_p (energy absorbed by pile)	115.30 K-ft	123.00 K-ft	131.00 K-ft	138.00 K-ft
E_f (energy absorbed by donut)	164.20 K-ft	156.50 K-ft	148.00 K-ft	141.00 K-ft
d_o (outside diameter)	12.78 ft	13.00 ft	13.08 ft	13.18 ft
h (height of donut)	5.13 ft	5.04 ft	4.41 ft	4.14 ft
d_i (inside diameter)	8.48 ft	8.63 ft	8.68 ft	8.75 ft
pressure	5.74 K/ft^2	5.74 K/ft^2	5.74 K/ft^2	5.74 K/ft^2
F (force)	550 K	499 K	456 K	418 K
M (moment)	400,000 K-in	479,000 K-in	465,000 K-in	451,000 K-in
f (stress)	26.42 Ksi	25.56 Ksi	24.82 Ksi	24.07 Ksi

tanker can handle. Thus, puncture or damage to the tanker's hull is very unlikely, reducing the risk of an oil spill caused by the mooring operation.

COMPUTER ANALYSIS RESULTS

General Pile and Fendering Donut Results:

Obviously, the pile and fendering donut design was analyzed and redesigned several times before the final design was selected. (That is, to utilize a 6.5 foot pipe pile with a 1 inch thick wall). Once the pipe pile size was chosen, then it became a matter of trial and error to determine the size of the fendering donut. The entire system; pipe pile and fendering donut was programmed to complete the analysis. In this case, the pipe pile was assumed to be a protective cell with a fender attached. In this situation, the program is set up only to provide output that contains stopping time, maximum deflection, hull pressure, and stress on the pile. The results are tabulated in Table 2: Results of Pile and Donut Design.

In the above analysis, the cantilever length (length from the soil to the free end of the pile) was chosen as 80 feet with a mudline length (length from the river bottom down through the soil to bedrock) of 40 feet and a soil subgrade modulus of 86 kips per cubic foot (a poor soil).

Platform Construction:

Figure 3 shows a typical cap plan of a platform structure that has been built and utilized in other offshore berthing situations and will be used in this facility. The platform is 60 feet by 64 feet consisting of a 4 foot thick concrete cap supported by 34-4 foot round concrete piles which are 120 feet in length. The cantilever length of the pile is assumed to equal 80 feet. The piles are spaced at eight feet, in groups of seven, six, and four units. No fender is

TABLE 2: Results of Pile and Donut Design

Vessel Size	Velocity	Stopping Time	Maximum Defl.	Hull Pressure	Stress
200,000 DWT	0.25 knots	8.45 seconds	24.5 inches	4.5 kips/ft^2	21 ksi
250,000 DWT	0.25 knots	12.66 seconds	31.7 inches	4.7 kips/ft^2	24 ksi
300,000 DWT	0.25 knots	17.01 seconds	41.0 inches	5.2 kips/ft^2	29 ksi

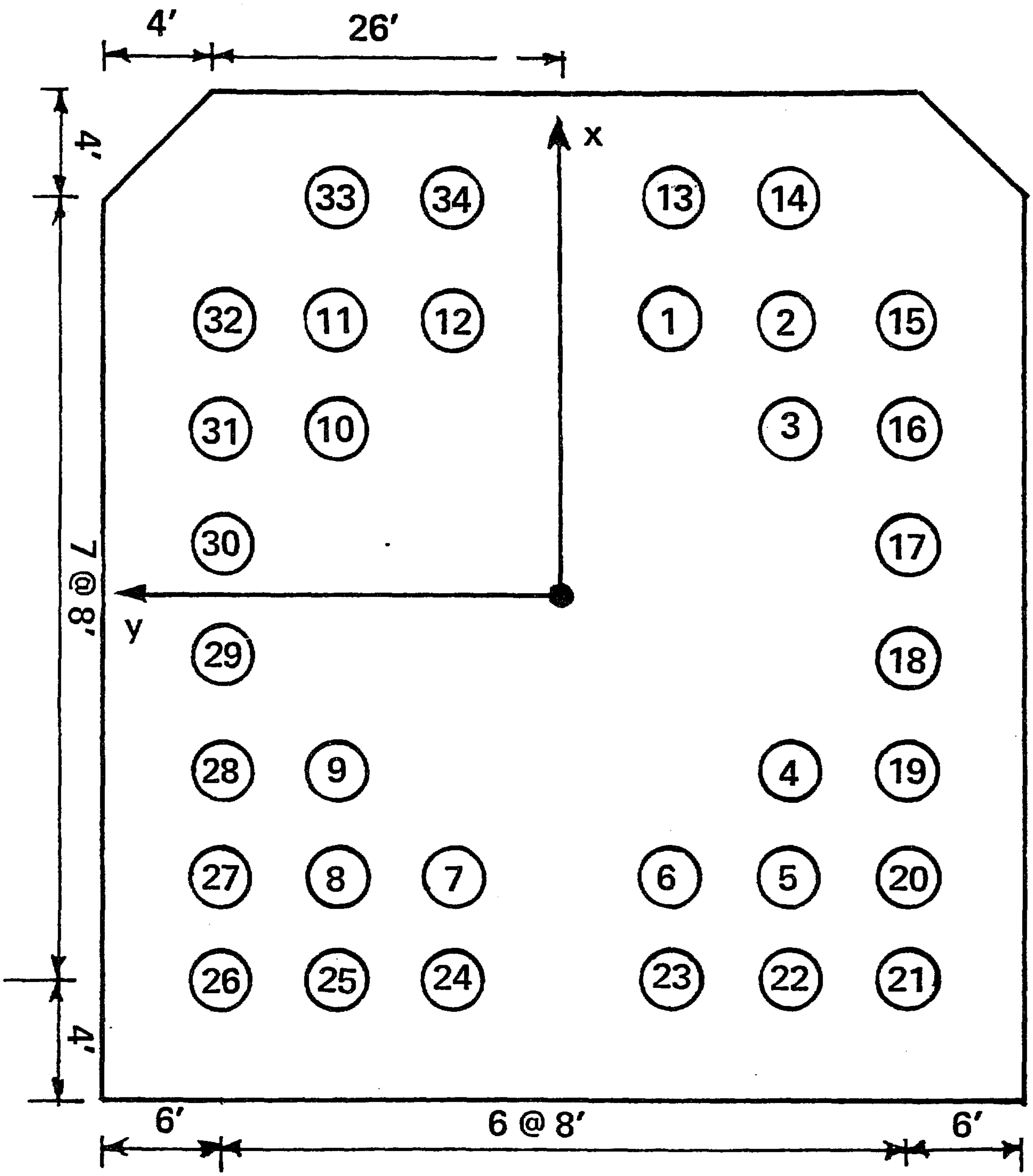


Fig. 3: Cap Plan

attached to the concrete cap.

Computer Modeling of Platform Structure (Input):

In the utilization of the computer program, the platform structure will be assumed to act as a rigid cap attached to the top of the piles. This assumption is reasonable considering the mass and rigidity of the cap. As shown in Figure 3, each pile is assigned a number such that it may be examined independently after a computer run.

The basic input data, for the modeled platform and vessel characteristics used in the computer program are shown in Table 3.

Computer Modeling of Platform Structure (Output):

The time to stop the 250,000 DWT vessel at a velocity of 0.3 knots is 0.42 seconds. The induced forces from time zero to 0.42 seconds have been evaluated at nine time intervals. For each of these intervals, the forces (Moment and Shear) and deformations along each of the 34 piles have been determined. A summary of the dynamic data and energy of the system is given in Table 4. A summary of the maximum forces and deformations is given in Table 5. Using these maximum moments and the section modulus of the 4 foot round section results in the maximum stresses given in Table 6. In Table 6, Stress 1 is for the unreinforced concrete piles and Stress 2 is for the reinforced concrete piles. Thus, assuming a maximum concrete compressive stress of 85 percent of the ultimate strength of concrete (f'_c) or for 5 ksi concrete gives a maximum stress of 4.25

ksi. This is less than those values given in Table 6 for the unreinforced concrete. This indicates the concrete requires reinforcement and this is verified by looking at the stress values for Stress 2 in Table 6. The amount of reinforcement can be determined by using the moment given in Table 5 as the design force.

TABLE 3

BASIC PROGRAM PARAMETERS

Weight of Ship = 250,000 Tons (560,000.00 Kips)
Velocity of Ship = 0.30 Knots
Length of Dolphin below ML = 40 feet
Mass of Ship = 1,450.51 Kips/in/sec/sec
Angle of Passive Failure = 0.500 feet
Dissipation Factor = 0.5000
Allowable Strain = 0.0300 in/in

Dynamic Results of Linear Springing

Max. Defl. at Point of Impact = 1.966 inches
Max. Ship Acceleration = 20.4894 in/sec**2
Max. Ship Force = 29,720.21 Kips
Stopping Time = 0.4658 Seconds
Initial Spring Constant = 16,494.34 K/in
Linear Lamba Factor = 3.3721 1/sec

TABLE 4

Dynamic and Energy Data

OUTPUT OF DYNAMIC DATA AT THE POINT OF IMPACT

TIME (SEC)	DEFL (IN)	VELOCITY (IN/SEC)	ACCELERATION (IN/SEC/SEC)	FORCE (K)	SPRING K (K/IN)
.0000	.00	6.08	.00	1.00	16494.34
.0466	.28	5.99	-3.76	5449.80	19347.87
.0932	.56	5.73	-7.41	10742.62	19347.87
.1397	.81	5.30	-10.84	15726.01	19347.87
.1863	1.05	4.73	-13.97	20256.44	19347.87
.2329	1.25	4.01	-16.69	24203.40	19347.87
.2795	1.42	3.18	-18.93	27453.22	19347.87
.3261	1.55	2.28	-20.82	29912.29	19347.87
.3727	1.63	1.28	-21.72	31509.77	19347.87
.4192	1.66	.29	-22.20	32199.65	19347.87

OUTPUT OF KINETIC AND POTENTIAL ENERGY FOR SYSTEM

TIME (SEC)	KINETIC ENERGY (IN-K)	POTENTIAL ENERGY (IN-K)	TOTAL PE + KE (IN--K)
.0000	26776.	0.	26776.
.0466	26010.	768.	26778.
.0932	23800.	2982.	26783.
.1397	20400.	6391.	26791.
.1863	16117.	10684.	26801.
.2329	11673.	15139.	26812.
.2795	7345.	19477.	26823.
.3261	3709.	23123.	26831.
.3727	980.	25858.	26838.
.4192	55.	26794.	26849.

TOTAL KINETIC ENERGY OF SHIP = 26776. K-IN
TOTAL POTENTIAL ENERGY OF DOLPHIN = 26794. K-IN
ERROR = -.07 PERCENT

MAXIMUM DEFLECTION AT ML = .107 INCHES

TABLE 5

Platform Analysis of Concrete Piling

Deflection Force Data

Time (Sec.)	Deflection (in)	Moment (K-in)	Shear (K)
.0466	0.28	20,189.	4,649.
.0932	0.56	46,649.	10,743.
.1397	0.81	68,288.	15,726.
.1863	1.05	87,961.	20,256.
.2329	1.25	105,100.	24,203.
.2795	1.42	119,212.	27,453.
.3261	1.55	129,891.	29,912.
.3727	1.63	136,828.	31,510.

TABLE 6

Stresses

Time (Sec.)	Modulus (In^3)	Stress 1* (Ksi)	Stress 2** (Ksi)
.0466	10,860.	1.86	0.50
.0932	10,860.	4.30	1.00
.1397	10,860.	6.29	1.66
.1863	10,860.	8.10	2.19
.2329	10,860.	9.68	2.44
.2795	10,860.	10.98	2.89
.3261	10,860.	11.96	3.04
.3727	10,860.	12.60	3.17
.4192	10,860.	12.88	3.33

* Unreinforced Concrete

** Reinforced Concrete

LAYOUT OF TERMINALS

Figures 4 and 4A show the general location and layout for the platform structure which might be located adjacent to the river end of Pier 14 in the Stapleton area of Staten Island, New York. Figures 5 and 5A show a similar platform structure for the site adjacent to the river end of Port Jersey between the Greenville Railroad Yards and the Military Ocean Terminal. Each of Figures 4A and 5A shows the location of the Sea Fence oil containment boom (as illustrated by the dotted lines) which costs $50,000 per foot and can be rolled into a storage deployment reel which costs $13,600. Figure 6 shows a schematic perspective of the mooring dolphins and unequipped platform structure.

These platform structures as shown are capable of handling an impact from a 250,000 DWT vessel traveling at a velocity of 3 knots. However, the normal berthing velocity would be 0.3 knots thus ensuring a greater factor of safety. In addition, the study parameters called for a channel depth of 60 feet and a pierside depth of 65 feet. The structure was to be capable of handling a 200,000 DWT tanker, fully laden, or up to a 260,000 DWT tanker partially laden to meet the depth restriction. In each of these cases, the deadweight tonnage would be less than that of the 250,000 DWT tanker used for design purposes. This provides an added safety factor.

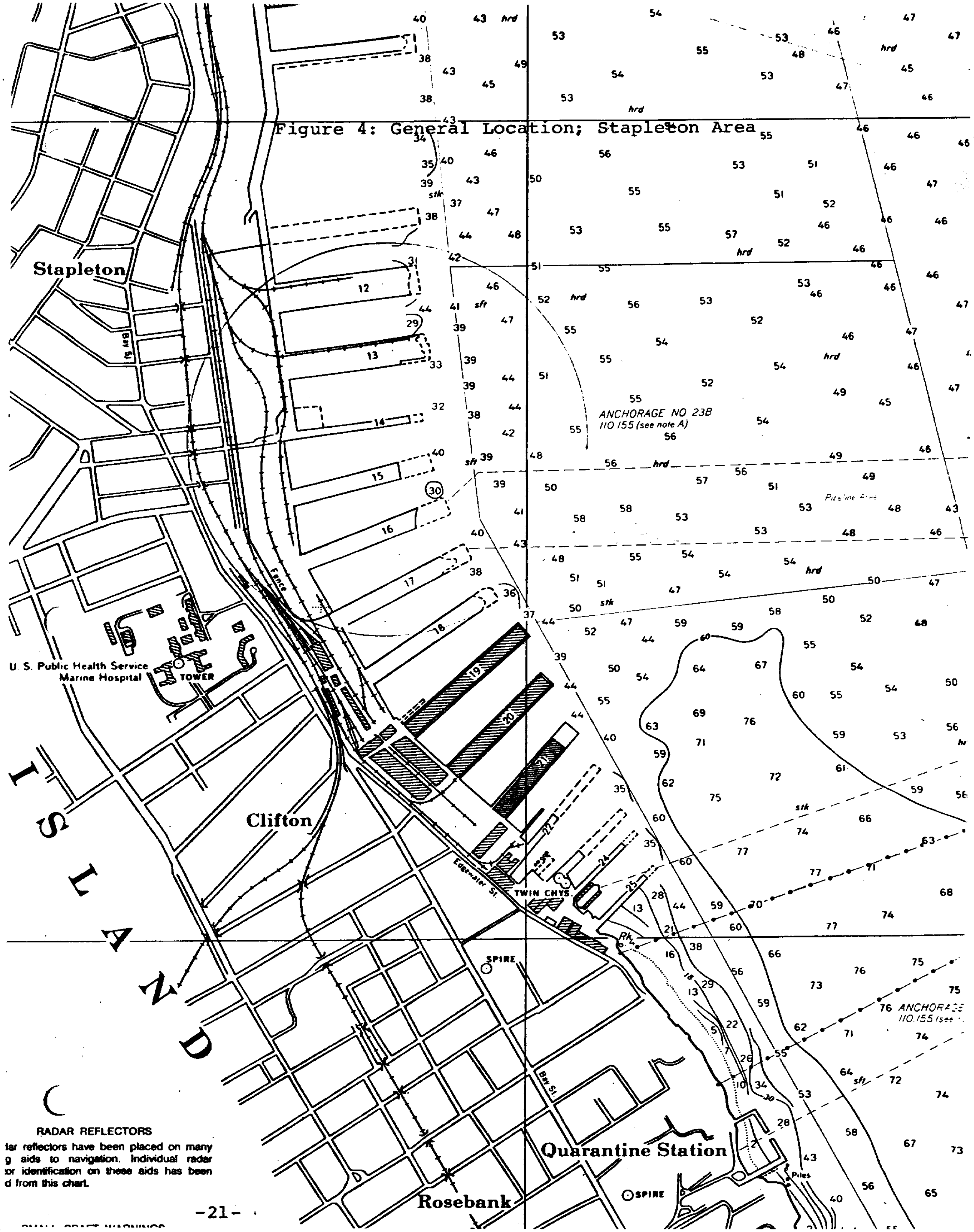
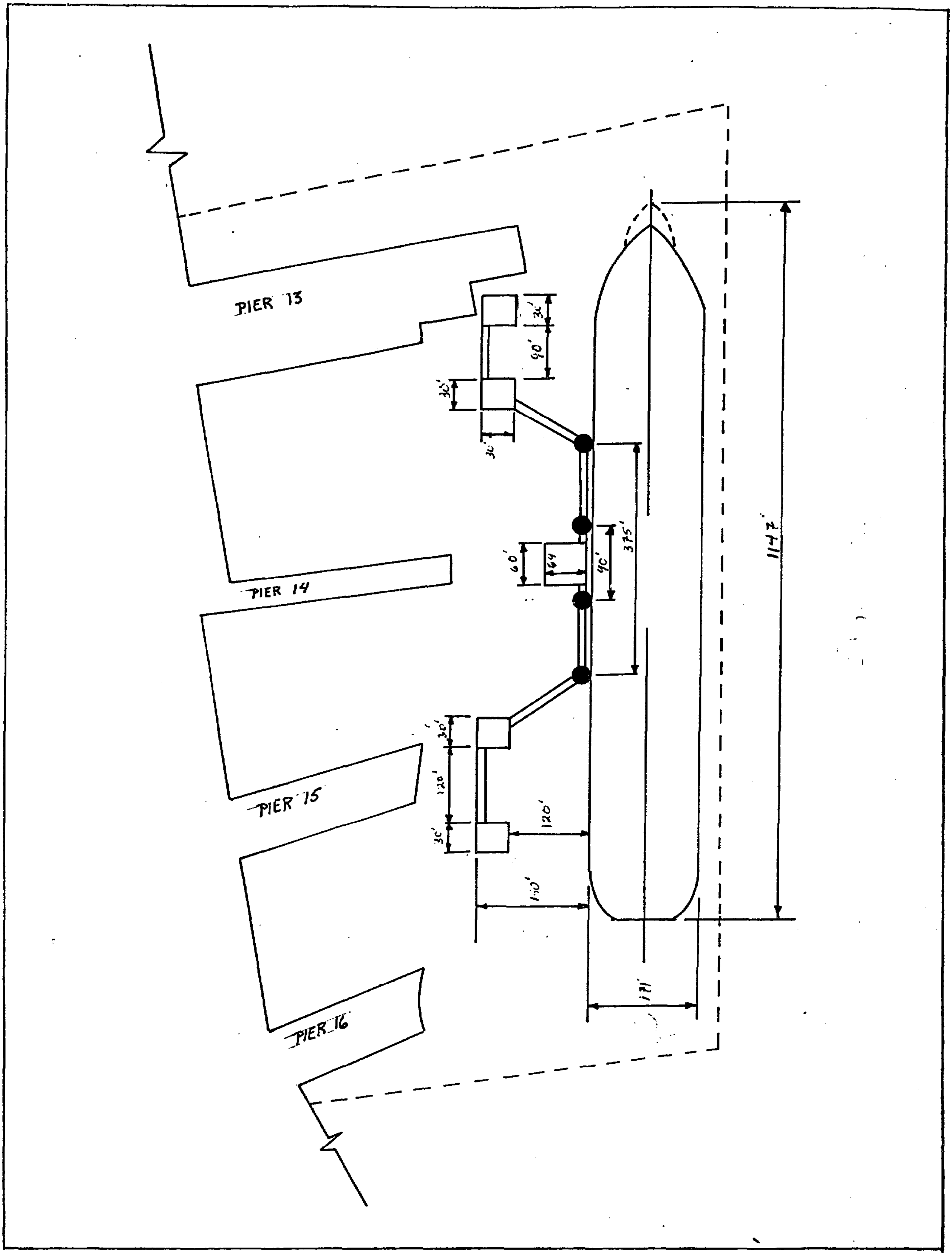


Figure 4: General Location; Stapleton Area


PIER 13
PIER 14
PIER 15
PIER 16
30'
90'
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30'
60'
64
90'
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120'
120'
30'
150'
171'

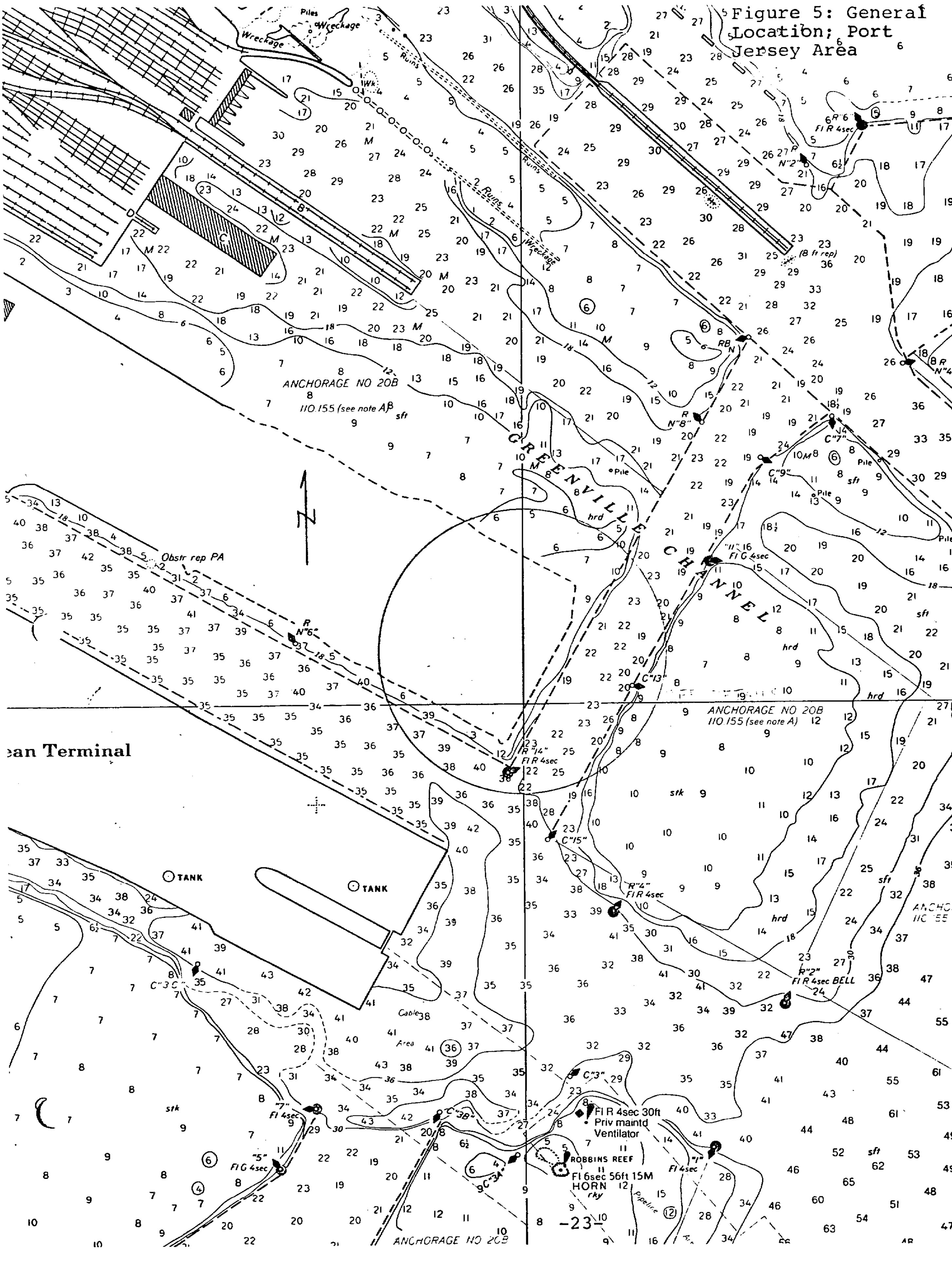

Figure 5: General Location; Port Jersey Area

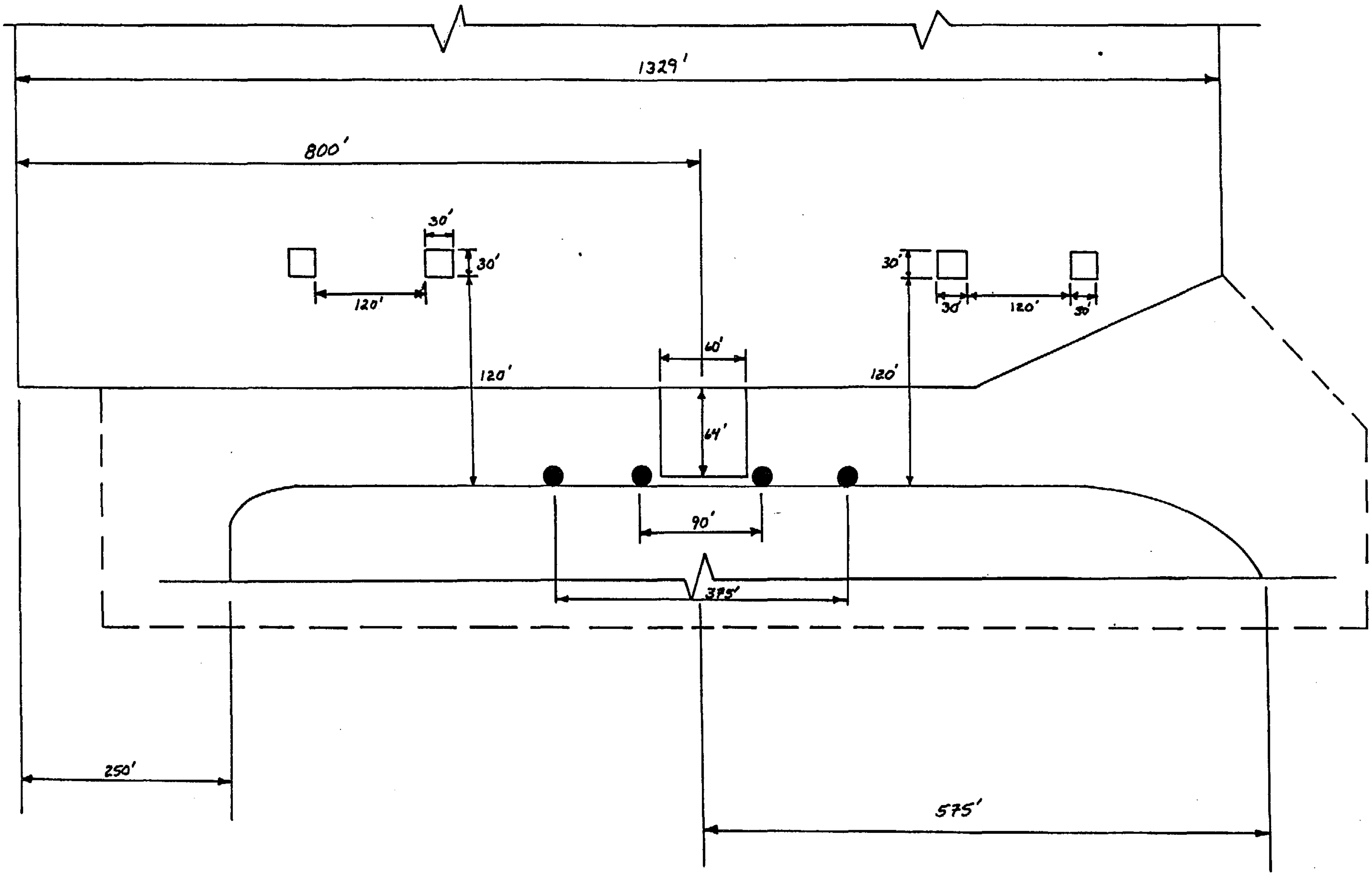

FIG. 5A

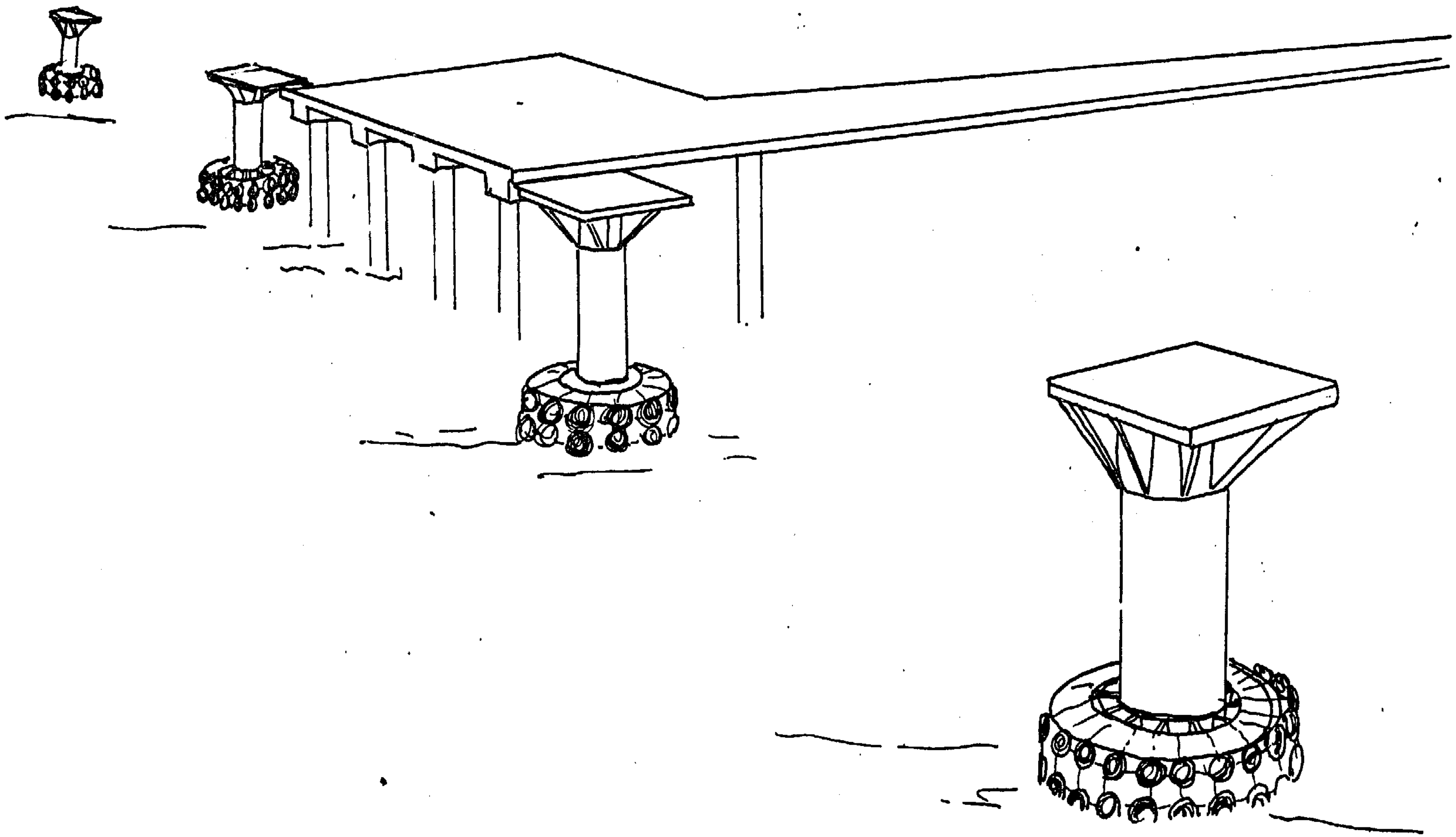

Figure 6

PRELIMINARY COST ESTIMATE FOR EITHER SITE

The cost estimate given herein is very, very rough as many variables do exist. However, the price does include purchase price, fabrication, and construction cost.

ITEM	UNIT	PRICE/UNIT	NO.	TOTAL
Fender Donuts	Each	$85,000	4	$340,000
Prepare and Drive Piles*	Lin.Ft.	$ 425	4	204,000
Test 1 Vertical Pile	Each	$28,000	1	28,000
Fabrication of Piles	Tons	$ 800	196	156,800
Piling Caps	Each	$10,500	4	42,000
Concrete Deck	Cu.Yd.	$ 370	450	166,500
Reinforcing Steel	Tons	$ 800	2	1,600
Concrete Piles	Cu.Yd.	$ 370	2000	740,000
Test Piles	Each	$20,000	5	100,000
Concrete Fill	Cu.Yd.	$ 370	600	222,000
Breasting Lines Platforms	Each	$200,000	4	800,000
			Total	$2,800,900

Price does not include drilling of anchor holes, boring holes, placing steel dowels, grouting rock anchor holes, testing rock anchor, any support systems on land, buildings, repair of existing pier if appropriate, monorails or quick release hooks, etc.

* The price of preparing and driving piles may vary as to whether they are diven, jetted, drilled or whatever. The length of each pile is 120 feet.

A FENDERING DEVICE FOR A SINGLE POINT MOORING BUOY

As part of this project, we considered the need for a fendering device for a single point mooring buoy system for off-loading oil tankers. The buoy was to be installed approximately 22 miles southeast of Atlantic City, N.J. in one hundred feet of water and was to be capable of handling up to a 300,000 DWT tanker; fully laden. A computer analysis was performed based upon parameters appropriate for such a system. It was found that no additional fendering protection was required beyond that provided by the installation method of the buoy itself. Therefore, no fendering system is recommended for a single point mooring buoy.

It is appropriate here to list some advantages of the platform structure as compared to the single point buoy. Conventional platform structures seem particularly advantageous when:

1. a location well sheltered from waves and currents and with easy access is available;
2. the direction of waves of period over eight seconds does not vary more than 30 degrees;
3. the currents have known directions and such directions do not vary more than 10 degrees for currents up to 2 knots;
4. the available area for maneuvering is very restricted;
5. <u>inspection, maintenance, and pollution risks are to be reduced to a minimum</u>.

PRELIMINARY VALUE ANALYSIS

A pier-end protective system has been designed for a platform structure to be located adjacent to the river end of the Stapleton area of New York or adjacent to the river end of Port Jersey between the Greenville Railroad Yards and the Military Ocean Terminal. The purpose of such a pier-end protective system is twofold. First, it serves to protect the platform structure from waterborne traffic (such as an oil tanker) and second, it protects the vessel from spilling its cargo into the marine environment.

In utilizing the design procedure as explained herein, the risk of oil spillage from contact between the tanker and the pier-end protective system has been greatly reduced. One of the design parameters as outlined in this project called for the use of a 200,000 DWT vessel. However, in the design procedure, a 250,000 DWT vessel was utilized for conservative reasons; thus, further reducing the risk of oil spillage.

Examples exist in the literature where protective systems did not exist or were insufficient resulting in damage to the vessel, bridge, and/or marine environment. Locally, in 1977, the Union Avenue Bridge across the Passaic River in New Jersey was hit by an empty oil barge when the tow-rope to the tug snapped. The barge hit a pier at the navigation span. The pier was destroyed and one of the adjacent bridge spans fell down. In addition, the barge developed a crack. Thus, if the vessel had contained oil, a spill would have resulted.

Internationally, an oil tanker Al Fountas (209,000 DWT) in 1977 hit an oil pier at Wilhelmshaven, West Germany. The collision des-

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troyed 350 feet of pier with slight damage to the vessel and the marine environment.

In 1968, a 90,000 DWT tanker did 1.25 million pounds worth of damage in a frontal collision with an oil pier in Liverpool, England. The vessel was damaged and an oil spill occurred.

In all of the above cases as well as in hundreds of others, if the pier had been adequately designed and protected, the bridge and/or pier and the vessel would have sustained little if any damage and the probability of an oil spill would have been greatly reduced.

Appendix A

THEORY

General Techniques:

The general response of a piling system, when subjected to a vessel, is computed by removing the pile and examining its effect as a cantilever beam. The interaction of lateral elements, if appropriate, are usually neglected and thus a conservative design results.

Two general theoretical equations are used by the designer, and are based on force-acceleration and kinetic energy relationships.

Force Acceleration:

The induced or applied force to the system, caused by the ship's impact is;

$$F_a = M({v_i}^2 - {v_f}^2)/2\Delta_s \tag{1}$$

where:

M = Mass of ship

Δ_s = Deformation of system at point of impact

v_i, v_f = Initial and final velocity

The resisting force of the system is;

$$F_r = 3\Delta_s E(I/D.F.)/L^3 + \Sigma k\Delta_s \tag{2}$$

where:

E = Modulus of elasticity of pile

I = Inertia of pile

D.F. = Lateral distribution of load due to lateral stiffness or effect

L = Cantilever length of pile

k = Spring constant of fendering

The induced moment and stress are computed from;

$$M = F_a \times L \quad \text{and;} \tag{3}$$

$$f = M/(S/D.F.) \tag{4}$$

where:

f = Induced stress

S = Section modulus

In applying this method, the designer would assume an allowable Δ_s and initial stiffness I. If the resisting force $F_r > F_a$, then the actual Δ_s would be smaller than assumed. The induced stress f would be compared to the allowable or ultimate stress of the material.

Kinetic Energy:

The induced energy caused by the ship is given by:

$$E_{in} = \frac{1}{2} Mv_{in}^2 (C_H)(C_s)(C_c)(C_E) \tag{5}$$

where:

v_{in} = Initial velocity

C_H = Hydrodynamic coefficient = $1 + \frac{2D}{B}$

where:

D = Draft of ship

B = Beam of ship

C_s = Softness coefficient

C_c = Configuration coefficients

C_E = Eccentricity coefficient

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The C coefficients (C_E, C_H, C_S, and C_C) can be set equal to 1.0 for the worst case. Other variations can be obtained for specific ship data.

The output energy or that energy that can be absorbed by the piling system is;

$$E_o = F \times \Delta_p + \Sigma \frac{1}{2} k\Delta_f^2$$

where:

$$\Delta_p = \text{deformation of pile} = FL^3/3E(I/D.F.)$$

therefore,

$$E_o = F^2L^3/[3E(I/D.F.)] + \Sigma \frac{1}{2} k\Delta_f^2 \qquad (6)$$

Using Equations (5) and (6) and assuming $\Delta = FL^3/[3E(I/D.F.)]$ or zero, the induced force F is determined. The resulting Δ can then be evaluated and used to re-evaluate E_o if $\Delta = 0$ was originally assumed. The resulting moment and stress is found as per Equations (3) and (4).

System Technique:

A complete pile system may be analyzed by assuming that it is a cantilever grid plate, subjected to a lateral load. The response of such a system can readily be determined by using matrix formulations or a finite difference scheme, the latter of which was used here.

If several interacting elements are considered and a uniform load is applied along each member, the load deformation response is given by the basic relationship;

$$\frac{d^4w}{dx^4} = \frac{q_x}{EI_x} \tag{7}$$

$$\frac{d^4w}{dy^4} = \frac{q_y}{EI_y} \tag{8}$$

where:

EI_x, EI_y = Member stiffness

w = Vertical deformation

q_x, q_y = External applied loads in force

Equations (7) and (8) can be written in difference form from the relationship;

$$\frac{d^4w}{dx^4} = (W_{ll}-4W_l+6W_o-4W_r+W_{rr})/\lambda_x{}^4 \tag{9}$$

$$\frac{d^4w}{dy^4} = (W_{aa}-4W_a+6W_o-4W_b+W_{bb})/\lambda_y{}^4 \tag{10}$$

where the subscripts represent node points.

Assuming now the total applied load on the grid is q (force per unit area), then the resistance is proportional to;

$$\frac{q_x}{y} + \frac{q_y}{x} = q \tag{11}$$

Substituting Equations (9) and (10) into (7) and (8) gives q_x and q_y, and then substituting into Equation (11) gives

$$D_x/\lambda_x{}^4(W_{ll}-4W_l+6W_o-4W_r+W_{rr})+D_y/\lambda_y{}^4(W_{bb}-4W_b+6W_o-4W_a+W_{aa}) = q \tag{12}$$

where:

$$D_y = EI_y/\lambda_x; \quad D_x = EI_x/\lambda_y \tag{13}$$

Defining $D_x = a\ D_y$ and $\lambda_x = n\ \lambda_y$ and substituting into Equation (10) gives the resulting mesh Equation (14).

$$\begin{array}{ccccc} & & n^4 & & \\ & & -\ 4n^4 & & \\ \alpha & -\ 4\ \alpha & 6(\alpha+n^4) & -\ 4\alpha & +\ \alpha \\ & & -\ 4n^4 & & \\ & & n^4 & & \end{array} \quad x \quad W = \frac{qn^4\lambda_y{}^4}{D_y}$$

Equation (14) represents the general load-deformation response of the grid when subjected to a uniform load q. In order to apply this equation to the cantilever plate, appropriate boundary conditions must be applied. For the basic cantilever plate, the free edges have boundary conditions $M = V = 0$ and along the fixed edge $W=\Theta=0$, where:

M = Bending moment

V = Shear face

W = Deflection

Θ = Slope

These modifications, considering all possible conditions along the plate, result in a total of twelve cases, including the general case given by Equation (14).

All of these cases and their resulting equations have been programmed for direct evaluation of the deformation of the system for any stiffness and loading. The application of this program will now be described.

Parametric Study:

As illustrated by the general theoretical techniques, the distribution factor is important if it is desirable to determine the system response. The determination of this factor (D.F.) has been obtained for typical grid stiffnesses (D_x, D_y) and span length (L) or height of the pile. A unit load effect was used in examining the system and single pile.

Longitudinal Stiffness (D_y):

The range in the stiffness $D_y = EI_y/\lambda_x$ where λ_x is the distance in the x direction, was determined by examination of typical steel H-piles, steel wide flanges, steel pipe piles, and round timbers all of which are used in piling systems.

Transverse Stiffness (D_x):

The range in the stiffness $D_x = EI_x/\lambda_y$, was determined by examining steel wide flanges and various timber sections.

Range in Parameters:

A study of all of the resulting stiffnesses indicated the following ranges;

Variable	Lower Boundary	Upper Boundary
D_y	2×10^4 K-in	6×10^5 K-in
D_x	4×10^3 K-in	10×10^4 K-in
L	20 ft	80 ft

Grid Difference Solutions

Using these ranges in parameters and applying a unit load, the maximum deformation in the system has been obtained. The solution of systems has given the Δ_{sys} which was then divided by the factor $L^3/3EI_y$, which is called the distribution factor (D.F.). These results were then plotted, (D.F.) vs. pile length (L) for direct use in Equations (2) and (6).

Appendix B

Energy Requirements:

In any fendering design procedure dealing with pier-end berthing facilities, the first step is to determine the effective berthing energy. Thus;

$$E_{in} = \frac{1}{2} Mv_{in}^2 \; (C_H)(C_s)(C_c)(C_E) \qquad \text{(per Eq. 5)}$$

where:

M = 250,000 DWT(500,000 kips)

v = Berthing Velocity; 0.25 knots or 5.07 in./sec.

C_H = Hydrodynamic Coefficient; $1 + \frac{2D}{B}$; $1 + \frac{2x62}{1015} = 1.12$

C_s = Stiffness Coefficient; 0.9

C_c = Configuration Coefficient; 1.0

C_E = Eccentricity Coefficient; Fifth Point; 0.4

$$E_{in} = \frac{1}{2}(500{,}000/32.2)(5.07x\frac{1}{12})^2 \; (1.12x0.9x1.0x0.4)$$

$$E_{in} = 559 \text{ K-ft}$$

This is the energy absorbed by the pile, fender donut, and the vessel. It is generally assumed that the vessel absorbs 50 percent of the energy and the combination of the pile and fender donut absorbs the remaining 50 percent.

However, the output energy or that energy that can be absorbed by the piling and fendering system must be interpreted as one-half of the induced energy and the remaining one-half is that energy absorbed by the vessel. Thus, it is assumed that the output energy is 279.5 K-ft for the pile and fendering donut. Thus;

$$E_o = F^2L^3/[3E(I/D.F.)] \qquad \text{(per Eq. 6)}$$

$$279.5 \text{ K-ft} = F^2(75)^3/[((3 \times 4,320,000)(8.81))/0.25)]$$

$$F^2 = 302579.10$$

$$F = 550.07 \text{ Kips}$$

Thus, by dividing the energy in half for use in the above equation, a more conservative answer will result. The moment is now determined

$$M = F \times L \qquad \text{(per Eq. 3)}$$

$$M = 550.07 \times 75 \times 12 = 495,000 \text{ K-in}$$

The stress is:

$$f = M/(S/D.F.) \qquad \text{(per Eq. 4)}$$

$$f = 495,000/[(8.81 \times 144 \times 144)/39)/0.25]$$

$$f = 26.42 \text{ Ksi} < 48 \text{ Ksi}$$

Explanation of Some Variables:

A berthing velocity of 0.25 knots is a reasonable number if the tanker is escorted by tugs which in this case it is. However, this system will handle a vessel traveling at a velocity of 0.3 to 5 knots. In the determination of the hydrodynamic coefficient, the draft of the vessel was taken as 62 feet and the length as approximately 1015 feet. The stiffness coefficient utilized was 0.9 as the facility is considered an open structure. The configuration coefficient is generally 1.0. The eccentricity coefficient is 0.4 if one assumes the vessel will impact the protective system at the fifth point. In the utilization of Eq. 6, the D.F. value was chosen as 0.25 which is the most conservative value available. Further, it was assumed

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after many trials to use a 6.5 foot diameter pipe pile with a 1 inch uniform thickness and a cantilever length of 75 feet and a design stress of approximately 48 ksi.

Fender Donut Design:

The fender donut design is based upon the energy requirements and several trial and error solutions of which the final design is shown here. The known values for the fender donut design are as follows:

f, Kip/ft^2, Maximum tensile stress in pile = 6912 K/ft^2

D, ft, Outside diameter of pile = 6.50 ft.

t, ft, Pile wall thickness = 1 inch = 0.083 ft.

L, ft, Length of pile (cantilever) = 75 ft.

E_t, K-ft, Total energy absorbed upon impact = 279.5 K-ft

K_E, K/ft^2, Energy Absorbsion Coefficient for donut = 0.1956 K/ft^2

K_F, K/ft^2, Reaction force coefficient for donut = 3.811 K/ft^2

E, K/ft^2, Tensile modulus of elasticity for pile = 4.32×10^6 K/ft^2

Calculated values are as follows:

1. Moment of Inertia:

$$I = \frac{\pi}{64}(D^4 - (D-2t)^4)$$

$$I = \frac{\pi}{64}(6.5^4 - (6.5-0.17)^4) = 8.81 \text{ ft}^4$$

2. Reaction force on donut:

$$F_f = F_p = \frac{2fI}{DL}$$

where:

F_p = Reaction force on pile

$$F_f = F_p = \frac{2(6912)(8.81)}{(6.5)(75)} = 249.82 \text{ K}$$

3. Energy absorbed by pile deflection:

$$E_p = \frac{2f^2LI}{3D^2E}$$

$$E_p = \frac{2(6912)^2(75)(8.81)}{3(6.5)^2(4.32\text{x}10^6)} = 115.30 \text{ K-ft}$$

4. Energy absorbed by donut:

$$E_f = E_t - E_p$$

$$E_f = 279.5 - 115.30 = 164.20 \text{ K-ft}$$

5. Outside diameter of donut:

$$d_o = \frac{K_F E_f}{K_E F_f}$$

$$d_o = \frac{(3.811)(164.20)}{(0.196)(249.82)} = 12.78 \text{ ft use } 13 \text{ ft}$$

6. Height of donut:

$$h = \frac{F_f}{K_F d_o}$$

$$h = \frac{249.82}{(3.811)(12.78)} = 5.13 \text{ ft}$$

7. Inside diameter of donut:

$$d_i = d_o/1.507$$

$$d_i = 12.78/1.507 = 8.48 \text{ ft}$$

Thus, this donut will fit over the 6.5 ft diameter pipe pile.

8.. Average Hull Reaction

Pressure = 5.74 K/ft^2

A similar fendering-donut was designed to handle a vessel of 150,000 DWT with an overall length of 900 feet.

Water Table Considerations:

In the preceding section, the design was based upon a cantilever length of 75 feet. Thus, this allowed for dredging to occur down to 65 feet leaving 10 feet above the mean,low water line. The normal fluctuation in the tide is 4.7 feet in the Hudson River area. The donut height in the preceding example was approximately 5 feet leaving plenty of room.

If it is desirable to leave additional space for 10 year and 100 year storms (or whatever), the length of the cantilever should be increased. Table 1 shows the design results for an increase in cantilever length to 90 feet and if desirable, these values should be used.