SYSTEMS ENGINEERING AND DEVELOPMENT OF COMMERCIALLY VALUABLE MARINE RESOURCES IN THE DELAWARE REGION

UNIVERSITY OF DELAWARE
SEA GRANT PROJECT
FINAL REPORT
1968-1970

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SEA GRANT PROJECT

SYSTEMS ENGINEERING AND DEVELOPMENT OF COMMERCIALLY VALUABLE MARINE RESOURCES IN THE DELAWARE REGION

University of Delaware, Newark, Delaware
and its
Marine Laboratories, Lewes, Delaware

Institutional Representative
Dr. Franklin P. Kilpatrick
Dean, College of Graduate Studies

Project Director
Dr. William S. Gaither
Dean, College of Marine Studies

Period Covered: 1 September 1968 to 31 August 1970

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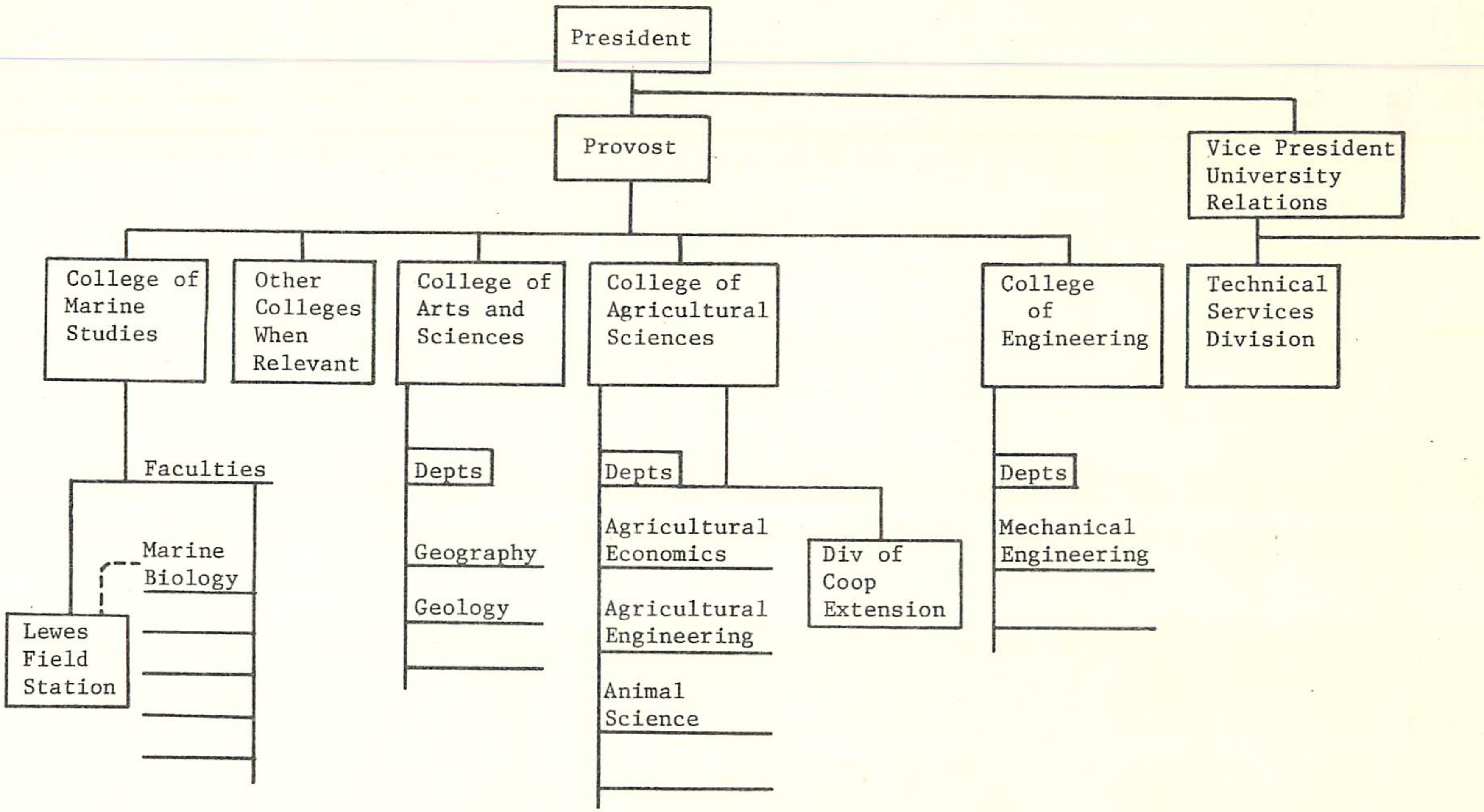
OBJECTIVES

The major goal of this Sea Grant Project was revival of the state's shellfish industry. It proposed to do this through systems engineered techniques for artificial shellfish culture, including the steps of breeding, holding brood stock, spawning them on command, rearing larvae and cultivating the progeny in the field. The primary emphasis was on oysters.

The multidisciplinary investigation carried out by the departments noted in the following organization chart, sought to define practical procedures for breeding including command spawning and culture including environmental control, supplemental feeding and growth in natural waters; all leading to the design of a commercial oyster hatchery with the potential for a lengthened spawning season and accelerated growth of larvae. Cost reductions were sought through studies of harvesting and processing techniques.

The systems engineering study was planned to provide a computer simulation of a closed environment oyster production plant which could be used to design a plant and analyze the effect of changes on investment and operating costs.

Carrying out the above program resulted also in strengthening the faculty and curricula in Marine Science and Engineering and contributed materially to the decision to establish a College of Marine Studies.


President
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Agricultural Economics
Agricultural Engineering
Animal Science
Div of Coop Extension
Depts
Mechanical Engineering

SUMMARY

College of Arts and Science

Department of Biological Sciences

Shellfish Culture Techniques

1. Selective Breeding

This study was undertaken (1) to improve the growth and survival rate of the local oyster species, Crassatrea virginica by selective breeding and (2) to develop hybrid oysters by cross breeding the local oyster with other species of the genus Crassatrea to produce hybrids which grow rapidly and are hardier to disease and environmental stress.

Hybrids were produced by crossing C virginica with C gigas (Japanese) which in the early stages at least, grew at roughly twice the rate of local oysters. Similar crosses will be made with the Portuguese oyster C augulatta. Additional work will be required to overcome the high mortality rate experienced to date.

2. Conditioning and Spawning of Oysters

The time and temperature schedule has been refined so that oysters can be successfully spawned year round and a formula derived to predict the time of command spawning.

3. Rearing Larvae

Oysters spawn naturally in July whereas the growing season is from May to October. It was found that by inducing spawning in May or earlier, young spat set in a hatchery (26° C) could be acclimated gradually to ambient water (10-12° C). The early placement of spat in the field would result in (1) maximum utilization of costly nursery facilities (2) increased survivorship because the larger spat would be less subject to predators and (3) production of commercial size oysters in shorter time.

An algal culture has been developed and used with moderate success in feeding larvae.

4. Setting

It was demonstrated that oysters produced a setting stimulant that can be detected by metamorphosing larvae. This offers a means of controlling setting for most desirable spacing.

Cultchless oysters were produced by setting on a fine screen, washing them off and supporting them on another screen.

Larvae were induced to set on ground cork and thereby lived in the water column two to three weeks beyond their natural planktonic life. This "free living" existence was accompanied by very rapid growth.

<u>Department of Geography</u>

The study of the influence of climatic water balance on conditions in the estuarine environment showed:

1. The expected seasonal trend of fresh water flow into the Delaware estuary from land run off and precipitation, the loss of water through evaporation, and the net flow of water across the mouth of the estuary (Cape May - Lewes) for a twenty year period;
2. The month to month movement of the salt line in the estuary;
3. The changes in land run off in a small sub-basin resulting from land use changes over the past thirty years.

Further studies are underway to correlate salinity at several points in the system with the flow of water in the estuary as well as with other factors of the water balance.

College of Agricultural Sciences

Department of Agricultural Engineering

Environmental Control for Culturing Oysters

This study's objective was the development of a controlled environmental system for oyster culture. Results to date indicated:

1. Oysters can be maintained and grown in confinement.
2. High flow rates of fresh sea water are not necessary.
3. Flow patterns and velocities around the oysters are critical for feeding and fecal removal rather than over-all flow rates.
4. Oyster nutrition problems remain. Combinations of algae and corn starch appear to hold the most promise for feeding oysters in a closed system.

Separating Valves of Oysters

The purpose of this study was the investigation of various physical stimuli on valve separation of oysters as a step in the mechanization of the oyster shucking process without reducing the quality of the meat.

Many schemes have been tried but none have been successful. The most promising energy sources for process development at this point appear to be (1) infrared heat concentrated in the muscle area of the shell and (2) whole body electromagnetic radiation with microwaves.

College of Engineering

Systems Engineering

A computer simulation of an oyster production facility has been completed and will be used in system optimization studies that will lead to maximizing the profit of the oyster industry. The simulation will lead to identification of research programs necessary to resolve unanswered technological problems.

The computer simulation will also be used to analyze the effect of design changes on the investment and operating costs of the plant.

Division of Technical Services

Administrative Coordination

Assistance has been given to the Project Director as appropriate.

A complementary project submitted to the Economic Development Administration for "Preliminary Design and Lay-out of a Commercial Oyster Hatchery in Sussex County, Delaware" has been approved in the amount of $16,400.

Division of Cooperative Extension Service

Four projects were initiated to enhance the aquatic resources of Delaware.

1. Planting Seed Oysters

   Funds were obtained from the Bureau of Commercial Fisheries to transplant 1200 bushels of seed oysters from the natural beds to three planted beds in Delaware Bay.

2. Clam Shell Cultch

A project was approved by the U. S. Public Health Service to place waste clam shells in the tributaries to Delaware Bay as cultch to increase natural seed oyster production. This project is still in progress.

3. Catfish Farming

A pond was stocked with catfish fingerlings and results indicate that rearing this species in Delaware is feasible.

4. Artificial Reef Construction

The Delmarva Artificial Reef Association was established as a non-profit Delaware Corporation to build a reef designed to increase the production of finfish and lobsters. Approval by the Army Corps of Engineers is needed before starting construction.

Complementary Projects

The additional projects engendered by the National Sea Grant Project are described in the departmental reports and are summarized below for ready reference:

1. Bureau of Commercial Fisheries - Trial planting of seed oysters in Delaware Bay - $3,600.
2. Delaware River Basin Commission - Rehabilitation of the Oyster Industry in Delaware Bay: Feasibility Study of Raft Culture of Oysters in the Delaware Bay Area - $100,000 over four years, 1 May 1969 to 30 June 1973.
3. U. S. Public Health Service - Utilize Waste Clam Shells for Oyster Cultch - $80,000 over two years.
4. Hatch Act Funds - Environmental Control System for Aquaculture - $2,200.
5. Hatch Act Funds - Impact of New Production, Harvesting and Procurement Methods on the Market Structure of the Fishing Industry in the North Eastern United States - $1,400.
6. University of Delaware Research Foundation - Study of finfish in impounded waters - $6,700.
7. Economic Development Administration - Preliminary Design and Layout of a Commercial Oyster Hatchery in Sussex County, Delaware - $16,400.

Publications

Several papers have been submitted describing results of some of the work done under the Sea Grant Project.

The following papers have been accepted for publication:

"The Delaware Oyster Industry: A Reality?" Transactions of the American Fisheries Society.
D. Maurer, L. Walting, and R. Keck

"Marine Shallow Water Amphipods of the Delaware Bay Region". Crustaceana. L. Watling and D. Maurer

"Shallow Water Hydroids of the Delaware Bay Region". Annals of Natural History. L. Watling and D. Maurer

"Proceedings of the National Shellfisheries Symposium on the Artificial Propagation of a Commercially Valuable Species". University of Delaware Publication.
K. Price and D. Maurer

Papers submitted for publication:

"The Setting Response of _Crassatrea_ _Virginica_ to Chemical Stimulants". Proceedings of the National Shellfisheries Association. R. Keck, D. Maurer, J. Kauer and W. Sheppard

"Holding and Spawning Delaware Bay Oysters (_Crassatrea Virginica_) Out of Season. II Temperature Requirements for Maturation of Gonads". Proceedings of the National Shellfisheries Association. K. Price and D. Maurer

NATIONAL SCIENCE FOUNDATION
Washington, D. C. 20550

RESEARCH GRANT BUDGET & FISCAL REPORT

Form Approved
Budget Bureau No. 99-R0013

Please read instructions on reverse side carefully before completing this form.

INSTITUTION AND ADDRESS	NSF PROGRAM	REPORTING PERIOD
University of Delaware Newark, Delaware 19711	Systems & Engrg. Dev. Marine Res.	FROM 9/1/68 THRU 8/31/70
	PRINCIPAL INVESTIGATOR(S) Dr. Franklin Daiber	[X] FINAL REPORT [ ] INTERIM REPORT (See instructions)

Grantee Account Number	GRANT NUMBER	DURATION	GRANT AMOUNT
	GH-30	2 years	$ 310,600.00

	NSF Funded Man Months Cal.	Acad.	Summ.	NSF GRANT BUDGET	GRANTEE CUMULATIVE EXPENDITURES (Do Not Round)
A. SALARIES AND WAGES					
1. Senior Personnel					
a. 1 (Co)Principal Investigator(s)	1			$	
b. 35 Faculty Associates	59	24.6			
Sub-Total				87,775.00	$ 88,857.91
2. Other Personnel (Non-Faculty)					
a. ___ Research Associates—Postdoctoral					
b. 3 Non-Faculty Professionals					
c. 4 Graduate Students					
d. 1 Pre-Baccalaureate Students					
e. 5 Secretarial - Clerical					
f. 6 Technical, Shop, and Other					
TOTAL SALARIES AND WAGES				171,580.00	163,134.86
B. FRINGE BENEFITS When Charged as Direct Cost				--	--
C. TOTAL SALARIES, WAGES, AND FRINGE BENEFITS (A+B)				171,580.00	163,134.86
D. PERMANENT EQUIPMENT				46,694.00	66,637.49
E. EXPENDABLE EQUIPMENT AND SUPPLIES				20,222.00	23,852.17
F. TRAVEL 1. Domestic					
2. International				9,771.00	7,066.09
G. PUBLICATION COSTS				3,250.00	--
H. COMPUTER COSTS When Charged as Direct Cost				--	1,336.00
I. OTHER COSTS (Itemize) Consultant fees 332.00 Physical Plant 771.05 Photo Service 157.69 Telephone 184.20 $ 1,444.94				4,000.00	1,444.94
J. TOTAL DIRECT COSTS (C through I)				255,517.00	263,471.55
K. INDIRECT COSTS				55,065.00	47,128.45
L. TOTAL COSTS (J plus K)				310,582.00	310,600.00
M. TOTAL BUDGET ROUNDED -AMOUNT OF AWARD				310,600.00	
N. UNEXPENDED BALANCE (M. budget minus L. expenditures)					
O. COST SHARING—GRANTEE PARTICIPATION				$164,253.00	$ 165,662.01

REMARKS: Use extra sheet if necessary

Salaries & Wages				Overhead
Off Campus	$47,364.76	x 35.9%	=	17,003.95
Agric.	23,463.09	x 50.5%	=	11,848.87
Campus	4,475.07	x 67.08%	=	3,001.88
Campus (NSF portion)	45,349.60	x 33.68%		15,273.75
Not Subject to O/H	42,482.34			--
Total	$163,134.86			$ 47,128.45

I CERTIFY THAT ALL EXPENDITURES REPORTED ARE FOR APPROPRIATE PURPOSES AND IN ACCORDANCE WITH THE AGREEMENTS SET FORTH IN THE APPLICATION AND AWARD DOCUMENTS

SIGNATURE OF XXXXXXXXXXXXXX	TYPED OR PRINTED NAME & TITLE	DATE
University Project Director	William S. Gaither	
Financial Officer [signature]	XXXXXXXXXXXXXXXX Henry J. Sawoska Contracts Manager	

Org. Code | Prog. Code | Obj. Class O/D res | Award No. | amt | Inst. Code | Unexpended Balance | Trans. | Lot

NSF Sea Grant

Final Report

DEVELOPMENT OF SHELLFISH CULTURE TECHNIQUES FROM THE LABORATORY TO THE FIELD

Dr. Donald L. Maurer

College of Arts and Science
Department of Biological Sciences
Marine Laboratories

SUMMARY

The principal accomplishments involved a variety of activities. In the area of spawning a formula to predict the time of local spawning after a certain temperature schedule was derived. In terms of nutrition the algal culture facility was finally developed to the point where it was used to rear oyster larvae. Preliminary efforts to monitor water quality indicated that this area of research will require considerably more attention than in the past. Some interesting experiments in setting larvae demonstrated that cultch treated with natural and artificial stimulants yielded higher counts of spat than untreated cultch. In other experiments cork and micro spat floats were new means to promote early rapid growth of young oysters. A large 6,000 gallon tank designed initially for mass growing of oysters was temporarily used as a super, semi-running water, larval rearing system. If the latter system can be refined, this may represent a breakthrough in the production of commercial numbers of set with low labor cost. Research on growing spat in running heated water for 6 months indicated that commercial sizes might be attained in hatcheries within a year. Experiments were conducted to acclimate hatchery set larvae for early spring field emplacement which would afford a longer growth period and allow for a more rapid turnover of expensive nursery facilities in the hatchery. Along hatchery lines experiments in holding oysters in bags and trays and various packing arrangements indicated that certain methods foster lower mortalities.

Research on shellfish pathology was started and a problem concerning bacteria in closed systems was defined for a master's thesis.

Spinoff from NSF activities involving the Delaware River Basin Commission and a private party interested in developing some oyster ponds is briefly described.

OBJECTIVES

The purpose of the subproject is to generate shellfish culture techniques which can be used to develop a pilot shellfish hatchery. Specific objectives to date were: 1) to refine the temperature-time schedule necessary for command spawning; 2) to perform greenhouse and hatchery activities; 3) to develop an algal culture facility; 4) to undertake experiments with setting stimulants, and cultchless oysters; 5) to construct a mass culture growing tank; 6) to begin work on defining vectors of shellfish disease, in particular bacteria.

RELEVANCE TO THE TOTAL PROJECT

Success in developing shellfish hatcheries is dependent on the knowledge of an oyster's response to closed environments. Thus, this subproject must provide new and refined information about artificial shellfish culture techniques for purposes of designing environmental systems and as input to the systems engineering analysis. Because of this, the subproject has a major role within the scope of the University's Sea Grant Project.

RESULTS

Introduction

In spite of specific disappointments, false starts, blind alleys, and unresolved problems, common to all research, general progress in the past two years has been most encouraging. Some of the goals so blithely outlined in proposals have actually been accomplished and in cases even improved with hard work and a certain amount of serendipidy. In fact some events surprised us so much as to change dubious views into hopeful ones. This subproject has demonstrated to us that the goal of the program is much closer to achievement than initially conceived.

Special Spawning Experiment

Reports from New England oyster hatcheries make it clear that northern oysters are easier to condition for command spawning than their southern counterparts. The temperature-time schedule appropriate for New England is not appropriate for local oysters. This situation forced us to refine the temperature-time schedule for command spawning of Delaware Bay oysters. To accomplish this a special spawning experiment was designed. The experiment included examination of about 550 oyster gonad thin sections taken at various temperatures and conditioning exposure times. From this experiment a working formula to predict the time of local spawning following a certain temperature schedule was derived. 1) $D = 700/T-12$, 2) $T = 700/D + 12$, where D is exposure time in days, and T is the daily mean exposure temperature within the approximate range of 12.0-30.0°C using Delaware Bay oysters removed from the field in Winter and Spring before ambient water temperatures have risen above 12.0°C. Even though this formula was designed for local oysters, it appears that it may be applicable to Chesapeake Bay oysters based on the literature. The approach is expected to be useful for researchers in other geographic areas with the provision that they insert their own seasonal water temperature records. Finally this formula is easier to develop and use than other formulae based on logarithms. This study is in manuscript form and will be submitted for publication in October.

Greenhouse and Hatchery Activities

A variety of experiments was conducted and procedures were tested. Among these, experiments were performed to determine whether spat held in trays grew better than spat held in plastic, large gauge, mesh bags. After one year it was found that 48% of the spat in the bags were dead and only 8% were dead in the trays. This experiment has been repeated with the addition of strung cultch. It is still in progress. In addition to the method of holding oysters, another aspect of growing oysters in a hatchery is the density and orientation of the oysters. An experiment in progress involves holding spatted shells in 2' by 2' plastic trays. The density and orientation of the spatted shells varies from rigidly packed, anteriorly-posteriorly, up right shells, to shells placed in imbrication, to shells randomly placed in the trays. Another experiment involves a series of plastic oyster trays with adults packed in the following manner; randomly, vertically, imbricately, three horizontal layers, four horizontal layers, five horizontal layers. To date as might be expected mortalities have been heaviest in the four and five layer packing arrangements. This exercise offers some criteria as to the maximum number of oysters which can be held in trays resulting in the highest survivorship.

Temperature as well as proper nutrition and selective breeding is a critical factor influencing the growth of oysters. The American oyster reaches commercial size (7.6 cm) in 3-4 years in Delaware and 1 year in the Gulf Coast. In a hatchery rapid growth is imperative. Experiments with growing oysters at temperatures considerably higher than ambient seawater for certain times of the year have indicated that a commercial sized oyster might be produced in a year. Growth was measured as shell and width. Problems involving the cost of heating running water, supplemental force feeding, continuous reproduction of fouling organisms in unfiltered seawater systems, semi-hibernation behavior of northern oysters, condition of oyster meats, still must be resolved. Nevertheless, the effect of heated, running water in the laboratory had a definite positive effect on shell growth.

The oyster growing season in Delaware Bay is from May to October whereas oysters normally spawn in middle July. By out of season spawning the initial growing period may be increased as much as eight weeks. To further extend the growing period a special spat maintenance experiment was performed to determine whether young spat set in a hatchery (26°C) in early spring could be acclimated to colder ambient water (10-12°C) and still survive. If hatchery larvae could survive, then hatchery production could begin even earlier than May. This would promote early placement of spat in the field allowing a rapid turnover of costly nursery facilities in the hatchery. Further, the growing season would be expanded, producing a larger yearling oyster, subsequently attaining commercial size in a shorter period. Moreover this procedure also increases survivorship because hatchery spat with an eight week growth advantage would be less subject to predators and pests than smaller natural spat. We found that spat progressively exposed to lower temperatures and finally subjected to ambient seawater did not suffer high mortalities. This experiment should be repeated several times to offer a basis of comparison for what constitutes good survivorship. It should also be conducted for a longer period of 2 to 3 months rather than 6 weeks to trace the fate of the acclimated spat. Nevertheless, the principle may have some commercial application.

Spawning for hatchery purposes performed in early June and July 1970 resulted in massive numbers of larvae. The June spawning effort produced 60 million larvae and almost 200 million were estimated for the July spawning. Another group of oysters spawned about 120 million larvae in August. The fate of these larvae will be described later in the report concerning the mass oyster growing tank.

Algal Culture Facility

Initial efforts to feed oyster larvae were made by pumping seawater through a high speed centrifuge into the greenhouse. Here it was incubated, pumped into the laboratory through a heat exchanger, and fed to the larvae. To avoid the cost of maintaining and servicing the centrifuge, filter bags with a wide range of pore sizes are now used. Natural phytoplankton feeding is very satisfactory during the late spring through the fall. However, from November through early May we have had erratic results raising larvae on natural food. Also in the summer, periods of "bad water" have been encountered. The "bad water" may be caused by excessive numbers of phytoplankton with associated toxic metabolites, freshets from heavy rains accompanied by extensive drainage of marshes with residual pesticides, dredging operations, or detergents from adjoining industries.

To reduce the effects of "bad water" on oyster culture work two approaches were used, algae culture and water quality monitoring. An algal culture facility was constructed. This consisted of a constant temperature (20°C) room with shelves lined with banks of grolux lights. Water is pumped to a settling tank, through an ultraviolet light system, and then through a millipore filter. It is then autoclaved and appropriate nutrient formulae are added. Inoculants of Monochrysis and Isochrysis are made in small containers. After several days these are placed in 5 gallon carboys for further incubation. Finally half the carboys are emptied daily to feed the oyster larvae. Fresh nutrient water is pumped to the carboys and the process continues again.

Preliminary feeding experiments with algae were inconclusive. Oyster larvae did not grow when they were fed inoculants of algae nor did the control larvae fed on natural seawater grow. In December 1969 and March 1970 larvae were reared to setting size on cultures of Monochrysis, Isochrysis, mixed Monochrysis-Isochrysis, and natural seawater. Larvae fed on natural seawater at this time of the year normally do not survive to setting size or if they do, it may require 21-35 days to set. The addition of these algal food supplements has greatly improved the growth rate and survival of larvae reared in the winter and early spring.

The development of the algal culture facility was aided by specialists from the Price Institute, New Jersey, who kindly supplied us with new cultures to reactivate moribund cultures, gave us some literature and offered recommendations on how to improve our methodology.

Although more progress was made in improving the algal culture facility in 1969 than ever before, we were still dissatisfied with our methodology. Initially the approach was to study the growing response of larvae feeding on algae. Our focus has shifted from a larval-algal problem to the study of algae per se which subsequently should return us to the application of algae as a larval food. To this purpose, in the summer of 1970, Mr. Kurt Langefoss, graduate student, Marine Biology, specialized in reviewing the conditions necessary to maintain algal cultures. He experimented with various ways of sterilizing large quantities of water and determining optimal concentrations of algal cells. He plans to acquire additional species of algae to incorporate into the program. His research has been aided by contact with Dr. Ravenna Ukeles, Bureau of Commercial Fisheries Laboratory, Milford, Connecticut. Water quality continues to plague the maintenance of healthy algal cultures and larval cultures. To circumvent some of the problems of water quality the feasibility of finding and operating a salt water well was explored. Salt water wells are used next door in a clam processing factory. Their salinity is 17 o/oo which is marginal for our purposes and their wells are sunk 65 feet. Aquapure, an oyster depuration plant in Lewes, Delaware, made some exploratory drillings in this area and found that iron sulphides were very prevalent in these saline pockets. Dr. Kraft, Chairman of the University's Geology Department, was consulted about this problem. He offered the opinion that saline pockets occurred at various depths and probably had low salinities and high iron content. Further he asserted that even if a high salinity, low iron pocket was located, its capacity might only satisfy present pumping needs for several months until it went dry.

During the winter Mr. Robert Eastburn, Research Assistant, Agricultural Engineering, was assigned the task of monitoring water quality in closed aquaria containing oyster feeding experiments of artificial food. Mr. Eastburn recorded data on pH, salinity, turbidity, total hardness, carbon dioxide, nitrate and nitrite nitrogen, phosphorous and dissolved oxygen. In a two month period in closed aquaria he found that pH varied from 6.5 to 8.0, salinity from 13.6 to 17.1 o/oo, total hardness from 2,600 to 2,990 ppm, carbon dioxide from 8 to 10 ppm, dissolved oxygen from 5-8 ppm. Nitrogen and phosphorous levels were erratic and showed no patterns.

At the shellfish laboratory, Mr. Paul Layton, Resident Biologist, ran some water quality tests. His most reliable and interesting results showed that at times detergents increased on the ebb tide. In passing it can be mentioned that the clam factory on the upstream side uses detergents in their washing activities. The association between their activities and high detergent levels on the ebb tide is certainly provocative. Finally Miss Barbara Prosser, graduate student in Marine Biology, continued monitoring water quality in the Shellfish Laboratory during the summer of 1970. She found that it was a full time job on a daily basis. It was the conclusion of Messers Eastburn, Layton and Miss Prosser that more refined tests than are presently available are needed to satisfactorily monitor water quality in closed aquaria and in a running sea water system. This problem will require a water quality specialist with modern instrumentation to really define the conditions of water used in the shellfish program.

Setting

In oyster research the pursuit of the perfect cultch and method of setting is akin to the search for the Holy Grail. During the last two years a great deal of time has been spent on setting experiments. More specifically experiments were performed to determine the effect of "chemical signals" or pheromones emitted by oysters on the setting of larvae, and to develop a means of producing cultchless oysters. Experiments on the pheromones will be discussed first. Detailed accounts are available in quarterly University reports. For the sake of brevity the highlights of the experiments are only included.

It has been demonstrated that adult oysters and even young spat produce a setting stimulant (pheromone) which can be chemically detected by metamorphosing larvae. We tested this observation by challenging larvae with spatted and unspatted oyster shells. It was found under a variety of conditions that the former shells always yielded higher concentrations of new set than the latter. This indicates a gregarious setting response by the larvae keyed to a chemical signal.

In order to more closely identify the stimulant other experiments were performed. Shells were soaked in oyster liquor, feces, and pseudofeces. Larvae were challenged with these treated shells and untreated control shells arranged randomly in a setting tank. In almost every experiment treated shells yielded higher spat counts than controls. These experiments were repeated with porcelin tiles to reduce the effect of unknown organics from shells subject to various degrees of exposure or aging. Again, treated tiles received higher numbers of spat than untreated ones. Among the treated shells and tiles shell liquor appeared to be the strongest stimulant.

Following these experiments a joint effort between chemists of the Du Pont Experimental Station, Wilmington, Delaware, and our group was established to further refine the identity of the setting stimulant. Du Pont chemists have developed five chemical fractions from oyster liquor. In turn these fractions were tested by us by soaking tiles in them and challenging larvae to the treated tiles. Two of the five chemical fractions showed greater promise than the other three. Another sidelight to these experiments was that larvae responded to the grooved side of the tiles rather than the smooth side. Spat characteristically set along grooves rather than randomly on any smooth portion of the tiles. Finally the spat normally set on the undersurface of the tiles. The effect of the interaction of several factors influencing setting can be deduced from these experiments. All these factors can be used in the future to control the spatial and timing pattern of setting in hatcheries. A manuscript on these setting experiments is completed and will be submitted for publication in October. Plans to continue the joint research with Du Pont chemists have already been made.

In addition to classical methods and problems of setting the production of cultchless oysters was pursued. After a variety of methods was tried cultchless oysters were produced. Larvae were set on fine nitex screen mesh. Periodically the screen was gently rinsed and the residue was caught on another screen and returned to a running seawater system.

A new wrinkle proposed by Earl Greenhaugh, Senior Laboratory Technician, involved using ground cork as a substrate. The larvae attached to the ground cork and lived in the water column two to three weeks beyond their natural planktonic life. By maintaining the young spat above the bottom of the tank, they are not subject to immediate siltation. Rather they continue a "free living" existence comparable to their larval stage as air stones move the cork bound larvae around the tank. Comparison of growth between cultchless spat and spat attached to cork of the same age indicated that the latter were growing four times faster than the former. Since that experiment, plastic beads, 1 mm in diameter were used as micro spat floats but setting was not successful. This method will be strongly pursued in the future as the initial early growth exhibited by the spat makes it a valuable tool.

<u>Construction</u>

From earlier work we realized there are serious engineering problems with certain shapes of tanks. Some tanks do not permit a uniform flow of water and therefore some oysters receive less food than others. At the same time waste products are also not removed in a uniform manner. As a result a large plywood tank with epoxy finish, 4' deep, 8' wide, and 26' long was constructed. A smaller scale model has been constructed by the agricultural engineers who are testing flow rates and patterns. Subsequently similar tests will be made in the large tank. Ultimately the engineers plan to install a system to produce a net laminar flow with a cross turbulent flow and at least fifteen percent recycling of water. Until this system is installed other uses were applied to the tank.

Reference was made earlier in the section on spawning to an August spawning of 120 million larvae. At that time we thought to use the large tank as a super setting tank. Normally larvae are set in smaller tanks 4' x 4' in standing water changed daily. A colleague, Dr. Kent Price, suggested rather than waiting the 10-14 days to rear the larvae to setting and then placing them in the large tank, it might be more desirable to rear the larvae in the large tank and then add cultch. Stimulated by this idea we tried to refine it by pumping filtered water on a flood tide through the tank. The outlet line was covered with a series of nitex screens to prevent larvae from being lost.

The larvae were placed in the tank and in 9-10 days they were ready for setting. This is not unusual but it must be considered very rapid growth. However after 12-14 days no setting occurred. Examination of the water showed very low numbers of larvae and very high numbers of barnacles, copepod, and polychaete larvae. From this we deduced that a finer mesh net was required on the intake lines. Following this failure, metamorphosing larvae reared in separate small containers with daily water changes were placed in the large tank with cultch. These larvae were successfully set which indicated that the large tank could be used as a super setting tank at least. With finer mesh nets on the intake line newly fertilized eggs were placed in the large tank. Within 12 days the larvae set in our semi-running water rearing system. This experiment was repeated late in August with a modification learned from the setting experiment. Spatted shell with two week old set was used as cultch. The spatted cultch in the large tank yielded commercial counts of spat per shell.

Obviously this large scale, semi-running water system for rearing and setting larvae requires considerable refinement. However, this system would dramatically reduce the cost of labor in handling smaller rearing containers. The running water approach also obviates the necessity of daily water changes. Certainly during summer months in middle latitudes there is no cost for heated water. We plan to continue this approach into the fall to determine how long such a system can run on naturally heated water, before heat exchangers must be used.

Disease

In oyster feeding experiments jointly supervised by the agricultural engineers and ourselves we began to look at problems of shellfish pathology in closed systems. These experiments involve feeding a variety of artificial foods to oysters in closed aquaria. Miss Barbara Prosser, graduate student, Marine Biology, was assigned the task of determining what microorganisms develop in these aquaria. Among the organisms identified were: Amoeba, Paramecium, Euplotes, Euglena, Zoothamnium, Melosira, Rhizosolenia, Chaetoceras and a variety of unidentified round worms and rotifers. Confronted with this large diversity it was decided that Miss Prosser would specialize in work on bacteria. She has experimented with a variety of techniques and culture media and her methodology is becoming stabilized. Miss Prosser found that species of bacteria vary from aquaria to aquaria depending on the artificial food fed to the oysters. One species was common to all the aquaria. Aquaria with the same food seemed to develop a similar microflora. In the immediate future she plans to establish aquaria with sterile rila sea salts and non-sterile rila mixtures to accommodate controls, various oyster foods, oysters and oysters with food.

The area of shellfish disease under hatchery conditions is another wide open area like shellfish genetics. Research on shellfish pathology has received great impetus from the MSX epizootics of the sixties and many of these studies will be applicable. Still, epizootics under hatchery conditions will require studies appropriate to controlled conditions. Excessive crowding, force feeding, high temperatures inherent in a controlled enclosed environment should be ideal to promote epizootics. These problems will eventually have to be faced and so research on disease is not premature. This area will become more important in the future.

NSF Spin Off

In an oyster project sponsored by the Delaware River Basin Commission to determine whether raft culture or off-bottom culture could be commercially feasible in the Delaware Bay region, the problem of winter ice was recognized. To circumvent winter ice a submersible oyster raft was conceived. Exposure to the civil engineers in the Sea Grant Program prompted us to seek their help. In a special Ocean Structures course taught by Dr. William Gaither, students were assigned the task of designing low cost and deluxe models of a submersible oyster raft. Specifications were reviewed by us and Dr. John Kelly of the Commission and certain models were selected for additional work. Finally two plastic scale models were constructed and tested in a flow tank by the students. Some problems still exist but models have enough merit to warrant further investigation under this project.

At present we are serving as informal advisers to Dr. Russel Down, New Jersey, who is interested in maraculture. Dr. Down has some semi-enclosed ponds fronting on a bay. During the planning stages of his operation he has consulted us several times. We have supplied him with larvae for the purpose of setting in his ponds. No setting occurred from this seeding but we plan to assist in this project as time and larvae will allow.

PERSONNEL ACTIVE ON THE PROJECT

Lester Watling	100% of the time
Barbara Prosser	50% of the time
Robert Gerard (later replaced by Kurt Langefoss)	50% of the time
Don Maurer	45% of the time

NSF Sea Grant

Final Report

SELECTIVE OYSTER BREEDING

Dr. Donald L. Maurer

College of Arts and Science
Department of Biological Sciences
Marine Laboratories

SUMMARY

Highlights of the 1968-1970 selective breeding experiments are briefly reviewed. The first year was concerned with attending a special selective breeding meeting, performing hybrid experiments, acquiring exotic species and building special rearing facilities to accommodate exotic species. These facilities were designed to prevent accidental introduction of exotic species to local waters. Two exotic species, the Japanese and Portuguese oysters, Crassostrea gigas and C. angulatta respectively, were acquired as experimental species in the hybrid breeding program. Attempts to spawn the Portuguese oysters were unsuccessful because they were in poor condition when we received them. Initial efforts to spawn the Japanese oyster and the American oyster were successful but hybrid larvae failed to set. At a special meeting on selective breeding programs of oysters, a panel of shellfish genetic consultants concluded that Delaware's attempt at hybridization was a fruitful means to solve a variety of shellfish problems.

In the second year of the research several hybrid experiments were performed which produced the first set of hybrids in the program. Early growth of the hybrids was faster than that of local oysters. It was suspected that older (8-9 years old) brood stock of C. gigas was more difficult to condition for artificial spawning than younger (2-6 year old) stock. As a result new brood stock was acquired from the West Coast.

OBJECTIVES

The primary objective of this subproject is to improve the growth and survival rate of the local oyster species, *Crassostrea virginica*, by selective breeding. The secondary objective is to investigate the feasibility of developing hybrid oysters by cross breeding the local oyster with other species of the genus *Crassostrea*. Specific phase objectives were: 1) construction of laboratory facilities for handling non-indigenous and hybrid species of oysters; 2) acquisition of additional exotic species for cross breeding experiments; 3) selective breeding experiments with *C. virginica* and *C. gigas*, the Japanese oyster; 4) acquisition of younger brood stock to replace older brood stock.

RELEVANCE TO THE TOTAL PROJECT

Selective breeding involving hybrids affords an important tool to produce a super oyster. This in turn has accelerated progress in the larger shellfish culture subproject in making hatcheries commercially feasible.

RESULTS

Introduction

Prior to the University's Sea Grant Program, our laboratories were engaged in a selective breeding program. During the MSX epizootic, mortality records on survivors indicated those populations of oysters which appeared to have acquired disease (MSX) resistance. These oysters became the brood stock for our selective breeding program initiated in 1962 and intensely pursued from 1967 to the present.

This program continues to be the main source for laboratory and field monitoring programs.

In the genus Crassostrea there are approximately six commercially important species of oysters most of which can be hybridized in the laboratory. The Japanese have performed the majority of experiments with some research by workers in the United States. Prior to the Sea Grant project our laboratories were engaged in hybrid experiments. The Japanese oyster, Crassostrea gigas was selected as the principal hybrid partner because it appears to be hardier to disease and environmental stress than C. virginica and grows faster than the American oyster. Thus, the hybrid program was incorporated as a subproject within the Sea Grant Project.

Laboratory Facilities for Handling Non-indigenous and Hybrid Species

Experimental work with exotic species requires precautions to prevent less desirable species from accidentally being introduced to local waters. Seawater used to maintain, condition, spawn, and rear exotic species must be prevented from directly entering local waters. To resolve this a 125 cubic foot French drain was constructed in a sand pit filled with surf clam shells. The shells and sand serve as a filtering device for waste water and products of biodeposition allowing us to perform breeding experiments without fear of introducing exotic species.

Acquisition of Additional Exotic Species for Crossbreeding

In addition to the Japanese oyster, specimens of the Portuguese oyster, C. angulatta, were obtained. This species is similar to C.

gigas and the Japanese have reported crossing *C. gigas* with *C. angulatta*. Moreover these two species were crossed in Florida by Mr. Ritchie. Unfortunately the specimens of *C. angulatta* were in poor condition when they were obtained and attempts to spawn these oysters were unsuccessful.

Oyster Breeding Experiments

In November 1968 spawning was induced in both species. Males and females were isolated and sex products were collected. Reciprocal hybrid and control crosses were made and three replicate cultures of each cross were set up. In all instances, fertilization of oyster eggs appeared normal and straight hinge larvae developed in 24 hours. Hybrid larvae survived 25 days but failed to set. Control batches of these species also did not set. A second hybrid breeding experiment was conducted in February 1969. The same *C. gigas* parents involved in the November experiment were crossed with different specimens of *C. virginica*. Neither hybrid crosses or control larvae were able to set. Other setting experiments with *C. virginica* at this time were also unsuccessful.

In November 1969 a meeting to review MSX programs involving selective breeding of disease resistant stocks was held at the Bureau of Commercial Fisheries Laboratory, Oxford, Maryland. Researchers from New Jersey, Virginia, Maryland, and Delaware briefly described their respective programs to a group of genetic consultants. Interest was expressed in Delaware's approach to produce hybrids from *C. virginica* and *C. gigas*. It was concluded by the group that hybridization may be a fruitful means to attempt to solve a variety of shellfish problems, in this case, disease resistance.

Encouraged by the consultant's views, a male C. gigas was crossed with a female C. virginica in December 1969. Fertilized eggs were produced but the larvae perished after several days. The brood stock of C. gigas were about eight or nine years old. We have found that younger oysters of C. virginica are easier to condition for command spawning than older ones. Based on our experience sex products of younger oysters are more viable than those of older brood stock. The same condition may exist for C. gigas.

In March 1970 spawning was induced in C. virginica but specimens of C. gigas were sacrificed to obtain eggs and sperm. A female C. gigas was isolated with moderately well developed gonads. Eggs were stripped and sperm from a spawning C. virginica were added. Fertilization followed and 2,000,000 trochophore larvae were observed within 24 hours. After 48 hours the straight hinge stage was attained but larvae had suffered about 98% mortality from the time of fertilization. Examination of the larvae indicated deviation from the D-shape normally observed after a few days, as the hinge in some cases was slightly bowed. After three to four weeks the first hybrids set. Mortality was excessive and only 52 hybrids were produced. In April 1970 another hybrid experiment was performed. Results were similar to the first experiment in that there were dramatically high mortalities with hinge line aberrations. Eighteen hybrids were set in the second experiment.

Table 1. Early Growth of Hybrid and Native Oysters

Date	Stock	Av.ht.(cm)	Av. width (cm)	Range ht. (cm)	Range width (cm)
4/70	Hybrid	3.7	3.0	1.3-4.6	1.5-3.7
4/70	Native	2.8	2.0	1.2-4.5	1.1-3.6
5/70	Hybrid	0.5	0.4	0.2-0.7	0.2-0.6
5/70	Native	$\cong$ 0.2	$\cong$ 0.2	$\cong$0.1-0.3	$\cong$0.1-0.2

Comparison of early growth between local oysters and hybrids indicates significant advantages to a shellfish hatchery (Table 1). If hybrids reared in middle Atlantic latitudes can attain commercial size in 1-1/2 to 2 years compared to native oysters which require 3 to 4 years, then a hybrid program will be extremely valuable.

Acquisition of new brood stock

Finally in May 1970, 60 specimens of two year old C. gigas were obtained from Tomales Bay, California. After several months in a temperature controlled, brood stock room mortalities were moderate. These oysters appear to be acclimating to their new living conditions. This young brood stock will be the base for our hybrid experiments throughout the coming year.

The facilities to spawn, rear and grow hybrids are available. Because of these facilities shellfish hybridization will receive increased attention within our Sea Grant Program.

PERSONNEL ACTIVE ON THE PROJECT

Don Maurer — 15% of the time

NSF Sea Grant

Final Report

THE INFLUENCE OF THE CLIMATIC WATER BALANCE IN THE ESTUARINE ENVIRONMENT

Dr. John R. Mather

College of Arts and Science
Department of Geography

FINAL REPORT

Objectives

The objectives of this sub-project have been to determine, from analysis of available climatic data, a) the volume of fresh water flow into the Delaware estuary and how this might change over time with changes in land use in the Delaware River basin, and b) the relation between this fresh water flow and salinity or other measures of water quality in the estuary of importance to shellfish.

The work on the project has proceeded along three separate though related lines.

1. Evaluation of long term daily and monthly climatic water balances for a large number of stations over the basin and the determination of quantitative information on water inflows and outflows in the estuary.
2. Study of the effect of changing land use on water runoff from one small sub-basin of the Delaware River.
3. Analysis of isochloric movements in the Delaware estuary during the five year period 1964-68.

Summary

The project began in July 1969 and has been in operation for 14 months. In that time, calculations have been completed of the monthly fresh water flow into the Delaware estuary from land runoff, and precipitation, the loss of water from the estuary through evaporation, as well as the net flow of water across the mouth of the estuary

(Cape May - Lewes) for a twenty-year period (1949-1968). The results show a marked seasonal trend as would be expected with high values of outflow in the late winter and spring and low values in the late summer and fall.

These flow values have been related to values of specific conductance (a measure of salinity) at four gaging stations in the river and estuary and significant correlations have been obtained. We have also studied the areal variation in the positions of the salt line (50 ppm, 100 ppm, 500 ppm etc) in the estuary and have prepared maps of the month to month movement of the various isochlors.

A detailed study of the changes in land runoff from one small sub-basin of the Delaware (Chester Creek basin) as a result of land use changes in the area over the past thirty years has also been completed. While only small changes in annual runoff have resulted, it is clear that a continuation of the suburbanization trend could accelerate the run-off changes noted.

Modification of Objectives

The work of the past year has resulted in the achievement of results on all major objectives of the sub-project. One of the original objectives, however, was the taking of certain meteorological observations of radiation, temperature, and evaporation near the estuary in order to obtain information on the reliability of our climatologic estimates of these factors. The instruments to obtain the measurements have now been obtained and are being installed but no data collection was begun during the first year of the program.

As a result of the first year of work it became clear that additional aspects of the relation between land and estuary hydrology needed to be investigated. The whole problem of the evaluation of the salinity observations themselves, their reliability and their representativeness, demanded more time than originally estimated. The question of the effect of land use change on runoff could profitably be expanded to other watersheds and cultural conditions. Thus, a proposal for a one year extension has been submitted and approved to allow for the achievement of even more useful results.

Relevance to Total Project

The availability of information on the flow of fresh water in the estuary and the monthly changes in salinity provides another necessary input to our whole study of the shellfish resources of the estuary since shellfish must respond strongly to salinity changes and overall water quality. While actual measurements of salinity are available in scattered locations, the ability to relate the more available climatic data to salinity and salinity movements, and also to provide predictions of possible future changes due to changes in land use will allow us to manage our shellfish resources more rationally and thus with less uncertainty.

Discussion of Significant Results

The net flow of water at the mouth of the estuary has been related to the changing salinity (specific conductance) at four gaging stations in the river and estuary. The net flow at the end of one month, as well as over a two or three month period have been related to the specific conductance figures at the beginning of the following month and it has been found that the most significant relation occurs when flow over a two month period is considered. This is because of the lag introduced by the slow movement of water from Trenton to the mouth of the estuary. The correlation coefficients are given below.

Correlation between Net Estuary Flow and Specific Conductance as Measured at Different Gaging Stations

	Lag		
	1 mo.	2 mo.	3 mo.
Net Estuary Flow vs Conductance at B. Franklin Br.	-0.90	-0.90	-0.84
Net Estuary Flow vs Conductance at Chester	-0.90	-0.93	-0.90
Net Estuary Flow vs Conductance at Del. Mem. Br.	-0.90	-0.91	-0.84
Net Estuary Flow vs Conductance at Reedy Island	-0.82	-0.84	-0.79

The correlation coefficients are high in all cases but the significance of the lag factor due to slow estuary flow is apparent. Further studies are still to be undertaken modifying the technique of lagging since clearly values of precipitation and evaporation directly over the bay need not be lagged as much as values of inflow from the river at Trenton or from other portions of the basin.

As a result of a detailed study of land use and runoff changes in the Chester Creek watershed, we have found that present land use changes have resulted in only a small increase in annual runoff, in line with similar results found in Rock Creek near Washington and from other small water-sheds. This appears to be due to the fact that suburbanization first results in an increase in wooded land as well as an increase in impervious surfaces. There is, of course, a decrease in pasture and cultivated land. While the impervious surface results in more rapid runoff and a greater volume of runoff, the wooded area will result in less runoff and a slower rate of runoff. These two aspects seem to balance so the net change in runoff is small initially. However, as suburbanization intensifies, the percentage of land in wooded areas will decrease and the amount of land in impervious cover will increase so that total runoff should increase. These trends have not yet been significant in the small watersheds studied but the results can be predicted from hydrologic considerations. The results of this study are being written up as part of a thesis for a Master's degree at the University.

Project Leadership

The study has been under the leadership of Dr. J. R. Mather, Chairman of the Department of Geography. Dr. Mather has worked approximately 20% of full time on the contract during the year. He has been assisted by Mr. Bruce Hartmann, a graduate student in the Department of Civil Engineering, who has worked 50% of full time during the year. Miss Ellen Bretz, a graduate student in the College of Education worked 75% of full time for one month on the contract while one undergraduate student, Miss Sharon Sartin, worked approximately 25% of full time during the academic year.

NSF Sea Grant

Final Report

ENVIRONMENTAL CONTROL SYSTEMS FOR CULTURING OYSTERS

Oscar R. Harman

College of Agricultural Sciences
Department of Agricultural Engineering

SUMMARY

The objective of the sub project was the development and analysis of a controlled environmental system for oyster culture.

Parameters studied were water quality, flow patterns and rates, temperature, population density and oyster location.

A 1000 gallon pilot closed system has been developed and constructed. Tests in the pilot system will be initated in October, 1970.

Results to date indicate:

1. Oysters can be maintained and grown in confinement.
2. Chemical analysis of the water showed little variation over long periods of time.
3. High flow rates of fresh sea water are not necessary.
4. Flow patterns and velocities are critical for feeding and fecal removement rather than flow rates.
5. A combination of sizing filters for larger particles and chemical filters for gas removal are effective.

Oyster nutrition remains the largest obstacle to confinement rearing. Combinations of fresh water algae and corn starch hold the most promise.

RELEVANCE TO TOTAL PROJECT

This sub project compliments and supplements the sub project "Development of Shellfish Culture Techniques from the Laboratory to the Field" by offering an alternative to open water culture of shellfish in the development of commercially valuable marine resources. Certain portions of the closed system approach may also be utilized to create a more efficient operation in early stages of open water culture.

DESCRIPTION OF SUB PROJECT AND RESULTS

Open water systems for shellfish culture are limited by climatic conditions and a necessity for a supply of acceptable sea water. With the problems of today's pollution this seawater supply may not always be the one most suitable for the organism that is being grown. It is, therefore, important to develop a closed system -- one which is self-supporting -- for the culture of aquatic organisms. This project dealt with the establishment of parameters for such a system and the development of a closed system based on the acceptable parameters.

Water Quality

Chemical analysis of the water showed little variation over long periods of time with proper filtering.

1. pH and salinity show minor variances with the source of variance most probably being evaporation from the tanks. Correction for pH should be applied only after salinity correction. The pH of the system seems to be seeking a pH of 7.
2. Total hardness measurements showed little change over a two-month period.
3. Dissolved oxygen levels can be considered fairly stable during the period provided the system is not polluted by over feeding.

4. Carbon dioxide levels were fairly constant over the test period.
5. Nitrogen tests showed no correlation among feeds but did show a continual rise. This indicates the need for plants in the system or other method of removal.
6. A combination of sizing filters for large particles and chemical filters (activated charcoal) for gas removal were effective in maintaining water quality in small tanks.

Flow Patterns, Rates and Velocities

Flow patterns and velocities rather than flow rates are critical for feeding and fecal removement. In rectangular tanks, intermittent counter flow was advantageous to move waste material from the leeward side of the oyster into the main flow stream and subsequently to the filters. In circular tanks a circular flow pattern causes the larger particles to congregate in the center where they may be siphoned off.

Minimum velocities sufficient to maintain the feces and pseudo feces in suspension are dependent upon oyster size and type of feces.

Pumping requirement may be substantially reduced by mechanical agitation.

Nutrition

Fresh water algae, corn meal, corn starch, soybean meal, trout mash and catfish chow were studied in feeding experiments. Some of the results indicated:

1. Corn starch and fresh water algae show the most promise.
2. Feeds with a high oil content tend to pollute the system and do not contribute to the nutritional requirements of the oyster.
3. Soybean meal was detrimental to oyster growth.

Oyster Placement

In initial studies oysters were located on the bottom of the tanks, however, due to the formations of an unsatisfactory micro environment, it became necessary to place the oysters on grids 4" from the bottom. Successive grids containing one layer of oysters may be stacked provided sufficient space be allowed between them to maintain flow patterns.

Orientation of the oyster to allow the flow to be directed to the open side facilitates feeding and feces removal.

Systems

A battery of 10 gallon systems have been utilized in determining the necessary parameters. The systems consist of a tank, pump, flow distributers sizing and chemical filters.

The pilot system with a 1000 gallon capacity is designed with gravel filters for sizing and utilizes harvestable plant life to digest waste products rather than expensive chemical filters.

FACILITY EXPANSION

The Agricultural Experiment Station of the University of Delaware has provided additional facilities for the marine environmental work since the inception of the project.

An aquacultural environmental research building with 1200 square feet of floor space and equipment to control water and air temperatures has accelerated the development of the closed system.

An aquaculture area to investigate the feasibility of pond culture has been made available which contains forty tanks 12 feet in diameter and 5 feet deep. Eight tanks are covered by a plastic greenhouse which can be heated in winter and ventilated in the summer. This structure will prevent dilution of the salt water from rainfall. In addition, the area contains three ¼ acre ponds and one 1/10 acre pond. Research in these structures have direct relevance to farm situations in Delaware. A major thrust will to develop programs to advise farmers as to the economical feasibility of including fin fish or shell fish culture as part of their farming enterprises.

INVOLVEMENT WITH OTHER GROUPS

This project has provided engineering assistance to the sub project "Development of Shellfish Culture Techniques from the Laboratory to the Field" in the design and construction of laboratory equipment for confined rearing of oyster larva and spat at the Lewes, Delaware laboratory.

Expertise in nutrition, chemical analysis and biological phenomena have been graciously provided by the staff in the department of Animal Science and Biochemistry, and Marine Biology.

The facilities of the controlled environment laboratory have been utilized by two Marine Biology graduate students in the study of micro organisms in closed systems.

PROJECT LEADERSHIP AND PERSONNEL

Oscar R. Harman, Assistant Professor in Agricultural Engineering.
Project Leader and Principal Investigator

Thomas H. Williams, Instructor in Agricultural Engineering
Faculty Associate

Robert P. Eastburn, Research Assistant in Agricultural Engineering
Co-investigator

Ernest N. Scarborough, Professor and Chairman of the Department of Agricultural Engineering
Faculty Associate

Clinton W. Woodmansee, Associate Research Professor in Animal Science and Agricultural Biochemistry
Faculty Associate

Dr. Robert L. Salsbury, Associate Professor in Animal Science and Agricultural Biochemistry
Faculty Associate

NSF Sea Grant

Final Report

REQUIREMENTS FOR SEPARATING VALVES OF OYSTERS

Thomas H. Williams

College of Agricultural Sciences
Department of Agricultural Engineering

SUMMARY

The purpose of this project was to investigate the effects of various physical stimuli on valve separation of the American oyster. This is a preliminary step in mechanizing the oyster shucking process without reducing the raw food quality of the meat.

Since the beginning of the grant period, sufficient laboratory facilities were established and the instrumentation necessary to conduct such an investigation were purchased.

Investigations have been conducted into:

1. physiology of "catch" muscles
2. electrical stimulation
3. ultrasonics
4. compressed air
5. thermal shock
6. physical properties
7. mechanical energy
8. concentrated heat
9. microwaves

The most promising energy sources for process development at this point appear to be infrared heat concentrated in the muscle area of the shell and whole body electromagnetic radiation with microwaves. Much more experimentation and development work needs to be done, however, before a mechanized oyster shucking process becomes commercially available.

OBJECTIVE

The objective of this project was to determine which physical and/or chemical stimuli would induce valve separation of the American oyster without changing the raw food quality of the meat. This is a preliminary step in mechanizing the oyster shucking process.

RELEVANCE TO THE TOTAL PROJECT

Oyster meat must be separated from the valves before additional processing for human consumption can take place. This oyster shucking operation is presently being accomplished in the industry with hand labor, with its associated scarcity, high cost, and low production rates. If a machine could be developed to extract the oyster meat from the shell, while maintaining or improving present quality, the disadvantages associated with hand labor could be overcome. Unless an oyster shucking device becomes available soon, the industry could face a critical labor situation.

DESCRIPTION

I. Background Review

The oyster industry today is at the brink of a labor crisis. The skilled oyster shuckers presently employed in raw oyster processing are becoming increasingly scarce. The average age of the current skilled shuckers is estimated to be in the 55 to 70 age group with very few younger persons willing to learn the necessary skills at the prevailing wage rates to replace those retiring. This leaves the industry with the alternatives of raising the wage rates and improving working conditions to attract more people into shucking houses or finding a method of mechanizing the oyster shucking process. The first alternative would undoubtedly price the product out of present markets whereas the second alternative could hold unit production costs down if a suitable process were found.

Many attempts have been made to mechanize the oyster shucking process. At least 20 U.S. Patents have been issued on oyster opening mechanisms since 1914. Research using chemical stimulants to open oysters was reported as early as 1932. In some parts of South Carolina a hot water dip method has been used to aid shucking of cluster oysters. More recently the Bureau of Commercial Fisheries Technological Laboratory, Gloucester, Massachusetts has been advocating the use of microwave ovens to facilitate shucking. Presently, there are at least 5 individuals or agencies known to be working on the oyster shucking problem. The industry to date, however, has not accepted any of the proposed methods.

II. Methodology

Literature Review on "Catch" Muscle Physiology

A literature review was accomplished to study the phenomena associated with "catch" mechanisms in molluscan muscles. Briefly, this study revealed that most of the research has been done using the excised anterior byssus retractor muscle in *Mytilus edulis* as a model and the results are not necessarily applicable to the adductor muscle in *Crassostrea virginica*. The physiological mechanism producing the "catch" phenomena is not yet well understood and the theories are still controversial among the various researchers. It was concluded that this study yielded no clues on simple techniques for releasing the "catch" muscle.

Electrical Stimulation

Physiologists had reported that if pulsed electrical stimuli are applied directly to the adductor while the muscle is in the tonic state, rapid relaxation would occur.

Therefore, experimentation was accomplished on direct stimulation of the oyster adductor muscle with electrical energy. Stimulation was applied through both silver and platinum electrodes inserted at various points directly into the muscle. The range of stimuli included:

a. direct current at levels of 1 to 300 volts

b. alternating current of 5 to 100,000 Hertz at 5 to 60 volts

c. pulsed direct current of 1 millisecond duration at 5 to 10 pulses per second at 10 volts

The stimulation time varied up to 30 seconds. The current between electrodes was held below 2 milli-amperes to prevent tissue burning. In all cases the use of electrical energy to induce muscle relaxation have been negative.

Ultrasonics

Several tests on oysters were conducted using an ultrasonic energy source feeding a one quart water bath. The ultrasonic generator had an output frequency of 40 kilohertz and power of 60 watts. Market size oysters placed in the water bath for up to 6 hours showed no gaping or other effects other than cleaner valves.

Thermally gaped oysters were also placed in the ultrasonic water bath to determine if this would cause valve and muscle separation. After ½ hour of exposure, there was no evidence of separation.

Compressed Air

A series of experiments were conducted using compressed air to gape oysters. High pressure air blasts (80-90 P.S.I.) were injected into the shell cavity through a 1/8 inch diameter probe. This caused temporary gaping with expulsion of water and bits of flesh from the cavity. When the pressure was released, the oysters would close. After repeated air blasts, the oysters were opened by hand and the meat was found to be severely damaged.

Low air pressures were also injected into the shell cavity. A bladder was used on the end of the probe to prevent the air pressure from escaping. Five to 20 pounds per square inch was enough pressure to cause temporary gaping with the oysters reclosing when pressure was removed. Thirty PSI was sufficient to cause permanent gaping of about 1/2 inch. This method did not seem to damage the meat. It was concluded, however, that there were too many disadvantages associated with the injection of compressed air to warrant further development.

Thermal Shock

Two methods of thermally shocking oysters were investigated. First, frozen oysters were dipped in hot water baths varying in temperature from 70° to 212° F. for up to one hour. The oysters did not gape in any of these tests. Secondly, oysters were placed in a flame oven with a temperature of 1600°F. for 1/2 to 1 minute, then dipped in a cool water bath. The results of this test varied depending on the size of the oysters. The smaller oysters were well cooked; the medium sized oysters were gaped and the meat could be easily shaken from the shell and did not appear cooked; there was no noticeable effect on the larger oysters. This method could merit further development if the oysters are graded by size and type and the heat and time of exposure adjusted accordingly. Due to the great variability of oysters, however, other methods will be investigated first.

Also, the Selas Corporation of Dresher, Pa. is pursuing this approach since this is the method they developed for processing surf clams.

Physical Properties

The physical characteristics were measured on a group of 25 oysters randomly selected from our holding aquarium to determine the variability and degree of correlation. The following parameters were determined: height; length; width; total weight; total volume; total density; meat volume; wet meat weight; dry meat weight; meat density; Engle's condition index; right valve weight; left valve weight; total shell weight; left valve volume; right valve volume; total shell volume; left valve density, right valve density; totalshell density; right muscle scar area; left muscle scar area; maximum, minimum and scar area shell thickness for left and right valves; weight, conductivity, density, and salt content of body fluid; percent weight of sea water, shell and body tissue. These data were statistically analyzed to determine the mean, standard deviation, standard error of the mean, and 95% and 99% confidence levels. These data will be useful in determining grading processes and the relationship between these properties and the energy from various sources required for gaping. Correlation tests were made between some parameters but were found to be insignificant.

Mechanical Energy

Forces and mechanical energies necessary to separate the valves were measured on 54 live oysters in various states of physical condition. This was accomplished by placing a tensile force on the valves in a pull test machine until the adductor muscle failed. Load and displacement were recorded on an X-Y recorder and the resulting graphs integrated to determine the work expended. The maximum forces recorded ranged from 5 to 76 pounds.

The energy expended until muscle failure ranged from 1.2 to 29.5 inch pounds. There was no particular relationship between these data and the oysters' physical characteristics. Although generally, the ones in better physical condition required more energy for valve separation.

Concentrated Heat

The adductor muscle in the oyster is attached to the shell by an adhesive organic film about 2 microns in thickness. A series of experiments conducted at Woods Hole concluded this material was collagen. Using this premise, preliminary tests were started on utilizing a small tipped oxy-acetylene torch to heat the shell very quickly only at the area of muscle attachment. It was found that the muscle became unattached from the shell within 5 to 10 seconds with the bond area reaching a temperature of about 140^{o}F. This temperature agrees with the breakdown temperature of moist collagen into gelatin reported in the literature. The oyster meat appeared to receive no cooking in the process. Further experimentation is planned in this area since a machine could be constructed using this technique. Another advantage to this method is the entire muscle is removed intact thereby improving the present product.

Microwaves

Work was begun on determining the effects of whole body electromagnetic radiation on oysters using microwaves. A power source was obtained with a 2.45 gigahertz fixed frequency and power output continuously variable from 50 to 2500 watts. The oysters were exposed in a microwave cavity with a preset timer, mode stirrer, and turntable. As expected at this frequency, the microwave energy is converted to heat within the oyster. This apparently weakens muscle tonus but does not necessarily cause gaping.

Also, too much exposure results in a cooked oyster which is unacceptable by present process criteria.

In order to limit the maximum temperature so that cooking is not evidenced, a relationship was established between the microwave energy per unit weight of oyster and the temperature rise.

A linear regression of the data on 60 oysters tested showed this to be $y = 1.7\,x + 5.5$ with a correlation coefficient of 0.8. Where:

y = microwave energy in cavity/oyster weight in joules per gram

x = temperature rise in the oyster meat in degrees Centigrade

1.7 = specific heat of oysters

5.5 = cavity loss factor

The next step in this investigation will be to determine if the microwave energy will divide between a group of oysters in proportion to their weight. If so, then a grading process will not be necessary and the total energy supplied can be programmed to the total weight of the oysters exposed. It will also have to be determined whether the rate the energy is applied has any effect on gaping. In addition, further mechanical treatment, such as shaking or vibration, may be effective in the total process.

INVOLVEMENT WITH OTHER GROUPS

This project involved not only the personnel and physical resources of the Department of Agricultural Engineering but the Biology Department, Electrical Engineering Department, and the Bayside Laboratory at the University of Delaware as well.

Three senior agricultural engineering students worked on special problems under this project.

Communication for idea exchange has been established with those persons and organizations currently working on oyster shucking mechanization. These are:

1. University of Maryland Seafood Processing Laboratory
2. University of Maryland Agricultural Engineering Department
3. Selas Corporation of America
4. Harris-Beaufort Company
5. Bureau of Commercial Fisheries
6. Oyster Institute of North America

Many persons,from State Legislators to high school students, have toured our facilities and been introduced to the work being done on this and other projects since the beginning of the grant period.

PROJECT LEADERSHIP AND PERSONNEL

Thomas H. Williams, Instructor in Agricultural Engineering.
Project Leader and Principal Investigator

Ernest N. Scarborough, Professor and Chairman of the Department of Agricultural Engineering.
Faculty Associate.

Oscar R. Harman, Assistant Professor in Agricultural Engineering.
Faculty Associate.

Ernest W. Walpole, Assistant Professor in Agricultural Engineering.
Faculty Associate.

Robert P. Eastburn, Research Assistant in Agricultural Engineering.
Co-investigator

Dr. Robert L. Salsbury, Associate Professor in Animal Science and Agricultural Biochemistry.
Facutly Associate.

Clinton W. Woodmansee, Associate Research Professor in Animal Science and Agricultural Biochemistry.
Faculty Associate

NSF Sea Grant

Final Report

MARINE EXTENSION PROGRAM

Rodner R. Winget

College of Marine Studies
and
University of Delaware Cooperative Extension Service

SUMMARY

During the 1968-1970 fiscal years, the University of Delaware marine extension service initiated four projects designed to enhance aquatic resources of Delaware. These involved planting clam shell oyster cultch in Delaware Bay and Delaware tributaries of the Bay, planting seed oysters in Delaware Bay, catfish culture, and artificial reef construction in the Atlantic Ocean near Indian River Inlet. The extension service also assisted the Aquapure Corporation in choosing a location for an oyster depuration plant.

OBJECTIVES

The objective of the marine extension subproject was to assist Delaware residents in gainful use of marine resources of Delaware through information dissemination, counseling and demonstration projects.

RELEVANCE TO TOTAL PROJECT

A major goal of the Sea Grant project was revival of the Delaware shellfish industry. The extension service supported this goal by initiating projects designed to rehabilitate the supply of oysters in Delaware Bay and its tributaries within Delaware, and to increase the lobster supply on the Atlantic Ocean near Delaware shores. This goal was also supported by counseling industry in the utilization of existing oyster supplies. Projects were also initiated to increase the supply of finfish to Delaware residents.

DESCRIPTION OF SUBPROJECT AND RESULTS

Oysters

All of the natural seed oyster setting areas in Delaware are State owned and no privately owned or leased areas are useful for seed oyster production. Oystermen are hesitant to plant imported oysters because of possible disease introduction. Therefore the extension service obtained funds to transplant 1200 bushels of seed oysters from the natural beds to three planted beds in Delaware Bay. Subsequent mortality studies indicated that the transplants were moderately successful.

Preliminary surveys indicated that Delaware tributaries to Delaware Bay possessed poor setting substrates for oyster larvae. Therefore funds were obtained for placing waste surf clam shells in these rivers as oyster cultch. To date approximately 100,000 bushels have been planted. The project is still in progress. This project is under direction of the State Department of Environmental Health.

The extension service also gave technical information and counseling to the Aquapure Corporation regarding the location of its oyster depuration plant in Lewes.

Lobster and Finfish

Attempts at catfish farming have been successful in other portions of the United States, particularly in the South. The feasibility of catfish culture in Delaware was examined by placing 4,000 fingerlings in the Ferris school pond. Results indicate that rearing this species in Delaware in feasible.

Most of the maritime states of the United States have attempted artificial reef construction. These reefs, made from a wide variety of material, attracted large numbers of fish. The major problem associated with construction material was cost and durability. Results of investigations by the Bureau of Sport Fisheries at Sandy Hook, New Jersey, indicate that the most practical material is weighted auto and truck tires.

The extension service initiated an artificial reef construction program to increase the supply of finfish and lobsters available to Delaware residents. Several hundred tires were weighted with cans filled with concrete. Tires are available without cost, and local fishermen are willing to transport them to the reef site 5 miles east of Indian River Inlet at their own expense. Although small quantities of tires can be weighted with waste concrete and cans donated by local industries, sinking large numbers of tires requires financing. We are currently investigating this problem.

One must have a permit from the Army Corps of Engineers to place reef material on the ocean floor, followed by a permit from the Coast Guard to mark the site with a buoy. We have been seeking a permit from the Corps since late January but have not obtained it as of this writing, although they have consistently indicated verbally that a permit would be forthcoming. Reef construction has not yet started for this reason.

To facilitate organization of reef building and utilization procedures, the Delmarva Artificial Reef Association was established as a non-profit Delaware corporation with two University personnel and a Lewes businessman as officers. This organization has addressed several citizens groups, such as the Indian River Inlet Captains

Association, Delmarva Hospitality Incorporated, and representatives of the Delmarva Advisory Council, Solid Waste Management groups, and local sport fishing interests to give information and receive suggestions concerning reef associated activities. These efforts have created considerable enthusiasm and a spirit of cooperation among many Delaware residents in a program designed to increase the production and utilization of marine resources. The only major obstacle has been the Army Corps of Engineers.

Extension activities also included consultation to the Delaware Department of Environmental Health concerning biological aspects of clam shell reef construction in the Harbour of Refuge, Delaware Bay.

PERSONNEL ACTIVE ON THE PROJECT

Name	Position	% of Salary
Rodner R. Winget	Resident Biologist	50
Theodore P. Ritchie	Resident Biologist	50
Howard H. Seymour	Resident Chemist	0

NSF Sea Grant

Final Report

SYSTEMS ANALYSIS OF OYSTER PRODUCTION

Dr. Frederick A. Costello

College of Engineering
Department of Mechanical and Aerospace Engineering

SUMMARY

As the first step in the development of a systematic procedure by which the development of commercially valuable marine resources can be effected, a computer simulation of an oyster-production facility has been completed. This simulation will be used in optimization studies and in the design of a research program that will lead to maximizing the profit of the oyster industry.

Goal

The goal of this task is the development of the systematic procedure mentioned in the summary.

Relevance to Total Project

This task will result in a procedure that will be useful in the cost-effectiveness studies of the various research programs proposed and being pursued in conjunction with the use of oysters as a marine resource.

Introduction

The purpose of this research task is to develop a systematic procedure by which the development of commercially valuable marine resources can be effected. To keep the procedure from becoming too abstract and to demonstrate its usefulness, the procedure is being developed concurrently with its application to the commercial production of oysters.

The approach taken involves a computer simulation of a closed-environment oyster-production plant, which will be used to design the plant based on the current state of knowledge and to analyze the effects of possible production improvements on the initial and operating costs of the plant. Estimates will be made of the magnitudes of these improvements in terms of the physical gains, such as accelerating the oyster growth rate. These estimates will be used in a sensitivity analysis using the computer simulation so the physical gains can be translated into cost reductions or profit improvements. In addition, the cost of implementing these improvements will be estimated. Finally, a research program will be developed that will have as its objective the development of an investment policy that should be followed in support of the research to maximize the profit from the industry over its entire life.

The above procedure will be developed on a deterministic basis, using, for example, the average growth rate of oysters for the growth rate of each oyster. In addition, so the technique will be useful in practice, the stochastic nature of the oyster growth pattern, occurrency of disease, the market, the predictions of research results, etc., will be included.

Present Personnel and Activities

The effort expended so far includes 1 man-month of faculty time and 6 man-months of graduate-student time. Dr. F. A. Costello of the Mechanical and Aerospace Engineering Department has assumed the leadership of this project, since Dr. Gaither had to relinquish his co-investigator position when he became Dean of the College of Marine Studies. Miss Margaret Lucas, a graduate student, is completing her Master's thesis involving the simulation of the oyster-production plant, following the system outlined in the American

Cyanimid report. Miss Ann (Wendy) Morrison, a new graduate student, has begun to investigate the development of the optimal research program. Mr. Brent L. Marsh, a Doctoral candidate who is not sponsored by this project, has begun the investigation of the optimization of the plant in the presence of uncertainty.

Schedule

Miss Lucas' work has been delayed slightly due to her participation in the Tektite program. The original schedule called for the completion of her work by August 31, 1970. The completion date will more likely by in October,1970. Miss Morrison's work should be completed by August 31, 1971. Mr. Marsh's work will take at least two years.

Summary of Research

Except for a few minor additions, such as the cost of the cooling coils in the algae tanks, the computer simulation of the oyster-production facility is complete. Figure 1 presents a layout of the plant, as simulated. No parametric studies have been made as yet; such a study will not be warranted until the final minor additions are made.

The following paragraphs show input data required by the computer program, a description of the organization and sub-programs of the simulation and typical output data. A listing of the computer program is presented in the Appendix to this section.

1. Input Data:

The following data is required as input for each computer analysis (Table 1 shows typical values):

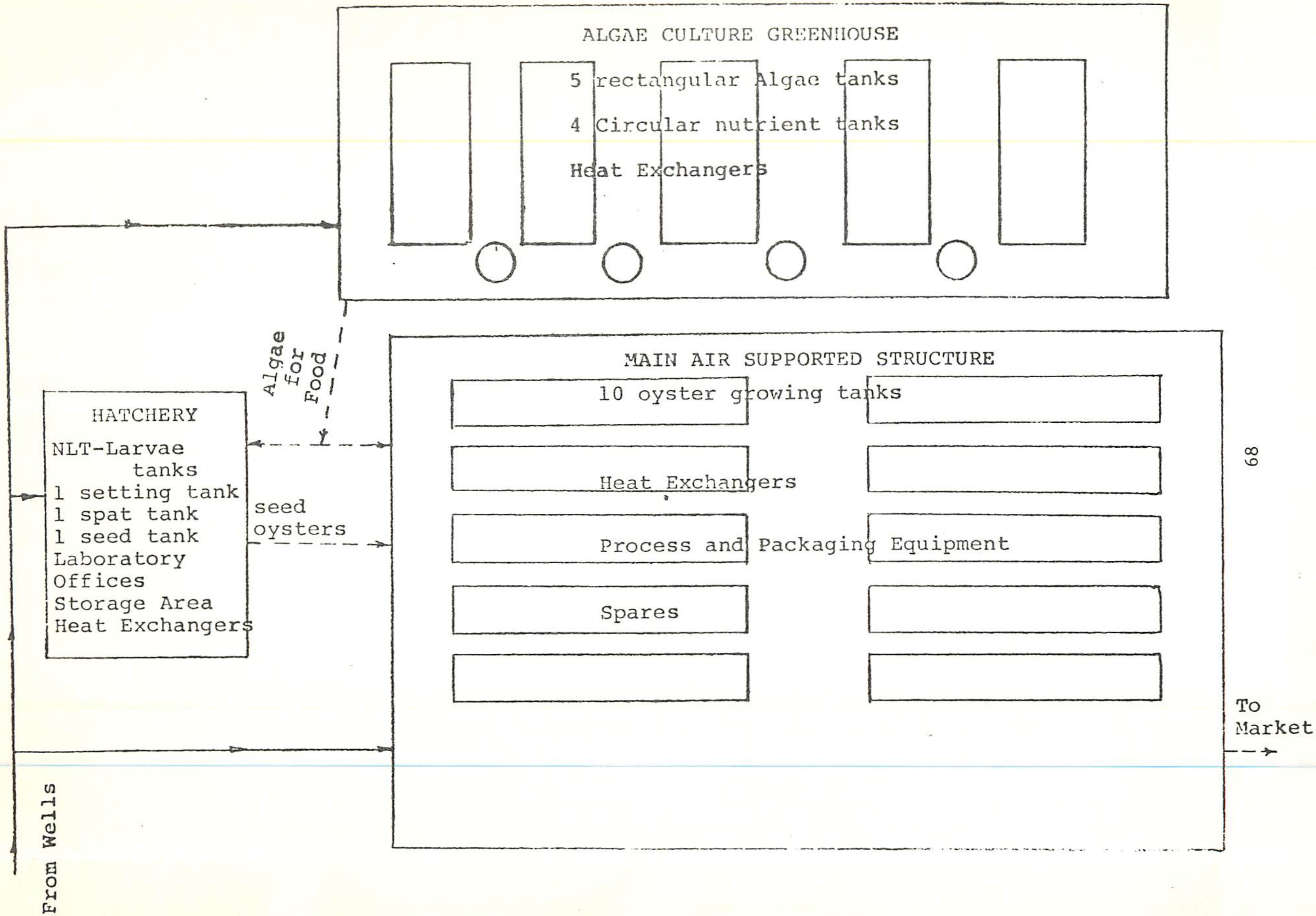

Figure 1: OYSTER COMPLEX

Card	Field	Symbol (internal to program)	Data
1	F7.3	A	Algae cells per day that are required
	F7.3	B	Concentration in cells per liter
	F7.3	D	Depth of shallow algae tank
	F7.3	W	Width of shallow algae tank
	F7.3	P	Price per sq. ft. of wall area
	F7.3	PP	Cost/sq.ft. of wall area per foot of height
	F7.3	Q	Cost per sq. ft. of bottom area
	F7.3	QQ	Cost per sq. ft. of linear area
	F7.3	R	Ratio that controls the shape of the corners for shallow tanks
	F7.3	Y	Depth of the deep algae tank
	F7.3	Z	Width of deep algae tank
2			(Arrays used to set as upper and lower limits and increment sizes for optimization program PATSRCH)
	F7.3	DX(1)	
	F7.3	XMIN(1)	
	F7.3	XMAX (1)	
	F7.3	DXMIN(1)	
	F7.3	DX(2)	
	F7.3	XMIN(2)	

	F7.3	XMAX(2)	
	F7.3	DXMIN(2)	
3	F7.3	DXX(1)	
	F7.3	XXMIN(1)	
	F7.3	XXMAX(2)	
	F7.3	DXXMIN(1)	
	F7.3	DXX(2)	
	F7.3	XXMIN(2)	
	F7.3	XXMAX(2)	
	F7.3	DXXMIN(2)	
4	F12.4	CAP	Capacity of larvae tanks
5-8	5F12.4	C(L)	Array of tank constants for setting tanks (5 per card)

FOR COLLECTION TANKS

C(1) = VERTICAL CLEARANCE BETWEEN COLLECTORS
C(2) = COLLECTOR STACKING
C(3) = VERTICAL CLEARANCE ABOVE COLLECTORS
C(4) = HEIGHT OF COLLECTOR
C(5) = COST OF COLLECTOR
C(6) = HORIZONTAL SPACING
C(7) = COST/SQ. FT. OF WALLS
C(8) = COST/SQ. FT./FT. OF WALL
C(9) = COST/SQ. FT. OF BOTTOM
C(10) = 0.0
C(11) = 0.0
C(12) = COST/SQ. FT. OF LINER
C(13) = NUMBER OF COLLECTORS / ROW
C(14) = LENGTH OF COLLECTOR
C(15) = WIDTH OF COLLECTOR
C(16) = DENSITY

Card	Field	Symbol	Data
9	F12.4	CAREA	Area of one collector
10-13	5F12.4	C(I)	Array of tank constants for spat and seed tanks (5 per card)

FOR SEED AND SPAT TANKS

C(1) = VERTICAL CLEARANCE BETWEEN COLLECTORS
C(2) = COLLECTOR STACKING
C(3) = VERTICAL CLEARANCE ABOVE COLLECTORS
C(4) = HEIGHT OF COLLECTOR
C(5) = 0.0
C(6) = HORIZONTAL SPACING
C(7) = COST/SQ. FT. OF WALLS
C(8) = COST/SQ. FT./FT. OF WALL
C(9) = COST/SQ. FT. OF BOTTOM
C(10) = 0.0
C(11) = 0.0
C(12) = COST/SQ. FT. OF LINER
C(13) = NUMBER OF COLLECTORS / ROW
C(14) = LENGTH OF COLLECTOR
C(15) = WIDTH OF COLLECTOR
C(16) = NUMBER OF TANKS

Card	Field	Symbol	Data
14	314	J,M,NT	J = oyster stacking M = 1 if deep tanks are to be used for growing tanks M = 2 if shallow tanks are to be used NT = number of months an oyster is allowed to grow in each tank
15-17	5F12.4	C(I)	Array of tank constants for oyster growing tanks (5 per card)

FOR DEEP TANK

C(1) = VERTICAL CLEARANCE BETWEEN BASKETS
C(2) = BASKET STACKING
C(3) = VERTICAL CLEARANCE ABOVE BASKETS
C(4) = BOTTOM AREA OF BASKETS
C(5) = COST OF ONE BASKET
C(6) = SEPARATION HORIZONTALLY BETWEEN BASKETS
C(7) = COST/SQ. FT. OF WALLS
C(8) = COST/SQ. FT./FT. OF WALL
C(9) = COST/SQ. FT. OF BOTTOM
C(10) = 0.0
C(11) = 0.0
C(12) = COST/SQ.FT. OF LINER
C(13) = NUMBER OF BASKETS PER ROW IN ONE LAYER
C(14) = LENGTH OF BASKET
C(15) = WIDTH OF BASKET

FOR SHALLOW TANK

C(1) = VERTICAL CLEARANCE BETWEEN BOTTOM AND GRID
C(2) = 1.0
C(3) = VERTICAL CLEARANCE ABOVE OYSTERS
C(4) = 1.0
C(5) = 0.0
C(6) = 0.0
C(7) = COST/SQ. FT. OF WALLS
C(8) = COST/SQ. FT./FT. OF WALL
C(9) = COST/SQ. FT. OF BOTTOM
C(10) = COST/SQ. FT. OF GRID
C(11) = COST/SQ. FT. OF MESH
C(12) = COST/SQ. FT. OF LINER
C(13) = TANK WIDTH
C(14) = 0.0

The following data is intrinsic to the program, being stored in BLOCK COMMON. If this data is to be changed, the BLOCK COMMON subroutine must be re-compiled.

W(I) = Array of average width of oyster for particular time time interval in mm.

XL(I) = Array of average length of oyster in mm.

H(I) = Array of average thickness of oyster in mm.

P(I) = Projected population of oysters in tanks for each interval of time.

Y(I) = Average flow of water required per oyster in liters/day - oysters for each interval of time.

S(I) = Arrays of available pipe diameters suitable for oyster and setting tanks.

EST(I) = Corresponding array of cost/ft. of pipes.

F(I) = Corresponding pipe factor ^{FN}.

LENGTH(I) = Corresponding standard length of pipes.

ETAP = Efficiency of pump.

ETAM = Efficiency of motor.

KWHC = Cost of electricity per kilowatt hour.

XINT	= Rate of appreciation of investment.
GAL(I)	= Array of space requirements of individual oysters in gallons/oyster.
S2(I)	= Array of available pipe diameters suitable for water supply and waste disposal system.
EST2(I)	= Corresponding array of cost/feet of pipes.
T2(I)	= Temperature level control for larvae.
T2(2)	= Temperature level control for spat and seed oysters.
T2(3)	= Temperature level control for oyster in oyster growing tanks.
T1(I)	= Temperature of input water for each month.
TG(I)	= Flow requirements for each development state (Larvae, Spat and Seed, and Oyster) in gpm.
RT	= Pumping cost per unit.
ERT	= Heating Cost per unit.
L1	= Estimated length of pipe leading from wells.
L2	= Estimated length of main without any additional water added for salinity adjustments.
L3	= Estimated length of main with salinity adjustment.
SGPM	= Maximum flow rate in main with salinity adjustment in gpm.

TABLE I TYPICAL DATA

```
                                               U U START OF SEGMENT ********** 16
      BLOCK DATA                                                  R 0000
      COMMON/BLK1/XL(20),H(20),W(20),P(20),GPM(20),Y(20)          R 0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,FTAM,KWHC,XINT  R 0000
      COMMON/BLK3/C(20),GAL(20)                                   R 0000
      COMMON/BLK4/S2(12),EST2(12),T1(12),T2(3),TG(3),RT,ERT       R 0000
      COMMON/BLK5/L1,L2,L3,SGPM                                   R 0000
      REAL KWHC                                                   R 0000
      REAL L1,L2,L3                                               R 0000
      DATA (W(I),I=1,13)/0.3,7.6,14.3,28.5,35.2,40.5,44.3,48.,51.,54.0,  R 0000
     +57.1,59.7,60.0/                                             R 0013
      DATA(XL(I),I=1,13)/.3,10.,19.,38.,47.,54.,59.,64.,68.,72.,76.,  R 0016
     +79.5,80./                                                   R 0029
      DATA(H(I),I=1,13)/0.0,5.,8.7,16.5,18.6,20.3,21.5,22.7,23.7,24.6,  R 0032
     +25.6,26.4,26.5/                                             R 0045
      DATA(P(I),I=1,13)/.6E07,.36E07,3*.32E07,2*.31E07,3*.29E07,  R 0048
     +2*.28E07,.26E07/                                            R 0061
      DATA(Y(I),I=1,13)/.0005,.07,.365,2.49,3.57,4.64,5.22,6.49,7.42,  R 0064
     +8.25,9.3,10.2,10.2/                                         R 0077
      DATA(S(I),I=1,18)/.125,.25,.375,.5,.75,1.,1.25,1.5,1.75,2.,2.5,3.,  R 0080
     +3.5,4.,5.,6.,8.,10./                                        R 0093
      DATA (EST(I),I=1,18)/.06,3*.08,.1,.15,.2,.27,.35,.44,.67,.92,1.2,  R 0096
     +1.75,2.5,3.75,6.25,10./                                     R 0109
      DATA (F(I),I=1,18)/13*1.5,5*1.4/                            R 0112
      DATA (LENGTH(I),I=1,18)/9*20,9*10/                          R 0128
      DATA ETAP,ETAM,KWHC,XINT/.75,.85,0.015,.08/                 R 0144
      DATA(GAL(I),I=1,13)/.000047,.000136,.0011,.005,.0095,.0134,.016,  R 0162
     +.018,.02,.021,.0225,.0236,.025/                             R 0176
      DATA(S2(I),I=1,12)/6.,8.,13.,12.,14.,16.,18.,24.,30.,36.,42.,72./  R 0179
                                                         SEGMENT 17 IS 237 LONG
      DATA(EST2(I),I=1,12)/1.55,3.85,3.5,5.25,6.6,8.8,12.,21.,33.,48.,  R 0195
     +68.,75./                                                    R 0208
      DATA(T2(I),I=1,3)/72.,80.,68./                              R 0211
      DATA(T1(I),I=1,12)/50.,58.,65.,65.,62.,57.,45.,40.,38.,36.,37.,  R 0227
     +44./                                                        R 0240
      DATA(TG(I),I=1,3)/110.,330.,39560./                         R 0243
      DATA RT,ERT/.0061326,.031462/                               R 0259
      DATA L1,L2,L3,SGPM/35000.,3000.,2000.,49600./               R 0271
      END                                                         R 0290
```

```
                                                                        START OF SEGMENT ***********   24
BLOCK DATA                                                                               R  0000
COMMON/BLK8/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT                            R  0000
REAL KWHC                                                                                R  0000
DATA(S(I),I=1,8)/1.,2.,3.,4.,5.,6.,8.,10./                                               R  0000
DATA(FST(I),I=1,8)/.268,.5851,1.21,1.7272,2.34,3.0394,5.2747,7.46/                       R  0016
DATA (F(I),I=1,18)/18*.5/                                                                R  0032
DATA(LENGTH(I),I=1,8)/8*20/                                                              R  0048
DATA ETAP,ETAM,KWHC,XINT/.75,.85,0.015,.08/                                              R  0064
END                                                                                      R  0082
```

```
 100.0
  .67          2.        .67        2.        1.
  .5          2.7        .26       2.0        0.0
 0.0           .052     5.0        1.0        1.51
    1.0
4000.0
   .67        4.0       3.2        2.0       0.0
    .3         2.7        .26       2.0      0.0
 0.0           .052     5.0        1.0       1.51
2.0
 4   1
    .25        20.      3.0        2.0        5.0
    .3          2.7      .26       2.0       0.0
    .0           .052     10.        2.       1.
```

2. <u>Program Organization</u>:

The program consists of the main program, seven major subroutines, five minor subroutines, and input data. For a set of input data, costs of building and operating a closed environment oyster facility are computed. Ideally this facility can be located in an area where land, taxes and labor are cheap; therefore not necessarily near the shore. There must be a source of unpolluted water but not necessarily saline. Artificial sea water can be produced chemically and the oyster facility will contain its own source of food in an algae-culture system.

Of the seven major subroutines the first six represent the subsystems of the plant operations and the seventh is mechanism for print out.

SUB I - Algae Culture System

SUB II - Hatchery

SUB III - Oyster Growing Tanks

SUB IV - Processing and Packaging

SUB V - Water Supply

SUB VI - Waste Disposal

SUB VII - Print out format

The five minor subroutines are called from one or more of the major subroutines. These are:

PIPEOP - Pipe Optimization for Hatchery and Oyster Growing Tanks

PO2 - Pipe Optimization for Water Supply and Waste disposal systems

CONSTRUCTION - Construction and Operating costs.

TANKS - Design of all tanks used in the facility except larvae.

PIPING - Installation, pumping and pipe costs for oyster tanks.

PATSRCH - An optimization subroutine called from Sub I for use with sizing Algae tanks.

COOL - Design and sizing for cooling pipes used in algae tanks.

XPIPING - Installation, Piping and Pipe cost for water and air system for shallow algae tanks.

PIPINA - Installation, Piping and Pipe cost for air system for deep algae tanks.

DEEP - Installation, Piping and Pipe cost for water system for deep algae tanks.

PIPEA1 - Pipe Optimization for air systems for algae tanks.

The following paragraphs describe each of the subroutines in some detail:

<u>SUB I - ALGAE CULTURE SYSTEM</u>

SUB I is called from the main program. In it, the computations are made for the cost of the algae system. The tank size and shape (deep or shallow) are optimized in the process of the computation.

<u>SUB II - HATCHERY</u>

SUB II is called from the main program and calculates the costs of building and operating the hatchery. The hatchery includes larvae tanks, setting tanks, spat and seed tanks, construction, and miscellaneous laboratory and operational equipment.

1. LARVAE

The capacity of the larvae tanks is a design variable input for each case. Limitations on this number is biological only in that the designer must know the quantity of larvae that the biologist can efficiently handle at one time. For example, the mortality rate may be high if large quantities of larvae (500 gallons) are placed in one container - at the other end of the spectrum, the cost of many small tanks (5 gallons) may be high. The ideal situation is to balance these two factors and find the most economical arrangement. Another assumption that is made is the required quantity of water for each individual oyster (Y(I)). This is determined by the biologist through experimentation.

To determine the number of larvae tanks needed (NLT=(GPM(1)/CAP)*.5), the required water flow is divided by the capacity of one tank and then multiplied by 0.5, since

> "The parent oysters do not spawn all the eggs at one time, but rather at certain time intervals, and the larvae stay only for a few days in one stage. All the tanks used for larvae rearing should be of the same size and construction, to permit interchangeability in use for the different stages of larval growth."

Therefore, the number of tanks is not water flow divided by the capacity of one tank but one-half that value.

The cost of the larvae tanks is calculated using the methods outlined for cost estimation in the text by RUDD and WATSON. This estimation is derived for tanks in the range of 50 to 100 gallon tanks. BASE 3 is the total base area required for the total number of larvae tanks. This value is used to calculate construction costs.

2. SETTING TANKS

From the larvae tanks the young oysters are placed in setting tanks where they remain until they have affixed themselves to the collectors. The size of the setting tank depends on the type of collectors used and the length of time they remain in the tank. The desired setting density is read in as input and is a direct function of length of time the collectors are in the tank. This should be determined by experimentation. The type and size of collectors is also described by the user and read in as data.

The setting area of one collector is also input data (CAREA), computed by the designer. Given the density of set, the total area required to set a batch of oysters and the number of collectors (NCOL) are computed. The tank design is performed in Subroutine TANK, which is called from subroutine SUB II.

SUB III - OYSTER GROWING TANKS

This subroutine controls the design of the oyster tanks. The parameter describing oyster growth (height, length, and width) are first changed from millimeters to feet, since further calculations are done in British units. The oyster size is a design variable. Other design variables are read from data cards; they are: oyster stacking (J), an indicator (M), frequency of tank design (NT) and an array of tank constants (C(I)).

Oyster stacking (J) refers to the arrangement of oysters within a tank. In the deep tanks the oysters will be arranged in baskets. Within the baskets the oysters will be stacked in any number (J) of levels. The shallow tanks are designed for stacked levels (J) on a large grid covering the base of the tank.

The indicator (M) tells the program which type of tank is to be designed. M=1 for deep tank and M=2 for shallow tank.

NT determines the number of different size tanks to be used. There can be a different size tank for each month of the oyster's growth or the oyster can remain in one tank for two months or more. Thus tanks will be designed to accommodate the oyster at the maximum age (size) that he will attain while in that tank. It is assumed that there will be one tank of oysters spawned and set during each month.

The tank constants impose some restraints upon the overall tank dimension. However, the size of the oysters and population in each tank basically determine size. NB is a function of these variables. V(I) is the volume of one oyster; V5 is the height of oysters (H(I)*J); NO is the part of an oyster per square ft; and NB gives the base area of a shallow tank or the number of baskets used in a deep tank.

In addition to the tank cost, construction cost for this part of the plant are calculated by way of Subroutine CONSTRUCTION.

SUB IV - PROCESSING AND PACKAGING

Processing and packing are an undefined system. There are several different ways in which the oyster can be marketed: in bushels (unshucked, fresh) shucked and canned, shucked and frozen and on the half shell. To set worth to any of these methods would require a detailed market analysis which is not available. For the scope of the analysis, processing and packing take the simplest form - fresh, packed in bushels - thus leaving the buyer the opportunity to further process them as he feels appropriate.

A bushel will contain an average of 300 oysters and the number of bushels per year (NBPY) is equal to the number of oysters at the end of the final month of growth times 12 months divided by 300 oysters. Cost of the processing system is assumed to be linear and vary directly with the number of oysters produced. Packaging supplies (SUP) are 5 cents per bushel and operating costs (UTIL) are .01 per bushel.

SUB V - WATER SUPPLY

Subroutine V is reserved for the water supply system. Currently, a well system is used with no recycling.

SUB VI - WASTE DISPOSAL

Subroutine SUB VI describes a waste disposal system that may be entirely unacceptable. It allows for a disposal of all waste directly in the environment without treatment. Wastes will be carried out through one large drain and cost is estimated as the cost to buy the needed length of pipe of the optimum size found by subroutine piping. More sophisticated systems can include recycle systems which would combine SUB V and SUB VI. As the systems are described for this analysis they are separate and the same flow of water leaves the system as enters it.

The structures used to house the hatchery and oyster tank operations will be of the air supported type. They require a cement flooring, the structure, blowers to keep the structure inflated and lights. Estimates for these variables are based on the assumption that they are linear function of required floor space. Values given in the CYANAMID report represent the constants of these equations.

PIPEOP, PO2 AND PIPEA1

Pipe optimization (PIPEOP, PO2 and PIPEA1) is done using the fact that an equivalent-first-cost-vs.-pipe diameter curve will have one minimum point. The cost (WORTH) includes the cost of the pipe itself plus the cost of pumping a given flow of water. The calculations are done for set values of pipe diameters (S(I) and S2 (I)) and respective costs (EST(I) and EST2 (I)) given in BLOCK DATA.

Starting with the largest pipe diameter, the subroutine searches along the curve until the cost increases. The optimum is taken as the size pipe of the preceding cost calculation (S(I)).

3. Output Data:

The following pages show typical output data from the computer program.

```
HATCHERY DESIGN

   COST OF  23 LARVAE TANKS                    11452.84     WITH A CAPACITYOF  100. GAL.
                                                         HEIGHT      6.
                                                         LENGHT     13.
                                                         WIDTH      11.

   COST OF SETTING TANK                         1613.11
     6.00
     1.25
     0.50
PUMPING COST        134.50
                                                         HEIGHT     14.
                                                         LENGHT     98.
                                                         WIDTH       9.

   COST OF   2 SPAT AND SEED TANKS             210177.06
   COST OF CONSTRUCTION                       43589.60

   COST OF UTILITIES                            3832.72

 TOTAL HATCHERY COSTS                         266832.60

        DEEP TANK DESIGN FOR OYSTER STACKING OF  4
     6.00
     1.50
     0.50
PUMPING COST        90.06
                                                         HEIGHT     15.
                                                         LENGHT     81.
                                                         WIDTH      13.
   COST OF TANKS FOR   5 MONTH OYSTERS     260794.64
     8.00
     1.50
     0.50
PUMPING COST        80.26
                                                         HEIGHT     15.
                                                         LENGHT    125.
                                                         WIDTH      13.

   COST OF TANKS FOR   7 MONTH OYSTERS     404712.08
```

8.00
1.50
0.50
PUMPING COST 162.21

HEIGHT 15.
LENGHT 154.
WIDTH 13.

COST OF TANKS FOR 9 MONTH OYSTERS 499978.82
8.00
1.50
0.50
PUMPING COST 261.47

HEIGHT 15.
LENGHT 187.
WIDTH 13.

COST OF TANKS FOR 11 MONTH OYSTERS 603386.46
8.00

1.50
0.50
PUMPING COST 273.70

HEIGHT 15.
LENGHT 191.
WIDTH 13.

COST OF TANKS FOR 13 MONTH OYSTERS 618116.55
COST OF CONSTRUCTION 129585.17

COST OF UTILITIES 24235.33

TOATL OYSTER TANK COSTS 2516573.72

360000.00	- Cost of wells
54250.00	- Cost of piping from wells
10500.00	- Cost of main
7000.00	- Cost of pipe for salinity adjustment
372853.38	- Pumping costs
612850.00	- Cost of U. V. sterilization
5386.36	- Cost of direct fired heater
19661.89	- Cost of exchanger for algae
46728.52	- Cost of exchanger for larvae
1594976.44	- Cost of exchanger for oyster
27928.82	- Cost of running algae exchanger
113687.94	- Cost of running larval exchanger
8251941.45	- Cost of running oyster exchanger

PHYSICAL PLANT COSTS

WATER FLOW OF [illegible]607[illegible] GPM

HATCHERY AND LAB	266832.60
OYSTER TANKS	2516573.72
PROCESSING	73440.00
WATER SUPPLY	3084206.59
WASTE DISPOSAL	17500.00
SUBTOTAL	5958552.91
INSTRUMENTS	297927.65
PHYSICAL PLANT COST	6256480.55

MANUFACTURING COSTS

SUPPLIES	100000.00
LABOR RELATED COST	574948.00
FIXED CHARGES	1188731.30
UTILITIES	8422034.46
MANUFACTURING PER YR	10285713.76
COST PER BUSHEL	102.86

Current Plans

Miss Morrison is working on the research and development aspects of the oyster-production problem. After orientation, she, along with the other investigators on this project (and anyone else in a position to help), will spend some time postulating ways of improving the production system. The list of variables generated in the first year of this project will be used to stimulate ideas. As reported in the first annual report, the following areas of improvement can be expected to be important:

1. Breeding: spawning control, sterilization, cultch design
2. Growth control: use of higher temperature for greater growth (may require temperature adaptation), optimizing salinity, optimizing water requirements, shape control, optimum diet
3. Waste control: treatment and uses
4. Energy conservation
5. Disease control
6. Market analysis

Once the improvements are postulated, the costs of effecting the improvement will be estimated for each possibility and an optimum investment policy will be developed on the basis of these estimates. Because there will be uncertainty in the estimates developed and in the results of the research and development programs considered, some consideration will be given to the stochastic nature of the problem. This aspect will be especially important in cases where the primary objective of the research is to reduce the uncertainty in one of the production parameters.

APPENDIX: The following is a listing of the computer program.

```
C     THE FOLLOWING ARRAYS GIVE THE PARAMETERS ASSOCIATED WITH INDIVI-        R  0000
C     DUAL OYSTERS FOR EACH MONTH OF GROWTH (ASSUMING GROWTH TO                 R  0000
C     MARKET SIZE IN 13 MONTHS).                                                R  0000
C             W(I)=WIDTH IN MM)                                                 R  0000
C             XL(I)=LENGTH IN MM.                                               R  0000
C             H(I)=THICKNESS IN MM.                                             R  0000
C             P(I) =POPULATION                                                  R  0000
C             Y(I)=INDIVIDUAL WATER REQUIREMENTS                                R  0000
C     S(I)=ARRAY OF STANDARD PIPE DIAMETERS                                     R  0000
C     EST(I)=COST PER FOOT OF PIPE                                              R  0000
C     F(I)=PIPE FACTORS                                                         R  0000
C     LENGTH(I)=STANDARD LENGTH OF S(I)                                         R  0000
C     ETAP=EFFICIENCY OF PUMP                                                   R  0000
C     ETAM=EFFICIENCY OF MOTOR                                                  R  0000
C     KWHC=COST OF ELECTRICITY/KILOWATT HOUR                                    R  0000
C     XINT=INTEREST RATE                                                        R  0000
                                           START OF SEGMENT ***********   1
      COMMON/BLK1/XL(20),H(20),W(20),P(20),GPM(20),Y(20)                        R  0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT            R  0000
      COMMON/BLK3/C(20),GAL(20)                                                 R  0000
      COMMON/BLK4/S2(12),EST2(12),T1(12),T2(3),TG(3),RT,FRT                     R  0000
      COMMON/BLK5/L1,L2,L3,SGPM                                                 R  0000
      COMMON/BLK6/PC                                                            R  0000
      REAL L1,L2,L3                                                             R  0000
      REAL KWHC                                                                 R  0000
      REAL LMTD                                                                 R  0000
      REAL NO                                                                   R  0000
      NZ=5                                                                      R  0000
      MZ=6                                                                      R  0000
C     CALCULATION OF WATER REQUIREMENTS                                         R  0000
      TGPM=0.0                                                                  R  0001
      DO 200 K=1,13                                                             R  0002
      Y(K)=Y(K)*.264/1440.                                                      R  0007
      GPM(K)=Y(K)*P(K)                                                          R  0014
  200 TGPM=TGPM+GPM(K)                                                          R  0019
C  COST OF HATCHERY                                                             R  0020
      WRITE(MZ,500)                                                             R  0021
```

```
  500 FORMAT(21X,"HATCHERY DESIGN"//)                                     R   0028
      CALL SUBI(TOT10)                                                     R   0028
      CALL SUBII(TOT20)                                                    R   0028
      CALL SUBIII(TOT30)                                                   R   0029
      CALL SUBIV(TOT40)                                                    R   0030
      CALL SUBV(TOT50,TGPM)                                                R   0031
      CALL SUBVI(TOT60,TGPM)                                               R   0032
      CALL SUBVII(TUT10,TOT20,TOT30,TOT40,TOT50,TOT60,TGPM)                R   0033
      CALL EXIT                                                            R   0035
      END                                                                  R   0037

                                          START OF SEGMENT **********    2
      SUBROUTINE SUBI(TOT10)                                               R   0000
      DIMENSION X(2),DX(2), XMIN(2), XMAX(2), DXMIN(2),EX(2),XBASE(2)      R   0000
      DIMENSION XX(2),DXX(2),XXMIN(2),XXMAX(2),DXXMIN(2),EXX(2),XXBASE(2)  R   0000
     1)                                                                    R   0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT       R   0000
      COMMON/BLK6/PC                                                       R   0000
      COMMON U1,U2,U3,U5,U4,SUP                                            R   0000
      REAL KWHC                                                            R   0000
      NIN=5                                                                R   0000
      NOUT=6                                                               R   0000
C      A IS THE CELLS PER DAY THAT ARE REQUIRED                            R   0000
C     B IS THE CONCENTRATION IN CELLS PER LITER                            R   0000
C     D IS THE DEPTH OF THE TANK                                           R   0000
C     W IS THE WIDTH OF THE SHALLOW TANK                                   R   0000
C     P IS THE PRICE PER SQ. FT. OF WALL AREA                              R   0000
C     PP IS THE COST PERSQ.FT. OF WALL AREA PER FOOT OF HEIGHT             R   0000
C     Q IS THE COST PER SQ. FT. OF BOTTOM AREA                             R   0000
C     QQ IS THE COST PER SQU.FT. OF LINER AREA                             R   0000
C     R IS THE RATIO THAT CONTROLS THE SHAPE OF THE CORNERS                R   0000
C     Y IS THE DEPTH OF THE TANK                                           R   0000
C     Z IS THE WIDTH OF THE TANK                                           R   0000
      READ(NIN,10) A,B,D,W,P,PP,Q,QQ,R,Y,Z                                 R   0001
   10 FORMAT (F7.3,E7.3,9F7.3)                                             R   0034
      WRITE(NOUT,17)A,B,D,W,P,PP,Q,QQ,R,Y,Z                                R   0034
   17 FORMAT (14H ORIGINAL DATA/F15.2)                                     R   0066
      READ(NIN,12)((DX(I),XMIN(I),XMAX(I),DXMIN(I)),I=1,2)                 R   0066
```

```
      READ(NIN,12)((DXX(I),XXMIN(I),XXMAX(I),DXXMIN(I)),I=1,2)          R  0096
   12 FORMAT(8F7.3)                                                     R  0126
      WRITE(NOUT,12)(DX(1),XMIN(1),XMAX(1),DXMIN(1))                    R  0126
      WRITE(NOUT,12)(DX(2),XMIN(2),XMAX(2),DXMIN(2))                    R  0149
      WRITE(NOUT,12)(DXX(1),XXMIN(1),XXMAX(1),DXXMIN(1))                R  0172
      WRITE(NOUT,12)(DXX(2),XXMIN(2),XXMAX(2),DXXMIN(2))                R  0195
C    POUNDS OF NUTRIENTS PER DAY                                        R  0215
      PND=60.*A                                                         R  0218
      NCOST=PND*365.*10.43                                              R  0219
C    GALS OF NUTRIENTS PER 2 DAYS                                       R  0220
      GNUT=(PND*10./62.5)*7.48                                          R  0223
C     NUTRIENT TANK SIZE--DESIGN FOR 4 TANKS                            R  0226
      TSIZE=GNUT/4.                                                     R  0228
C    TANK COST                                                          R  0229
      TCOST=4.*(380.*(TSIZE/50.)**.39 )                                 R  0230
C    PUMPING COST                                                       R  0234
      CFS=GNUT/(3600.*48.*7.48)                                         R  0235
      HP=(CFS*2.*62.5)/550.                                             R  0241
      PCOST=2.*(1300.*(HP/10.)**.68)                                    R  0245
C    POUNDS OF CO2 PER DAY                                              R  0252
      CO=214.*A                                                         R  0253
      CFM=CO*360./44.*.03                                               R  0254
      CFS=CFM/60.                                                       R  0258
C    COST OF COMPRESSOR                                                 R  0259
      CHP=(CFM*2.*.076)/3300.                                           R  0260
      CCOST=582.*CFM**.32*CHP**.25                                      R  0265
      AI=CHP*130.7                                                      R  0273
C    COST OF CO2                                                        R  0274
      COCOST=CO*.03                                                     R  0276
      K=0                                                               R  0279

      IF (K .EQ.0) GO TO  42                                            R  0280
      KOPT=1                                                            R  0282
   19 X(1)=D                                                            R  0284
      X(2)=W                                                            R  0285
   20 CALL PATSRCH (X,DX,2,TOT,XMIN,XMAX,DXMIN,EX,XBASE,KOPT)           R  0287
      WRITE(NOUT,50)D,W,TOT                                             R  0295
```

```
   50 FORMAT(5F12.2)                                              R 0311
      D=X(1)                                                      R 0311
      W=X(2)                                                      R 0312
   42 CONTINUE                                                    R 0313
C     HTERM IS COST OF WALL/FT**2                                 R 0313
      HTERM=P+PP*(D+.5)                                           R 0313
      WRITE (NOUT,51) HTERM                                       R 0317
   51 FORMAT (F11.3)                                              R 0329
C     COST OF THE LONG WALL                                       R 0329
      VOL=A*.352E14/B                                             R 0329
      ZENTH=VOL/(W*D )                                            R 0332
      ZENITH=ZENTH                                                R 0334
      WRITE (NOUT,473) ZENTH                                      R 0334
  473 FORMAT (6H ZENTH,F12.2)                                     R 0347
      WALLL=ZENTH*(D+.5)                                          R 0347
      WALLLC=WALLL*HTERM*2.                                       R 0351
      WRITE (NOUT,51)WALLLC                                       R 0352
C     WLINL COST OF 2 LONG WALLS                                  R 0357
      WLINL=WALLL*QQ*2.                                           R 0365
      WRITE (NOUT,51)WLINL                                        R 0366
C     COST OF SHORT WALLS                                         R 0371
      WALLS=2.*HTERM*W*(D+.5)                                     R 0379
      WRITE (NOUT,51)WALLS                                        R 0384
C     WLINS COST WALL LINER SHORT                                 R 0388
      WLINS=2.*QQ*W*(D+.5)                                        R 0396
      WRITE (NOUT,51)WLINS                                        R 0401
C     BOTT COST OF BOTTOM                                         R 0405
      BOTT=VOL/D*Q                                                R 0413
      WRITE (NOUT,51)BOTT                                         R 0414
C     BOTTL COST BOTTOM LINER                                     R 0419
      BOTTL=VOL/D*QQ                                              R 0427
      WRITE (NOUT,51)BOTTL                                        R 0428
C     TINT TOTAL LINER COST                                       R 0433
         TINT=WLINL +WLINS +BOTTL                                 R 0441
C     TOTAL TANK COST-LINER  TOTA                                 R 0441
      TOTA=WALLS +WALLLC+ BOTT                                    R 0442
C     TOTAL TANK TOT                                              R 0443
```

```
C$$$$$$$$$$FOR 10 PERCENT CHANGE IN VOLUME/HR                              R  0443
C        FLOW IN GPM                                                        R  0443
      U1=0.0                                                                R  0444
      CALL XPIPING(ACOST,1,WB,XNR,D,ZENITH,W,CFS)                           R  0445
      U1=PC+U1                                                              R  0448
C   REQUIRED ILLUMINATION                                                   R  0448
      XILUM=500.                                                            R  0450
C   TANK AREA                                                               R  0450
      TAREA=W*ZENITH                                                        R  0450
      XLUM=XILUM*TAREA/(.75*.75)                                            R  0452
C  NUMBER OF FIXTURES                                                       R  0455
      NF=XLUM/(67.*400.)                                                    R  0457
      CI=(XLUM/67.)*.65*4.*.1752                                            R  0460
C    COST OF FIXTURES AND INSTALLATION                                      R  0463
      FCOST=NF*75. + NF*15.                                                 R  0466
C   WATTS OF ENERGY AS HEAT                                                 R  0467
      WATTS=(XILUM*TAREA/67.)*.25                                           R  0469
C   BTU/HR OER TANK                                                         R  0470
      Q=WATTS*57.*60./1000.                                                 R  0472
C   TEMPERATURE LEVEL CONTROL = 72 DEGREES F                                R  0474
C   WELL WATER ENTERS AT 54 DEGREE F AN LEAVES AT 62 DEGREE F               R  0474
      XLMTD=(72.-54.)-(72.-62.)/ALOG((72.-54.)/(72.-62.))                   R  0475
      AA=Q/75.*XLMTD                                                        R  0479
C   FLOW PER TANK IN GPM                                                    R  0480
      WW=Q/(62.-54.)*550.                                                   R  0481
      WW=WW/(60.*7.48)                                                      R  0483
      CALL COOL(COLC,1,WB,XNR,D,ZENITH,W,WW)                                R  0487
      U1=PC+U1                                                              R  0489
      XFLOW=.1*VOL/60.*7.48                                                 R  0491
      CALL XPIPING(COST,2,WB,XNR,D,ZENITH,W,XFLOW)                          R  0497
      U1=PC+U1                                                              R  0500
      TOT=TOTA+TINT+COST+ACOST+COLC                                         R  0502
      AREA=TAREA*5.                                                         R  0505
      CALL CONSTRUCTION(AREA,CT,UTIL)                                       R  0506
      U1=U1+UTIL+CI+AI                                                      R  0507
      ATOT=CT+TOT*5.+COCOST+CCOST+TCOST+PCOST+NCOST+FCOST                   R  0510
      IF (K .EQ.0) GO TO  43                                                R  0515
```

```
      IF(KOPT.LT.6) GO TO 19                                            R  0517
      KOPT=1                                                            R  0519
   29 XX(1)=Y                                                           R  0520
      XX(2)=Z                                                           R  0521
   30 CALL PATSRCH(XX,DXX,2,TOTD,XXMIN,XXMAX,DXXMIN,EXX,XXBASE,KOPT)    R  0523
      WRITE(NOUT,50)Y,Z,TOTD                                            R  0531
      Y=XX(1)                                                           R  0547
      Z=XX(2)                                                           R  0548
   43 CONTINUE                                                          R  0549
C     DEEP TANK LENGTH DTLEN                                            R  0549
C     AREA IS AREA OF FACE                                              R  0549
C****R IS RATIO OF CHAMFER TO TOTAL HEIGHT                              R  0549
      AREA=Z*Y-2*R**2*Y**2                                              R  0549
      WRITE (NOUT,51)AREA                                               R  0552
      DTLEN=VOL/AREA                                                    R  0565
      WRITE (NOUT,51)DTLEN                                              R  0566
      HTERM=P+PP*Y                                                      R  0578
C     SECM IS  OST OF PANELS 5 AND 6                                    R  0578
      SECM=(Y-2.*R*Y)*DTLEN*HTERM*2.                                    R  0579
      WRITE (NOUT,51)SECM                                               R  0583
C     SECD COST OF PANELS 1,2,3,4                                       R  0588
      SECD=4.*(1.41*R*Y*DTLEN)*HTERM                                    R  0595
      WRITE (NOUT,51)SECD                                               R  0599
C     BOTTS COST OF BOTTOM                                              R  0604
      BOTTS=(Z-2.*R*Y)*DTLEN*Q                                          R  0612
      WRITE (NOUT,51)BOTTS                                              R  0615
C     ENDS COST OF ENDS                                                 R  0620
      ENDS=AREA*HTERM*2.                                                R  0627
      WRITE (NOUT,51)ENDS                                               R  0628
C     LINER COSTS TO INDICATED PARTS                                    R  0633
      SEML=(Y-2.*R*Y)*DTLEN*QQ*2.                                       R  0641
      WRITE (NOUT,51)SEML                                               R  0644
      SECDL=4.*1.41*R*Y*DTLEN*QQ                                        R  0657
      WRITE (NOUT,51)SECDL                                              R  0661
      ENDL=AREA*QQ*2.                                                   R  0674
```

```
      WRITE (NOUT,51)ENDL
      BOTSL=(Z-2.*R*Y)*DTLEN*QQ                                         R   0688
      WRITE (NOUT,51)BOTSL                                              R   0691
C     TINTD COST OF LINER                                               R   0696
      TINTD=SEML+SECOL+BOTSL+ENDL                                       R   0703
C     TOTAL TOTD                                                        R   0704
C**********REQUIRES 5 CFM PER FOODT OF LENGTH                            R   0704
      FLOW=5.0*DTLEN                                                    R   0705
C   ****INCLUDES ONLY CO2+AIR PIPES-NO CIRC. OR COOLING                 R   0707
      BU=0.0                                                            R   0708
      GPM=150.                                                          R   0708
      FL=.1*GPM/(60.*7.48)                                              R   0709
      CALL DEEPP(DCOST,Y,DTLEN,Z,FL)                                    R   0716
      BU=BU+PC                                                          R   0717
      CALL PIPINA(DTCOST,2,WB,XNR,Y,DTLEN,Z,FLOW)                       R   0719
C    REQUIRED ILLUMINATION                                              R   0721
      XILUM=1000.                                                       R   0721
C    TANK AREA                                                          R   0721
      TAREA=DTLEN*Z                                                     R   0722
      XLUM=XILUM*TAREA/.75*.75                                          R   0723
      NF=XLUM/67.*400.                                                  R   0729
      CI=(XLUM/67.)*.1752*4.*.65                                        R   0732
      FCOST=NF*75.+NF*15.                                               R   0738
      WATTS=(XILUM*TAREA/67.)*.25                                       R   0741
      Q=WATTS*57.*60./1000.                                             R   0744
      XLMTC=(72.-45.)-(72.-62.)/ALOG((72.-54.)/(72.-62.))               R   0747
      AA=Q/75.*XLMTD                                                    R   0751
      WW=Q/(62.-54.)*550.                                               R   0753
      WW=WW/(63.*7.48)                                                  R   0755
      U1=0.0                                                            R   0759
      CALL COOL(COLC,1,WB,XNR,Y,DTLEN,Z,WW)                             R   0760
      BU=BU+PC                                                          R   0762
      TOTD=TINTD+ENDS+BOTTS+SECM+DTCOST+COLC+DCOST+SECD                 R   0764
      AREA=TAREA*5.                                                     R   0768
      CALL CONSTRUCTION(AREA,CT,UTIL)                                   R   0769
      BU=BU+UTIL+CI+AI                                                  R   0770
      BTOT=CT+5.*TATD+COCOST+CCOST+TCOST+PCOST+NCOST+FCOST              R   0773
```

```
      IF(BTOT.LT.ATOT) GOTO 203                                            R    0777
      IF (K .EQ.0) GO TO  45                                               R    0780
      IF(KOPT.LT.6) GO TO  29                                              R    0782
   45 CONTINUE                                                             R    0785
      WRITE(NOUT,751)COST                                                  R    0785
  751 FORMAT(22HPIPE COST SHALLOW TANK/F12.3)                              R    0797
      WRITE (NOUT,471) TOT,TINT,TOTD,TINTO                                 R    0797
  471 FORMAT(24H TOTAL COST SHALLOW TANK,F12.2/24H LINER COST SHALLOW TANK,  R  0815
     1NK,F12.2/21H TOTAL COST DEEP TANK,F12.2/21H LINER COST DEEP TANK,F12.2)  R  0815
     212.2)                                                                R    0815
      WRITE(NOUT,205) ATOT                                                 R    0815
  205 FORMAT(1X"TOTAL ALGAE SYSTEM COST",F20.2)                            R    0827
      TOT10=ATOT                                                           R    0827
      GOTO 204                                                             R    0827
  203 WRITE(NOUT,205) BTOT                                                 R    0829
      TOT10=BTOT                                                           R    0841
      U1=BU                                                                R    0841
  204 CONTINUE                                                             R    0843
      RETURN                                                               R    0843
      END                                                                  R    0846
                                               START OF SEGMENT **********       3
      SUBROUTINE SUBII(TOT20)                                              R    0000
      REAL KWHC                                                            R    0000
      COMMON U1,U2,U3,U5 ,U4,SUP                                           R    0000
      DIMENSION HCOST(10)                                                  R    0000
      COMMON/BLK1/XL(20),H(20),W(20),P(20),GPM(20),Y(20)                   R    0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT       R    0000
      COMMON/BLK3/C(20),GAL(20)                                            R    0000
      COMMON/BLK6/PC                                                       R    0000
      NZ=5                                                                 R    0000
      MZ=6                                                                 R    0000
C     NUMBER OF LARVAE TANKS                                               R    0000
      READ(NZ,908) CAP                                                     R    0001
      XG=4700.                                                             R    0013
      NLT=(XG/CAP)*.5                                                      R    0016
```

```
C  COST CALCULATION GOOD IN THE RANGE OF 50 TO 100 GAL.                R 0017
      HCOST(1)=NLT*(380.*(CAP/50.)**.39)                              R 0020
      WRITE(MZ,501) NLT,HCOST(1), CAP                                 R 0026
  501 FORMAT(6X,"COST OF"I4," LARVAE TANKS",9X,F13.2,5X,"WITH A CAPACITY   R 0043
     +OF"F6.0," GAL.")                                                R 0043
      BASE3=NLT*.1*CAP                                                R 0043
C  SETTING TANKS                                                      R 0045
C  FOR COLLECTION TANKS                                               R 0045
C          C(1)=VERTICAL CLEARNACE BETWEEN COLLECTORS                 R 0045
C          C(2)=COLLECTOR STACKING                                    R 0045
C          C(3)=VERTICAL CLEARANCE ABOVE COLLECTORS                   R 0045
C          C(4)=HEIGHT OF COLLECTOR                                   R 0045
C          C(5)=COST OF COLLECTOR                                     R 0045
C          C(6)=HORIZINTAL SPACING                                    R 0045
C          C(7)=COST/SQ FT OF WALLS                                   R 0045
C          C(8)=COST/SQ FT/FT OF WALL                                 R 0045
C          C(9)=COST/SQ FT OF BOTTOM                                  R 0045
C          C(10)=0.0                                                  R 0045
C          C(11)=0.0                                                  R 0045
C          C(12)=COST/SQ FT OF LINER                                  R 0045
C          C(13)=NUMBER OF COLLECTORS / ROW                           R 0045
C          C(14)= LENGTH OF COLLECTOR                                 R 0045
C          C(15)=WIDTH OF COLLECOTR                                   R 0045
C          C(16)=DENSITY                                              R 0045
      READ(NZ,998)(C(K),K=1,16      )                                 R 0046
      AREA=P(1)/(C(16)*20.)                                           R 0066
  998 FORMAT(5F12.4)                                                  R 0069
C  AREA OF ONE COLLECTOR                                              R 0069
      READ(NZ,908) CAREA                                              R 0069
  908 FORMAT(F12.4)                                                   R 0082
C  NUMBER OF COLLECTORS                                               R 0082
      NCOL=AREA/CAREA                                                 R 0082
      CALL TANKS(  3,1,1,HT,XLT,WT,CTC,     NCOL,BASE1)               R 0083
      HCOST(2)=CTC                                                    R 0086
      WRITE(MZ,502) HCOST(2)                                          R 0087
```

```
  502 FORMAT(6X,"COST OF SETTING TANK"13X,F13.2)                         R 0101
C  SPAT AND SEED TANKS                                                   R 0101
C  FOR SFED AND SPAT TANKS                                               R 0101
C         C(1)=VERTICAL CLEARNACE BETWEEN COLLECTORS                     R 0101
C         C(2)=COLLECTOR STACKING                                        R 0101
C         C(3)=VERTICAL CLEARANCE ABOVE COLLECTORS                       R 0101
C         C(4)=HEIGHT OF COLLECTOR                                       R 0101
C         C(5)=0.0                                                       R 0101
C         C(6)=HORIZINTAL SPACING                                        R 0101
C         C(7)=COST/SQ FT OF WALLS                                       R 0101
C         C(8)=COST/SQ FT/FT OF WALL                                     R 0101
C         C(9)=COST/SQ FT OF BOTTOM                                      R 0101
C         C(10)=0.0                                                      R 0101
C         C(11)=0.0                                                      R 0101
C         C(12)=COST/SQ FT OF LINER                                      R 0101
C         C(13)=NUMBER OF COLLECTORS / ROW                               R 0101
C         C(14)= LENGTH OF COLLECTOR                                     R 0101
C         C(15)=WIDTH OF COLLECOTR                                       R 0101
C         C(16)=NUMBER OF TANKS                                          R 0101
      READ(NZ,998)(C(K),K=1,16          )                                R 0101
      NCOL=20*NCOL                                                       R 0121
      CALL TANKS(  4,1,3,HT,XLT,WT,STC,     NCOL,BASE2)                  R 0122
      HCOST(3)=C(16)*STC                                                 R 0125
      IC=C(16)                                                           R 0127
      WRITE(MZ,503) IC,HCOST(3)                                          R 0128
  503 FORMAT(6X,"COST OF"I4," SPAT AND SEED TANKS"4X,F13.2)              R 0144
      TB=BASE1+C(16)*BASE2+BASE3                                         R 0144
      DO 200 KK=1,6                                                      R 0146
  200 TOT20=TOT20+HCOST(KK)                                              R 0152
      CALL CONSTRUCTION(TB,TOT90,UTIL)                                   R 0154
      U2=PC+UTIL                                                         R 0155
      TOT20=TOT20+TOT90                                                  R 0157
      WRITE(MZ,506) TOT20                                                R 0158
  506 FORMAT(/1X,"TOTAL HATCHERY COSTS" 20X,F13.2)                       R 0171
      RETURN                                                             R 0171
      END                                                                R 0174
```

```
                                                       START OF SEGMENT **********   4
      SUBROUTINE SUBIII(TOT30)                                          R  0000
      COMMON U1,U2,U3,U5 ,U4,SUP                                        R  0000
      DIMENSION V(20),TOTAL(10)                                         R  0000
      COMMON/BLK1/XL(20),H(20),W(20),P(20),GPM(20),Y(20)                R  0000
      COMMON/BLK3/C(20),GAL(20)                                         R  0000
      COMMON/BLK6/PC                                                    R  0000
      REAL NO                                                           R  0000
      NZ=5                                                              R  0000
      MZ=6                                                              R  0000
      DO 123 I=1,13                                                     R  0001
      H(I)=H(I)*.00327                                                  R  0006
      XL(I)=XL(I)*.00327                                                R  0011
      W(I)=W(I)*.00327                                                  R  0016
  123 CONTINUE                                                          R  0022
      READ(NZ,909) J,M                                                  R  0022
  909 FORMAT(2I4)                                                       R  0037
      GOTO(508,509),M                                                   R  0037
  508 WRITE(MZ,507) J                                                   R  0043
  507 FORMAT(//12X, "DEEP TANK DESIGN FOR OYSTER STACKING OF" I3)       R  0055
      GOTO 511                                                          R  0055
  509 WRITE (MZ,510) J                                                  R  0056
  510 FORMAT(//12X,"SHALLOW TANK DESIGN FOR OYSTER STACKING OF",I3)     R  0068
  511 CONTINUE                                                          R  0068
      READ(NZ,998)(C(I),I=1,15        )                                 R  0068
  998 FORMAT(5F12.4)                                                    R  0088
C     C(I)=ARRAY OF TANK CONSTANTS                                      R  0088
C     FOR DEEP TANK                                                     R  0088
C        C(1)=VERTICAL CLEARANCE BETWEEN BASKETS                        R  0088
C        C(2)=BASKET STACKING                                           R  0088
C        C(3)=VERTICAL CLEARANCE ABOVE BASKETS                          R  0088
C        C(4)=BOTTOMAREA OF BASKETS                                     R  0088
C        C(5)=COST OF BASKETS                                           R  0088
C        C(6)=SEPARATION HORIZONTALLY BETWEEN BASKETS                   R  0088
C        C(7)=COST/SQ FT OF WALLS                                       R  0088
C        C(8)=COST/SQ FT/FT OF WALL                                     R  0088
C        C(9)=COST /SQ ST OF BOTTOM                                     R  0088
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```
C         C(10)=0.0                                                       R  0088
C         C(11)=0.0                                                       R  0088
C         C(12)=COST/SQ FT OF LINER                                       R  0088
C         C(13)=NUMBER OF BASKETS                                         R  0088
C         C(14)=LENGTH OF BASKET                                          R  0088
C          C(15)=WIDTH OF BASKET                                          R  0088
C      FOR SHALLOW TANK                                                   R  0088
C         C(1)=VERTICAL CLEARANCE BETWEEN BOTTOM AND GRID                 R  0088
C         C(2)=1.0                                                        R  0088
C         C(3)=VERTICAL CLEARANCE ABOVE OYSTERS                           R  0088
C         C(4)=1.0                                                        R  0088
C         C(5)=0.0                                                        R  0088
C         C(6)=0.0                                                        R  0088
C         C(7)=COST/SQ FT OF WALLS                                        R  0088
C         C(8)=COST/SQ FT/FT OF WALL                                      R  0088
C         C(9)=COST /SQ ST OF BOTTOM                                      R  0088
C         C(10)=COST/SQ FT OF GRID                                        R  0088
C         C(11)=COST/SQ FT OF MESH                                        R  0088
C         C(12)=COST/SQ FT OF LINER                                       R  0088
C         C(13)=TANK WIDTH                                                R  0088
C         C(14)=0.0                                                       R  0088
C          C(15)=1.0                                                      R  0088
      BOT=0.0                                                             R  0088
      TOT30=0.0                                                           R  0088
      DO 100 I=5,13,2                                                     R  0089
C   VOLUMF OF INDIVIDUAL OYSTER                                           R  0094
      V(I)=XL(I)*H(I)*W(I)                                                R  0095
      VS=J*H(I)                                                           R  0100
      NO=VS/V(I)                                                          R  0102
      NB=(P(I)/(NO*C(4)))+ .5                                             R  0104
      CALL TANKS(  M,J,I,HT,XLT,WT,TCT,     NB,B)                         R  0110
      TCT=TCT*2.                                                          R  0113
      WRITE(MZ,512) I,TCT                                                 R  0114
  512 FORMAT(6X,"COST OF TANKS FOR",I4," MONTH OYSTERS",F13.2)            R  0128
      U3=PC+U3                                                            R  0128
      BOT=BOT+2.*B                                                        R  0130
      TOT30=TOT30+TCT                                                     R  0131
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100 CONTINUE                                                       R  0133
    CALL CONSTRUCTION(BOT,TOT90,UTIL)                              R  0133
    TAN=TOT30+TOT90                                                R  0134
    TOT30=TAN                                                      R  0136
    U3=U3+UTIL                                                     R  0136
    WRITE(MZ,513) TAN                                              R  0138
513 FORMAT(//1X,"TOATL OYSTER TANK COSTS",17X,F13.2)               R  0151
                                                   SEGMENT    5 IS  125 LONG
    RETURN                                                         R  0151
    END                                                            R  0154
                                          START OF SEGMENT **********    6
    SUBROUTINE SUBIV(TOT40)                                        R  0000
    COMMON U1,U2,U3,U5 ,U4,SUP                                     R  0000
C     PROCESSING                                                   R  0000
    COMMON/BLK1/XL(20),H(20),W(20),P(20),GPM(20),Y(20)             R  0000
    NZ=5                                                           R  0000
    MZ=6                                                           R  0000
    NBPY=(P(13)*12.)/300.                                          R  0001
    PACOST=20000.+(NBPY-100000.   )*.1                             R  0004
    SUP=NBPY*.5                                                    R  0011
    U4=NBPY*.01                                                    R  0014
    TOT40=PACOST                                                   R  0017
    RETURN                                                         R  0017
    END                                                            R  0020
                                          START OF SEGMENT **********    7
    SUBROUTINE SUBV(TOT50,TGPM)                                    R  0000
    COMMON U1,U2,U3,U5 ,U4,SUP                                     R  0000
    DIMENSION WCOST(10),EXPY(12),EX(12),Q(12)                      R  0000
    COMMON/BLK4/S2(12),EST2(12),T1(12),T2(3),TG(3),RT,ERT          R  0000
    COMMON/BLK5/L1,L2,L3,SGPM                                      R  0000
    NZ=5                                                           R  0000
    MZ=6                                                           R  0000
    REAL L1,L2,L3                                                  R  0001
    REAL LMTD                                                      R  0001
COST OF WELLS                                                      R  0001
```

```
      XNW=TGPM/1000.                                                   R  0001
      NW=XNW+.5                                                        R  0002
      WCOST(1)=NW*10000.                                               R  0006
C  COST OF PIPING                                                      R  0007
C    LEADING FROM WELLS                                                R  0007
      CALL PO2 (1000.,L1,WCOST(2))                                     R  0009
C    MAIN--WITHOUT SALINITY ADJUSTMENT                                 R  0011
      CALL PO2 (TGPM,L2,WCOST(3))                                      R  0012
C    MAIN--WITH SALINITY ADJUSTMENT                                    R  0014
      CALL PO2 (SGPM,L3,WCOST(4))                                      R  0014
C  PUMPING COST ASSUMING 120 PSIG -- 270 FT. HEAD                      R  0016
      WCOST(5)=RT*TGPM*120.                                            R  0016
C  COST OF ULTRAVIOLET STERILIZATION                                   R  0018
      XNUV=TGPM/50.                                                    R  0019
      NUV=XNUV+.5                                                      R  0020
      WCOST(6)=NUV*850.                                                R  0024
C  COST OF HEAT EXCHANGERS                                             R  0025
      DO 110 I=1,2                                                     R  0026
      Q(I)=0.0                                                         R  0031
      EXPY(I)=0.0                                                      R  0033
      DELTA=180.-T2(I)                                                 R  0035
      TEMP=T2(I)                                                       R  0037
      DO 101 J=1,12                                                    R  0038
      IF(T1(J).GE.T2(I))GOTO 101                                       R  0044
      BETA=140.-T1(J)                                                  R  0048
      IF(DELTA.EQ.BETA)LMTD=DELTA                                      R  0050
      IF(DELTA.NE.BETA)LMTD=(DELTA-BETA)/ALOG(DELTA/BETA)              R  0052
      EXPY(I)=ERT*TG(I)*(T2(I)-T1(J))*30.+EXPY(I)                      R  0057
      IF(T1(J).GE.TEMP) GOTO 101                                       R  0064
      TEMP=T1(J)                                                       R  0067
  101 CONTINUE                                                         R  0069
      Q(I)=510.*TG(I)*(T2(I)-TEMP)                                     R  0069
      B=Q(I)/(120.*LMTD)                                               R  0074
      N=(B/31000.)+1.                                                  R  0076
      A=B/N                                                            R  0080
  110 EX(I)=N*10000.*(A/400.)**.6                                      R  0082
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```
C  COST OF HEATERS                                                            R  0086
      A=(Q(1)+Q(2)+Q(3))/100000.                                               R  0090
      WCOST(7)=800.*(A/300.)**.38                                              R  0094
      WRITE(MZ,105)(WCOST(I),I=1,7),(EX(I),I=1,3),(EXPY(I),I=1,3)              R  0099
  105 FORMAT(1X,F24.2,3X"COST OF WELLS"/1X,F24.2,3X"COST OF PIPING FROM       R  0140
     +WELLS"/1X,F24.2,3X"COST OF MAIN"/1X,F24.2,3X"COST OF PIPE FOR SALI       R  0140
     +NITY ADJUSTMENT"/1X,F24.2,3X"PUMPING COST"/1X,F24.2,3X"COST OF UV        R  0140
     +STERILIZATION"/1X,F24.2,3X"COST OF DIRECT FIRED HEATERS"/1X,F24.2,       R  0140
     +3X"COST OF EXCHANGER FOR ALGAE"/1X,F24.2,3X"COST OF EXCHANGER FOR        R  0140
     +LARVAE"/1X,F24.2,3X"COST OF EXCHANGER FOR OYSTERS"/1X,F24.2,3X           R  0140
     +"COST OF RUNNING ALGAE EXCHANGER"/1X,F24.2,3X"COST OF RUNNUNG LARV       R  0140
     +AE EXCHANGER"/1X,F24.2,3X"COST OF RUNNING OYSTER EXCHANGER")             R  0140
      TOT50=0.0                                                                R  0140
      DO 565 I=1,7                                                             R  0140
      U5=EXPY(1)+EXPY(2)+ EXPY(3)                                              R  0146
  565 TOT50=TOT50+WCOST(I)+EX(I)                                               R  0150
      RETURN                                                                   R  0153
      END                                                                      R  0156
                                                START OF SEGMENT **********   8
      SUBROUTINE SUBVI(TOT60,TGPM)                                             R  0000
C       WASTE DISPOSAL                                                         R  0000
      NZ=5                                                                     R  0000
      MZ=6                                                                     R  0000
      CALL P02(TGPM,5000.,TOT60)                                               R  0001
      RETURN                                                                   R  0004
      END                                                                      R  0007

      SUBROUTINE SUBVII(TOT10,TOT20,TOT30,TOT40,TOT50,TOT60,TGPM)
      COMMON U1,U2,U3,U5 ,U4,SUP                                               R  0000
      MZ=6                                                                     R  0000
      NZ=5                                                                     R  0000
      WRITE(MZ,700)TGPM                                                        R  0001
  700 FORMAT(20X,"PHYSICAL PLANT COSTS"////,1X,"WATER FLOW OF ", F7.0,         R  0014
     +" GPM")                                                                  R  0014
      WRITE(MZ,701) TOT10                                                      R  0014
  701 FORMAT(1X,"ALGAE SYSTEM"10X,F20.2/)                                      R  0026
  702 FORMAT (1X,"HATCHERY AND LAB "5X,F20.2/)                                 R  0026
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      WRITE(MZ,702) TOT20                                               R  0026
      WRITE(MZ,703) TOT30                                               R  0038
703   FORMAT(1X,"OYSTER TANKS"10X,F20.2/)                               R  0050
      WRITE(MZ,704) TOT40                                               R  0050
704   FORMAT(1X,"PROCESSING"11X,F20.2/)                                 R  0062
      WRITE(MZ,705) TOT50                                               R  0062
705   FORMAT(1X,"WATER SUPPLY"10X,F20.2/)                               R  0074
                                                          SEGMENT     10 TS  125 LONG
      WRITE(MZ,706) TOT60                                               R  0074
706   FORMAT(1X,"WASTE DISPOSAL"8X,F20.2/)                              R  0086
      TOTAL=TOT20+TOT30+TOT40+TOT50+TOT60 +TOT10                        R  0086
707   FORMAT(7X,"SUBTOTAL"6X,F20.2/)                                    R  0090
      WRITE(MZ,707) TOTAL                                               R  0090
      XINST=TOTAL*.05                                                   R  0102
      WRITE(MZ,708)XINST                                                R  0104
708   FORMAT(1X,"INSTRUMENTS"11X,F20.2/)                                R  0117
      PHYP=TOTAL+XINST                                                  R  0117
      WRITE(MZ,709) PHYP                                                R  0118
709   FORMAT(1X,"PHYSICAL PLANT COST" F23.2////)                        R  0130
      SUP=SUP+50000.                                                    R  0130
      WRITE(MZ,710) SUP                                                 R  0134
710   FORMAT(20X,"MANUFACTURING COSTS"/1X"SUPPLIES"12X,F20.2/)          R  0147
      XLRC=1.79*(42200.+279000.)                                        R  0147
      WRITE(MZ,711) XLRC                                                R  0154
711   FORMAT(1X"LABOR RELATED COST"2X,F20.2/)                           R  0166
      FXC=.19*PHYP                                                      R  0166
      WRITE(MZ,712) FXC                                                 R  0169
712   FORMAT(1X,"FIXED CHARGES"7X,F20.2/)                               R  0181
      UTIL=U2+U3+U5  +U1                                                R  0181
      WRITE(MZ,713) UTIL                                                R  0184
713   FORMAT(1X,"UTILITIES"11X,F20.2/)                                  R  0196
      XMFG=SUP+XLRC+FXC+UTIL                                            R  0196
      WRITE(MZ,714) XMFG                                                R  0198
714   FORMAT(1X"MANUFACTURING PER YR"F20.2/)                            R  0211
      CPB=XMFG*.00001                                                   R  0211
      WRITE(MZ,715) CPB                                                 R  0213
715   FORMAT(1X,"COST PER BUSHEL"5X,F20.2/)                             R  0226
      RETURN                                                            R  0226
      END                                                               R  0229
```

```
                                                          START OF SEGMENT ********** 11
      SUBROUTINE TANKS(  M,J,I,HT,XLT,WT,TOT30,     NB,AREA)          R  0000
      COMMON/BLK1/XL(20),H(20),W(20),P(20),GPM(20),Y(20)              R  0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT  R  0000
      COMMON/BLK3/C(20),GAL(20)                                       R  0000
      DIMENSION COST(10)                                              R  0000
      REAL L1,L2,L3                                                   R  0000
      REAL KWHC                                                       R  0000
      NZ=5                                                            R  0000
      MZ=6                                                            R  0000
C     M=INDICATOR USED TO DESIGNATE WHICH TYPE OF TANK TO BE DESIGNED.  R  0000
C             1=DEEP TANK                                             R  0000
C             2=SHALLOW TANK                                          R  0000
C             3= SETTING TANK                                         R  0000
C             4= SEED AND SPAT TANKS                                  R  0000
      WT=C(13)*C(15) + (C(13)+1.0)*C(6)                               R  0001
      IWT=WT+.5                                                       R  0006
      WT=IWT                                                          R  0010
      COST(1)=NB*C(5)                                                 R  0011
      GOTO (300,300,302,302),M                                        R  0013
  300 HT=C(2)*(H(13)*J+C(1))+C(3)                                     R  0020
      GOTO (301,303,301,301),M                                        R  0023
  302 HT= C(2)*(C(4)+C(1))+C(3)                                       R  0031
  301 XNR=NB/(C(2)*C(13))                                             R  0035
      NR=XNR+.5                                                       R  0037
      XNR=NR                                                          R  0041
      XLT=XNR*C(14)+(XNR+1.)*C(6)                                     R  0042
      LT=XLT+.5                                                       R  0045
      XLT=LT                                                          R  0049
      GOTO 310                                                        R  0050
  303 XLT=NB/WT                                                       R  0051
      LT=XLT+.5                                                       R  0052
      XLT=LT                                                          R  0056
  310 VT=HT*XLT*WT                                                    R  0057
      IF(VT.LT.GAL(I)) HT=GAL(I)/(XLT*WT)                             R  0058
      WALL=C(7)+HT*C(8)                                               R  0063
C  COST OF WALLS                                                      R  0064
      COST(2)=(2.0*(XLT+WT)*HT)*WALL                                  R  0065
C  COST OF TANK BOTTOM                                                R  0069
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      COST(3)=XLT*WT*C(9)                                              R  0070
C   COST OF GRID                                                       R  0072
      COST(4)=NB*C(10)                                                 R  0073
C   COST OF MESH                                                       R  0074
      COST(5)=NB*C(11)                                                 R  0075
C COST OF LINER                                                        R  0076
      COST(6)=(2.*(XLT+WT)*HT+(XLT*WT))*C(12)                          R  0077
      TOT30=0.0                                                        R  0081
      IF(M.FQ.3) GOTO 305                                              R  0082
      XGPM=GPM(I)                                                      R  0084
      CALL PIPING(TOT30,M,C(13),XNR,HT,XLT,WT,XGPM)                    R  0086
  305 AREA=XLT*HT                                                      R  0090
      WRITE(MZ,504) HT,XLT,WT                                          R  0091
  504 FORMAT(55X,"HEIGHT"F7.0/55X,"LFNGHT" F7.0/55X,"WIDTH" F8.0)      R  0107
      DO 304 JJ=1,6                                                    R  0107
  304 TOT30=TOT30+COST(JJ)                                             R  0113
      RETURN                                                           R  0115
      END                                                              R  0118
                                          START OF SEGMENT **********  12

      SUBROUTINE PIPING(TCOST,M,WR,XNR,HT,XLT,WT,XGPM)                 R  0000
C     COMPUTATION OF PIPE AND PIPE INSTALLATION COSTS USING THE        R  0000
C     PREVIOUSLY CALCULATED TANK DIMENSIONS.                           R  0000
      DIMENSION DCOST(5), FLOW(10)                                     R  0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),FST(20),ETAP,FTAM,KWHC,XINT   R  0000
      COMMON/BLK3/C(20),GAL(20)                                        R  0000
      COMMON/BLK6/PC                                                   R  0000
      REAL KWHC                                                        R  0000
      FLOW(1)=XGPM                                                     R  0000
      RATE=6.00                                                        R  0001
      NZ=5                                                             R  0003
      MZ=6                                                             R  0004
      FLOW(1)=FLOW(1)/(60.*7.48)                                       R  0005
      GOTO(341,342,341,341),M                                          R  0009
C COST OF SUPPORTS                                                     R  0009
  341 CONTINUE                                                         R  0016
      IF(M.EQ.4) XC=35.                                                R  0016
      IF(M.EQ.1)XC=95.                                                 R  0018
      DCOST(1)=XNR*XC                                                  R  0020
```

```
C COST OF RACKS                                                     R 0021
      NROD=WB*XNR*4.0                                               R 0022
      XLR=NROD*(HT*3.0)                                             R 0026
      DCOST(2)=XLR                                                  R 0030
C COST OF MAIN                                                      R 0030
      XLM=HT+XLT+10.0                                               R 0031
      CALL PIPEOP(FLOW(1),XLM,PCOST,SIZE,PF,STRDL)                  R 0034
      IDL=(XLM/(XNR+1.))+.5                                         R 0037
      DL=IDL                                                        R 0042
      V=(FLOW(1)*4.*144.)/(3.1416*SIZE**2)                          R 0043
      RN=(V*SIZE*1.94)/(12.*.000021)                                R 0048
      A=(.3164)/(RN**.25)                                           R 0056
      HL=(A*V**2*(DL+HT+10.)*12.)/(SIZE*64.4)                       R 0061
      INR=XNR                                                       R 0068
      NH=XNR+1.0                                                    R 0069
      FLOW(2)=FLOW(1)/NH                                            R 0073
      DO 240 I=2,INR                                                R 0075
      FLOW(1)=FLOW(1)-FLOW(2)                                       R 0080
      U=(FLOW(1)*4.*144.)/(3.1416*SIZE**2)                          R 0083
      RN=(U*SIZE*1.94)/(12.*.000021)                                R 0088
      HL=HL+(A*U**2*DL*12.)/(SIZE*64.4)+(.6*V**2/64.44)             R 0096
      A=(.3164)/(RN**.25)                                           R 0108
      V=U                                                           R 0113
  240 CONTINUE                                                      R 0115
      HL=HL+(1.8*V**2/64.4)                                         R 0115
      NCM=(XNR+1.0)*2.*(XLM/STRDL)                                  R 0122
      HOURS=NCM*SIZE*PF                                             R 0126
      DCOST(3)=1.5*HOURS*RATF+PCOST                                 R 0128
C COST OF HEADER ARMS                                               R 0132
      XLHA=WT*NH                                                    R 0133
      NPA=WB+1.                                                     R 0134
      FLOW(3)=FLOW(2)/NPA                                           R 0136
      CALL PIPEOP(FLOW(2),XLHA,PCOST,SIZE,PF,STRDL)                 R 0138
      FLOW(2)=FLOW(2)/2.                                            R 0140
      IDL=WB+1.                                                     R 0142
      DL=IDL                                                        R 0144
      V=(FLOW(2)*4.*144.)/(3.1416*SIZE**2)                          R 0145
      RN=(V*SIZE*1.94)/(12.*.000021)                                R 0150
```

```
      A=(.3164)/(RN**.25)                                              R  0158
      HL=HL+(A*V**2*DL*12.)/(SIZE*64.4)                                R  0163
      INR=WB/2.+.5                                                     R  0170
      FLOW(2)=FLOW(2)+FLOW(3)                                          R  0174
      DO 241 I=1,INR                                                   R  0176
      FLOW(2)=FLOW(2)-FLOW(3)                                          R  0181
      U=(FLOW(2)*4.*144.)/(3.1416*SIZE**2)                             R  0184
      RN=(U*SIZE*1.94)/(12.*.000021)                                   R  0189
      A=(.3164)/(RN**.25)                                              R  0197
      HL=HL+(A*U**2*DL*12.)/(SIZE*64.4)+(.6*V**2/64.44)                R  0202
      V=U                                                              R  0215
  241 CONTINUE                                                         R  0216
      HL=HL+(.9*V**2/64.4)                                             R  0216
      NCA=(WB-1.)*2.+4.                                                R  0223
      HOURS=NCA*SIZE*PF                                                R  0225
      DCOST(4)=1.5*HOURS*RATE+PCOST                                    R  0227
C COST OF HEADERS                                                      R  0231
      XLH=(HT+2.)*NPA*NH                                               R  0232
      CALL PIPEOP(FLOW(3),XLH,PCOST,SIZE,PF,STRDL)                     R  0234
      DL=HT-2.                                                         R  0237
      V=(FLOW(3)*4.*144.)/(3.1416*SIZE**2)                             R  0238
      RN=(V*SIZE*1.94)/(12.*.000021)                                   R  0243
      A=(.3164)/(RN**.25)                                              R  0251
      HL=HL+(A*V**2*DL*12.)/(SIZE*64.4)                                R  0256
      NCH=2.*(XNR+1.)                                                  R  0263
      HOURS=NCH*SIZE*PF                                                R  0265
      DCOST(5)=1.5*RATE*HOURS+PCOST                                    R  0267
      DO 343 II=1,5                                                    R  0272
  343 TCOST=TCOST+DCOST(II)                                            R  0278
      DP=2.+HL                                                         R  0280
      PP=(DP*62.5*FLOW(3))/550.                                        R  0281
      R=(PP/ETAM*ETAP)*KWHC*8960.*.745                                 R  0286
      PW=R/XINT                                                        R  0293
      PC=2480.*(PP/25.)**.86+PW                                        R  0295
      RETURN                                                           R  0302
  342 CONTINUE                                                         R  0306
C  COST OF MAIN                                                        R  0306
      CALL PIPEOP(FLOW(1),XLT,PCOST,SIZE,PF,STRDL)                     R  0306
      CON1=5.                                                          R  0308
```

```
      HOURS=NCM*SIZE*PF                                                 R  0309
      DCOST(1)=1.5*HOURS*RATE+PCOST                                     R  0313
      IH=XLT/CON1+.5                                                    R  0315
      H=IH                                                              R  0320
      FLOW(2)=FLOW(1)/H                                                 R  0324
      IDL=CON1                                                          R  0325
      DL=IDL                                                            R  0327
      V=(FLOW(1)*4.*144.)/(3.1416*SIZE**2)                              R  0328
      RN=(V*SIZE*1.94)/(12.*.000021)                                    R  0329
      A=(.3164)/(RN**.25)                                               R  0334
      HL=(A*V**2*DL*12.)/(SIZE*64.4)                                    R  0342
      INR=H                                                             R  0347
      DO 244 I=2,INR                                                    R  0353
      FLOW(1)=FLOW(1)-FLOW(2)                                           R  0354
      U=(FLOW(1)*4.*144.)/(3.1416*SIZF**2)                              R  0359
      RN=(U*SIZE*1.94)/(12.*.000021)                                    R  0362
      A=(.3164)/(RN**.25)                                               R  0367
                                                                        R  0375
      HL=HL+(A*U**2*DL*12.)/(SIZE*64.4)+(.6*V**2/64.44)                 R  0380
      V=U                                                               R  0393
  244 CONTINUE                                                          R  0394
      HL=HL+(1.8*V**2/64.4)                                             R  0394
C   COST OF HEADERS                                                     R  0400
      XLH=H*WT                                                          R  0401
      CALL PIPEOP(FLOW(2),XLH,PCOST,SIZE,PF, STRDL)                     R  0402
      FLOW(2)=FLOW(2)/2.                                                R  0405
      IDL=WT/2.+.5                                                      R  0407
      DL=IDL                                                            R  0411
      V=(FLOW(2)*4.*144.)/(3.1416*SIZE**2)                              R  0412
      RN=(V*SIZE*1.94)/(12.*.000021)                                    R  0417
      A=(.3164)/(RN**.25)                                               R  0425
      HL=HL+(A*V**2*DL*12.)/(SIZE*64.4)                                 R  0430
      DP=2.+HL                                                          R  0437
      PP=(DP*62.5*FLOW(3))/550.                                         R  0438
      R=(PP/ETAM*ETAP)*KWHC*8960.*.745                                  R  0443
      PW=R/XINT                                                         R  0450
      PC=2480.*(PP/25.)**.86+PW                                         R  0452
```

```
      NCH=H*(WT/STRDL)                                                  R   0459
      HOURS=NCH*SIZE*PF                                                 R   0461
      DCOST(2)=1.5*RATE*HOURS*PCOST                                     R   0463
      TCOST=DCOST(1)+DCOST(2)                                           R   0468
      RETURN                                                            R   0469
      END                                                               R   0472
                                        START OF SEGMENT **********  13
      SUBROUTINE PO2(FLOW,XL,PCOST)                                     R  0000
C     OPTIMIZATION SUBROUTINE TO DETERMINE THE MOST ECONOMICAL SIZE     R  0000
C     PIPE FOR A GIVEN FLOW RATE.  HEAD LOSS AND COST CALULATIONS ARE   R  0000
C     DONE ON THE BASIS OF 100 FT FOR EACH FLOW RATE.                   R  0000
C        V=VELOCITY IN FT/SEC FOR GIVEN PIPE DIAMETER                   R  0000
C        RN=ESTIMATED REYNOLDS NUMBER                                   R  0000
C        A=FRICTION FACTOR                                              R  0000
C        HL=HEADLOSS                                                    R  0000
C        PP=PUMPING POWER NEEDED                                        R  0000
C        PW=PRESENT ESTIMATED WORTH OF PP                               R  0000
C        PCOST=COST OF PIPE FOR LENGTH DESCRIBED BY TANK DDSIGN         R  0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT    R  0000
      COMMON/BLK4/S2(12),EST2(12),T1(12),T2(3),TG(3),RT,ERT             R  0000
      NZ=5                                                              R  0000
      MZ=6                                                              R  0000
      REAL L1,L2,L3                                                     R  0001
      REAL KWHC                                                         R  0001
      CFS=FLOW/(60.*7.48)                                               R  0001
      CHECK=1.E+20                                                      R  0005
    3 DO 2 I=1,12                                                       R  0008
C   HEADLOSS                                                            R  0008
      V=(CFS*4.*144.)/(3.1416*S2(I)**2)                                 R  0013
      RN=(V*S2(I)*1.94)/(12.*.000021)                                   R  0019
      A=(.3164)/(RN**.25)                                               R  0027
      HL=(A*V**2*1200.)/(S2(I)*64.4)                                    R  0032
C   COST ESTIMATION                                                     R  0039
      PP=(CFS*HL*62.5)/(ETAP*ETAM*550.)                                 R  0040
      R=PP*KWHC*8960.*.745                                              R  0045
      PW=R/XINT                                                         R  0051
      WORTH=PW+(EST2(I)*100.)                                           R  0053
```

```
      IF(WORTH.GT.CHECK) GOTO 1                                    R  0055
      CHECK=WORTH                                                  R  0058
      BSIZE=S2(I)                                                  R  0058
      PCOST=EST2(I)*XL                                             R  0060
    2 CONTINUE                                                     R  0063
      IF(BSIZE.EQ.0.0) BSIZE=S2(1)                                 R  0063
    1 CONTINUE                                                     R  0066
      RETURN                                                       R  0066
      END                                                          R  0069
                                          START OF SEGMENT ********** 14
      SUBROUTINE CONSTRUCTION(AREA,CT,UTIL)                        R  0000
      NZ=5                                                         R  0000
      MZ=6                                                         R  0000
      AREA=1.3*AREA                                                R  0001
C   CONCRETE FLOORING                                              R  0004
      C1=1.0*AREA                                                  R  0005
C   COST OF AIR SUPPORTED STRUCTURE                                R  0007
      C2=2.35*AREA                                                 R  0008
C   NUMBER OF BLOWERS                                              R  0010
      XNB=.001*AREA                                                R  0011
      NB=XNB+.5                                                    R  0014
      XNB=NB                                                       R  0017
C COST OF TRUCK OR CRANE AND/OR MISCELLANEOUS EQUIPMENT            R  0017
      C4=30000.                                                    R  0018
C   LIGHTING                                                       R  0018
      XNL=.0003*AREA                                               R  0020
      NL=XNL+.5                                                    R  0024
      XNL=NL                                                       R  0027
      C3=XNL*400.                                                  R  0028
C   TOTAL CONSTRUCTION COST                                        R  0028
      CT=C1+C2+C3+C4                                               R  0029
C   COST OF UTILITIES                                              R  0030
C   BLOWERS                                                        R  0030
      U1=XNB*130.7                                                 R  0031
C   LIGHTING                                                       R  0031
      U2=XNL*24.*150.*.02                                          R  0034
C   HEATING                                                        R  0036
      U3=.67*AREA                                                  R  0038
```

```
C  COST OF POWER FOR CRANE,TRUCK, AND/OR THRESHER                    R  0041
      U4=C4*.02                                                      R  0042
      UTIL=U1+U2+U3+U4                                               R  0044
      WRITE(MZ,505) CT,UTIL                                          R  0047
  505 FORMAT(6X,"COST OF CONSTRUCTION" 11X,F13.2//6X,"COST OF UTILITIES R  0061
     +"14X,F13.2)                                                    R  0061
      RETURN                                                         R  0061
      END                                                            R  0064
      SUBROUTINE PIPEOP(CFS,XL,PCOST,BSIZE,BPF,STRDL)  START OF SEGMENT ********
                                                                     R  0000
C     OPTIMIZATION SUBROUTINE TO DETERMINE THE MOST ECONOMICAL SIZE  R  0000
C     PIPE FOR A GIVEN FLOW RATE.  HEAD LOSS AND COST CALULATIONS ARE R 0000
C     DONE ON THE BASIS OF 100 FT FOR EACH PLOW RATE.                R  0000
C        V=VELOCITY IN FT/SEC FOR GIVEN PIPE DIAMETER                R  0000
C        RN=ESTIMATED REYNOLDS NUMBER                                R  0000
C        A=FRICTION FACTOR                                           R  0000
C        HL=HEADLOSS                                                 R  0000
C        PP=PUMPING POWER NEEDED                                     R  0000
C        PW=PRESENT ESTIMATED WORTH OF PP                            R  0000
C        PCOST=COST OF PIPE FOR LENGTH DESCRIBED BY TANK DDSIGN      R  0000
C        S=DIAMETER IN INCHES                                        R  0000
C        LENGTH=STANDARD LENGTH OF PEIPE IN FEET                     R  0000
C        F=LABOR FACTOR FOR INSTALLATION                             R  0000
C        EST=COST OF PIPE PER FOOT                                   R  0000
C        KWHC=COST PER KILOWATT - HR                                 R  0000
C        XINT=INTEREST RATE IN DECIMAL(E.G.10 PERCENT=.10)           R  0000
C        ETAM=EFFICIENCY OF MOTOR                                    R  0000
C        ETAP=EFFICIENCY OF PUMP                                     R  0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT R  0000
      REAL KWHC                                                      R  0000
      MZ=6                                                           R  0000
      CHECK=1.E+20                                                   R  0000
    3 DO 2 I=1,18                                                    R  0004
C  HEADLOSS                                                          R  0004
      V=(CFS*4.*144.)/(3.1416*S(I)**2)                               R  0009
```

```
C     REYNOLDS NO                                              R  0014
C      VISCOSITY OF H2O IS .00001 FT2/SEC                      R  0014
      RN=V*S(I)/(12.*.00001)                                   R  0015
      A=(.3164)/(RN**.25)                                      R  0020
C        HL IS HEAD LOSS IN FT PER 100 FT OF PIPE              R  0025
      HL=(A*V**2*1200.)/(S(I)*64.4)                            R  0025
C COST ESTIMATION                                              R  0032
C        62.5 IS DENSITY OF H2O                                R  0032
      PP=(CFS*HL*62.5)/(ETAP*ETAM*550.)                        R  0033
C        8960 IS NO. OF HOURS/YEAR                             R  0038
      R=PP*KWHC*8960.*.745                                     R  0038
      PW=R/XINT                                                R  0044
      WORTH=PW+(EST(I)*100.)                                   R  0046
      IF(WORTH.GT.CHECK) GOTO 1                                R  0048
      CHECK=WORTH                                              R  0051
      BSIZE=S(I)                                               R  0051
      STRDL=LENGTH(I)                                          R  0053
      BPF=F(I)                                                 R  0054
      PCOST=EST(I)*XL                                          R  0056
    2 CONTINUE                                                 R  0059
    1 WRITE(MZ,5)BSIZE                                         R  0060
    5 FORMAT(6H BSIZE/F12.3)                                   R  0072
      IF(BSIZE.EQ.0.0) BSIZE=S(1)                              R  0072
      IF(BSIZE.EQ.0.0) BPF=F(1)                                R  0074
      IF(BSIZE.EQ.0.0) STRDL=LENGTH(1)                         R  0077
      IF(BSIZE.EQ.0.0) PCOST=EST(1)*XL                         R  0079
      RETURN                                                   R  0082
      END                                                      R  0085
                                      START OF SEGMENT ********** 16
      BLOCK DATA                                               R  0000
      COMMON/BLK1/XL(20),H(20),W(20),P(20),GPM(20),Y(20)       R  0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT R  0000
      COMMON/BLK3/C(20),GAL(20)                                R  0000
      COMMON/BLK4/S2(12),EST2(12),T1(12),T2(3),TG(3),RT,ERT    R  0000
      COMMON/BLK5/L1,L2,L3,SGPM                                R  0000
      REAL KWHC                                                R  0000
```

```
      REAL L1,L2,L3                                                      R 0000
      DATA (H(I),I=1,13)/0.3,7.6,14.3,20.5,35.2,40.5,44.3,48.,51.,54.0,  R 0000
     +57.1,59.7,60.0/                                                    R 0013
      DATA(XL(I),I=1,13)/.3,10.,19.,38.,47.,54.,59.,64.,68.,72.,76.,     R 0016
     +79.5,80./                                                          R 0029
      DATA(H(I),I=1,13)/0.0,5.,8.7,16.5,18.6,20.3,21.5,22.7,23.7,24.6,   R 0032
     +25.6,26.4,26.5/                                                    R 0045
      DATA(P(I),I=1,13)/.8E07,.36E07,3*.32E07,2*.31E07,3*.29E07,         R 0048
     +2*.28E07,.26E07/                                                   R 0061
      DATA(Y(I),I=1,13)/.0005,.07,.365,2.49,3.57,4.64,5.22,6.49,7.82,    R 0064
     +8.25,9.3,10.2,10.2/                                                R 0077
      DATA(S(I),I=1,18)/.125,.25,.375,.5,.75,1.,1.25,1.5,1.75,2.,2.5,3., R 0080
     +3.5,4.,5.,6.,8.,10./                                               R 0093
      DATA (EST(I),I=1,18)/.06,3*.08,.1,.15,.2,.27,.35,.44,.67,.92,1.2,  R 0096
     +1.75,2.5,3.75,6.25,10./                                            R 0109
      DATA (F(I),I=1,18)/13*1.5,5*1.4/                                   R 0112
      DATA (LENGTH(I),I=1,18)/9*20,9*10/                                 R 0128
      DATA ETAP,ETAM,KWHC,XINT/.75,.85,0.015,.08/                        R 0144
      DATA(GAL(I),I=1,13)/.000047,.000136,.0011,.005,.0095,.0134,.016,   R 0162
     +.018,.02,.021,.0225,.0236,.025/                                    R 0178
      DATA(S2(I),I=1,12)/6.,8.,13.,12.,14.,16.,18.,24.,30.,36.,42.,72./  R 0179
                                                    SEGMENT   17 IS  237 LONG
      DATA(EST2(I),I=1,12)/1.55,3.85,3.5,5.25,6.6,8.8,12.,21.,33.,48.,   R 0195
     +68.,75./                                                           R 0208
      DATA(T2(I),I=1,3)/72.,80.,68./                                     R 0211
      DATA(T1(I),I=1,12)/50.,58.,65.,65.,62.,57.,45.,40.,36.,30.,37.,    R 0227
     +44./                                                               R 0240
      DATA(TG(I),I=1,3)/110.,330.,39560./                                R 0243
      DATA RT,ENT/.0461326,.031462/                                      R 0259
      DATA L1,L2,L3,SGPM/35000.,3000.,2000.,49600./                      R 0271
      END                                                                R 0290
```

```
      SUBROUTINE PATSRCH(X,DX,NX,Y,XMIN,XMAX,DXMIN,EX,XBASE,KOPT)        R 0000
C     A SUBROUTINE USING PATTERN-SEARCH TO FIND THE MINIMUM              R 0000
C     X=ARRAY OF INDEPENDENT VARIABLES                                    R 0000
C     DX=ARRAY OF INITIAL STEP SIZES FOR RESPECTIVE INDEPENDENT VARIABLE  R 0000
C     NX=SIZE OF X, DX,XMIN,XMAX,DXMIN,EX,XBASE ARRAYS                    R 0000
C     Y=FUNCTION TO BE MINIMUZED                                          R 0000
C     XMIN=ARRAY OF MINIMUM VALUES ALLOWED FOR RESPECTIVE XS              R 0000
C     XMAX=ARRAY OF MAXIMUM VALUES ALLOWED FOR RESPECTIVE XS              R 0000
C     DXMIN=ARRAY OF SMALLEST USEFUL STEP SIZES (OPTIMIZATION TERMINATES  R 0000
C     IF DX(I)-DXMIN(I)GT 0 FOR ALL I                                     R 0000
C     EX=SCRATCH ARRAY USED TO STORE EXTRAPOLATED XS                      R 0000
C     XBASE=SCRATCH ARRAY USED TO STORE BASE XS                           R 0000
C     KOPT=PARAMETER FOR COMPUTES GO TO, MUST BE EXTERNALLY SET TO ONE    R 0000
C     AT BEGINNING OF OPTIMIZATION PROCESS                                R 0000
      DIMENSION X(NX),DX(NX),XMIN(NX),XMAX(NX),DXMIN(NX),EX(NX),XBASE(NX R 0000
     1)                                                                   R 0000
      COMMON /PATSRC/I,YBASE                                              R 0000
      GO TO (5,15,25,35,85),KOPT                                          R 0000
C     EXPLORATION                                                         R 0000
    5 DO 10 I=1,NX                                                        R 0008
      XBASE(I)=X(I)                                                       R 0014
   10 EX(I)=X(I)                                                          R 0019
      KOPT=2                                                              R 0023
      RETURN                                                              R 0024
   15 YBASE=Y                                                             R 0028
      I=1                                                                 R 0029
   20 IF(I.GT.NX)   GO TO 60                                              R 0030
   21 X(I)=EX(I)+DX(I)                                                    R 0033
      IF(X(I).LT.XMIN(I))X(I)=XMIN(I)                                     R 0039
      IF(X(I).GT.XMAX(I))X(I)=XMAX(I)                                     R 0047
      IF (X(I).EQ.EX(I)) GO TO 26                                         R 0056
      KOPT=3                                                              R 0061
      RETURN                                                              R 0062
   25 IF(Y.LE.YBASE)GO TO 50                                              R 0065
   26 DX(I)=-DX(I)                                                        R 0068
      X(I)=EX(I)+DX(I)                                                    R 0072
      IF(X(I).LT.XMIN(I))X(I)=XMIN(I)                                     R 0076
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```
      IF(X(I).GT.XMAX(I))X(I)=XMAX(I)                                   R  0086
      IF (X(I).EQ.EX(I)) GO TO 36                                       R  0095
      KOPT=4                                                            R  0100
      RETURN                                                            R  0101
   35 IF(Y.LE.YBASE)GO TO 50                                            R  0105
   36 DX(I)=-DX(I)                                                      R  0108
      X(I)=EX(I)                                                        R  0112
      I=I+1                                                             R  0116
      GO TO 20                                                          R  0118
   50 YBASE=Y                                                           R  0119
      I=I+1                                                             R  0120
      GO TO 20                                                          R  0121
C     EXTRAPOLATION                                                     R  0121
   60 KOUNT=0                                                           R  0123
      DO 70 I=1,NX                                                      R  0123
      EX(I)=2.*X(I)-XBASE(I)                                            R  0130
      IF(EX(I).LT.XMIN(I))EX(I)=XMIN(I)                                 R  0136
      IF(EX(I).GT.XMAX(I))EX(I)=XMAX(I)                                 R  0145
      IF(ABS(EX(I)-X(I)).LT.ABS(DX(I)))  KOUNT=KOUNT+1                  R  0153
   70 CONTINUE                                                          R  0163

      IF(KOUNT.GE.NX)GO TO 100                                          R  0163
   71 DO 75 I=1,NX                                                      R  0166
      A=X(I)                                                            R  0172
      X(I)=EX(I)                                                        R  0174
   75 EX(I)=A                                                           R  0179
      KOPT=5                                                            R  0182
      RETURN                                                            R  0182
   85 DO 86 I=1,NX                                                      R  0186
      A=X(I)                                                            R  0192
      X(I)=EX(I)                                                        R  0194
   86 EX(I)=A                                                           R  0199
      IF(Y.GT.YBASE)GO TO 95                                            R  0202
   87 DO 90 I=1,NX                                                      R  0205
      XBASE(I)=X(I)                                                     R  0211
   90 X(I)=EX(I)                                                        R  0216
      GO TO 15                                                          R  0220
```

```
   95 DO 96 I=1,NX                                                         R   0221
      XBASE(I)=X(I)                                                        R   0227
   96 EX(I)=X(I)                                                           R   0232
      I=1                                                                  R   0236
      GO TO 20                                                             R   0237
C     TERMINATION                                                          R   0237
  100 KOUNT=0                                                              R   0238
      DO 110 I=1,NX                                                        R   0238
      DX(I)=0.5*DX(I)                                                      R   0245
  110 IF(ABS(DX(I)).LT.DXMIN(I))  KOUNT=KOUNT+1                            R   0252
      IF (KOUNT.GE.NX) GO TO 111                                           R   0258
      DO 109 I=1,NX                                                        R   0261
      XBASE(I)=X(I)                                                        R   0267
  109 EX(I)=X(I)                                                           R   0272
      I=1                                                                  R   0276
      GO TO 20                                                             R   0277
  111 KOPT=6                                                               R   0278
C     KOPT=6 IMPLIES THAT THE MINIMUM HAS BEEN REACHED.  USE KOPT=6 AS A   R   0278
C     SIGNAL TO CALL FOR PRINT-OUT IN MAIN PROGRAM.                        R   0278
      RETURN                                                               R   0278
      END                                                                  R   0281

                                          START OF SEGMENT **********  20
      SUBROUTINE XPIPING(COST,M,WB,XNR,D,ZENITH,W,CFS)                     R   0000
C     COMPUTATION OF PIPE AND PIPE INSTALLATION COSTS UNING THE            R   0000
C     PREVIOUSLY CALCULATED TANK DIMENSIONS.                               R   0000
      DIMENSION FLOW(3),ALCOST(3)                                          R   0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT       R   0000
      COMMON/BLK6/PC                                                       R   0000
      REAL KWHC                                                            R   0000
      RATE=6.00                                                            R   0000
      FLOW(1)=CFS                                                          R   0002
      XLM=ZENITH +D+10.                                                    R   0003
      GOTO (22,21),M                                                       R   0005
   21 CALL PIPEOP(FLOW(1),XLM,PCOST,SIZE,PF,STRDL)                         R   0011
      DEN=62.5                                                             R   0014
      VIS=.00001                                                           R   0016
      GOTO 30                                                              R   0019
```

```
22 CALL PIPEAI( FLOW(1),XLM,PCOST,SIZE,PF,STRDL)              R  0021
   DEN=.076                                                    R  0023
   VIS=.00017                                                  R  0026
30 DL=40.                                                      R  0030
   V=(FLOW(1)*4.*144.)/(3.1416*SIZE**2)                        R  0030
   RN=V*SIZE/(12.*VIS)                                         R  0035
   A=.3164/RN**.25                                             R  0038
   HL=(A*V**2*(DL+D*10.)*12.)/(SIZE*64.4)                      R  0043
   NH=XLM/DL                                                   R  0050
   FLOW(2)=FLOW(1)/NH                                          R  0051
   DO 24 L=2,NH                                                R  0053
   FLOW(1)=FLOW(1)-FLOW(2)                                     R  0059
   U=(FLOW(1)*4.*144.)/(3.1416*SIZE**2)                        R  0062
   RN=U*SIZE/(12.*VIS)                                         R  0067
   A=.3164/RN**.25                                             R  0070
   HL=HL+(A*U**2*DL*12.)/(SIZE*64.4)+.6*V**2/64.4              R  0075
   V=U                                                         R  0088
24 CONTINUE                                                    R  0089
   HL=HL+1.8*V**2/64.4                                         R  0089
   NCM=NH*2+XLM/STRDL                                          R  0096
   HOURS=NCM*SIZE*PF                                           R  0098
   ALCOST(1)=1.5*HOURS*RATE+PCOST                              R  0100
   XLHA=W*NH                                                   R  0105
   GOTO (26,27),M                                              R  0106
27 CALL PIPEDP(FLOW(2),XLHA,PCOST,SIZE,PF,STRDL)               R  0112
   GOTO 31                                                     R  0115
26 CALL PIPEAI(FLOW(2),XLHA,PCOST,SIZE,PF,STRDL)               R  0116
31 FLOW(2)=FLOW(2)/2.                                          R  0119
   V=(FLOW(2)*4.*144.)/(3.1416*SIZE**2)                        R  0121
   RN=V*SIZE/(12.*VIS)                                         R  0126
   A=.3164/RN**.25                                             R  0129
   HL=HL+(A*V**2*(W/2.)*12.)/(SIZE*64.4)                       R  0134
   NCH=2.*(W/STRDL)*NH+1.                                      R  0141
   ALCOST(2)=1.5*NCH*RATE*SIZE*PF+PCOST                        R  0144
   DP=2.*HL                                                    R  0150
   PP=DP*DEN*FLOW(2)/550.                                      R  0151
   R=(PP/ETAM*ETAP)*KWHC*8960.*.745                            R  0153
```

```
                                                   START OF SEGMENT **********  19
      SUBROUTINE COOL(PICOST,M,WB,XNR,D,ZENITH,W,WW)           R  0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT  R  0000
      COMMON/BLK6/PC                                           R  0000
      REAL KWHC                                                R  0000
      XLM=400.+ZENITH*2.                                       R  0000
      NL=10                                                    R  0001
      CALL PIPEOP(WW,XLM,PCOST,SIZE,PF,STRDL)                  R  0002
      RATE=6.                                                  R  0004
      NCM=XLM/STRDL*NL*4.                                      R  0005
      PICOST=PCOST+SIZE*RATE*1.5*PF*NCM                        R  0008
      IDL=XLM/NL                                               R  0013
      DL=IDL                                                   R  0014
      XNL=NL*W                                                 R  0015
      FW=WW/NL                                                 R  0016
      V=(WW*4.*144.)/(3.1416*SIZE*2)                           R  0018
      RN=(V*SIZE*1.94)/(12.*.000021)                           R  0022
      A=.3164/RN**.25                                          R  0030
      HL=(A*V**2*(400.+DL)*12.)/(SIZE*64.4)+(0.9*V**2/64.4)    R  0035
      DO 22 L=2,NL                                             R  0048
      ZF=WW-FW                                                 R  0053
      U=(ZF*4.*144.)/(3.1416*SIZE**2)                          R  0055
      RN=(U*SIZE*1.94)/(12.*.000021)                           R  0059
      A=.3164/RN**.25                                          R  0067
      HL=HL+(A*U**2*DL*12.)/(SIZE*64.4)+(0.6*V**2/64.4)        R  0072
      V=U                                                      R  0085
   22 CONTINUE                                                 R  0086
      CALL PIPEOP(FW,XNL,PCOST,SIZE,PF,STRDL)                  R  0086
      NCL=(W/STRDL)*NL                                         R  0088
      PICOST=PICOST+PCOST+SIZE*RATE*1.5*PF*NCL                 R  0091
      HL=HL+1.8*V**2/64.4                                      R  0097
      V=(FW*4.*144.)/(3.1416*SIZE**2)                          R  0103
      RN=(V*SIZE*1.94)/(12.*.000021)                           R  0107
      A=.3164/RN**.25                                          R  0115
      HL=HL+(A*V**2*W*12.)/(SIZE*64.4)                         R  0120
      PP=HL*62.5*WW/550.                                       R  0127
      R=(PP/ETAM*ETAP)*KWHC*8960*.745                          R  0131
      PW=R/XINT                                                R  0138
      PC=2480.*(PP/25.)**.86+PW                                R  0140
      RETURN                                                   R  0147
      END                                                      R  0150
```

```
                                                START OF SEGMENT **********  21
       SUBROUTINE PIPINA(DTCOST,M,WB,XNR,HT,XLT,WT,FLOW)          R  0000
      COMMON/BLK8/S(20),LENGTH(20),F(20),EST(20),FTAP,FTAM,KWHC,XINT    R  0000
      COMMON/BLK6/PC                                              R  0000
      REAL KWHC                                                   R  0000
C     COMPUTATION OF PIPE AND PIPE INSTALLATION COSTS UNING THE   R  0000
C     PREVIOUSLY CALCULATED TANK DIMENSIONS.                      R  0000
      DIMENSION DCOST(5)                                          R  0000
C        LABOR RATE $6/HR                                         R  0000
      RATE=6.00                                                   R  0000
      NOUT=6                                                      R  0002
  342 CONTINUE                                                    R  0004
C  COST OF MAIN                                                   R  0004
      XL=XLT                                                      R  0004
      CALL PIPEAI(FLOW,XL,PCOST,SIZE,PF,STROL)                    R  0004
C        SPACING OF DIFFUSER PIPES                                R  0006
      CON1=20.                                                    R  0007
C        NCM=LENGTH/STD LENGTH*2 CONNECTIONS PER COUPLING*        R  0007
C        1 CAP+1 CONNECTION PER DISTRIBUTION TUBE                 R  0007
      NCM=(XLT/STROL)*2.+1.+(XLT/CON1)                            R  0007
      HOURS=NCM*SIZE*PF                                           R  0011
      DCOST(1)=1.5*HOURS*RATE+PCOST                               R  0013
      XYZ=SIZE/12.0                                               R  0018
C     COST OF FEEDER ARMS                                         R  0018
      I=XLT/CON1   +1.0                                           R  0020
      XLH=I*HT                                                    R  0025
      XL=XLH                                                      R  0026
      V=(FLOW*4.*144.)/(3.1416*SIZE**2)                           R  0027
      RN=(V*SIZE)/(12.*.00001)                                    R  0032
      A=.3164/RN**.25                                             R  0037
      HL=(A*V**2*CON1*12.)/(SIZE*64.4)                            R  0042
      IJ=I                                                        R  0048
      CFS=FLOW/I                                                  R  0048
      DO 28 K=2,IJ                                                R  0050
      FLOW=FLOW-CFS                                               R  0055
```

```
      U=(FLOW*4.*144.)/(3.1416*SIZE**2)                                R 0057
      RN=(U*SIZE)/(12.*.00001)                                          R 0061
      A=.3164/RN**.25                                                   R 0066
      HL=HL+(A*U**2*CON1*12.)/(SIZE*64.4)+(0.6*V**2/64.4)               R 0071
      U=V                                                               R 0084
   28 CONTINUE                                                          R 0085
      HL=HL+1.8*V**2/64.4                                               R 0085
      FLOW=CFS                                                          R 0092
      CALL PIPEAI(FLOW,XL,PCOST,SIZE,PF,STRDL)                          R 0092
      NCH=I*((HT/STRDL) + 2.0 )                                         R 0095
C        2. IS FOR ELBOWS                                               R 0098
      HOURS=NCH*SIZE*PF                                                 R 0099
C        COST AS IF OPTIMIZED                                           R 0100
      DCOST(2)=1.5*RATE*HOURS+PCOST                                     R 0101
      V=(FLOW*4.*144.)/(3.1416*SIZE**2)                                 R 0106
      RN=(V*SIZE)/(12.*.00001)                                          R 0110
      A=.3164/RN**.25                                                   R 0115
      HL=HL+(A*V**2*XL*12.)/(SIZE*64.4)  +(1.8*V**2/64.4)               R 0120
C   LB/SEC                                                              R 0132
      FLOWI=FLOW*.074/60.                                               R 0133
C        SIZE FOR HIGH DELTA P FOR PROPER DISTRIBUTION,NOT USED FOR COST YET.   R 0135
      CFS=FLOW/60.                                                      R 0136

      V=CFS*4./(3.1416*XYZ**2)                                          R 0137
      RN=V*XYZ/.00017                                                   R 0141
C        .00017 IS VISCOSITY OF AIR                                     R 0142
C                 A=4F                                                  R 0142
      A=.3164/RN**.25                                                   R 0145
C        DP2M=P2**2-P1**2                                               R 0148
      DP2M=16.*A*XLT*FLOWI**2*1544.*528./(32.2*29.*3.14159**2*XYZ**5)   R 0151
C        SIZE OF FEED LINES HAVE DELTA P SQUARED 5 TIMES THAT OF MAIN   R 0164
C     LET DP2H=5.*DP2M                                                  R 0164
C        DP2M PROP. TO W**1.75*D**(-4.75)                               R 0164
C        DP2H/DP2M=5=WH**1.75*DH**(-4.75)/(WM**1.75*DM**(-4.75))        R 0164
C        DH=5.*DM*(WH/WM)**1.75                                         R 0164
      DH=5.*SIZE*I**(-1.75)                                             R 0165
C        MAKES PIPE SIZE STANDARD SIZE                                  R 0169
```

```
      I=1                                                                R 0171
   10 IF(S(I).GT. DH) GO TO 20                                           R 0172
      I=I+1                                                              R 0175
      IF(I.LT. 8) GO TO 10                                               R 0176
   20 DH=S(I)                                                            R 0179
      WRITE(NOUT,756)SIZE,DH,DP2M                                        R 0180
  756 FORMAT(" SIZE"F10.3,"   DH",F10.3,"   DP2M",F10.3)                 R 0197
C     COST OF DIFFUSER                                                   R 0197
C        FIRST TERM=NO.CONNECTIONS   DUE TO STD LENGTH                   R 0197
C        2ND TERM=CAPS                                                   R 0197
C        3RD TERM=CONNECTIONS FOR DIFFUSERS           /                  R 0197
C        4TH TERM=COST OF DRILLING HOLE IN DIFFUSER                      R 0197
      NCD=(XLT/STRDL)*2.0 +2.0 +(XLT/CON1) +(XLT/3.0)                    R 0197
      XL=XLT                                                             R 0207
      CALL PIPEAI(FLOW/2.,XL,PCOST,SIZE,PF,STRDL)                        R 0208
      V=(FLOW/2.)*4.*144./(3.1416*SIZE**2)                               R 0211
      RN=(V*SIZE)/(12.*.00001)                                           R 0216
      A=.3164/RN**.25                                                    R 0221
      HL=HL+(A*V**2*CON1*12.)/(SIZE*64.4)                                R 0226
      PP=(HL*62.5*(FLOW/2.))/550.                                        R 0233
      R=(PP/FTAM*ETAP)*KWHC*8960.*.745                                   R 0238
      PW=R/XINT                                                          R 0245
      PC=2480.*(PP/25.)**.86+PW                                          R 0247
      HOURS=NCD*SIZE*PF                                                  R 0254
      DCOST(3)=1.5*HOURS*RATE + PCOST                                    R 0256
      TCOST= DCOST(1) + DCOST(2) + DCOST(3)                              R 0261
      WRITE (NOUT,755) FLOW,XLH,PCOST,SIZE,PF,STRDL,DCOST,TCOST          R 0263
  755 FORMAT (8F9.2)                                                     R 0291
      RETURN                                                             R 0291
      END                                                                R 0294

                                          START OF SEGMENT ********** - 22
      SUBROUTINE DEEPP(PCOST,Y,XLM,Z,FL)                                 R 0000
      COMMON/BLK2/S(20),LENGTH(20),F(20),EST(20),FTAP,ETAN,KWHC,XINT     R 0000
      COMMON/BLK6/PC                                                     R 0000
      REAL KWHC                                                          R 0000
      CALL PIPEOP(FL,XLM,PCOST,SIZE,PF,STRDL)                            R 0000
      V=(FL*4.*144.)/(3.1416*SIZE**2)                                    R 0002
```

```
      RN=(V*SIZE)/(12.*.00001)                                   R  0007
      A=.3164/RN**.25                                            R  0012
      HL=(A*V**2*XLM*12.)/(SIZE*64.4)+(1.8*V**2/64.4)            R  0017
      PP=(HL*62.5*FL)/550.                                       R  0029
      R=(PP/ETAM*ETAP)*KWHC*8960.*.745                           R  0032
      PW=R/XINT                                                  R  0039
      PC=2480.*(PP/25.)**.86+PW                                  R  0041
      PC=PC+.1*PC                                                R  0048
      RETURN                                                     R  0052
      END                                                        R  0055
                                            START OF SE                    23
      SUBROUTINE PIPEAI(FLOW,XL,PCOST,BSIZE,BPF,STROL)           R  0000
C     OPTIMIZATION SUBROUTINE TO DETERMINE THE MOST ECONOMICAL SIZE R  0000
C     PIPE FOR A GIVEN FLOW RATE.  HEAD LOSS AND COST CALULATIONS ARE R  0000
C     DONE ON THE BASIS OF 100 FT FOR EACH PLOW RATE.            R  0000
C        V=VELOCITY IN FT/SEC FOR GIVEN PIPE DIAMETER            R  0000
C        RN=ESTIMATED REYNOLDS NUMBER                            R  0000
C        A=FRICTION FACTOR                                       R  0000
C        HL=HEADLOSS                                             R  0000
C        PP=PUMPING POWER NEEDED                                 R  0000
C        PW=PRESENT ESTIMATED WORTH OF PP                        R  0000
C        PCOST=COST OF PIPE FOR LENGTH DESCRIBED BY TANK DDSIGN  R  0000
      COMMON/BLK8/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT R  0000
      REAL KWHC                                                  R  0000
      MZ=6                                                       R  0000
      CFS=FLOW                                                   R  0000
      CHFCK=1.E+20                                               R  0001
    3 DO 2 I=1,8                                                 R  0005
C   HEADLOSS                                                     R  0005
      V=(CFS*4.*144.)/(3.1416*S(I)**2)                           R  0010
C        .00017 IS VISCOSITY OF AIR                              R  0015
      RN=(V*S(I))/(12.*.00017)                                   R  0016
      A=(.3164)/(RN**.25)                                        R  0021
C        HEAD LOSS IN FT PER 100 FEET                            R  0026
```

```
      HL=(A*V**2*1200.)/(S(I)*64.4)                                    R  0026
C   COST ESTIMATION                                                    R  0033
C         .076 IS DENSITY OF AIR                                       R  0033
      PP=(CFS*HL*0.076       )/(ETAP*FTAM*550.)                        R  0034
      R=PP*KWHC*8960.*.745                                             R  0039
      PW=R/XINT                                                        R  0045
      WORTH=PW+(EST(I)*100.)                                           R  0047
      IF(WORTH.GT.CHECK) GOTO 1                                        R  0049
      CHECK=WORTH                                                      R  0052
      BSIZE=S(I)                                                       R  0052
      STRDL=LENGTH(I)                                                  R  0054
      BPF=F(I)                                                         R  0055
      PCOST=EST(I)*XL                                                  R  0057
    2 CONTINUE                                                         R  0060
    1 WRITE(MZ,5)BSIZE                                                 R  0061
    5 FORMAT(6H BSIZE/F12.3)                                           R  0073
      IF(BSIZE.EQ.0.0) BSIZE=S(1)                                      R  0073
      IF(BSIZE.EQ.0.0) BPF=F(1)                                        R  0075
      IF(BSIZE.EQ.0.0) STRDL=LENGTH(1)                                 R  0078
      IF(BSIZE.EQ.0.0) PCOST=EST(1)*XL                                 R  0080
      RETURN                                                           R  0083
      END                                                              R  0086
                                         START OF SEGMENT **********   24
      BLOCK DATA                                                       R  0000
      COMMON/BLK8/S(20),LENGTH(20),F(20),EST(20),ETAP,ETAM,KWHC,XINT   R  0000
      REAL KWHC                                                        R  0000
      DATA(S(I),I=1,8)/1.,2.,3.,4.,5.,6.,8.,10./                       R  0000
      DATA(EST(I),I=1,8)/.268,.5851,1.21,1.7272,2.34,3.0394,5.2747,7.46/ R  0016
      DATA (F(I),I=1,18)/18*.5/                                        R  0032
      DATA(LENGTH(I),I=1,8)/8*20/                                      R  0048
      DATA ETAP,ETAM,KWHC,XINT/.75,.85,0.015,.08/                      R  0064
      END                                                              R  0082
```

NSF Sea Grant

Final Report

FACULTY AND CURRICULUM IMPROVEMENT

Dr. Frederick E. Camfield

College of Engineering
Department of Civil Engineering

The purpose of this subproject was to provide support for further development of Ocean Engineering education at the University of Delaware. Prior to initiation of Sea Grant support, the Ocean Engineering program within the Department of Civil Engineering consisted of one course, Ocean Engineering I, taught by William S. Gaither (at that time an Associate Professor of Civil Engineering).

In September 1968, Dr. Jan Jordaan was added to the department faculty as an additional staff member in the area of Ocean Engineering. Four new courses were added to the curriculum during the first year of NSF Sea Grant support, CE 871 Marine Structures I and CE 872 Marine Structures II taught by W. S. Gaither, and CE 672 Ocean Engineering II and CE666 Engineering in a Coastal Environment taught by J. Jordaan.

Dr. Jordaan initiated a proposal to the University to obtain wave making and towing equipment for installation in a large existing flume. Also, during this time, he prepared a proposal for studying the energy budget along the Delaware coastline and in lower Delaware Bay, the proposal being funded the following year under project Oceans-Themis. In September 1969 Dr. Jordaan left the University of Delaware to return to his home country, and Dr. Frederick E. Camfield was added to the Department faculty as an assistant professor at that time to replace Dr. Jordaan.

During the second year of the program, Dr. Camfield continued the development of three of the Ocean Engineering courses, CE 671, CE 672, and CE 666. The content of these courses was revised and new course materials were obtained in a continuing effort to improve the Ocean Engineering instruction within the Department of Civil Engineering. In addition, Dr. Camfield taught CE 837 Free Surface Flow and CE 839 Applied Hydraulics.

Dr. Camfield assumed direction of the Oceans-Themis subproject originally proposed by Dr. Jordaan, and also continued the planning for obtaining wave and towing equipment. During this year, Dr. Camfield also planned and arranged for a Symposium on Long Waves which was held at the University of Delaware on September 10-11, 1970. This symposium brought together various persons working in this area to discuss the present state-of-the-art in the analysis of long waves in water.

During the second year of the program, Dr. Gaither became a special assistant to the President of the University of Delaware, and later was appointed Dean of the new College of Marine Studies. Dr. Hsiang Wang was added to the Department of Civil Engineering faculty as an associate professor, replacing Dr. Gaither. Dr. Wang taught CE 872 during the second semester of the year.

Twenty-seven students were enrolled (for credit) in Ocean Engineering courses for the period September 1, 1968 to August 31, 1970.

Graduates who have taken substantial course work in the area of Ocean Engineering have included:

2 naval ensigns who have reported to assignments with the U.S. Navy. (An additional ensign is enrolled in 70-71.)

1 man who accepted a job with the Naval Civil Engineering Laboratory in Port Hueneme, prior to entering the Navy O.C.S. program.

1 woman Margaret (Peggy) Lucas is now completing her thesis. She served as engineer for the all woman team on Tektite II.