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EARTH SCIENCES DIVISION

DRAFT
ENVIRONMENTAL ASSESSMENT OCEAN THERMAL
ENERGY CONVERSION (OTEC) PILOT PLANTS

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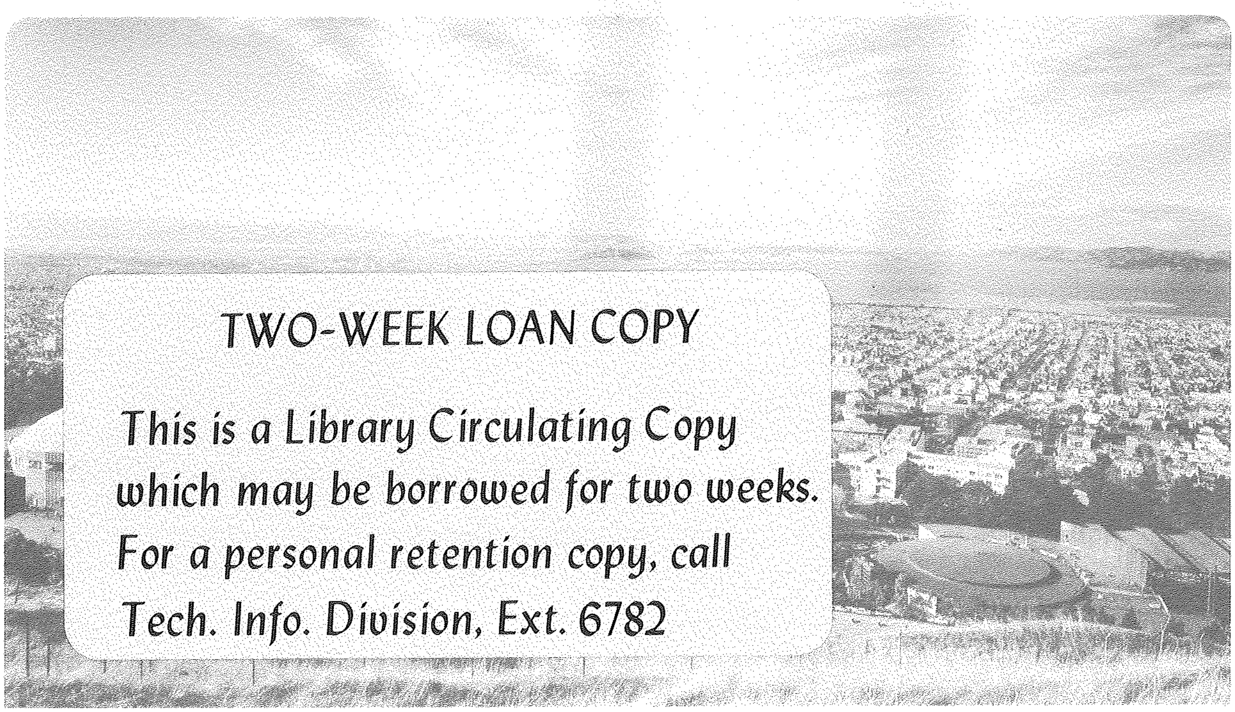

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ENVIRONMENTAL ASSESSMENT
OCEAN THERMAL ENERGY CONVERSION (OTEC)
PILOT PLANTS

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SUMMARY

This Environmental Assessment (EA) has been prepared, in accordance with the National Environmental Policy Act of 1969, for the deployment and operation of a commercial 40-Megawatt (MW) Ocean Thermal Energy Conversion (OTEC) Pilot Plant (hereafter called the Pilot Plant). It is concluded that environmental disturbances associated with Pilot Plant activities could potentially cause significant environmental impacts; however, the magnitude of these potential impacts cannot presently be assessed, due to insufficient engineering and environmental information. A site- and design-specific OTEC Pilot Plant Environmental Impact Statement (EIS) is required to resolve the potentially significant environmental effects associated with Pilot Plant deployment and operation.

PROPOSED ACTION

The proposed action considered in this EA is the deployment and operation of a commercial 40-MW OTEC Pilot Plant. The Pilot Plant, expected to be deployed in 1985-1986, will provide baseload electricity to an island community for approximately 30 years. The Pilot Plant is an integral part of the U.S. Department of Energy's (DOE) program to demonstrate the technological, economic, and environmental feasibility of OTEC power plants. The Pilot Plant will lend impetus to the OTEC Program by serving as a subscale prototype of a large-scale commercial plant and demonstrating the viability of commercial baseload systems.

The Pilot Plant is presently in an early development phase, with several different platform designs being considered, including the Spar, Moored Plantship, Bottom-Resting Tower, and Land-Based configurations. The Pilot Plant will use four 10-MW closed-cycle heat-exchanger units to produce electric power from the temperature differential between warm surface and cold deep-ocean water. The electricity will be delivered to the local power grid either directly (for Land-Based plants) or by means of submarine transmission cables.

EXISTING ENVIRONMENT

The DOE is considering four sites deemed representative of the island communities where an OTEC Pilot Plant will be located. The candidate sites include:

- Kahe Point, Oahu
- Key West, Florida
- Punta Tuna, Puerto Rico
- Saint Croix, Virgin Islands

Due to the early development phase of the Pilot Plant Program, limited site-specific information is available for the candidate sites; however, data from DOE-funded surveys and historical literature suggests that the sites are biologically and oceanographically similar, due to their proximities to shore and tropical locations. With one exception, candidate sites have steep, rugged bottom topography and slow to moderate (10 to 80 cm sec^{-1}) surface currents. The Key West site is the exception, having a wide Continental Slope with few irregularities, and high surface currents (100 to 300 cm sec^{-1}). The biota at candidate sites are characterized by coastal marine populations superimposed on an oceanic assemblage.

POTENTIAL ENVIRONMENTAL IMPACTS

The OTEC Pilot Plant may potentially affect air quality, the terrestrial environment, and the marine ecosystem in the vicinity of the deployment and operation site. Atmospheric effects or climatic alterations from carbon dioxide release and sea-surface temperature cooling are not anticipated to result from Pilot Plant operation. Construction of a Land-Based Pilot Plant may necessitate the total destruction of the existing terrestrial habitat. Grading for roads, utility corridors, and the central utility terminus may result in a change of land use from natural to improved (developed) land.

The majority of environmental effects associated with Pilot Plant deployment and operation center on the marine ecosystem since it is the source of evaporating and condensing waters, and receiver of effluent waters used by the plant. Marine environmental effects associated with the various Pilot Plant configurations being considered can be categorized as: (1) major (those causing significant environmental impacts), (2) minor (those causing insignificant environmental disturbances), and (3) potential (those occurring only during accidents). Pilot Plant characteristics and their corresponding environmental effects include:

(1) Major Effects of Deployment and Operation

- Platform presence - Attraction of fish, invertebrates, and birds
- Withdrawal of surface and deep-ocean waters - Organism impingement and entrainment
- Discharge of biocides - Effects on nontarget organisms
- Discharge of waters at or near the thermocline - Redistribution of ocean properties, particularly nutrients and planktonic organisms

(2) Minor Effects of Deployment and Operation

- Power cycle erosion and corrosion - Effects from trace constituent release on resident organisms
- Implantation of cold-water pipe and transmission cable - Habitat destruction and turbidity during dredging

(3) Potential Effects from Accidents

• Potential working fluid release from spills or leaks	– Toxic effects of released working fluid on resident organisms
• Potential oil releases	– Toxic effects of oil on resident organisms

The Pilot Plant will serve as an artificial reef and provide a habitat for a large number of organisms. The increased population near the plant will compound environmental impacts by exposing greater numbers of organisms to the effects associated with routine plant operation, such as entrainment and impingement, and risk of nonroutine events, such as spills.

Preliminary (order-of-magnitude) estimates indicate that the most serious marine ecosystem effects caused by Pilot Plant operation are associated with the seawater intakes and discharges. The Pilot Plant will withdraw and discharge approximately 100 times more water than a similarly sized fossil-fuel or nuclear power plant. The potential impacts associated with seawater withdrawal and discharge include entrainment of larval stages, impingement of ecologically and commercially important species, toxic substance release, and ocean water redistribution.

- Entrainment of ichthyoplankton (fish eggs and larvae) and meroplankton (benthic invertebrate eggs and larvae) may reduce adult populations downstream of the plant. Around islands the maintenance of a larval population near the spawning site is vital to adult population existence. Ichthyoplankton and meroplankton populations at candidate sites must be assessed so that the entrainment rate of eggs and larvae can be estimated and compared to the population available for recruitment.

- Impingement of organisms on the intake screens may reduce the population of ecologically or commercially important species in the vicinity of the plant. Data on platform attraction rates, species affected by impingement, impingement rates, and mortality rates should be collected during operation of OTEC-1, and the results extrapolated to the Pilot Plant.

- Biocides (chlorine and its seawater-reaction products) and protective hull coatings released from the Pilot Plant may be toxic to resident organisms or taken up in the tissues of ecologically or commercially important species. Descriptive studies on the seawater chemistry of chlorine, acute/chronic toxicity studies, and food-chain investigations are required for evaluating the effects of these releases.

- The release of working fluids and oil during a catastrophic accident could significantly impact the marine environment. The risk of accident occurrence should be assessed, and a spill contingency plan prepared.

- The discharge of nutrient-enriched deep waters within the surface layers of the water column may increase the primary productivity of the receiving waters. Data for evaluating nutrient redistribution effects on the ecosystem includes physical-model predictions, phytoplankton uptake rates, and food-chain investigations. Results of physical models will provide estimates of the plume stabilization depth, downstream nutrient concentrations, and area affected. Phytoplankton uptake rates and food-chain investigations are important for estimating the increase in biomass and its resulting effect on trophic-level structures.

To assess the potential effects of Pilot Plant deployment and operation, the ecological, physical, and chemical characteristics of the site must be determined prior to plant deployment, and an environmental monitoring plan (for evaluation of plant operational effects) prepared. After Pilot Plant deployment, environmental monitoring data must be obtained and used for determining the long-term environmental effects associated with Pilot Plant operation. The collected data will be used in regulatory compliance reporting, but should also be compared with environmental predictions made prior to deployment in order to validate theoretical results.

RISK OF CREDIBLE ACCIDENTS

Operations in the marine environment present several unique hazards or potential for accidents. Collisions, extreme meteorological conditions, military or political terrorism, and human error may endanger the safety of the platform crew and the population served by the Pilot Plant. Pilot Plant crew members, the population adjacent to the plant, and communities served by the plant will be exposed to potential accidents and power failures.

The DOE will require the preparation of a Safety Analysis Report (SAR) for the Pilot Plant. A SAR identifies the hazards associated with operation and describes an approach to eliminate or control the hazards. The development of a health risk assessment model, a fundamental component of a SAR, is necessary to fully assess the potential of both man-made and nature-induced accidents.

Ship traffic around the Pilot Plant must be carefully monitored to minimize the potential for collisions. Large volumes of working fluid (ammonia) will be stored aboard the Pilot Plant and present certain health hazards should a collision or large leak occur. A spill contigency plan should be prepared after the Pilot Plant platform and deployment site has been selected.

FEDERAL AND STATE PLANS AND POLICIES

The Pilot Plant will operate in either the territorial sea of the adjacent coastal state or in the United States Economic Resource Zone. The territorial sea, which extends 3 nmi (10.8 nmi for Puerto Rico) from shore, is under the jurisdiction of the adjacent coastal state; Federal jurisdiction extends from the limit of State jurisdiction to 12 nmi from shore. Land-Based, Bottom-Resting Tower, and moored Pilot Plants could be located within State jurisdictional limits at Punta Tuna (Puerto Rico) and Saint Croix (Virgin Islands). In general, Pilot Plant deployment and operation will be influenced by both State (by virtue of submarine cable to shore) and Federal (by virtue of funding) regulations. In the absence of appropriate State regulations, Federal regulations will be applied.

Several Congressional bills were recently signed into law and will significantly influence OTEC development. The OTEC Act of 1980 (Public Law 96-320) establishes a licensing regime and provides financial incentives for OTEC plants. The OTEC Act of 1980 allows the Secretary of Energy to make all licensing decisions and determinations for Pilot or Demonstration OTEC plants, thereby reducing lead time required for receiving permits. The OTEC Research, Development, and Demonstration Act (Public Law 96-310) provides for the acceleration of the OTEC program to achieve early commercialization.

Jurisdiction of vessel-crew and process-system safety is a joint responsibility of the U.S. Coast Guard (USCG) and the Occupational Safety and Health Administration (OSHA). A Memorandum of Agreement on occupational health standards for work areas aboard inspected vessels establishes cooperation between USCG and OSHA towards addressing significant health hazards not covered by existing standards.

ALTERNATIVES

The Pilot Plant will be a permanent structure that will be on site for up to 30 years. The alternatives in the Pilot Plant Program are in the environmental and engineering categories, each considered from the point of mitigating or reducing potential environmental impacts. The environmental alternative is the selection of the deployment site. Achieving maximal usage from the Pilot Plant at minimal economic cost and environmental disturbance requires selection of the optimal deployment site. Engineering alternatives include the type of platform, choice of heat exchangers (plate-type or tube-in-shell), design of the intake structure, and design of the discharge structure.

ORGANIZATION OF THE ENVIRONMENTAL ASSESSMENT

The organization and approach of this EA follows the format previously established in the Preoperational Test Platform (OTEC-1) EA. A description of the proposed action is presented in Section 1. A generic environment typical of the candidate Pilot Plant siting regions is described in Section 2. Section 3 provides an assessment of the potential environmental impacts associated with the proposed action. Section 4 considers the risk of credible accidents and mitigating measures to reduce these risks. Section 5 describes the Federal and State plans and policies the proposed action will encompass. Alternatives to the proposed action are presented in Section 6. Appendix A presents the navigation and environmental information contained in the U.S. Coast Pilot for each of the candidate sites. Appendix B provides a brief description of the methods and calculations used in the EA.

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Section 1
THE PROPOSED ACTION

The proposed action in this Environmental Assessment is the deployment and operation of a commercial 40-MW OTEC Pilot Plant off a subtropical- tropical island community. The Pilot Plant, expected to be deployed by 1985-1986, will provide baseload electricity to an island community for approximately 30 years. The EA is prepared in compliance with the National Environmental Policy Act of 1969 (NEPA) and considers the potential environmental consequences associated with OTEC Pilot Plant deployment and operation. This EA is generic in that it considers several different Pilot Plant designs for various island communities.

Ocean Thermal Energy Conversion (OTEC) has been studied in the United States since 1972. The objective of the U.S. Department of Energy's (DOE) OTEC Program is to demonstrate the technological, economic, and environmental feasibility of OTEC power plants (DOE, 1979a). Recent advances in power-cycle design and system integration have allowed DOE to consider the feasibility of deploying and operating a 40-MW OTEC Pilot Plant. The Pilot Plant will add impetus to the OTEC Program by (1) serving as a subscale prototype of a large-scale commercial plant, and (2) demonstrating the viability of the commercial system. To accomplish these goals the Pilot Plant must achieve several objectives:

- Penetrate the utility market in an island community and demonstrate that large-scale commercial OTEC plants are capable of supplying electrical power at a competitive price.

- Verify that heat-exchanger designs, including materials and cleaning methods, will achieve acceptable efficiency during long-term operation.

- Adapt and develop the technology of submarine electrical energy transmission.

- Perform mission and equipment analyses in order to define optimal commercial designs.

- Assess potential short- and long-term marine-ecosystem impacts of OTEC operation.

The Pilot Plant is presently in an early development phase. The OTEC Pilot Plant Program Opportunity Notice was released in September 1980, with the choice of platform design and deployment site being made by DOE and the successful contractor. The preliminary schedule for the OTEC Pilot Plant Program is given in Figure 1-1. The Pilot Plant Program will consist of six phases: (I) Conceptual Design, (II) Preliminary Design, (III) Detailed Design, (IV) Construction, Deployment, and Acceptance Test, (V) Joint Operational Test and Evaluation, and (VI) Transfer of Ownership and Contractor Operation. Since the final plant design and deployment site have not yet been selected, this generic Environmental Assessment (EA) considers all likely platform designs and siting locations.

Subsection 1.1 describes the OTEC concept; the candidate Pilot Plant platform designs being considered by the DOE are described in Subsection 1.2.

1.1 CONCEPT DESCRIPTION

OTEC uses the temperature differential between warm surface and cold deep-ocean waters to produce electric power via either a gas or steam turbine. In the closed-cycle OTEC system, warm water is pumped through an evaporator containing a working fluid (e.g., ammonia, Freon™). The warm water vaporizes the working fluid, which drives a turbine and provides power for the plant. After passing through the turbine the vaporized working fluid is condensed by cold seawater (drawn up from the deep ocean) and pumped back into the evaporator for reuse. No conventional fuel is used; the enclosed working

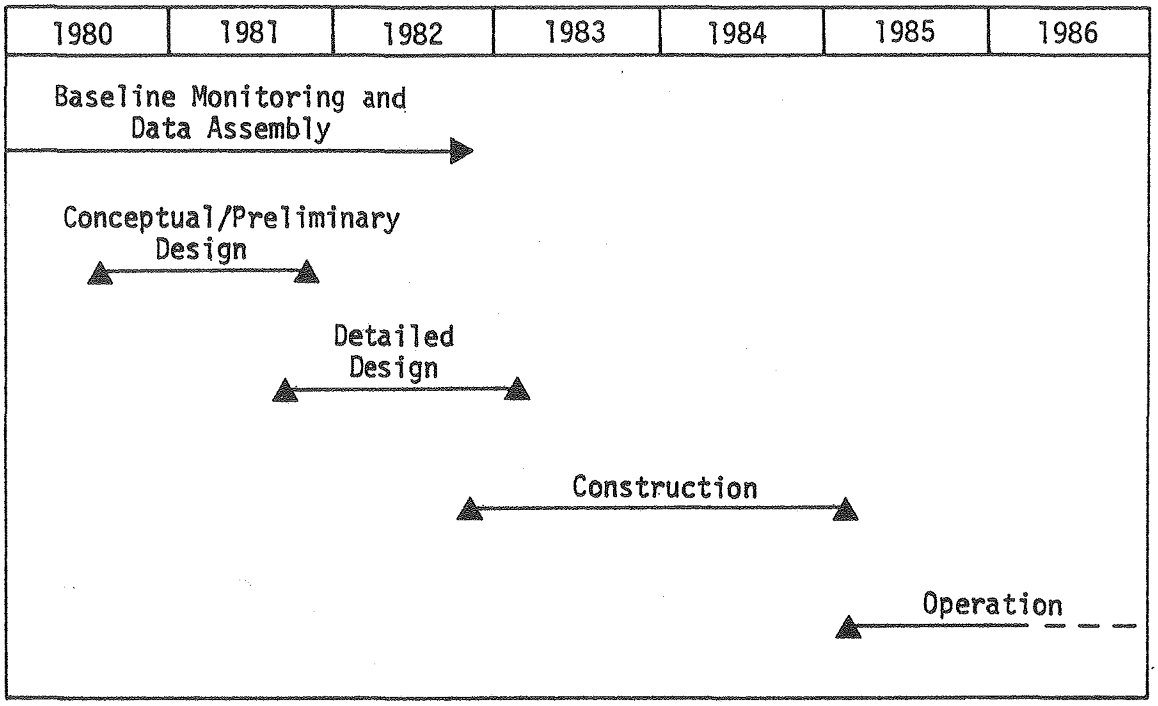


Figure 1-1. Preliminary Schedule for the OTEC Pilot Plant Program

fluid is evaporated and condensed repeatedly by the warm surface and cold deep-ocean waters drawn into the plant. A schematic diagram of the closed-cycle OTEC power system appears in Figure 1-2.

The open-cycle OTEC system operates in much the same way as the closed-cycle system, except that seawater is used as the working fluid, obviating the need for heat-exchanger surfaces. Warm surface seawater flows into a partially evacuated evaporator, where the lowered pressure changes the fluid to steam. The steam passes through a turbine, providing power for the plant, and is then condensed by cold seawater. Again, no conventional fuel is used (DOE, 1979a).

The greater probability of achieving OTEC Pilot Plant goals with a closed-cycle system has led to its selection for initial demonstration.

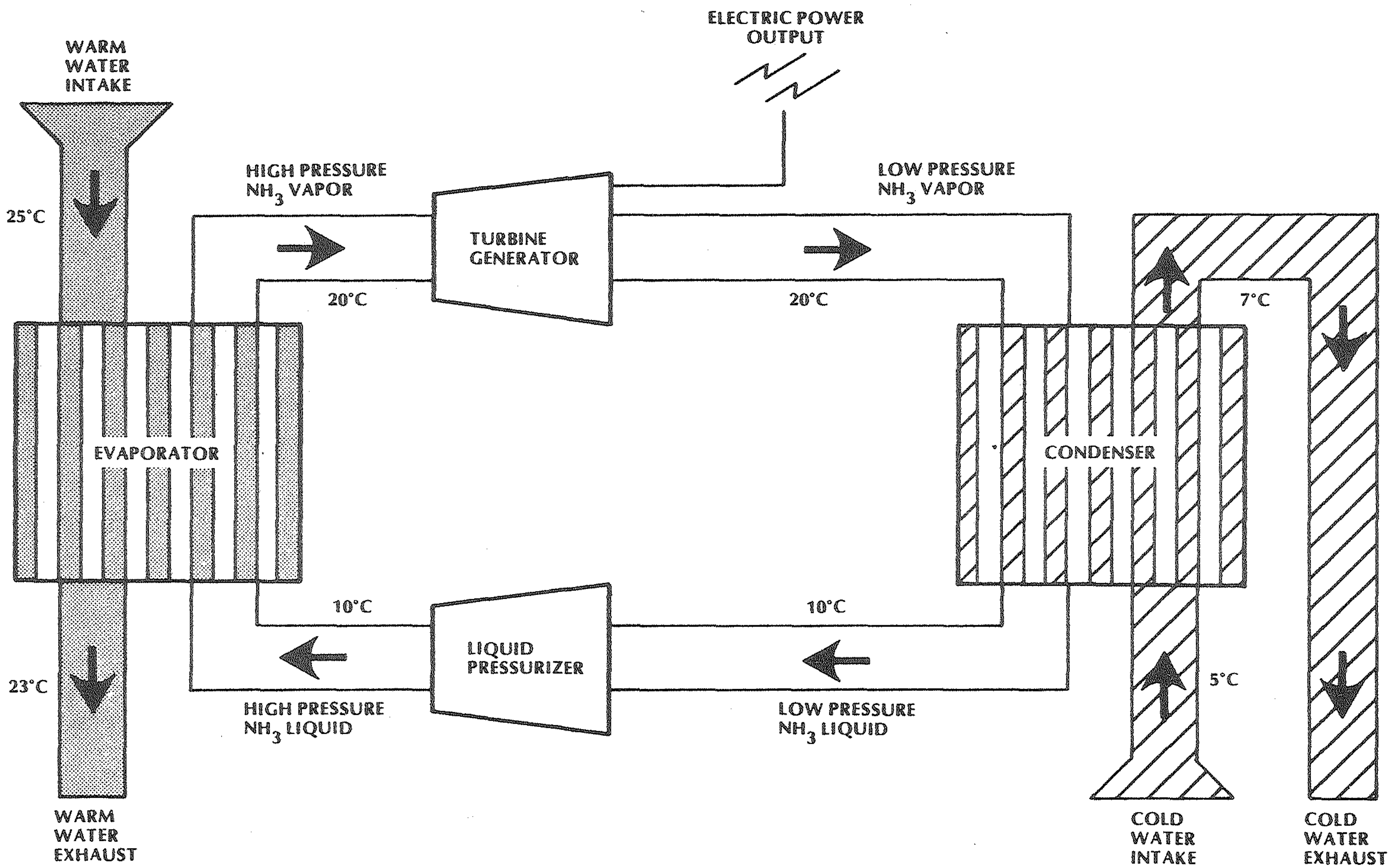


Figure 1-2. Closed-Cycle OTEC Power System
Source: Adapted from DOE (1979a)

Although the current DOE OTEC Program emphasizes the closed-cycle system, the open-cycle system is being evaluated for possible second-generation application, as warranted by technological developments and analyses (DOE, 1979a).

1.2 TECHNOLOGY DESCRIPTION

This EA considers several Pilot Plant designs under evaluation by the DOE, including the Spar, Moored Plantship, Bottom-Resting Tower, and Land-Based Plants. Although the designs differ, the engineering features which must be described for assessment of potential environmental impacts or risk of credible accidents are similar in all plants considered. These features include:

- Platform design and configuration
- Protective hull coatings used to retard biofouling
- Configuration of the warm- and cold-water intake structures
- Configuration of the discharge (outfall) structures
- Trace metals which will be eroded or corroded from the power cycle
- Working fluids which may be released due to system leaks or spills
- Biocides released for biofouling control
- Design of the submarine transmission cable
- Waste-disposal and pollution-control systems
- Safety systems to reduce or mitigate risk of accidents

These environmentally significant components of the OTEC Pilot Plant are described to the extent possible. For system elements not defined, the reasonable candidates are identified and described.

1.2.1 Platform Description

Candidate Pilot Plant platform designs include the Spar, Moored Plantship, Bottom-Resting Tower, and Land-Based plant. The Land-Based design will provide baseload electricity directly to the local power grid. The others will transmit electricity to shore by means of submarine transmission cables. All plant configurations will be designed to survive 100-year events at candidate sites (e.g., earthquakes; extreme winds, waves, and currents). The Pilot Plant will be able to operate in sea conditions up to and including 5-m significant wave heights, 15-m sec^{-1} winds, and 100-cm sec^{-1} surface currents.

Living quarters will be provided in offshore designs for as many as 50 personnel, including operating crew, scientists, technicians, and visitors. The deckhouse will accommodate all habitation, platform-control, and scientific functions, as well as generators, shops, and helicopter facilities. The platform will be resupplied and serviced monthly, requiring between 10 and 15 additional personnel for shore-support and maintenance activities. Approximately 300 m^3 of diesel fuel for the generators and diesel engines and 15 m^3 of helicopter fuel will be stored aboard the Pilot Plant.

Specific descriptions of each platform design are presented below.

1.2.1.1 Spar - The Spar design (Figure 1-3), as described by Moak et al. (1980), is a semi-submerged platform moored by a single mass anchor. A submerged cylindrical hull approximately 45m in diameter serves as the primary source of static and reserve buoyancy, and contains the turbo-generators, power-conditioning equipment, and power modules. A surface-piercing column supports the deckhouse and acts as a trunk for access, equipment removal, and support-service runs. The Spar is constructed of high-strength steel (ASTM A-572 Grade 50), and incorporates active and passive corrosion-control systems.

A cold-water pipe (10m wide and 900m long) is attached to the bottom of the Spar, through which cold water is drawn from depth into the plant. A hollow steel insert in the cold-water pipe serves two purposes: (1) during deployment the steel insert is filled with oil to provide buoyancy for transit to the site (the oil is pumped into a receiving tanker during cold-water-pipe upending), and (2) during operation the steel insert gives the cold-water pipe rigidity (Moak et al., 1980). A mass anchor will be connected by mooring cable to the steel insert in the cold-water pipe, permitting the platform to swing through a 100-m-diameter watch circle.

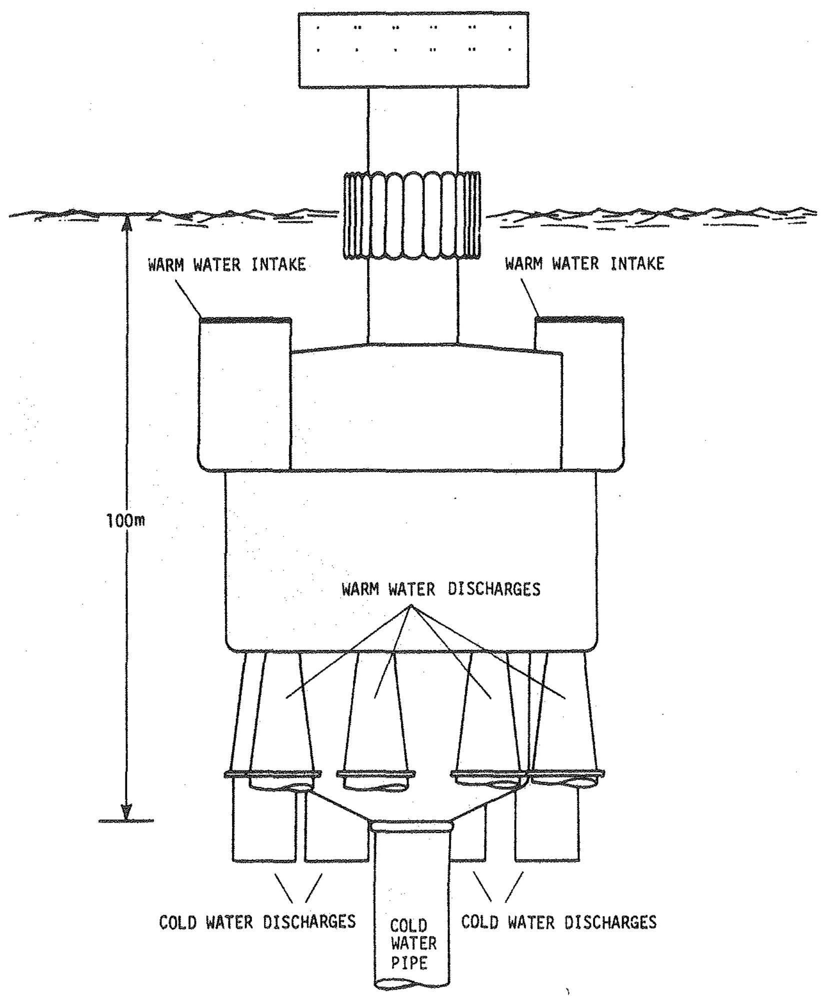


Figure 1-3. Typical Spar Design
Source: Moak et al., 1980

1.2.1.2 Moored Plantship - The Moored Plantship (Figure 1-4), as described by George and Richards (1980), is a barge-like structure constructed of prestressed reinforced concrete. The platform is 115m long, 37m wide (48m at the warm-water pumps), with a draft of 20m, and freeboard of 7m. Warm-water pumps are located in sponsons near the corners of the platform. The cold-water pipe is attached midships and is surrounded by the power system.

The cold-water pipe is 900m long and 10m wide, and is constructed of post-tensioned lightweight concrete. The cold-water pipe is hinged at the platform connection and at 15-m intervals, allowing free rotation around any axis. The Moored Plantship incorporates a multiple-anchor, deep-water mooring system, which permits moorings at depths to 2,200m. One proposed system consists of 10 catenary mooring lines connected at the corners of the hull. This mooring arrangement would allow the platform to move through a 600-m-diameter watch circle.

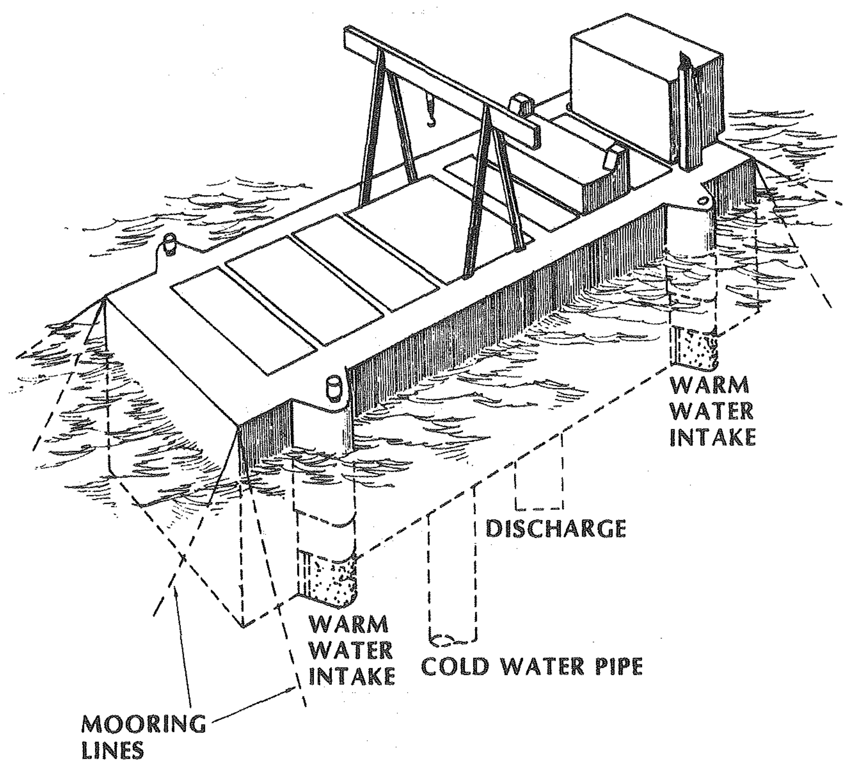


Figure 1-4. Moored Plantship Design
Source: George and Richards, 1980

1.2.1.3 **Bottom-Resting Tower** - The Bottom-Resting Tower (Figure 1-5) is designed for installation at depths less than approximately 300m and provides a stationary platform upon which the Pilot Plant may be built (Pharr, 1979). The platform is supported above the surface by four double-walled steel columns anchored in the seabed by means of piles. The steel columns are connected by an extensive system of diagonal braces both for lateral strength and to prevent buckling (Pharr, 1979). Guy wires leading from the platform to embedded anchors may be attached to towers installed in water deeper than 300m, to give additional stability.

The cold-water pipe extends from the platform to the bottom, and down the Continental Slope to the appropriate depth (Gibbs & Cox, 1979). Material for the cold-water pipe depends on bottom topography: light (buoyant) material (e.g., fiberglass reinforced plastic [FRP] or rubber-coated nylon [RCN]) for extremely irregular slopes, or heavy (resting on the seabed) material (e.g., concrete or steel) for areas with a uniform slope (Brewer et al., 1979).

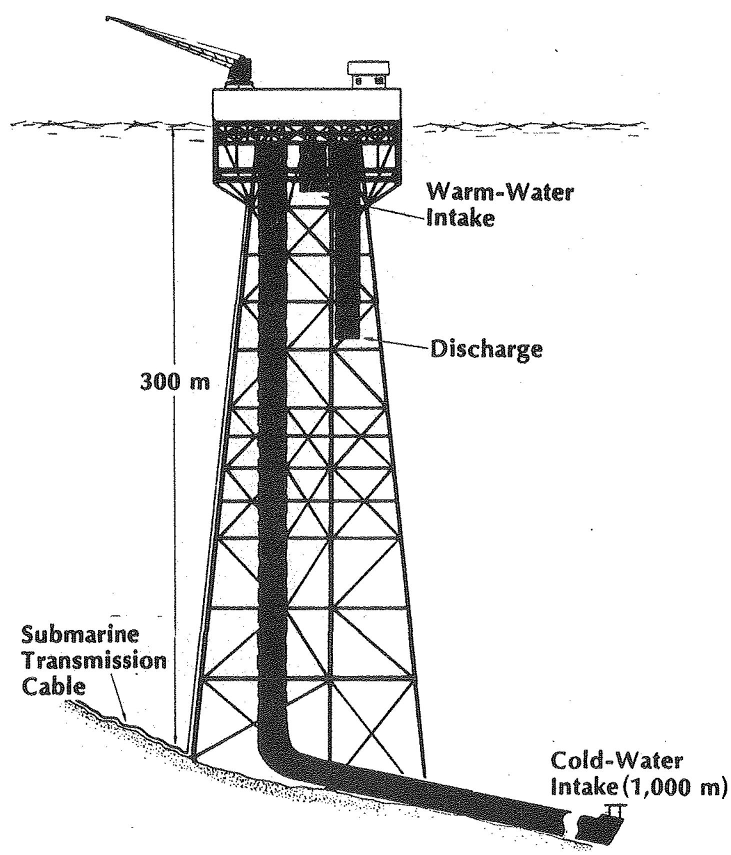


Figure 1-5. Typical Bottom-Resting Tower Design

1.2.1.4 <u>Land-Based</u> - A Land-Based OTEC Pilot Plant (Figure 1-6) will be constructed at sea level in order to avoid large power losses to the pumps (Brewer et al., 1979). The plant will be designed with the working fluid loop and power generation components directly in line between the condenser and evaporator. Power lines lead from each generator to a substation landward of the plant.

The cold- and warm-water discharge pipes are to be parallel, but separated. The warm-water intake may be an open channel with direct access to the warmest available water (Brewer et al., 1979). However, few shore-based fossil-fuel or nuclear-powered plants use intake canals for withdrawing marine waters; most plants use pipes to withdraw water from short distances offshore. The cold-water pipe extends from the plant along the seabed to the appropriate depth. Intake and discharge pipes are trenched and buried in shallow-water zones (less than 100m deep). As in the Bottom-Resting Tower design, materials for the cold-water pipe could include concrete, steel, FRP, or RCN.

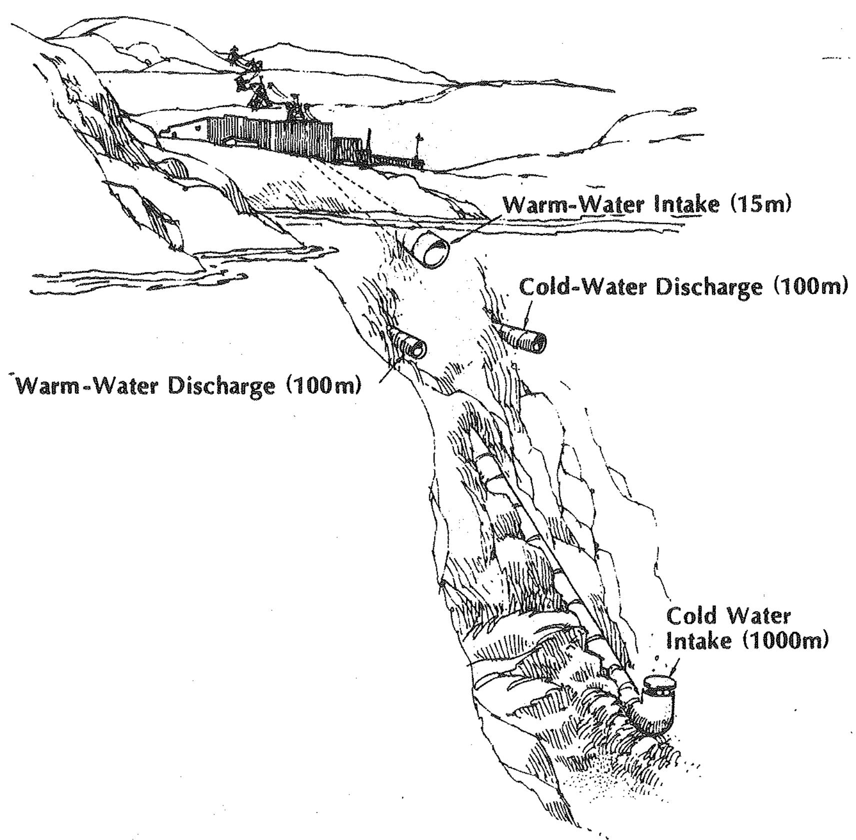


Figure 1-6. Typical Land-Based Design

1.2.2 Protective Hull Coatings

Attachment of macrofouling organisms on the hull surface will add weight and drag to the Spar and Moored Plantship platforms. Protective hull coatings, consisting of a matrix containing a soluble toxic compound which either diffuses from the matrix or gradually erodes and exposes a fresh toxic surface, may be applied to retard macrofouling growth. Protective hull coatings to be used on the OTEC Pilot Plant have not yet been determined.

Heavy-metal salts, primarily copper and zinc, are the toxic substances most commonly used in protective hull coatings. These coatings require a protective primer, which is applied to prevent galvanic corrosion. Other candidate coatings include thermoplastics, organotins, organoleads, and organotin fluorides. The biocidal properties of these compounds have been demonstrated in both the paper industry and in antifouling coverings (Luijten, 1972). The Federal government has restricted the use of some paints (e.g., mercury-based types) due to their potential adverse environmental effects. Typical release rates of cuprous oxide average about 30 ug cm^{-2} day^{-1} (De et al., 1976), with organometallic coatings leaching approximately one order of magnitude slower (Montemarano and Dyckman, 1973).

1.2.3 Intake Description

The OTEC Pilot Plant will utilize either single or multiple warm-water intakes to withdraw water from the top 20 to 30m of the water column. A single cold-water pipe, approximately 10m in diameter, will extend from the platform to the cold-water resource at 1,000-m depth. The depths of the warm- and cold-water intakes will be determined by the thermal resource at the site; a temperature differential of at least 20°C between the warm and cold water is required for optimal Pilot Plant operation.

The 40-MW OTEC Pilot Plant will withdraw approximately 128 m^3 sec^{-1} of cold water from 1,000-m depth, and 132 m^3 sec^{-1} of warm water from the surface layer. The expected intake velocity at the warm- and cold-water intakes is approximately 50 cm sec^{-1}. Several intake configurations are being evaluated (Figure 1-7). Pilot Plant intakes may be bell-shaped to reduce flow

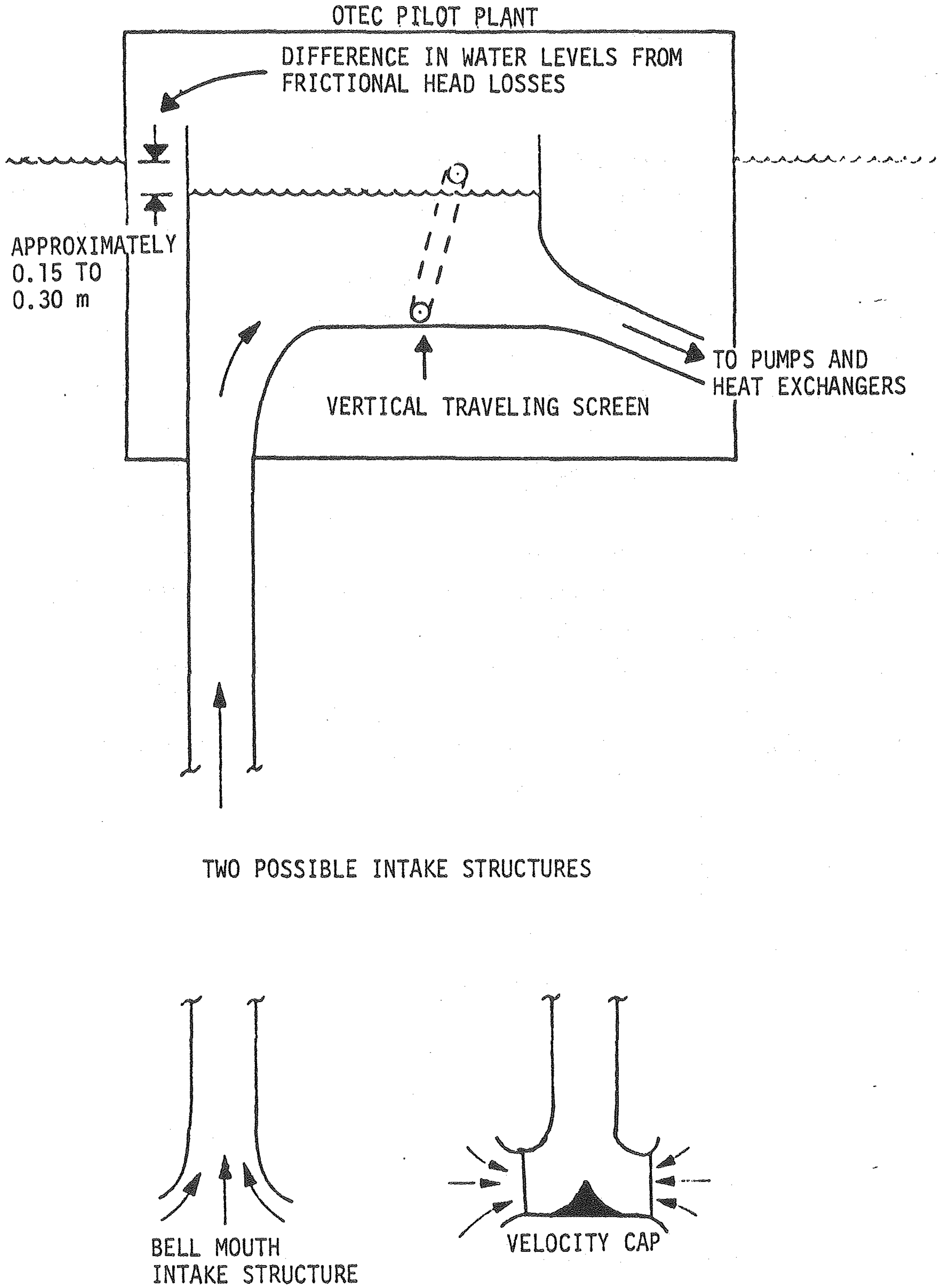


Figure 1-7. Example of OTEC Sump Accommodating Vertical Traveling Screens
Source: Hansen, 1978

velocities, or may employ velocity caps, producing horizontal flow fields much more readily sensed and avoided by fish than vertical flows (Hansen, 1978).

The warm and cold waters withdrawn by the OTEC Pilot Plant must be screened to prevent intake of materials which could clog the heat exchangers. Most conventional power plants use vertical traveling screens at their intakes. The tops of these screens are above water for easy cleaning and servicing. The Pilot Plant requires a different approach because the intakes are too deeply submerged for conventional screen cleaning. Sumps located between the warm- and cold-water intakes and the heat exchangers are proposed (Thomas, 1979). These sumps would provide an air-water interface where conventional screening could be used (Figure 1-7).

The type of screen to be used on the Pilot Plant has not been selected. Recent literature on OTEC-related screening technology includes papers by Nath et al. (1977), and Thomas (1979), who described three basic types of intake screens applicable to OTEC: (1) static, (2) traveling, and (3) bar screens.

Static screens are usually fixed wire-mesh screens. The preoperational OTEC platform (OTEC-1) uses static screens, with clear openings of 1.59 mm by 76 mm at the warm-water intake and at the cold-water sump.

Traveling screens are oriented perpendicular to the water flow, allowing water to pass through both ascending and descending screen panels. The standard mesh size range for static and traveling screens is from 0.95 to 1.3 cm (Hansen, 1978). Traveling screens are made of monel wire, with sacrificial anodes or induced current for corrosion protection.

A bar screen consists of vertical parallel bars positioned over the intake. The principal function of the bar screen is to prevent passage of large objects which may damage static or traveling screens. Coastal power plants usually use 8.9-cm by 1.3-cm flat steel bars with clear openings of 7.6 to 10.2 cm. When heavy loads of debris are anticipated, a traversing rake or a brush assembly is used for regular cleaning.

1.2.4 Discharge Description

Several different discharge configurations, including mixed, separate, horizontal, and vertical releases, have been considered for OTEC platforms. Several different depths for release have been proposed, ranging from the surface to 140-m depth. Mixing of warm- and cold-water discharges dilutes nutrient-rich deep waters with the nutrient-depleted surface waters, and gives the discharge plume a deeper stabilization depth in the water column. Vertical discharges inject waters deeper into the water column than horizontal releases.

Four vertical warm-water discharge structures, alternated with four cold-water discharge structures, have been proposed for the Spar, Moored Plantship, and Bottom-Resting Tower designs. These discharge structures would be situated at 100-m depths and have a flow rate of approximately 60 cm sec^{-1}. The Land-Based Pilot Plant uses separate warm- and cold-water pipes which discharge horizontally at or near the thermocline.

1.2.5 Heat Exchangers

The OTEC Pilot Plant will use four 10-MW closed-cycle heat-exchanger units. Heat-exchanger surface areas constitute sources of metals which may be released into the marine environment due to erosion and corrosion. Two types of heat-exchanger designs are being considered for OTEC Pilot Plants: tube-in-shell and plate.

The tube-in-shell configuration (Figure 1-8) consists of a number of parallel tubes, the ends of which are mated to a flat tube sheet. A shell is then wrapped around a bundle of tubes between the tube sheets. Seawater is circulated inside the tubes, with the working fluid applied to the outside of the tubes. The orientation of the tube bundles may be either horizontal or vertical.

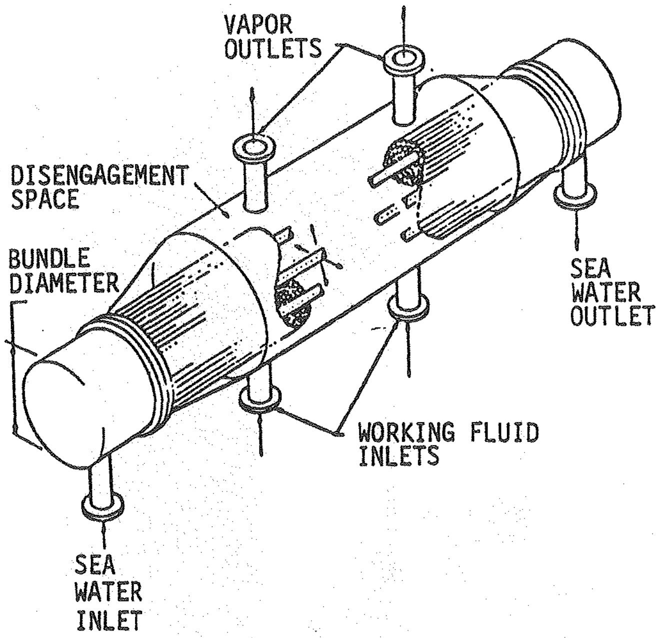


Figure 1-8. Tube-in-Shell Heat Exchanger
Source: Sands, 1980

The plate heat exchanger (Figure 1-9) consists of a series of closely packed thin metal plates. The plates are sealed together in pairs with open spaces between each sealed pair. The working fluid circulates between the pairs of sealed plates.

Various heat-exchanger materials have been studied to determine their suitability for use in an OTEC plant. The most likely candidates for the Pilot Plant are commercially pure titanium, aluminum alloys, and steel alloys. The ideal candidate should be readily formed and tooled, have a high thermal conductivity, be corrosion- and erosion-resistant, and be inexpensive. Summarized studies relating candidate materials to required performance parameters have been published by Rosales et al., (1978).

1.2.5.1 **Titanium** has high thermal conductivity and outstanding corrosion-erosion characteristics in both seawater and ammonia environments. The cost per unit weight is high, but costs may be reduced by using thinner stock. This is possible since an extra thickness for corrosion allowance is not required and the metal is strong and easily formed.

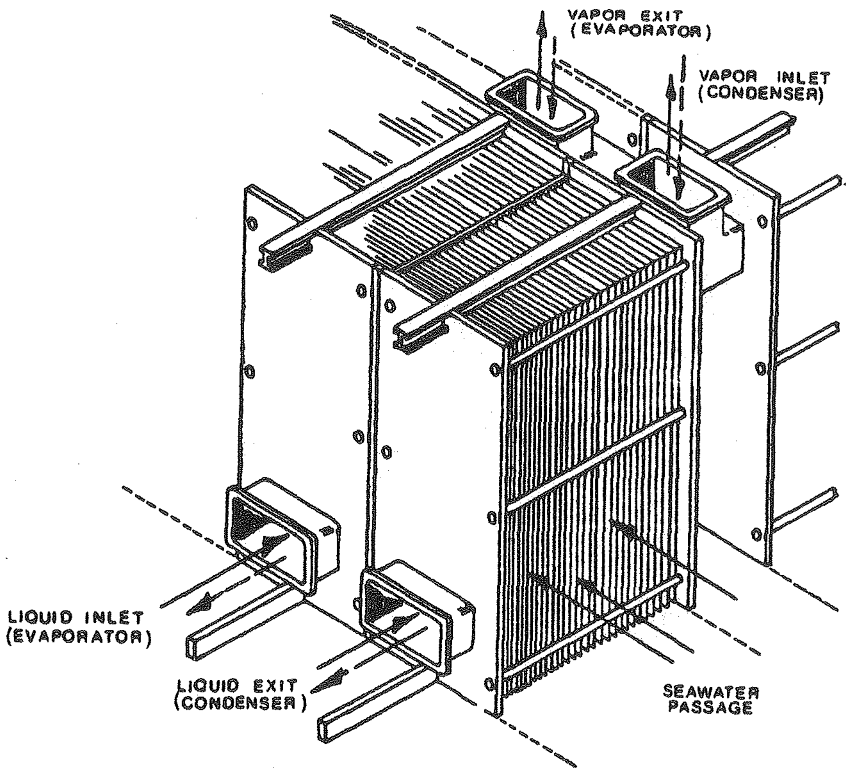


Figure 1-9. Plate Heat Exchanger
Source: Berndt and Connel, 1978

1.2.5.2 **Aluminum alloys** exhibit excellent thermal conductivity, are easy to form, inexpensive, easily obtained, and have a low density. A major drawback is undesirable corrosion characteristics occurring in ammonia and seawater. Among all aluminum alloys, 5052 is best-suited for use in a seawater environment. Alloy 6063 is readily extrudable in a fluted configuration, whereas 5052 is not; however, 6063 is much more prone to pitting than 5052.

1.2.5.3 **Stainless steel** has high nickel and chromium contents, and displays excellent corrosion resistance in seawater. Stainless steel is easily formed, readily available, and has an adequate thermal conductivity. Stainless-steel alloys are dense; Rosales et al. (1978) reported that, for equal thicknesses, stainless steel tubing may be as expensive as titanium. One alloy, Allegheny 6X CRES, is frequently mentioned as the steel alloy most desirable for use in OTEC operations since it exhibits excellent resistance to pitting and corrosion.

1.2.6 Working Fluids

The ideal OTEC working fluid must have a low boiling point and be compatible with the heat-exchanger material (DOE, 1979a). Ammonia and Freon™ are the most viable candidates for the closed-cycle working fluid. Owens (1978) compared ammonia, Freon™, and other candidate working fluids, based on the area of heat exchanger required to produce 25-MW net power output of an optimized plant design. Ammonia requires the least amount of surface area per kilowatt of net power, resulting in decreased heat exchanger costs. Therefore, ammonia will probably be selected as the working fluid in the Pilot Plant.

Approximately 220 m^3 (140,000 kg) of ammonia will be stored on the Pilot Plant. Ammonia will fill and drain from the power cycle through the vent and drain system. A transfer compressor will regulate the flow to and from the tank by pressure differential, and a four-way valve will reverse the compressor flow. The same arrangement will fill the storage tank from a portable facility. After draining the liquid ammonia and evacuating residual vapor from the power-cycle piping and equipment, nitrogen will purge the remaining ammonia gas to ensure a safe working environment for equipment inspection and maintenance.

1.2.7 Biofouling Control

OTEC plants operate at extremely low efficiencies (3 to 4%), therefore the heat exchangers are very large and represent about 50% of capital costs. Fouling has a strong effect on the performance of such a major cost item and limits design options which may be employed in order to reduce overall costs.

Fouling is a general term which includes all types and sources of materials deposited or formed on a surface. Fouling occurs throughout the power and process industries, but is not yet well-understood. Fouling may be classified into two general categories: (1) microfouling - slime films, composed of organisms too small to be seen by the naked eye, and (2) macrofouling - visible organisms (e.g., worms, barnacles, and mussels).

The effects of microfouling on OTEC heat-exchanger surfaces is a major concern because a 50-um-thick slime layer causes a 15 to 25% decrease in heat transfer efficiency (Bell, 1977). Although microfouling cannot be completely prevented with available technology, a combination of techniques must be used to control microfouling and maintain the heat-exchanger surfaces at optimal efficiency.

Biofouling control and cleaning methods can be divided into two categories: (1) chemical methods and (2) mechanical methods. Chemical methods are usually used to slow biofouling rates, although they do not remove the material. Mechanical methods are necessary to remove the biofoulants. Mechanical and/or chemical cleaning methods can be used in tube-in-shell heat exchangers; only chemical or abrasive cleaning methods can be employed in plate-type heat exchangers.

1.2.7.1 Chemical Methods - One of the most widely used methods to control fouling is chlorination. Besides being extremely effective, chlorine is also economical to produce and can be generated electrolytically from seawater. Production of chlorine on the Pilot Plant eliminates the need for storing and handling the hazardous gas. The discharge rate for chlorine is restricted to 0.2 mg liter^{-1} during a 2-hour period each day (EPA, 1974). The OTEC-1 platform continuously releases chlorine along with its discharge waters at a concentration of 0.1 mg liter^{-1}.

Chemical cleaning (clean-in-place method) requires draining and isolating the heat-exchanger module, followed by foaming, recirculating, soaking, and purging the acidic or basic cleaning solutions. Isolating heat-exchanger modules prevents complete plant shutdown during cleaning periods. Cleaning compounds dissolve, decompose, and/or loosen bonds between fouling layers and heat-exchanger surfaces. One proposed clean-in-place system would utilize continuous low-level chlorination, supplemented with chemical cleaning of each heat-exchanger module at least once a month. After isolating a heat-exchanger module, a 3% solution of sodium hydroxide and surfactant in seawater is circulated for approximately 8 hours. Subsequently, the heat exchanger must be drained and rinsed. The cleaning solution is vented into a storage tank for later reuse or disposal (Moak et al., 1980).

Incorporation of a chemical cleaning system in the Pilot Plant requires several special features, including: (1) addition of heat-exchanger modules with appropriate valving, which allows isolation of smaller units to minimize overall shutdown periods, (2) a piping network to connect submodules to storage and treatment facilities, (3) proper venting capabilities, and (4) large acid/base storage and treatment tanks. The proposed clean-in-place system requires a 40-m^3 sodium hydroxide tank, a 2-m^3 surfactant tank, a 450-m^3 storage tank, and a small EDTA sequestering tank.

1.2.7.2 <u>Mechanical Methods</u> - When fouling reaches the maximum allowable level, mechanical cleaning devices may be used to remove the fouling material. Mechanical cleaning methods suggested for OTEC platforms with tube-in-shell heat exchangers are Amertap™ balls and M.A.N.™ (Machinefactory Augsburg-Nurenberg) flow-driven brushes. The Amertap™ system continuously cleans the tubes with slightly oversized foam rubber balls that are injected into the water in front of the tube sheets. The balls are compressed as they traverse the condenser tube and the rubbing and abrasive action cleans the tube. At the end of the heat exchangers a screening mechanism removes the balls from the water flow; the balls are then recirculated through the heat exchangers. The continuously circulating balls remove the primary slime layers soon after formation, and eliminate later fouling stages. The Amertap™ system has been found to maintain heat-exchanger cleanliness at levels sufficient for OTEC operation, even with intermittent application (Drake, 1977).

The ball size, composition, density, and surface texture (abrasive banding) may be adjusted to solve many tube fouling conditions. Amertap™ balls may also be soaked in a biocide to increase their effectiveness; however, additional research on this alternative is necessary.

The large heat exchangers required by OTEC may not permit simple injection of Amertap™ balls into the water system. A radially indexed rotating-arm emitter and collector device has been developed for the Amertap™ system to provide complete coverage of the heat-exchanger tube sheet.

The M.A.N.™ brush system is an automatic mechanical tube scrubber. The brushes are cylindrical, tufted brushes held in a plastic cage which guides the brush through the tube. Protruding tufts scrub deposits off the walls as the brushes are pumped back and forth through the tubes by reversing the flow direction of the seawater. Braswell et al. (1979) report that the fouling resistance of heat-exchanger tubes was maintained far below the maximum acceptable limit for OTEC operation, although entrained debris (and macrofouling on the brush itself) may clog the brush-retaining cages and render the tube out-of-service. The M.A.N.™ system is adaptable to the cleaning of enhanced surface-texture tubes, but is sensitive to blockages. Additional piping and valves are required to reverse the flow within the tubes.

Abrasive cleaning, which is an alternate means of mechanical cleaning, is performed by adding an abrasive mixture (e.g., sand, diatomaceous earth, or detergents) to the water flowing through the heat exchangers. The abrasive mixture dislodges the material that has attached to the heat exchangers. The dislodged material may also act as an abrasive as it passes out of the heat exchangers. This method efficiently removes fouling deposits and withdraws the material from the system, but the slurry also causes the destruction of protective films and the erosional loss of the heat exchanger surface material.

At present the only slurry medium found to be compatible with the Pilot Plant design is diatomaceous earth. However, an amount equivalent to an entire year's production in the United States of diatomaceous earth would be needed to make a 2.5% slurry for a 24-hour cleaning cycle of the Pilot Plant. Thus, unless an inexpensive recovery and recirculation procedure is developed, or an abundant material, such as sand, is found to be acceptable, slurry cleaning of the Pilot Plant is not feasible.

1.2.8 Submarine Transmission Cable

Offshore Pilot Plant designs will supply baseload electricity to local electrical grids through submarine transmission cables. Moored plants require bottom and riser cables, whereas the Bottom-Resting Tower requires only bottom cables. Bottom cables are semi-rigid and extend along the bottom from the plant to the shore. The bottom cable is usually embedded 2 to 3m into the substrate from the land distribution point to the 100-m contour, and rests on the seafloor for the remaining distance. Previously, no high-voltage power cables have been laid at depths greater than 550m (Pieroni et al., 1979).

The riser cable system links moored OTEC Pilot Plants to the high-voltage bottom cable on the sea floor. Multiple riser cables (a minimum of four) are required for the Pilot Plant (Pieroni et al., 1979). The riser cables must be able to withstand stresses from current drag, strumming, platform motions, corrosion, and biofouling growth. The cables must be designed to withstand abrasion at the touchdown point, caused by the cable scouring the bottom as the platform moves through its watch circle. Various methods have been proposed for bringing the riser cables from a point on the ocean bottom to the moored OTEC plant (Figure 1-10). Most methods permit 300m of riser cable to sweep a 100-m-wide section of the seafloor.

Two types of submarine cables are viable candidates for the OTEC Pilot Plant: the self-contained oil- or gas-filled laminated dielectric (OF) cable and the extruded dielectric (ED) cable (Garrity and Morello, 1979; Pieroni et al., 1979). Oil-filled dielectric cables have been used successfully in traditional submarine cable crossings.

1.2.9 Waste Disposal and Pollution Control

Sanitation facilities aboard the OTEC Pilot Plant will be in accordance with standard regulations of the U.S. Public Health Service and U.S. Coast Guard (USCG). Sewage will be collected and processed in a USCG-certified, Type II aerated biological unit Marine Sanitation Device before the acceptable

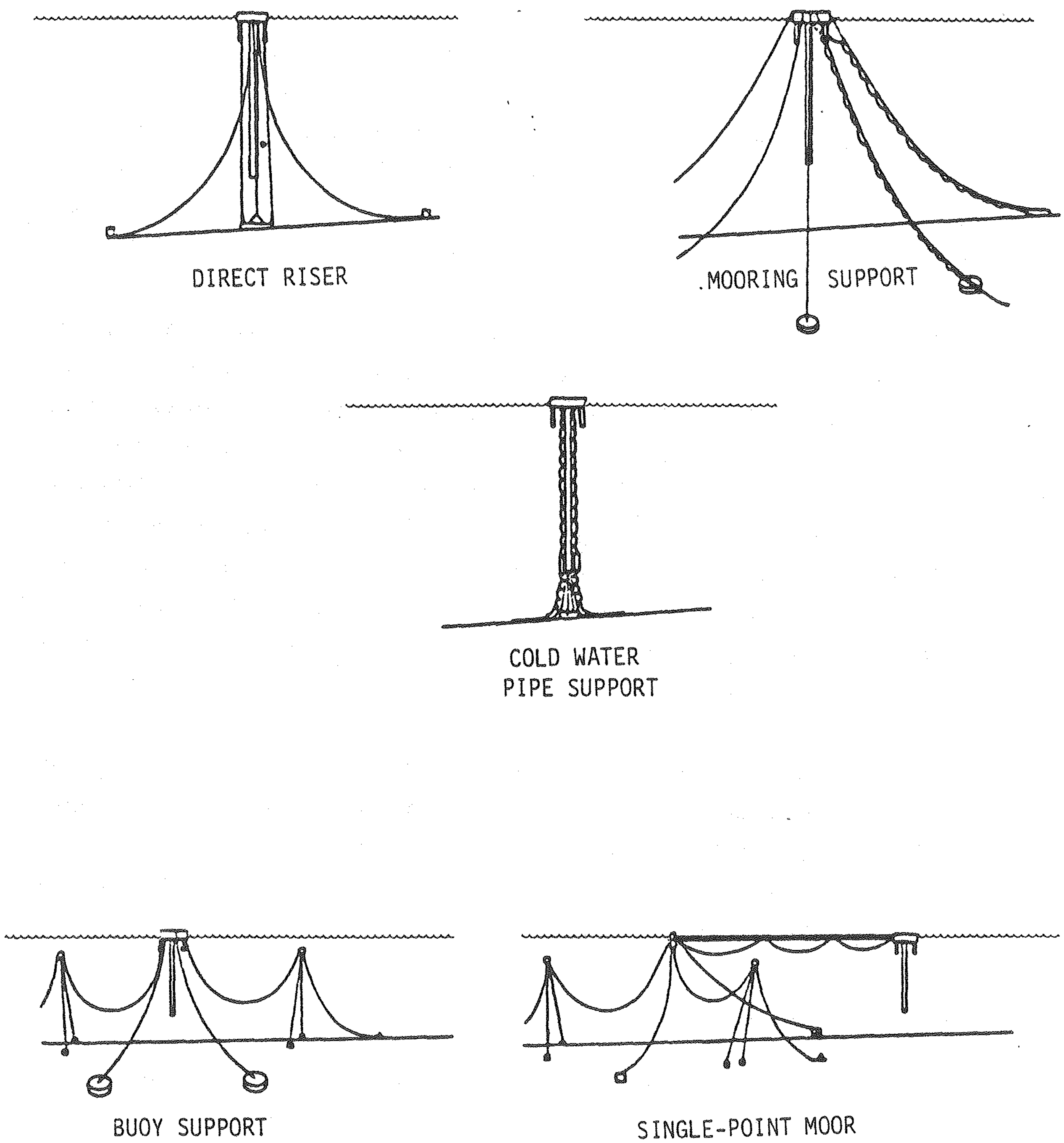


Figure 1-10. Riser Cable Mooring System Concepts
Source: Pieroni et al., 1979

effluent is discharged overboard. An incinerator and trash compactor will be installed for disposal of solid wastes. Compacted solid wastes will be removed to land-based sanitary fills for final disposal.

Oil systems will incorporate spill containment and oil-transfer-procedure regulations, in accordance with USCG regulations. Oily bilge water will be collected and processed in an oil-water separator. The contaminated oil residue will be stored in a 7.5 m^3 tank for disposal ashore, while the clean effluent from the separator will be discharged overboard. The effluent quality will be in accordance with National Pollutant Discharge Elimination System (NPDES) permits.

1.2.10 Safety Systems

1.2.10.1 Firefighting - The Pilot Plant will be provided with comprehensive firefighting equipment in accordance with the American Bureau of Shipping and USCG regulations. Portable fire extinguishers will be installed in appropriate locations throughout the Pilot Plant. Firefighting detection and alarm systems and portable fire extinguishers will be strategically located throughout the platform. A fixed carbon dioxide extinguishing system will be installed, which can be actuated locally or from the bridge. As carbon dioxide is released into the appropriate compartment, a siren will be triggered and the air supply fan to the compartment will be automatically shut off.

A firemain system will provide seawater to a number of fire hydrants strategically located around the platform, so that any part of the vessel can be reached by two streams of water. A separate fire system will be installed for the heliport, in accordance with the FAA and National Fire Protection Association (NFPA) requirements.

1.2.10.2 Ammonia Washdown - Ammonia irritates skin and eyes, and the vapor can be explosive when mixed with air; thus, several precautions must be taken to minimize hazards. For example, access to emergency air-breathing systems (masks) will be available at all work stations and living quarters. Ammonia gas dissipates upward rapidly; therefore, pressure safety valves and vents will be connected to a stack which vents ammonia away from the working elevations. The stack will also be used for venting the system during purging.

A saltwater deluge system will be installed for ammonia washdown purposes only. The system piping will be supplied by two pumps connected in parallel.

1.2.10.3 Lifesaving Equipment - The lifesaving equipment systems aboard the Pilot Plant must conform to the requirements of the USCG and provisions of the International Convention for Safety of Life at Sea (1960). At least two motor lifeboats must be installed, each supplied with a water-spray system and independent air supplies, and certified to carry all persons aboard the Pilot Plant. Inflatable life rafts, life preservers, life buoys, line-throwing devices, boarding ladders or embarkation aids, and an international flare kit must also be provided.

Section 2
THE EXISTING ENVIRONMENT

This section describes a generic environment typical of the candidate Pilot Plant siting regions. Parameters are presented that describe the salient environmental and economic features under which the Pilot Plant will operate, and facilitate the assessment of impacts. Sites having environmental characteristics which deviate significantly from the typical are described.

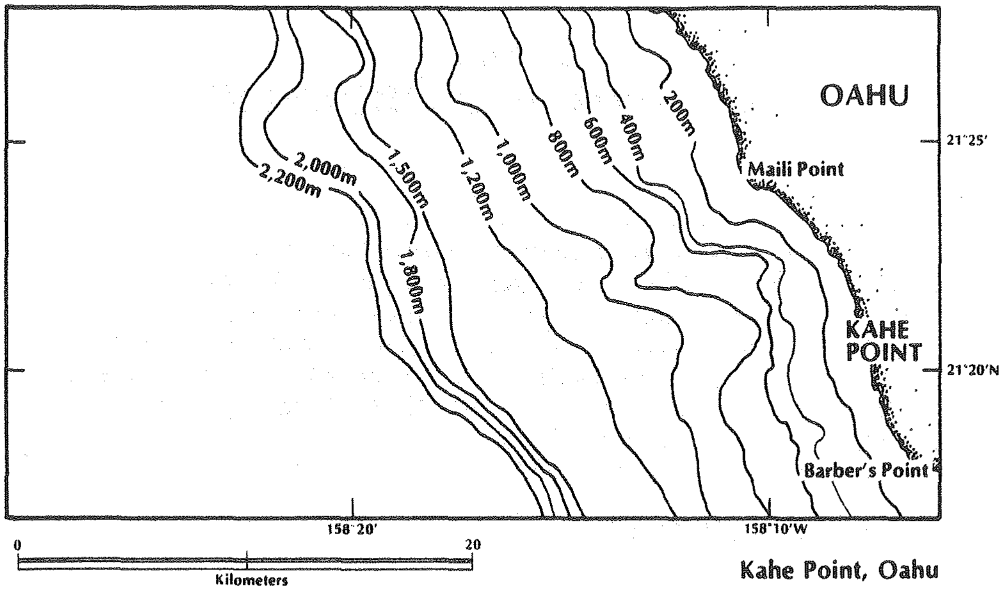
2.1 CANDIDATE PILOT PLANT SITES

The DOE is considering four candidate sites (Figure 2-1) that are representative of the island communities where the Pilot Plant will be sited. The candidate sites include:

- Kahe Point, Oahu
- Key West, Florida
- Punta Tuna, Puerto Rico
- Saint Croix, Virgin Islands

Due to the early nature of the Pilot Plant Program, limited site-specific information is available for the candidate sites. DOE-funded oceanographic studies, in support of Pilot Plant environmental assessment and technical operations, are being conducted near several of the candidate sites. Seasonal measurements of physical, chemical, and biological parameters have been collected at the Punta Tuna, Puerto Rico site. Benchmark surveys at the other candidate sites have begun (Lawrence Berkeley Laboratory, 1980). Navigation and environmental information for each of the candidate sites have been described in the U.S. Coast Pilot (DOC, 1978c and d) and are included as Appendix A.

Data from DOE-funded surveys and historical literature suggest that the sites are biologically and oceanographically similar, due to their proximities to shore and tropical-subtropical locations. Economically and socially,



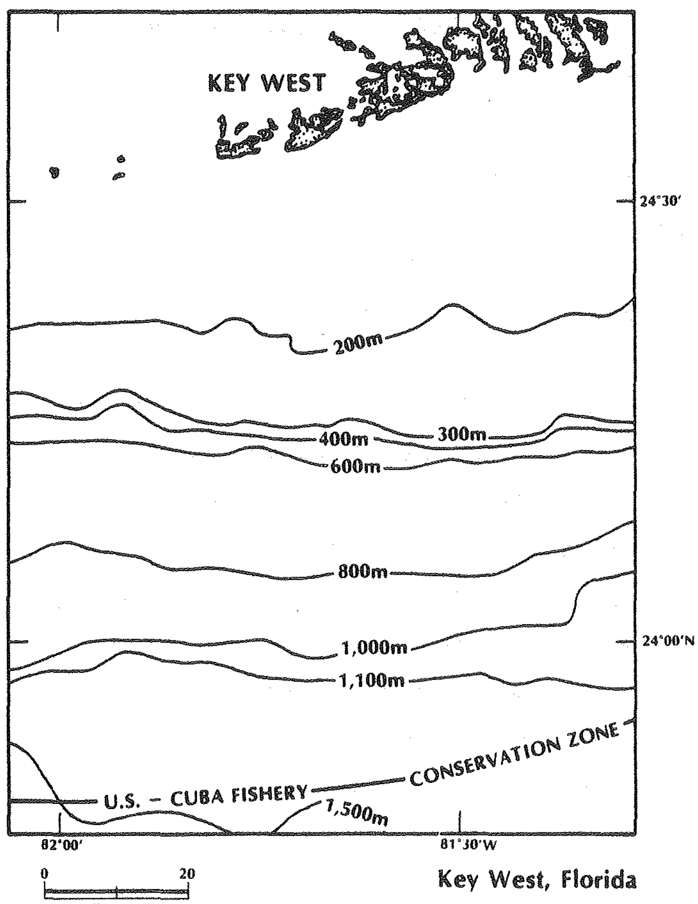
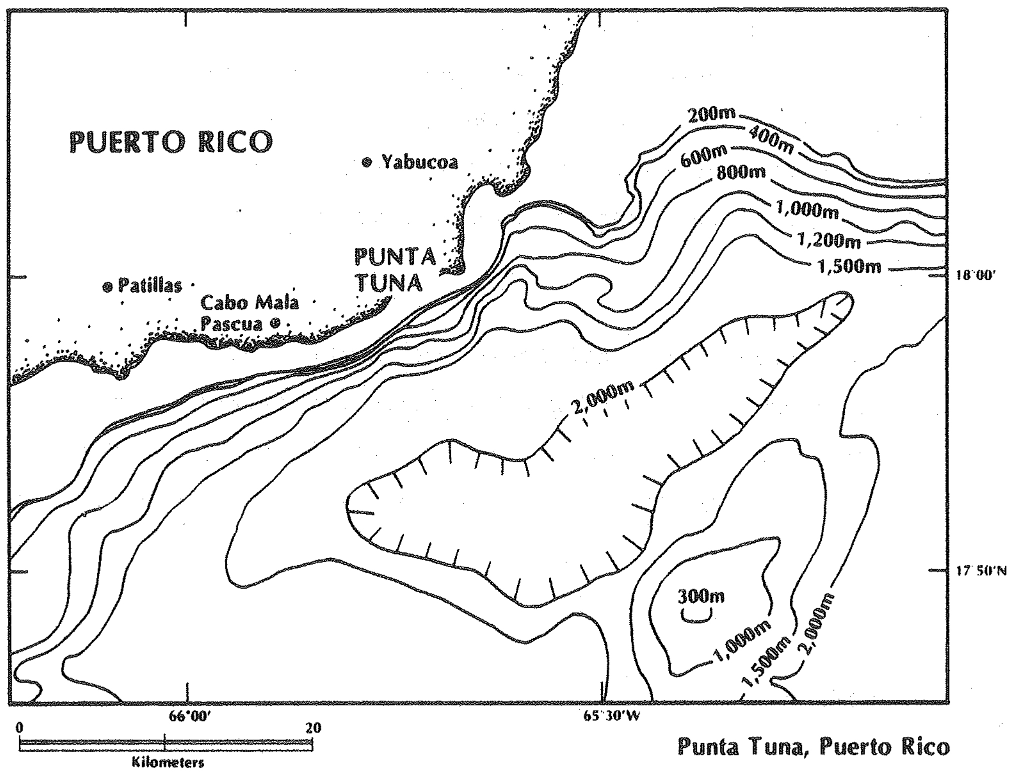
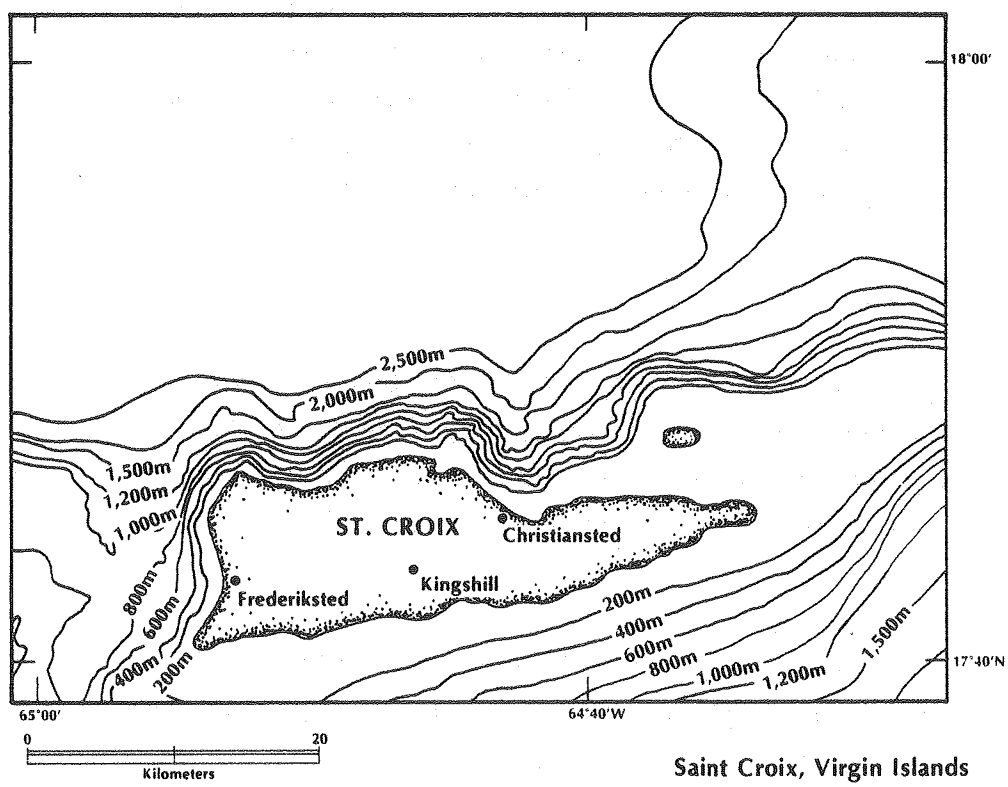


Figure 2-1. Candidate Pilot Plant Sites



Punta Tuna, Puerto Rico



Saint Croix, Virgin Islands

Figure 2-1. Candidate Pilot Plant Sites (continued) however, the island communities are quite different. The communities vary in population size, growth-rate, and adequacy of electricity-generating facilities. Some communities are under the pressure of a rapidly increasing population and rely on outdated electricity-generating equipment, whereas other island communities have stable populations and adequate electricity-generating facilities.

This section tabularizes the available information from candidate Pilot Plant sites and presents typical values for those environmental parameters of importance to impact or risk assessment. Sites having environmental characteristics which deviate significantly from the typical are described.

2.2 GEOLOGY

2.2.1 Data Requirements

Geological data defining stratigraphy, soil mechanics, and bathymetry are important to the siting of the Pilot Plant. Stratigraphy describes the substrate composition to determine the ease of submarine cable installation and suitability for anchoring. Soil-mechanics data assess the anchor-holding capacities of substrates. Bathymetric data are required to examine bottom slopes, irregularities, and roughness of cable routes.

2.2.2 Description

With one exception, candidate sites rise quickly from great depths, and have narrow shelves and rugged topography (Figure 2-2). Coral reefs and sediments composed of biogenic and terrigenous clastic materials are common at depths less than 50m. Ocean floor morphology is irregular in water over 50m deep.

The Key West site has a wide Continental Shelf and terraced limestone slopes with few irregularities. The terraces are generally devoid of sediment because of Gulf Stream current scour (Shepard, 1973).

Detailed information on stratigraphy and soil mechanics at the candidate sites is not available.

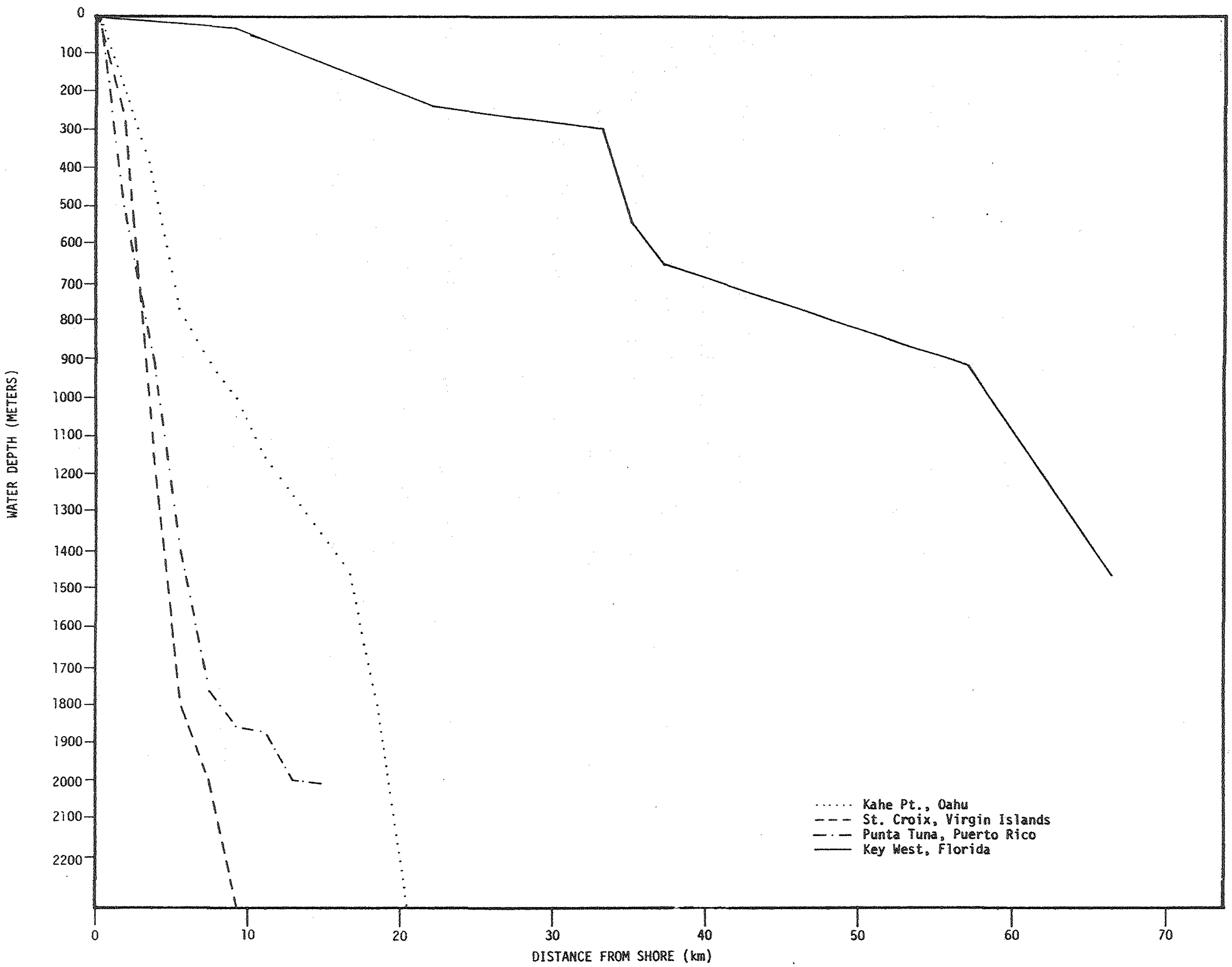


Figure 2-2. Depth Profiles of Candidate Pilot Plant Sites

2.3 METEOROLOGY

2.3.1 Data Requirements

The historical meteorological conditions of the sites are critical to Pilot Plant operation and survival. The frequencies of occurrence, paths, durations, and strengths of tropical storms and hurricanes are important considerations in designing Pilot Plant operational and survival limits. The potential effects of credible accidents can be assessed by evaluating prevailing meteorological conditions at the sites, including wind speed and direction, precipitation, and visibility.

2.3.2 Description

Pilot Plant candidate sites are located in the tropical northeasterly tradewind zone. Prevailing winds are generally constant and from the east-northeast. Wind velocities range from 15 to 45 km hr^{-1}; the higher velocities occur in the late autumn and winter (Craig et al., 1978; Munier et al., 1978). Visibility in offshore areas near the sites is good, with visibility less than 1 nmi occurring only 7 to 15 days out of the year (U.S. Naval Weather Service Command, 1955).

The frequencies of wind speeds and significant wave heights for each site are given in Tables 2-1 and 2-2. The annual probability of a hurricane passing within 500 km of the candidate sites is 44% for all sites except Kahe Point, Oahu; hurricanes near Kahe Point have an annual occurrence probability of 14% (Harris Inc., 1977).

2.4 PHYSICAL OCEANOGRAPHY

2.4.1 Data Requirements

Several physical oceanographic parameters are important for Pilot Plant operation. A description of the thermal profile in the upper 1,000m of the water column is fundamentally important because Pilot Plant siting areas must

TABLE 2-1
YEARLY PERCENT FREQUENCY OF WAVE CONDITIONS AT CANDIDATE SITES

Location	Wave Height (meters)													
	<0.3	0.3-0.8	0.8-1.3	1.3-1.8	1.8-2.3	2.3-2.8	2.8-3.3	3.3-3.8	3.8-4.8	4.8-5.8	5.8-6.8	6.8-7.8	7.8-9.8	>9.8
Kahe Point, Oahu	5.2	16.2	33.1	21.2	13.6	5.9	2.8	0.9	0.7	0.1	0.1	0.1	*	0.0
Key West, Florida	13.7	35.6	29.6	12.8	5.2	1.6	0.7	0.3	0.2	*	*	0.0	*	0.0
Punta Tuna, Puerto Rico	4.7	25.4	38.5	19.5	7.8	2.6	1.0	0.3	0.3	*	*	0.0	0.0	0.0
Saint Croix, Virgin Islands	5.4	19.5	33.0	23.6	11.7	4.2	1.5	0.5	0.5	0.1	0.1	0.0	0.0	0.0

*Greater than 0.05, but less than 0.1

Source: U.S. Naval Weather Service Command, 1970, 1971, 1974a, 1974b

Source: U.S. Naval Weather Service Command, 1970, 1971, 1974a, 1974b

TABLE 2-2
YEARLY PERCENT FREQUENCY OF WIND SPEEDS AT CANDIDATE SITES

Location	Wind Speed (km hr^{-1})					
	0-6	7-19	20-39	40-61	62-87	88+
Kahe Point, Oahu	8.6	36.5	46.0	8.8	0.2	0.0
Key West, Florida	8.8	44.2	41.8	4.9	0.3	*
Punta Tuna, Puerto Rico	3.7	35.0	55.7	5.5	0.1	0.0
Saint Croix, Virgin Islands	4.7	40.6	51.2	3.5	0.1	0.0

*Greater than 0.05 but less than 0.1

Source: U.S. Naval Weather Service Command, 1970, 1971, 1974a, 1974b have annual minimum temperature differentials of at least 20°C between surface and deep-ocean waters. The thermal profile provides information on the depth of the mixed layer. Mixed-layer depths must be deep enough to ensure that the warm-water resource is available at the intake depth. The mixed-layer depth is also a consideration for selecting the discharge depth; the discharge of waters below the mixed layer minimizes possibilities of recirculation.

Circulation patterns at candidate sites are important features governing resource renewal, plume dynamics, and platform stability. Currents maintain the thermal resource at the site by replenishing and dispersing water used by the plant. Surface currents and waves apply forces which act on the platform; subsurface currents and countercurrents apply stresses to the cold-water pipe.

The photic-zone depth is essential for defining the extent of biological impacts associated with redistribution of nutrients.

2.4.2 Description

2.4.2.1 Thermal Resource - With one exception, each site has a temperature difference throughout the year of at least 20°C between the surface and 1,000-m depth (Table 2-3). Between January and March the temperature difference at the Key West site drops to slightly less than 20°C (ODSI, 1977a). In summer the temperature differential at all sites is generally higher by 2°C to 3°C.

The mixed-layer depth can be defined as the level at which the temperature drops 1°C below the surface-water value and indicates the top of the thermocline (ODSI, 1977a). The mixed layer migrates seasonally with the maximum depth observed at the onset of winter. The yearly averages of the mixed-layer depths at the candidate sites range from 20 to 100m, with an overall average of about 60m (Table 2-3).

TABLE 2-3
PHYSICAL OCEANOGRAPHIC CHARACTERISTICS OF CANDIDATE PILOT PLANT SITES

Parameter	Site				
	Kahe Point, Oahu	Punta Tuna, Puerto Rico	Key West, Florida	St. Croix, Virgin Islands	General Island
Distance from shore (km) to 1,000-m contour	7	4	60	1	-
Monthly delta t (°C) (max/min)	22.8/20.0[a]	23.9/20.9[b]	24.1/19.2[c]	23.4/20.7[d]	-
Compensation depth (m)	140[e,f]	120[g]	No Data	No Data	130
Mixed layer depth (m) (summer/winter)	50/90[a]	50/100[b]	20/60[c]	20/100[h]*	60
Surface current speed (cm/sec)	10 to 50[i]	10 to 40[j,k]	240[l] 100 to 300[m]	20 to 80[h]	10 to 40

*Maximum and minimum values

Sources:
(a) ODSI, 1977a
(b) OSDI, 1977b
(c) ODSI, 1977c
(d) Munier et al., 1978
(e) Gundersen et al., 1976
(f) Walters, 1976
(g) Hargraves et al., 1970
(h) Lee et al., 1978
(i) Bathen, 1978
(j) U.S. Naval Oceanographic Office, 1965
(k) Burns and Car, 1975
(l) Harris, Inc., 1977
(m) Gross, 1977
(n) EG&G Environmental Consultants, 1980

2.4.2.2 <u>Circulation</u> - Oceanic and diurnal currents affect the rate of discharge-plume mixing downstream of the Pilot Plant, and determine the rate of warm-water reso rce renewal. Ocean currents are site-specific phenomena influenced by local features. Surface current velocities in the vicinity of all candidate sites, except Key West, are typically 10 to 80 cm sec^{-1}. Due to the constriction of flow through the Straits of Florida, surface currents at the Key West site are fast, ranging between 100 and 300 cm sec^{-1} (Gross, 1977). In general, current velocities decrease with depth at all sites, diminishing to an estimated 10% of surface velocities at 1,000m (Bretschneider, 1977).

2.4.2.3 **Photic Zone Depth** - The depth at which light is attenuated to 1% of its surface value is an approximation of the compensation depth, which is generally considered to be the bottom of the photic zone (Parsons et al., 1977). Below the compensation depth, net photosynthesis does not occur. Available data for the candidate sites indicate that the photic zone depths range between 120 and 140m, with an average of 130m (Table 2-3). This depth of light penetration is characteristic of clear-blue ocean waters.

2.5 CHEMICAL OCEANOGRAPHY

2.5.1 Data Requirements

Chemical characteristics important for Pilot Plant environmental assessment include nutrient and dissolved oxygen profiles encompassing the intake, discharge, and plume stabilization depths. Nutrient values are needed to assess the affect of ocean water redistribution. Dissolved oxygen concentrations are necessary in order to determine the amount of oxygen depleted due to decomposition of biomass destroyed by plant operation.

2.5.2 Description

2.5.2.1 **Nutrients** - Nutrient levels vary with depth in a similar manner at all candidate sites. Typical nitrate concentrations are low at the surface (0.3 μg-at liter^{-1}), exhibit sharp increases immediately below the photic zone, and attain a maximum of about 30 μg-at liter^{-1} at 600 to 800m (Figure 2-3). Phosphate concentrations follow the same pattern; surface minimums are approximately 0.2 μg-at liter^{-1}, while maximum values are approximately 2 μg-at liter^{-1} at 600 to 800m (Figure 2-4).

2.5.2.2 **Dissolved Oxygen** - Dissolved oxygen concentrations decrease with depth to a minimum, which approximately corresponds to the nutrient maximum (Figure 2-5). Typical values decrease from about 5.0 ml liter^{-1} at the surface to between 1.0 and 3.0 ml liter^{-1} at the minimum.

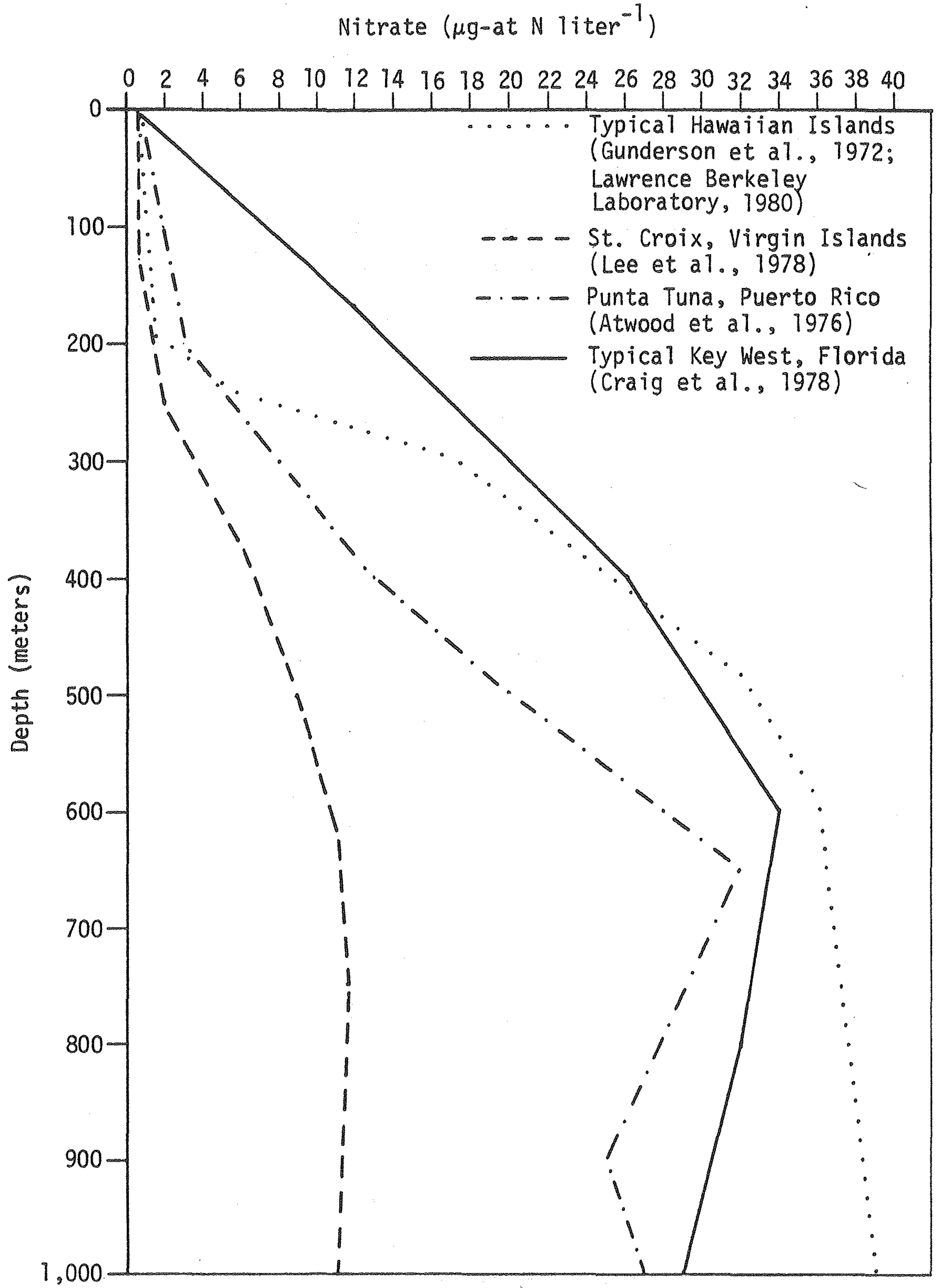


Figure 2-3. Nitrate Profiles for Candidate Sites

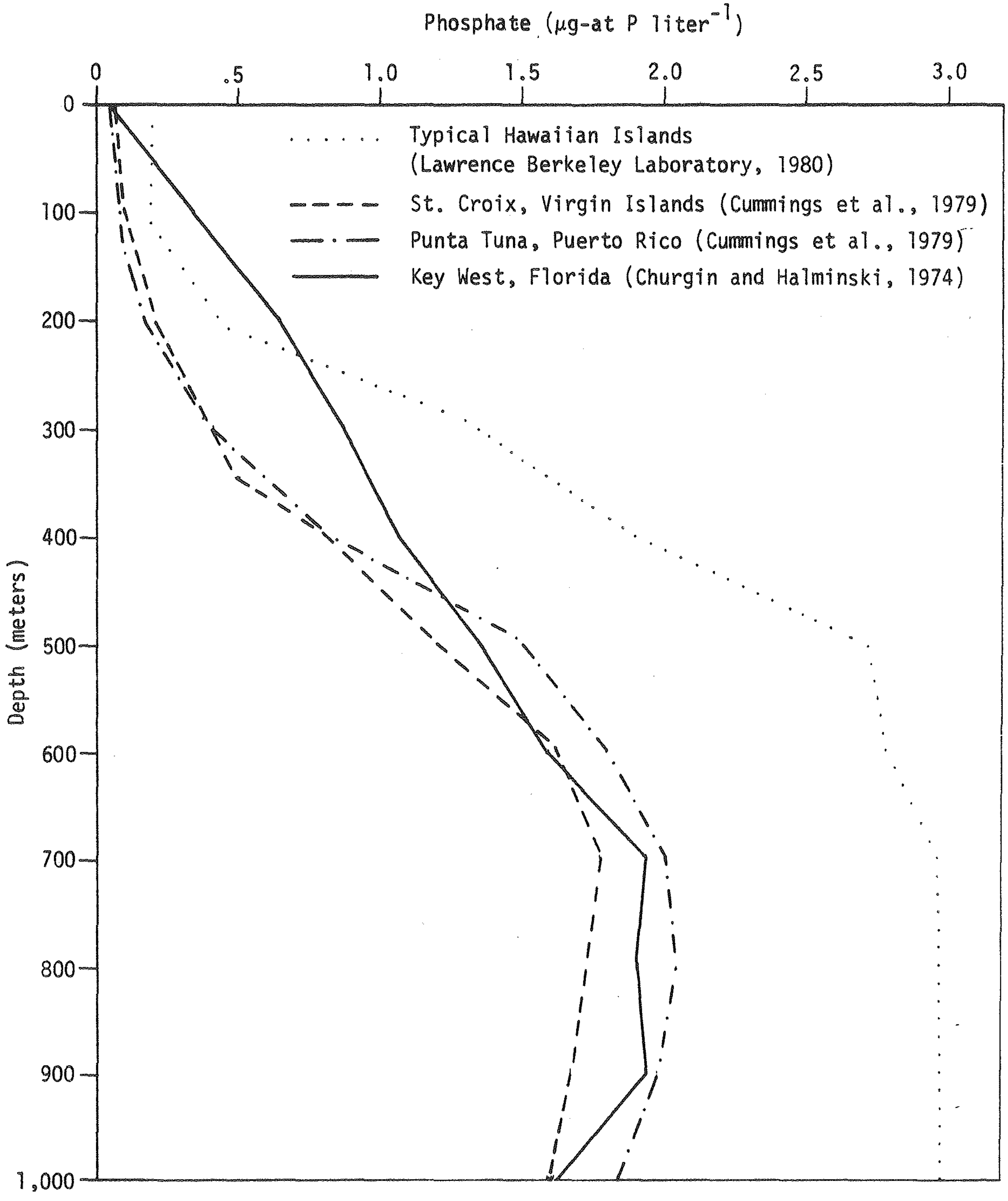


Figure 2-4. Phosphate Profiles for Candidate Sites

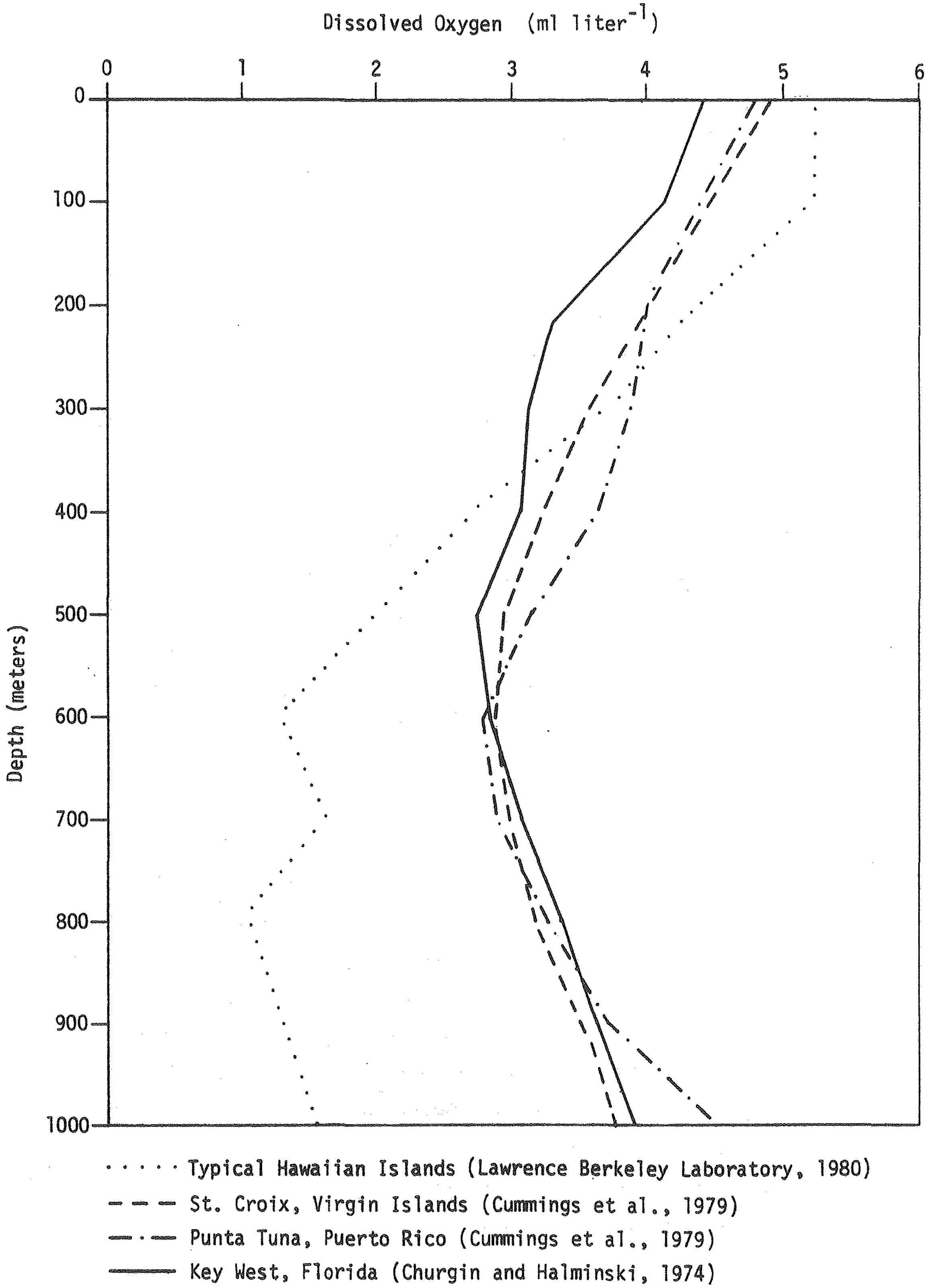


Figure 2-5. Dissolved Oxygen Profiles for Candidate Sites

2.6 BIOLOGICAL OCEANOGRAPHY

2.6.1 Data Requirements

The OTEC Pilot Plant will affect the marine environment from the neuston layer at the air-sea interface to the boundary layer between the mesopelagic and bathypelagic zones at depths exceeding 1,000m. Effects are expected to be more significant in the epipelagic zone (0 to 200m) than in the mesopelagic (200 to 1,000m) zone; however, data from all depths are required because organisms migrate between layers.

A biological profile of a region must include all aspects of the ecosystem, from the nutrient-light regimes through the lower trophic levels of microbiota, up to and including the higher trophic levels of nektonic carnivores (e.g., squid, fish, sea turtles, marine mammals) and sea birds. Descriptions of the vertical distribution of phytoplankton, zooplankton, ichthyoplankton, micronekton, and nekton are necessary in order to assess the potential environmental impacts on biota. Special attention must be given to the transient occurrences of endangered and threatened species and species of commercial or economic importance.

2.6.2 Data Description

2.6.2.1 Phytoplankton - Phytoplankton are free-floating algae upon which the rest of the marine food chain is based. The measurement of chlorophyll *a*, a photosynthetic pigment, provides an estimate of phytoplankton biomass. Typically, surface chlorophyll *a* values near the candidate sites are low, about 0.1 mg m^{-3}, increasing to a subsurface maxima of approximately 0.15 to 0.4 mg m^{-3} (Table 2-4). The depth of the subsurface maximum, between 80 and 130m, varies spatially and seasonally. Nannoplankton (cells less than 10 μm in size) contribute 80% to 90% of the phytoplankton biomass and primary production in tropical oceanic regions (Malone, 1971); however, few studies have specifically investigated nannoplankton.

TABLE 2-4
BIOLOGICAL CHARACTERIZATION OF CANDIDATE PILOT PLANT SITES

Parameter	Depth (m)	Hawaiian Islands	Key West, Florida	Punta Tuna, Puerto Rico	St Croix, Virgin Islands	Typical Island Community
Primary productivity mg C m^{-2} day^{-1}	0-130	53-84[a]	60-100[p]	30-280[b]	No Data	100
Chlorophyll a mg m^{-3}	0-50	0.03-0.12[a,c,d,e] 0.05-0.07[n]	0.08[p]†	0.06-0.25[d,f] 0.04-0.12[n]	0.1-0.15[f]†	0.1
	80-130	0.12-0.39[a,c,d,e] 0.10-0.19[n]		0.15-0.36[d,f] 0.15-0.18[n]		0.2
Microzooplankton mg C m^{-3}	0-10	0.2[c]	No Data	No Data	No Data	0.2
	0-200	0.1-1.3[c]	No Data	No Data	No Data	0.8
	200-350	0.1[g]	No Data	No Data	No Data	0.1
	350-1,000	0.01[h]	No Data	No Data	No Data	0.01
Macrozooplankton Night:Day Biomass Ratio	0-150	1.25-1.65[i]	1.7[o]	2.1[q]	No Data	1.5
Macrozooplankton Biomass* mg C m^{-3}	0-150	0.5-0.8[i,j,k,l]	2.0[o]	2.5[q]	No Data	1.0
	150-1,000	0.2-0.25[j,m]	0.08-0.28[o]	No Data	No Data	0.25

Sources:
(a) Gilmartin and Revelante, 1974
(b) Beers et al., 1968
(c) Gundersen et al., 1976
(d) Johnson and Horne, 1979
(e) Bathen, 1977
(f) Hargraves et al., 1970
(g) Beers and Stewart, 1969
(h) Beers, 1978
(i) Nakamura, 1955
(j) King and Hida, 1954
(k) King and Hida, 1957
(l) Shomura and Nakamura, 1969
(m) Hirota, 1977
(n) Lawrence Berkeley Laboratory, 1980
(o) Hopkins et al., 1979
(p) Jones et al., 1973
(q) Youngbluth, 1977a,b
* Biomass conversions from Weibe et al., 1975
† Average chlorophyll a concentration in 0 to 130-m layer

Primary production values range from 30 to 280 mg C m^{-2} day^{-1} (Table 2-4). Although production varies with season, cloud cover, and mixed-layer depth, average production in all areas is about 100 mg C m^{-2} day^{-1}.

2.6.2.2 Zooplankton - Zooplankton are passively floating or weakly swimming animals of the water column, and form the second trophic level of the marine food chain. Zooplankton are divided into two groups: microzooplankton and macrozooplankton. Microzooplankton are the organisms which pass through the 202 μm mesh fraction of filtration netting. Microzooplankton include naupliar and copepodid stages of copepods, ciliate and sarcodine protozoans, and larvaceans. Macrozooplankton are retained in a 202 μm mesh net and are dominated by copepods and chaetognaths; however, in surface waters the eggs and larvae of many types of nearshore invertebrates and fish are superimposed on the basic dominants. Available data for microzooplankton and macrozooplankton at the candidate sites are summarized in Table 2-4.

Microzooplankton are concentrated in the upper 200m, with an average biomass of 0.8 mg C m^{-3} (Gundersen et al., 1976). However, stocks vary from 0.2 mg C m^{-3} at the surface to a maximum of 3.3 mg C m^{-3} between 60 and 200-m depth (Beers and Stewart, 1971; Gundersen et al., 1976; Hirota, 1977). Standing stocks below 200-m depth are about 10% of those at shallower depths (Beers and Stewart, 1969), and at 900m probably decrease to 1% of those at the surface (Beers, 1978).

Macrozooplankton populations at the candidate sites are composed of coastal organisms and meroplankton superimposed on an offshore zooplankton assemblage. Macrozooplankton in the upper 1,000m display a distinct vertical distribution (Table 2-4). In the upper 150m, concentrations are generally four times greater than in the 150 to 250-m layer (Hida and King 1955; Michel and Foyo 1976; Hirota 1977). Biomass and numbers decrease by a factor of 10 from the surface to 1,000m (Vinogradov, 1970; Vinogradov and Rudyakov, 1971; Hopkins et al., 1979).

2.6.2.3 Ichthyoplankton - Ichthyoplankton are composed of free-floating fish eggs and weakly swimming fish larvae. The ichthyoplankton assemblage near candidate Pilot Plant sites is composed of inshore (neritic), oceanic, and deep benthic species. The inshore component of the ichthyoplankton includes eggs and larvae of many bay, coastal, and reef species. The oceanic component of the ichthyoplankton is primarily composed of the eggs and larvae of mesopelagic fish (myctophids, gonostomatids, and sternoptychids) and epipelagic fish (Coryphaenidae, Scombriade, and Exocoetidae). The abundance of inshore and neritic ichthyoplankton decreases offshore, while fish eggs and larvae of oceanic species are abundant in both inshore and offshore areas.

The average fish larvae abundance in surface inshore waters is approximately 0.1 individuals m^{-3} during the day and 0.2 individuals m^{-3} at night (King and Hida, 1957; Miller et al., 1979). Tuna larvae abundance in the upper 100m of inshore waters average 0.002 individuals m^{-3} during the day and 0.010 individuals m^{-3} at night (Miller, 1979; Matsumoto, 1958).

Hirota (1977) reported that oceanic fish larvae abundance in the upper 200m of the central Pacific ranged between 0.3 and 0.9 larvae m^{-3}, with a mean of approximately 0.6 larvae m^{-3}. Loeb (1979) found that the maximum abundance of fish larvae occurred near the bottom of the mixed layer. Loeb captured an average of 0.35 larvae m^{-3} in the surface 100 m, 0.03 larvae m^{-3} between 100 and 350-m depth, and 0.01 larvae m^{-3} between 350 and 600-m depth. Hirota (1977) found very few larval fish below 200m.

2.6.2.4 Micronekton - Micronekton are an assemblage of actively swimming organisms ranging from 1 to 10 cm in length, and are usually sampled with midwater trawls. In general, the dominant micronekton groups are: (1) fish: myctophids, gonostomatids, sternoptychids; (2) crustaceans: penaeid and caridean shrimps, euphausiids, mysids; (3) cephalopods; and (4) gelatinous organisms: siphonophores, scyphomedusae, salps, pteropods.

Vertical distribution and taxonomic composition of micronekton stocks near candidate sites have recently received considerable attention (Amesbury, 1975; Blackburn, 1976; Walters, 1976; Hirota, 1977; Loeb, 1979; Backus, 1970; Young, 1978). Micronekton investigations have shown the community to be dominated by gonostomatid and myctophid fishes. During the day micronekton are found at considerable depths (greater than 200m), whereas at night large numbers of the population migrate to the upper layers of the water column (Figure 2-6).

Maynard et al. (1975) offer the only available data on the day and night biomass of micronekton at various depth intervals at the candidate sites. It was found that the upper 400m of a 1,200-m water column had an average micronekton biomass (wet weight) of 0.82 mg m^{-3} during the day, and 6.26 mg m^{-3} at night. Between 400 and 1,200 m, the micronekton biomass averaged 5.79 mg m^{-3} during the day, and 3.05 mg m^{-3} at night.

2.6.2.5 Nekton - The occurrence and abundance of nekton in oceanic waters is generally a problem of fisheries dynamics, with the abundances related to catch rates per unit of effort, rather than per unit of habitat. Nekton schools are highly mobile, migrate over long distances, and have unknown depth ranges; thus, their study is somewhat limited and qualitative. However, rough estimates of nekton standing stocks can be made using existing fisheries catch data presented in Section 2.7.

The major taxa of tunas and oceanic epipelagic fish of commercial and sport value include the following species (Blackburn, 1976; Uchida, 1978): (1) tunas and jacks: Thunnus albacares (yellowfin), T. alalunga (albacore), T. obesus (bigeye), Euthynnus affinis (little tuna), Katsuwonus pelamis (skipjack), and Serrola dorsalis (yellowtail); (2) dolphinfishes: Coryphaena hippurus and C. equiselis; (3) billfishes: Makaira nigricans (blue marlin), Tetrapturus audax (striped marlin), Xiphias gladius (swordfish), and Istiophorus platypterus (sailfish), among others.

Numerous species of marine mammals are indigenous to the candidate sites (Payne, 1978), including the humpback whale (Megaptera novaeangliae), sperm whale (Physeter catadon), pilot whale (Globicephala spp.), finback whale (Baleanoptera physalus), pygmy sperm whale (Kosia breviceps), spinner dolphin (Stenella longirostris), spotted dolphin (S. sp.), bottlenose dolphin (Tursiops spp.), false killer whale (Pseudorca crassidens), and pygmy killer whale (Feresa attenuata).

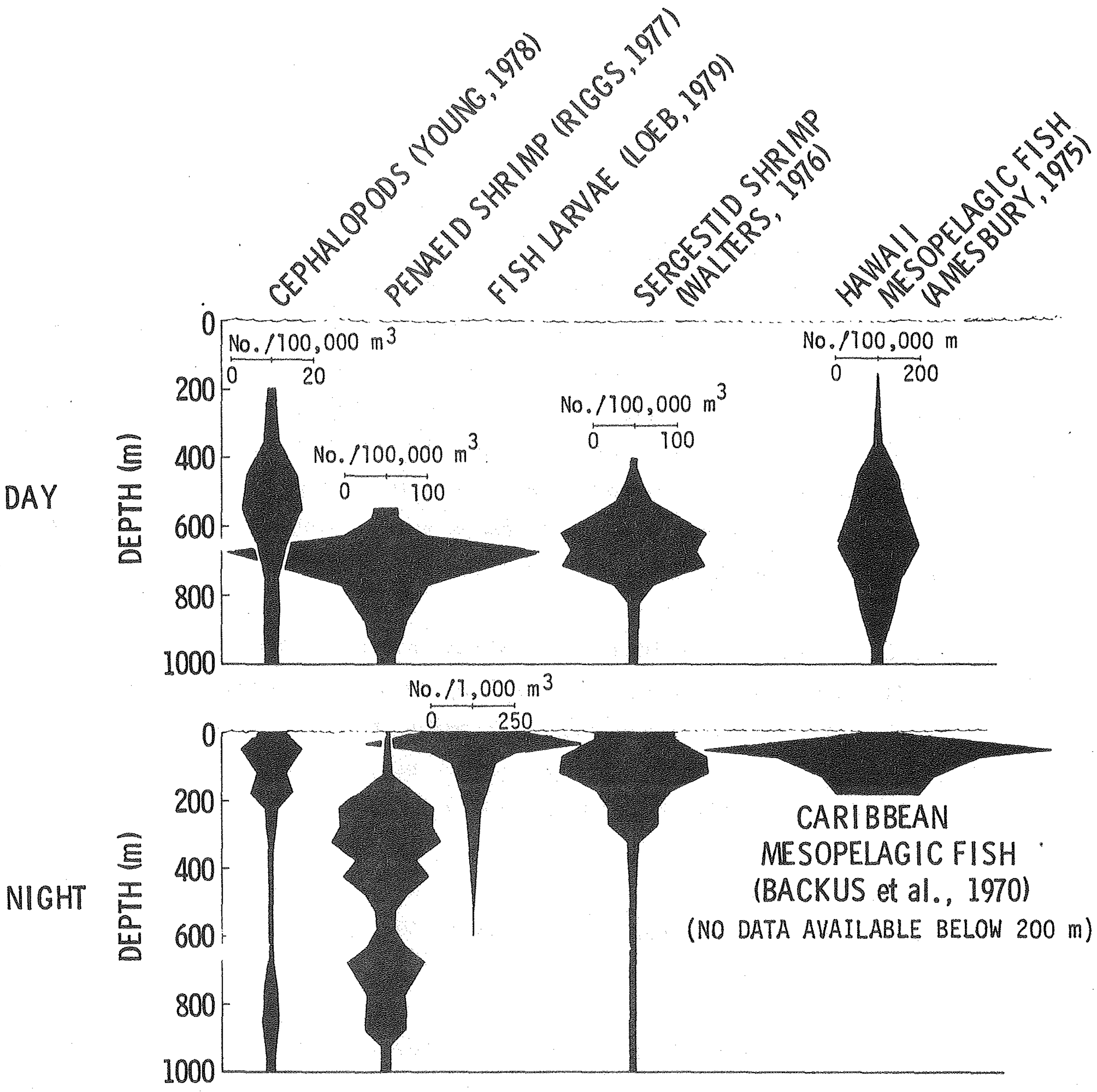


Figure 2-6. Diel Vertical Distribution of Micronekton Standing Stocks
Source: Sullivan, 1979

2.6.2.6 Endangered and Threatened Species - Many endangered and threatened species inhabit the candidate sites. Table 2-5 lists the species and their known distributions. Many species listed are confined to coastal wetlands, and are included because they could be vulnerable to the construction and operation of a Land-Based Pilot Plant. Tower or moored Pilot Plants will affect only oceanic endangered species, none of which are endemic to small regions.

2.6.2.7 Benthic and Coral Communities - Quantitative information on the benthos at the candidate sites is limited in comparison to available data on plankton and nekton. Generalities about deep-sea benthic macrofauna and megafauna include geographical distributions of biomass (Hessler, 1974), distributions of biomass with depth (Rowe et al., 1974), high diversity of deep-sea fauna (Hessler, 1974; Hessler and Jumars, 1974; Jumars, 1976), postulated importance of mobile scavengers in maintaining high diversity by cropping (Dayton and Hessler, 1972), and the extremely slow metabolic rates of organisms in deep-sea habitats (Hessler and Jumars, 1974).

Macrobenthic biomass (retained by 0.42-mm sieve) decreases with depth (Moiseev, 1971; Rowe and Menzel, 1971; Thiel, 1975). Several investigators have reported the average macrobenthic biomass to be 1.3 g m^{-2} on the Continental Shelf, 0.4 g m^{-2} on the Continental Slope, and 0.06 g m^{-2} on the abyssal plain (Hessler, 1974; Rowe et al. 1974).

Corals are found on the Continental Shelf at all candidate sites. Percent coverage and diversity is highest in the upper 50m, decreasing with depth to very low values below 200m.

2.6.2.8 Birds - Avifauna at the candidate sites are of three major types: (1) oceanic pelagic species (e.g., shearwaters and petrels), (2) coastal and island-associated species (e.g., pelican, gulls, booby), and (3) transitory migrants. A review of the pelagic distribution of sea birds in the central and eastern Pacific is given by King (1974), including information on the wedge-tailed shearwater (*Puffinus pacificus*), albatross (*Diomedea* spp.), and several species of petrels (family Hydrobatidae).

TABLE 2-5
ENDANGERED AND THREATENED SPECIES OF CANDIDATE SITES

Scientific Name	Common Name	Status*	Distribution
MARINE MAMMALS			
Balaenoptera musculus	Blue whale	E	Oceanic, Pacific, Atlantic
Balaenoptera borealis	Sei whale	E	Oceanic, Pacific, Atlantic
Balaenoptera physalus	Finback whale	E	Oceanic, Southern Hemisphere
Eubalaena glacialis	Right whale	E	Oceanic, Pacific, Atlantic
Megaptera novaeangliae	Humpback whale	E	Oceanic, Caribbean, North Pacific, Atlantic
Physeter catadon	Sperm whale	E	Oceanic, Caribbean, Pacific, Atlantic
Trichechus manatus	Caribbean manatee	E	Off Florida, Caribbean
Monachus schauinslandi	Hawaiian monk seal	E	Northwest Hawaiian Islands (NWHI)
Monachus tropicalis	Caribbean monk seal	E	Caribbean (extinct ?)
SEA TURTLES			
Chelonia mydas	Green sea turtle	T E	Hawaii Florida
Eretmochelys imbricata	Hawksbill	E	Tropical Pacific, Caribbean
Dermochelys coriacea	Leatherback	E	Tropical Pacific, Caribbean

* E = Endangered
T = Threatened

TABLE 2-5. (Continued)

Scientific Name	Common Name	Status	Distribution
		SEA TURTLES	
Lepidochelys kempii	Kemp's ridley	E	Caribbean
Lepidochelys olivacea	Olive ridley	T	Tropical circumglobal
Caretta caretta	Loggerhead	T	Tropical circumglobal
		OTHER REPTILES	
Cyclura pinquis	Anegada Island ground iguana	E	Virgin Islands
Cyclura stejnegeri	Mona Island ground iguana	T	Puerto Rico
Ameiva polops	St. Croix ground lizard	E	St. Croix, Virgin Islands
Eprcrates inornatus	Puerto Rican boa	E	Puerto Rico
		AMPHIBIANS	
Eleutherodactylus jasperi	Golden coqui	T	Puerto Rico
		BIRDS	
Pelecanus occidentalis	Brown pelican	E	Caribbean, U.S. west coast, Gulf coast
Puffinus puffinus newelli	Newel's Manx shearwater	T	Hawaiian Islands
Acrocephalus familiaris kingi	Nihoa miller-bird	E	Nihoa, Hawaiian Islands

* E = Endangered
T = Threatened

TABLE 2-5. (Continued)

Scientific Name	Common Name	Status	Distribution
		BIRDS	
Psittirostra cantans cantans	Laysan finch	E	Laysan, Hawaiian Islands
Anas laysannensis	Laysan duck	E	Laysan, Hawaiian Islands
Anas wyvilliana	Hawaiian duck	E	Hawaiian Islands
Pterodroma phaeopygia sandwichensis	Hawaiian dark-rumpled petrel	E	Hawaiian Islands
Fulica americana alai	Hawaiian coot	E	Hawaiian Islands
Himantopus himantopus knudseni	Hawaiian stilt	E	Hawaiian Islands
Gallinula chloropus sandvicensis	Hawaiian gallinule	E	Hawaiian Islands
Branta sandvicensis	Hawaiian goose	E	Hawaiian Islands
Caprimulgus noctitherus	Puerto Rican Whip-poor-will	E	Puerto Rico
Amazona vittata	Puerto Rican Parrot	E*	Puerto Rico
Columba inornata wetmorei	Plain Pigeon	E	Puerto Rico
Agelaius xanthomus	Yellow-shouldered Blackbird	E	Puerto Rico
Falcon peregrinus anatum	American Peregrine Falcon	E	North American, Carribean

* E = Endangered
T = Threatened

2.7 ECONOMIC PROFILES

2.7.1 Data Requirements

In order to penetrate the baseload generating market, the Pilot Plant must possess an economic advantage over other forms of energy production. Careful consideration of present populations, economies, natural resources, and power-production capabilities and needs will determine the optimal site for Pilot Plant deployment.

2.7.2 Description

Brief descriptions of populations, economies, natural resources, and electricity needs of Oahu, Key West, Puerto Rico, and St. Croix are presented to serve as a general economic profile of each community. Table 2-6 summarizes the population, electricity power-generation capabilities, and cost of electricity at each candidate site.

TABLE 2-6
POPULATION AND ELECTRICITY-GENERATING CAPABILITIES AND COSTS AT CANDIDATE ISLAND COMMUNITIES

Candidate Island Community	Resident Population (year)	Existing Total Power Output (MW)	Commercial Electricity Cost (KWhr)	Residential Electricity Cost (KWhr)
Oahu, Hawaii	724,000 (1977)	1,210	4.4¢	5.2¢
Key West, Florida	35,000 (1979)	110	7.9¢	7.5¢
Puerto Rico	3,300,000 (1978)	4,187	6.9¢	6.1¢
Saint Croix, Virgin Islands	48,000 (1979)	72.5	15.6¢	13.1¢

2.7.2.1 Oahu, Hawaii

a. Population - The 1977 resident population of Oahu was approximately 723,400 people (Schmitt, 1978), which represents 81% of the State's population. The southern half of Oahu accounts for 82% of the island population (Figure 2-7). Statewide projections indicate a 38% increase between 1977 and 1995, and a 115% increase between 1977 and 2020.

b. Economy - The Hawaiian economy is divided into four major components: tourism, Federal defense expenditures, Federal non-defense expenditures, and agriculture. The last component is the only inherent sector, with the first three being considered import income. The Gross State Product tripled between 1965 and 1975, rising to $7.4 billion in 1976.

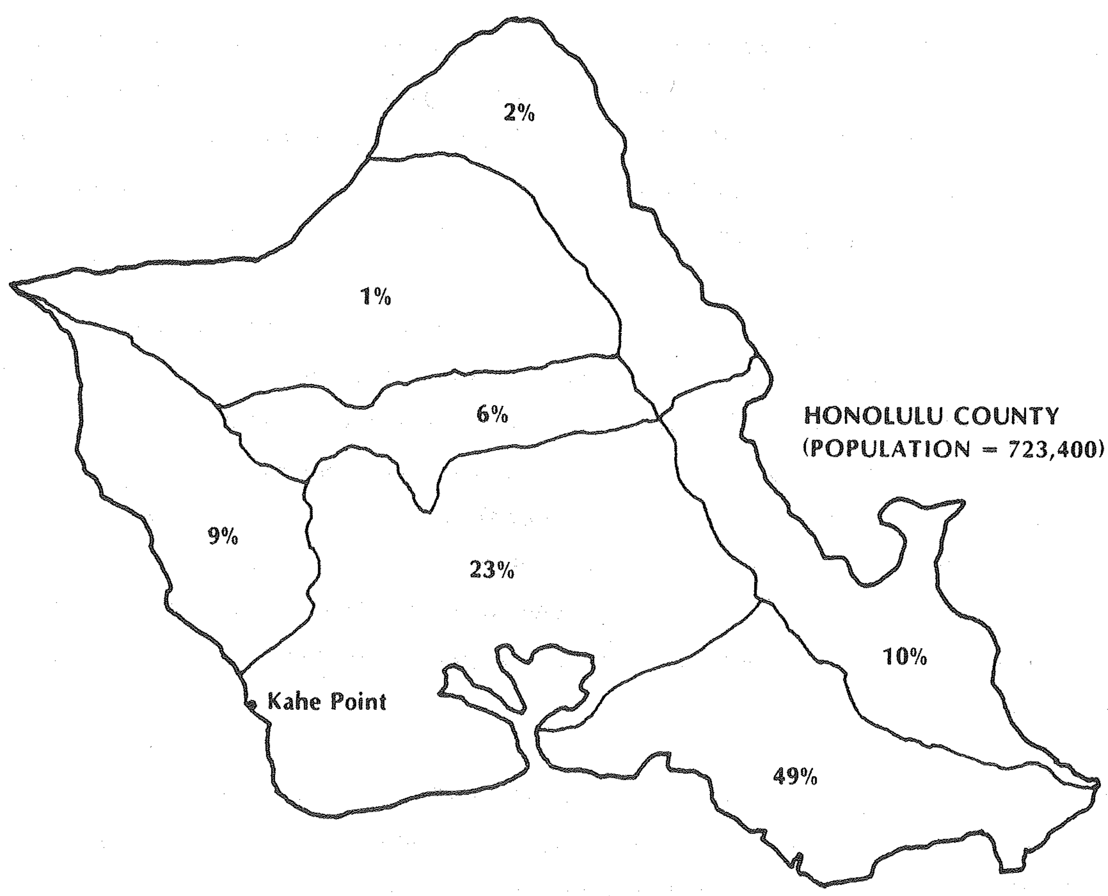


Figure 2-7. Percent Population by District (Oahu, Hawaii)
Source: Schmitt, 1978

The State of Hawaii has developed its State Plan on the premise that tourism will be the major growth industry. In order to achieve an acceptable unemployment rate, a 5% growth rate should be maintained until 1985. With this guideline, tourism will account for 74% of the new civilian jobs by 1985 (State of Hawaii, 1978). Statewide, the average number of daily visitors is expected to double by 1985, reaching 116,700 people per day. Visitor arrivals for 1985 are projected to be 5.06 million, which will necessitate construction of additional hotels.

Visitors spent $1.8 billion, and defense expenditures were $1.09 billion in 1977. Agricultural crops contributed the third-largest amount ($610 million), with pineapple and sugarcane production reaching $162 million and $227 million, respectively (Schmitt, 1978).

Kahe Point, Oahu is one of the largest fishing zones in the Hawaiian chain. The 1,950,000 kg of fish landed in this area in 1978 was equivalent to 31% of the total commercial fish landing in Hawaii. Fishing off Oahu contributed a total of over $3.5 million to the Hawaiian economy (State of Hawaii, 1980).

c. Natural Resources - Hawaii's mineral industry is dominated by non-metallic construction materials. Masonry and cement products accounted for 90% of the $50 million worth of mineral production in Hawaii in 1975 (Kerns, 1976). Manganese is the only metal which could play a significant role in Hawaii's mineral industry. Rich offshore deposits of manganese nodules and crust deposits have been discovered in the North Pacific, and Hawaii is the closest land where processing could take place. Studies are now in progress to determine the feasibility of such an industry.

d. Electricity - Hawaii is almost totally dependent upon imported petroleum for energy. The electrical power grid of Oahu is shown in Figure 2-8. The installed generating capacity on Oahu is approximately 1,210 MW (Schmitt, 1978).

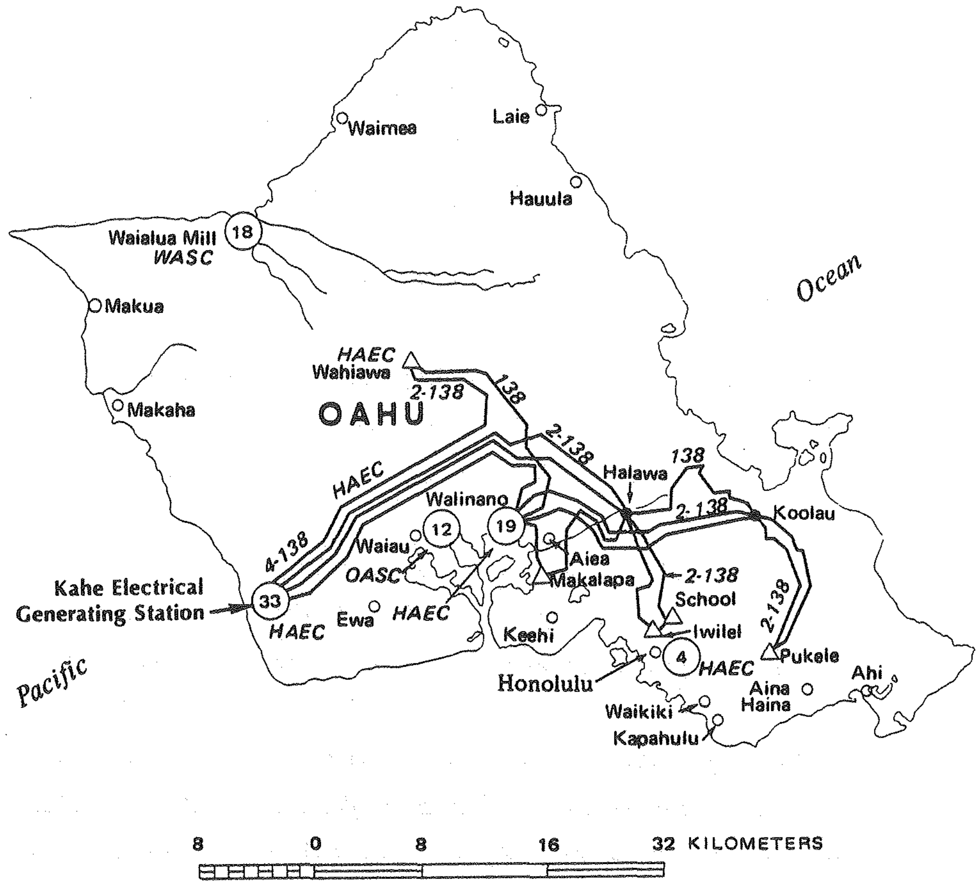


Figure 2-8. Electrical Power Grid for Oahu, Hawaii
Source: DOE, 1978

The island of Oahu accounts for 75% of total electric utility users for the State of Hawaii. Residential users comprise 87% of the customers, but consume only 29% of the electricity (Schmitt, 1978). The 1977 average annual use was 7,970 kilowatt-hours (kWh) for residential and 133,540 kWh for commercial/industrial users. Costs per kWh increased from 2.7¢ in 1967 to 5.2¢ in 1977 for residential users, and from 2¢ in 1967 to 4.4¢ in 1977 for industrial users (Stretch, 1979; Schmitt, 1978). No future cost projections are available; however, Hawaiian Electric has projected sales ranging from 6.0 to 6.9 billion kWh for the years 1980 to 1985 (Stretch, 1979).

2.7.2.2 Key West, Florida

a. **Population** - The population of Key West is estimated to be 30,000 to 40,000 (Smith, 1980). Growth has been restricted since 1977 by a building moratorium and the removal of military personnel from the area. The Big Pine area, about 37 km east of Key West, is the only area in the Keys in which construction is allowed. This area is expected to equal the population of Key West by 1990.

The Boca Chica Naval Station in Key West maintained an average of 19,000 personnel between 1965 and 1975. Presently, approximately 3,000 persons are stationed on the base (Smith, 1980).

b. **Economy** - Tourist-related activities (including retail trade, lodging, and personal services) account for 40% of the total employment in Key West. About 1 million tourists visit the area each year (Smith, 1980).

Fishing is another major component of the economy. The main fishing grounds are about 100 km west of Key West. In 1978, fishing in Monroe County (which includes Key West) contributed approximately $29.3 million to Florida's economy, comprising 30% of Florida's total fishing revenue (Snell, 1980). Local fisheries netted 70,000,000 kg in 1978 (Snell, 1980), with primary efforts directed at mackerel, lobster, and shrimp.

c. **Natural Resources** - There are no significant natural resources on the island of Key West. There is little soil, and no ground water. Fresh water is supplied by a desalinization plant on the island.

d. **Electricity** - The electrical power grid for the island of Key West is shown in Figure 2-9. Power is supplied by several outdated fuel-oil plants with a total capacity of 132 MW (Kelly, 1980). Frequent equipment failures reduce power output to about 110 MW. Brownouts often occur due to increased demands and frequent

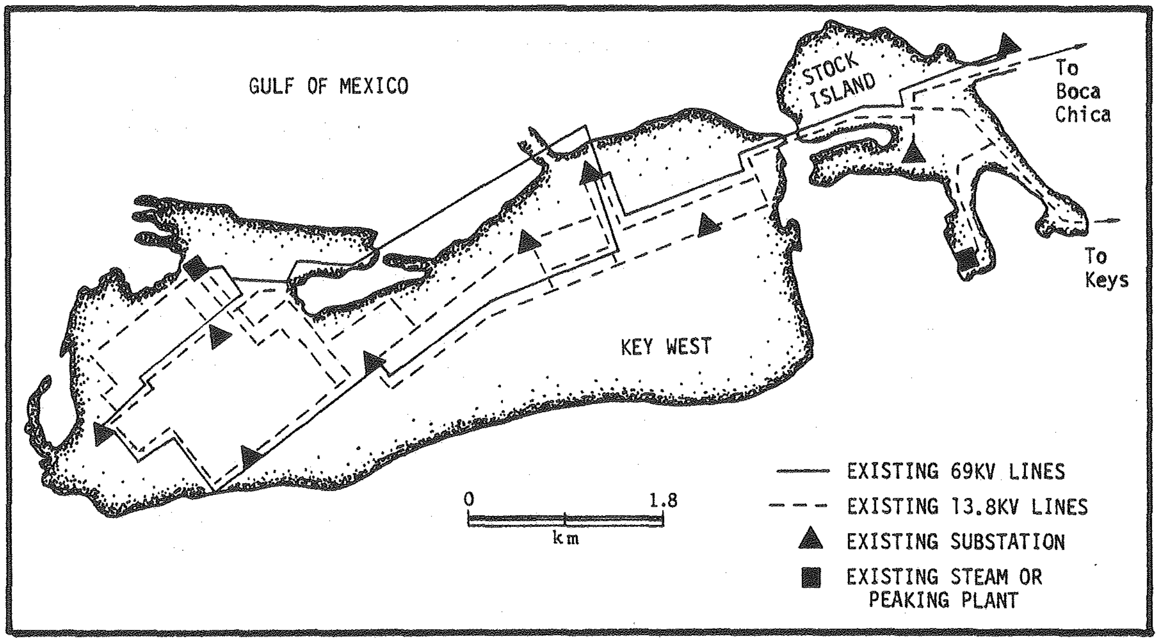


Figure 2-9. Electrical Power Grid for Key West, Florida
Source: Kelly, 1980

breakdowns. Key West consumed 3 million kWh of electricity in 1979. Residential rates average 7.5¢ kWh^{-1}, while commercial rates are about 7.9¢ kWh^{-1} (Kelly, 1980). Plans are being considered to connect Key West to the Georgia-Florida power grid, via a cable to the mainland.

2.7.2.3 Puerto Rico

a. Population - The Puerto Rican Department of Labor estimated the 1978 population to be 3.3 million, with over half the population residing in San Juan and the immediately surrounding regions of Bayamon, Caguas, and Carolina. One third of the population resides in the west and the southwest-to-south-central regions of Mayaguez and Ponce, respectively.

Total populations for 1995 and 2000 are projected to be 4.6 and 4.7 million persons, respectively (Pinsky, 1979), representing increases of 39.3% from 1978 to 1995, and 43.9% from 1978 to 2000. Projected regional estimates for 1995 and 2000 predict greatest density increases in the regions surrounding San Juan.

b. Economy - Since 1950, Puerto Rico has developed from an agrarian economy to an industrialized, urbanized society. Industrialization began in the early 1950's, with the introduction of a heavy chemical industry based on inexpensive, imported crude oil. Since 1950, employment in agriculture has dropped from 36% to 6.6%. The greatest increase in employment has been in local government, from 7.5% in 1950 to 20.4% in 1975 (DOC, 1972).

The greatest contribution to the economy in 1978 was from industry, which comprised 42% of the Gross National Product (GNP) of $8.939 billion. Since 1960, industry has grown tenfold. From 1970 to 1978 the Manufacturing Gross Product (a measure of industrial growth) tripled. The intensive growth experienced in the 1960's was due to Puerto Rico's advantages of low wages and a favorable business climate, as compared to the U.S. mainland. The Manufacturing Gross Product is projected to increase 33% by 1981, when industry will contribute $5.026 billion to Puerto Rico's GNP.

Puerto Rico's economy is highly sensitive to the U.S. mainland, because the U.S. is the main importer of goods and services. In 1977, the island imported $3.5 billion worth of goods, the majority of which included food, livestock, and manufactured goods. In turn, Puerto Rico exported $3.9 billion worth of goods to the U.S. in 1977, a third of which were chemical products. Unemployment (18.8% in 1978) continues to be a major problem in Puerto Rico. The largest growth industry in 1979 was the construction industry.

Most commercial fishing occurs on the east coast of Puerto Rico. Fishing employs about 1,180 people and is mainly from boats less than 6m long. In 1974, 275,000 kg of fish were landed, contributing $350,000 to the territory's economy (Rolon, 1975). The relative economic importance of this cash input is small; however, fishing may be highly valuable as a food source for local residents.

c. Natural Resources - Except for construction materials, there is no significant mining industry in Puerto Rico. Commercially valuable copper deposits exist in the central mountain area, but have not yet been exploited. There are no deposits of coal or natural gas; however, some oil exploration is beginning.

The principal port in Puerto Rico is San Juan, located on the north coast. Four major ports are located on the south coast. Three of the four are petrochemical ports (Guayanilla, Yabucoa, and Las Mareas). Guanica, on the southwestern coast, specializes in grain and chemical handling (DOC, 1972).

d. Electricity - Puerto Rico depends on imported petroleum for 98% of its electrical-power generation; hydroelectric power accounts for the other 2% (Marina, 1979). Continued efforts to build a nuclear power plant are being thwarted by environmental problems at prospective sites (Pinsky, 1979). Existing power plants have a maximum generating capacity of 4,199 MW, and a dependable capacity of 4,187 MW. The peak load for 1978 was approximately 2,249 MW. A peak load of 2,800 MW is projected for 1984. The total system of plants and transmission lines is illustrated in Figure 2-10.

During the year ending June 30, 1978 the average cost per kWh was 6.09¢ for residential users, 4.37¢ for industrial users, and 6.92¢ for commercial users (Pinsky, 1979).

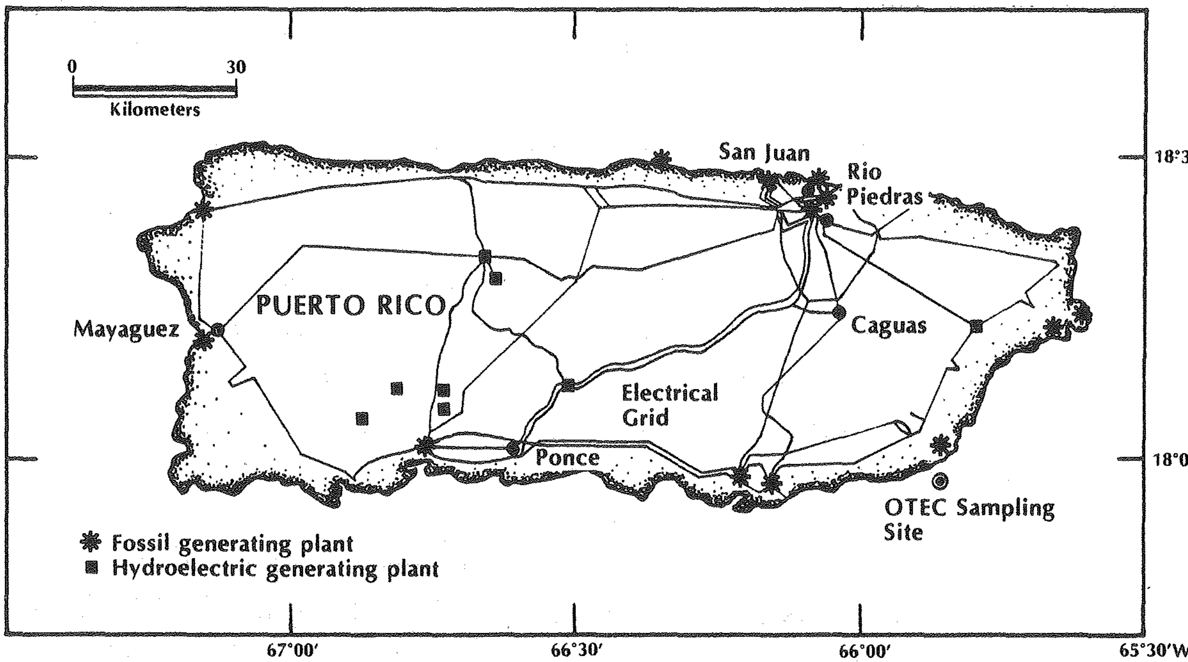


Figure 2-10. Electrical Power Grid for Puerto Rico
Source: DOE, 1978

2.7.2.4 Saint Croix, Virgin Islands

a. Population - Saint Croix, with a population of about 48,000, contains over 50% of the population of the Virgin Islands. Over the past 16 years the population of the Virgin Islands has tripled; by 1985 the population is projected to reach 120,000. Sixty percent of the estimated increase is expected to occur on St. Croix (DOC, 1979).

b. Economy - Tourism is the major component of the local economy. Tourist related activities, including retail trade, hotels and lodgings, and personal services represent over 30% of the total employment in the area. Sportfishing is an important part of the tourist industry; one of the largest centers of sportfishing activity is on the north shore of Saint Croix.

Another important sector of the labor market is local government, representing about 25% of the total employment (DOC, 1978b). Construction and manufacturing have almost doubled in the past 10 years, and presently employ about 25% of the work force (DOC, 1978b). Most of the manufacturing employment is attributable to two large industrial operations, Hess Oil and Martin Murrietta Alumina, both of which are in Saint Croix.

To meet the increasing demand for employment in the Virgin Islands, over 1,200 new jobs must be added each year until 1985 (DOC, 1978b). In anticipation of this demand for employment, an Industrial Development Program has been established in Saint Croix. Preliminary information indicates that new business development is severely hampered by a lack of adequate electrical power on the island (Rozynski, 1980).

c. <u>Natural Resources</u> - There are few economically important natural resources on Saint Croix. Industry and manufacturing plants rely on imported resources such as oil and bauxite.

Rainfall on Saint Croix is sparse and sporadic. Water for agriculture is supplied by irrigation. The public water supply system relies on flash-distillation desalinization plants which operate as an adjunct to the electricity-producing system. These plants cannot reliably supply enough water to fulfill the agricultural needs of the community. Subsequently, although 85% of the suitable farmland in the Virgin Islands is located on Saint Croix, local agriculture supplies only a fraction of the community's needs.

d. <u>Electricity</u> - Saint Croix is totally dependent on oil-powered generating systems. All electricity on Saint Croix is supplied by the Virgin Islands Water and Power Authority (WAPA). The rated capacity of WAPA facilities on Saint Croix is 72.5 MW (Martin, 1980). Regular power outages occur as a result of frequent breakdowns. To circumvent this problem, the main industries on the island own and operate private generating plants to provide power for their own needs.

The island relies on a simple radial distribution system with no loop interconnections between feeders. Power is supplied to residential users at approximately 13.2¢ kWh^{-1} and to commercial users for 15.6¢ kWh^{-1} (Martin, 1980). Hampered by antiquated equipment, the facilities of WAPA are insufficient to meet local demands. The shortage of electricity imposes severe limitations on the economic growth of the area, thus inhibiting industrial development (Rozynski, 1980; DOC, 1978b).

Section 3
POTENTIAL ENVIRONMENTAL IMPACTS

> The OTEC Pilot Plant may affect air quality, the terrestrial environment, and the marine ecosystem in the vicinity of the deployment site. This section qualitatively and quantitatively evaluates environmental issues associated with deployment and operation of the Pilot Plant. Data requirements for assessing the magnitude of potential environmental impacts are described, and the need for an Environmental Impact Statement is discussed.

Evaluation of potential environmental impacts associated with Pilot Plant deployment and operation is presently a matter of conjecture; little data has been collected near an operating OTEC plant. During the first deployment of Mini-OTEC at Keahole Point, Hawaii, the number and species of fish attracted to the platform were monitored (Nolan, 1980). Environmental monitoring for the OTEC preoperational platform (OTEC-1), also near Keahole Point, has begun (Menzies et al., 1980), but it is presently too early in the monitoring program for the evaluation of results.

Several reports have preliminarily evaluated potential environmental impacts associated with OTEC plants. The full range of environmental issues surrounding OTEC development, demonstration, and commercialization was described in the DOE OTEC Environmental Development Plan (DOE, 1979a). An Environmental Assessment (EA) was prepared (DOE, 1979b) and supplemented (Sinay-Friedman, 1979) for OTEC-1. A draft of the OTEC Programmatic EA, considering the environmental effects of the development, demonstration, and commercialization of several OTEC technological designs, plant configurations, and power usages, has been completed (Sands, 1980).

This section quantitatively and qualitatively assesses the potential air, land, and marine impacts associated with Pilot Plant deployment and operation. The potential for atmospheric or climatic effects resulting from the cooling of sea-surface temperatures and carbon dioxide releases are considered in Subsection 3.1. Subsection 3.2 describes the land-use changes that may result from the establishment of a Land-Based Pilot Plant facility. A discussion of potential Pilot Plant impacts on the marine environment is presented in Subsection 3.3. Economic effects are discussed in Subsection 3.4. An overview of OTEC Pilot Plant environmental data requirements is presented in Subsection 3.5.

3.1 ATMOSPHERIC ISSUES

Pilot Plant operation may cause climatic alterations as a result of two operational phenomena: (1) cooling of surface waters, and (2) release of carbon dioxide.

3.1.1 Sea-Surface Temperatures

The Pilot Plant will discharge large volumes of cold water at or near the thermocline. The potential for the cold discharged water to mix with warm surface water and alter sea-surface temperatures has caused environmental concern, because climatic alterations resulting from small (less than 1°C) sea-surface temperature changes over large ocean areas (greater than 1,000 km^2) have been reported (Namias, 1979; Barnett, 1978; Davis, 1978; White and Haney, 1978).

At least some of the cold water discharged by the Pilot Plant will be advected through the mixed layer; however, the majority of the displaced water will remain deep in the water column (below the thermocline), and not alter the sea-surface temperature. Furthermore, Bathen (1975) estimated that OTEC plants smaller than 100 MW would not produce local or regional climatic alterations. Therefore, no climatic alterations are expected as a result of Pilot Plant operation.

3.1.2 Carbon Dioxide

The earth's atmospheric carbon dioxide (CO_2) concentrations are increasing (Brewer, 1978). This increase, coupled with the ability of carbon dioxide molecules to absorb radiation at certain wavelengths while transmitting radiation at others, has aroused the concern of environmental scientists. Carbon dioxide is transparent to the majority of the incoming solar radiation spectrum. High-energy, short-wavelength radiation passes through the atmosphere and warms the earth below. The earth in turn reradiates energy towards space at longer wavelengths. Carbon dioxide blocks longer wavelengths, thus causing absorption of energy and warming of the atmosphere. After increased warming the wavelengths of the reradiated energy shift toward shorter wavelengths, consistent with Planck's law of black body radiation, pass through the atmosphere and back into space. Equilibrium is reached when incoming radiation equals outgoing radiation, and an average global temperature is maintained. It is believed that increases in atmospheric carbon dioxide levels will shift the equilibrium temperature of the planet, so that average global temperatures will increase.

Operation of the OTEC Pilot Plant requires that large volumes of cold, carbon dioxide-rich water are brought to the surface. The decreased pressure, increased temperature, and increased salinity will decrease the ability of the discharged water to retain carbon dioxide in solution, and a net outgassing of carbon dioxide may occur.

An attempt to quantify carbon dioxide release resulting from Pilot Plant operation can be made by assuming that the amount of carbon dioxide contained in the deep water which exceeds the carbon dioxide in surface waters would be liberated. The carbon dioxide efflux from the 40-MW Pilot Plant is estimated at approximately 1.9×10^5 kg day^{-1} (Appendix A). This is probably an overestimate because all excess carbon dioxide might not be released.

For comparison a typical 40-MW coal-fired power plant produces about 8.6×10^5 kg carbon dioxide day^{-1} (Ditmars, 1979), which is over four times the carbon dioxide the Pilot Plant will produce. Such releases of carbon dioxide are not expected to cause significant effects on local or regional climate.

3.2 LAND ISSUES

Construction of a Land-Based Pilot Plant would necessitate the total destruction of the existing terrestrial habitat, and potentially affect coastal marine resources (e.g., coral reefs). Grading for roads, utility corridors, and the central utility terminus would result in a change of land use from natural to improved (developed) land, particularly with respect to vegetation and wildlife.

Construction activities may have a local and temporary effect on noise levels, air quality, and aesthetic quality of the area. Blasting may be required. Dust and exhaust fumes will be generated by construction equipment. The construction activities and equipment will be visually obtrusive, as compared to the natural untouched land. These disturbances will diminish after construction is completed.

Since the location of Land-Based Pilot Plants have not been determined, and the flora and fauna at candidate sites is extremely diverse, the availability of terrestrial information is not known. Due to a lack of terrestrial field data and insufficient plant design detail, an assessment of impacts cannot be performed. After the Pilot Plant design and deployment site is determined, sufficient terrestrial data can be obtained for the evaluation of land impacts.

3.3 WATER ISSUES

Environmental issues that may affect the oceanic environment due to Pilot Plant deployment and operation can be related to specific plant activities. These activities and their associated environmental effects include:

• Platform presence	Biota attraction
	Protective hull coatings release
	Sanitation discharges
	Oil discharges
	Pipe and transmission cable implantation
• Warm- and cold-water withdrawal	Organism impingement
	Organism entrainment

- Water discharge — Ocean water redistribution

  Biocide release

  Working fluid release

  Trace constituent release

These effects (illustrated in Figure 3-1) will primarily impact the biological community. The organisms inhabiting the candidate sites are tropical-subtropical in nature and have adapted to a stable, relatively pristine, marine environment. Slobodkin and Sanders (1969) hypothesized that organisms adapted to stable, predictable environments would be more "fragile" or vulnerable to environmental stress than organisms adapted to unstable, unpredictable environments. This effect has been demonstrated for the lower food-chain members of an oceanic community (Fisher et al., 1973; Fisher, 1977).

In order to facilitate a clear discussion, the biological community is divided into the following categories:

- Phytoplankton
- Zooplankton (microzooplankton and macrozooplankton)
- Ichthyoplankton (fish eggs and larvae)
- Micronekton (mesopelagic fishes, cephalopods, crustaceans, and gelatinous organisms)
- Nekton
- Benthic and coral communities

The environmental issues affecting each biological category are summarized in Table 3-1.

3.3.1 Approach

The various Pilot Plant configurations being considered will be superimposed on a typical tropical-subtropical oceanic island environment (as described in Section 2), and estimates of biota losses associated with

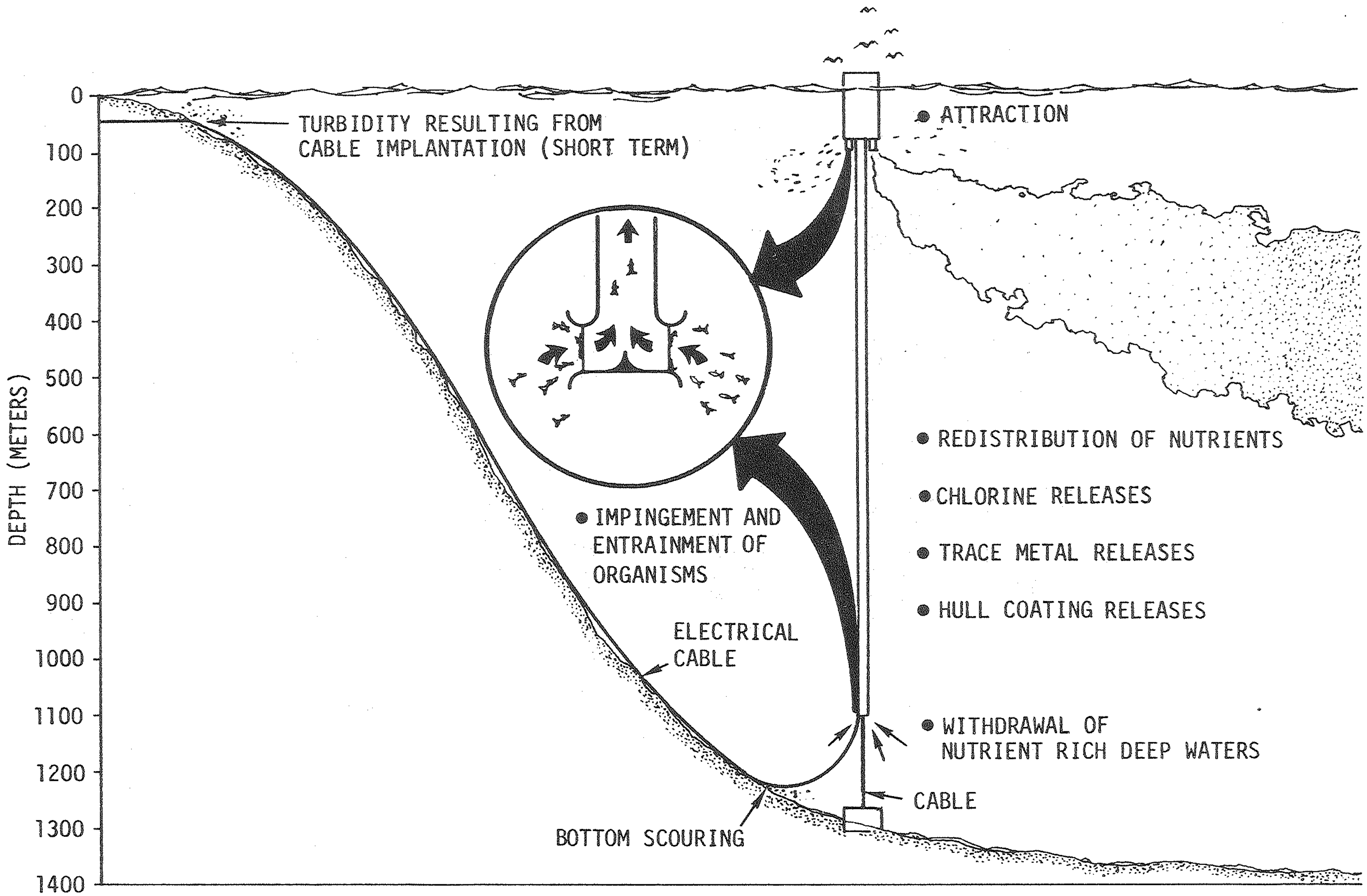


Figure 3-1. Environmental Effects of Pilot Plant Operation

TABLE 3-1
CATEGORIES OF POTENTIAL IMPACTS

Issue	Chemical Categories		Biological Categories						
	Nutrients	Dissolved Oxygen	Phyto-plankton	Zooplankton	Ichthyo-plankton	Micro-nekton	Nekton	Mammals, Birds	Benthos
Platform									
Biota attraction									
Structure				Major		Major	Major	Major	
Lights				Major		Major	Major	Major	
Oil Releases								Potential	Potential
Protective hull coatings release			Minor	Major	Minor	Major	Major	Major	
Sanitation discharges	Minor	Minor	Minor						
Mooring/cable/pipe implantation									Minor
Cold- & warm-water withdrawal									
Impingement						Major	Major		
Entrainment			Major	Major	Major				
Water discharge									
Water redistribution	Major		Major						
Biocide release			Major	Major	Major	Major	Major	Major	
Working fluid release			Potential	Potential	Potential	Potential	Potential	Potential	
Trace constituent release			Minor	Minor	Minor	Minor	Minor	Minor	

Major = Deployment and operation effects causing potentially significant environmental impacts.
Minor = Deployment and operation effects causing insignificant environmental disturbances.
Potential = Environmental disturbances which occur only during accidents.
Blank spaces imply no environmental effect.

Source: Adapted from Sands, 1980

potential impacts will be calculated. Biota losses from each potential impact are estimated by assuming the populations within the affected volume of water, or in the volume of water required to obtain the lowest reported toxic concentration level, will suffer 100% mortality. The loss associated with each potential impact will be put into perspective by comparing them with a reference background. Complete descriptions of calculations and methods employed to assess potential impacts are provided in Appendix B.

The reference background is taken as the parcel of ocean water passing the Pilot Plant in one day which is affected in some manner by plant operations (Figure 3-2). The depth of the parcel ranges from the surface down to 1,000m, just below the cold-water intake. The parcel width is taken as 650m, the distance over which it is estimated that the discharge plume will spread in 1 day (Appendix B).

Although the horizontal spread of the plume increases with time, it is assumed that the reference parcel is of constant width; equal to the plume width after 1 day. The length of the parcel will vary according to the depth. The mixed layer (0 to 60m) of the reference parcel is set at 10 km long, corresponding to a surface flow of about 12 cm sec^{-1}, which is the minimum daily averaged surface current speed that will be required for the selected Pilot Plant site. The layer between 60 and 350m is taken as 5 km in length, while the 350 to 1,000m layer is set at 1.5 km. These lengths correspond to 50% and 15% of surface flows, respectively, which equals expected current velocities at these depths (Bretschneider, 1977). Thus, the total volume of the reference parcel is approximately 2×10^9 m^3.

Populations within the reference parcel serve as standard references for putting losses due to Pilot Plant operation into perspective. Population biomass in the reference water parcel is determined by multiplying the typical biomass concentration of each layer of the reference parcel by the volume of that layer, and then summing all layers. The biomass of oceanic organisms within the reference water parcel is small compared to the total population in the area of the site that can be drawn from for replacements. However, the reference water parcel does provide a conservative comparison of population losses to the potential replacement population coming in contact with Pilot Plant operations.

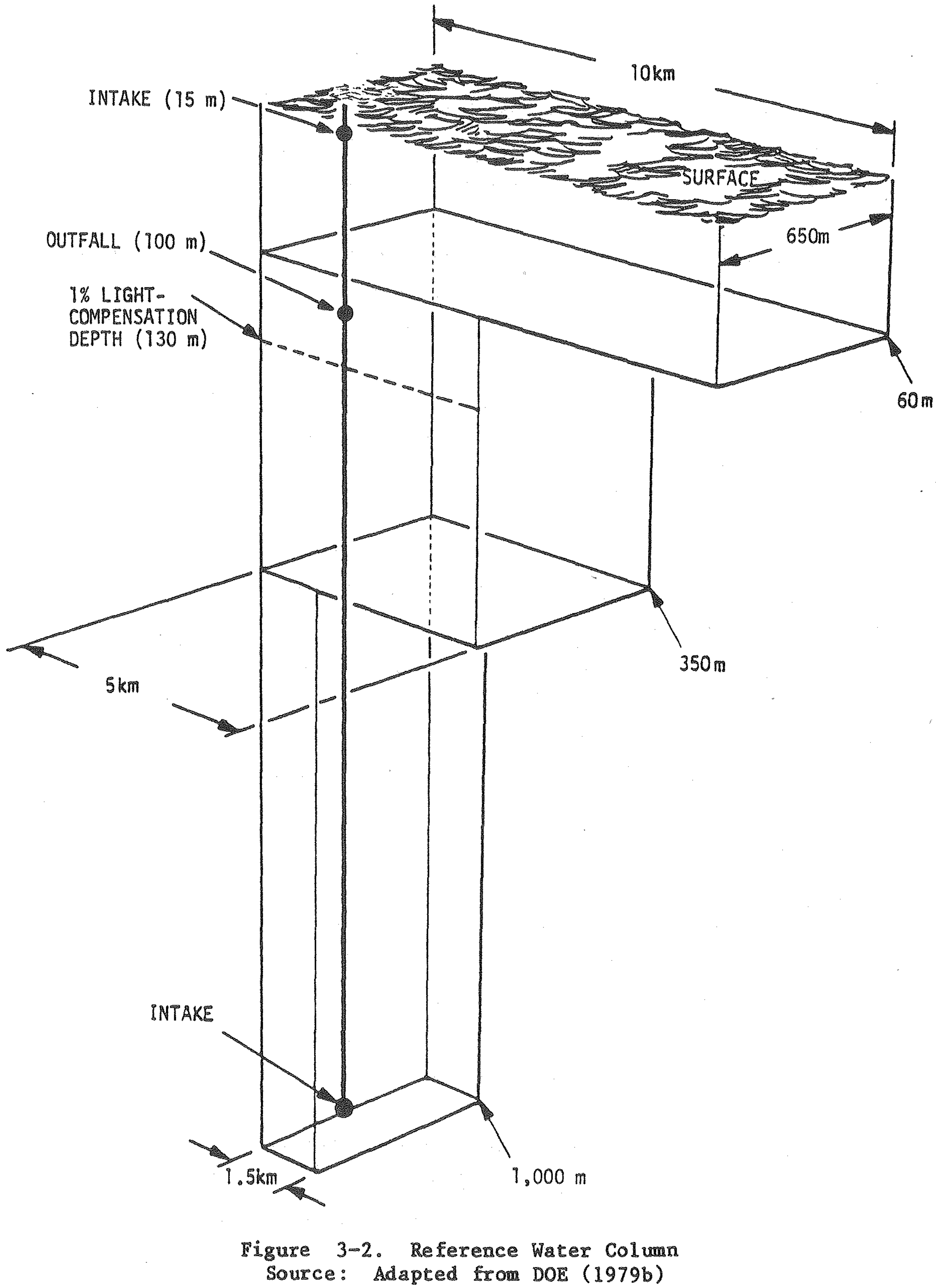


Figure 3-2. Reference Water Column
Source: Adapted from DOE (1979b)

3.3.2 Platform Effects

3.3.2.1 Attraction - Studies in the eastern Gulf of Mexico (Hastings et al., 1976), off Hawaii (Gooding and Magnuson, 1967; Nolan, 1980), and in the Pacific Ocean (Greenblatt, 1978; Hunter and Mitchell, 1976) have shown that fish congregate around offshore structures, presumably seeking protection and food. At night, lights are an additional attractive force. Consequently, the Pilot Plant is expected to act as an artificial reef and provide a habitat for a large number of organisms. The increased population near the plant will: (1) compound environmental impacts, (2) increase the difficulty of monitoring environmental effects resulting from plant operation, and (3) potentially increase the risk of diver-related accidents due to shark attraction. Because of the synergistic effect attraction has on impacts, attraction is probably the most important environmental effect associated with platform deployment.

Attraction rates are difficult to estimate because they are functions of the site, the structural design of the plant, and the illumination of lights. No information is available on the increase of biomass due to deployment and operation of OTEC plants. Therefore, an approximation is made in this EA to illustrate the multiplicative power of attraction on impacts. The attraction factor, as a result of platform presence, is assumed to be twice the ambient biomass; attraction to lights is presumed to cause an additional twofold increase in biomass at night near the surface.

3.3.2.2 Hull Coating Releases - Information on the toxicity of protective hull coating materials to marine invertebrates or fish indigenous to tropical-subtropical oceanic regions is limited (EPA, 1976a). Saifullah (1978) found that copper inhibits productivity in three species of marine dinoflagellates at concentrations above 1.0 mg liter^{-1}, although exposure to 0.02 mg liter^{-1} for more than 20 hours decreased growth rates.

When considering the potential effects of protective hull coating releases, the release rate and flow past the platform are important. Preliminary estimates indicate that, with a cuprous oxide release rate of 30 μg cm^{-2} day^{-1}

(De et al., 1976) and a current speed of 12 cm sec^{-1}, only a layer of water within 3 cm of the hull will have a concentration of copper one-tenth of that (1.0 mg $liter^{-1}$) found to inhibit productivity in marine dinoflagellates (Appendix B). Therefore, protective hull coatings will primarily affect biofouling organisms. However, bioaccumulation through the food chain due to feeding on biofouling organisms could pose a hazard to sport and commercial fisheries in the vicinity of the plant. Bioaccumulation in sport and commercial fish of substances released from protective hull coatings may be significant, but cannot be fully assessed due to insufficient information on attraction rates and food-chain dynamics.

3.3.2.3 <u>Sanitation Releases</u> - The Pilot Plant will comply with U.S. Coast Guard regulations for sanitation releases. Hence, all sewage from the Pilot Plant will be collected and processed in a USCG-certified aerated biological unit before discharge overboard.

A maximum of 50 persons will man the Pilot Plant, and each person will generate about 0.4 m^3 (100 gallons) of waste water each day. The 20 m^3 of waste water generated each day will contain approximately 8 kg total dissolved solids, and an undetermined number of coliforms (EPA, 1973). The mortality rate for coliforms and human enteroviruses after 24 to 48 hours in seawater is greater than 90% (Anderson et al., 1979; Fujioka et al., 1980). The discharged material will have a combined biological and chemical oxygen demand of 2×10^6 mg oxygen, which is approximately 0.00003% of the oxygen available in the mixed layer of the reference water column. Therefore, the effect of sanitation releases from the Pilot Plant will be negligible.

3.3.2.4 <u>Mooring/Pipe/Cable Implantation</u> - The mooring of the Pilot Plant and implantation of the submarine transmission cable and cold-water pipe are the only potential impact that the Pilot Plant will have on the benthic community. The mooring lines and riser cable system will cause bottom scouring near the touchdown points as the platform moves through its watch circle. Roughly assuming each mooring line and electrical cable will scour approximately 15,000 m^2 of ocean bottom (Moak et al., 1980), less than 0.2 km^2 of ocean bottom will be affected (Appendix B). Since the benthic scouring will be a small disturbance located in deep water where the benthic biomass is low, the benthic community will not be significantly impacted.

Submarine transmission cables and bottom-resting pipes may be laid on the ocean floor (Morello, 1978) and will cause minimal disturbance of benthic life. However, at the 100-m contour, cables and pipes will be implanted 2 to 3m into the ocean floor, and benthic community disturbances may result. The effects of cable and pipe implantation (by dredging) include a localized increase of water column turbidity and habitat destruction. Environmental impacts will be severe if the dredging occurs in ecologically sensitive areas. The cable/pipe route should follow natural breaks in the coral reef whenever possible. A full assessment of potential impacts associated with pipe and cable implantation must be performed after the dredging route has been determined.

3.3.2.5 Oil Releases - Oil spills from accidents at sea, or petroleum leaks from minor spills, may occur due to the increased ship traffic expected after Pilot Plant deployment. Oil releases could occur during the deployment of the cold-water pipe. One proposed method for deploying the cold-water pipe involves filling a steel insert within the pipe with 10,000 m^3 of oil for buoyancy, and floating the pipe to the deployment site. The cold-water pipe would then be up-ended during deployment activities by pumping the oil out of the steel insert into a nearby barge or tanker (Moak et al., 1980). An accident during such an operation could cause total release of the oil, resulting in significant environmental impacts.

The toxic effects of petroleum product spills have been summarized by Cox (1977). The potential damages to marine organisms from oil pollution are:

- Coating and asphyxiation of organisms
- Contact poisoning of organisms
- Exposure to water-soluble toxic components of oil

A large oil spill would potentially affect the entire environment and disrupt local populations of phytoplankton, zooplankton, nekton, marine mammals, and birds. A complete assessment of the effects of an oil spill resulting from Pilot Plant deployment activities cannot be provided due to limited environmental and engineering information. However, careful consideration of the risk of credible accidents must accompany the design of the Pilot Plant, to ensure that oil releases will not create significant problems.

3.3.3 Warm- and Cold-Water Withdrawal

The 40-MW OTEC Pilot Plant will withdraw approximately the same volume of water as a 4,000-MW fossil-fueled or nuclear-powered plant. The major impacts associated with the withdrawal of large volumes of warm and cold water are impingement of organisms on the intake screens and entrainment of organisms through the plant.

3.3.3.1 **Impingement** - Impingement of organisms will be one of the most visible effects of Pilot Plant operation on the marine environment. Impingement is also a plant operational concern, due to high maintenance costs of intake screen cleaning and plant downtime.

The only available information on organisms with limited avoidance capabilities, but large enough to be impinged on the cold- or warm-water intake screens, is obtained from midwater trawl collections. The intake velocity for the Pilot Plant (approximately 50 cm sec^{-1}) is less than towing speed of midwater trawls (100 to 200 cm sec^{-1}); however, the species and quantities of organisms which will be impinged on Pilot Plant screens will probably resemble those caught in midwater trawls (Nath et al., 1977). This is primarily due to velocity being less significant than volume as a factor in determining impingement rates (EPA, 1976b; Edwards et al., 1976). Therefore, the organisms which will be most affected by impingement include small epipelagic fish, mesopelagic fish, macroplanktonic crustaceans (penaeid and caridean shrimps, mysids, large euphausiids), and cephalopods.

Nekton will occasionally be impinged on the warm-water intake screens. Results from studies at Unit 5 of the Kahe Generating Station provide an example of impingement rates in tropical-subtropical marine waters. Located on Kahe Point, Oahu, Unit 5 withdraws approximately 9.5 m^3 sec^{-1} of nearshore waters (at intake velocities similar to those of the Pilot Plant) and impinges an average of 250g wet weight of fish daily (McCain, 1977). Nekton impingement rates on Pilot Plant screens cannot be estimated due to the lack of information on nekton behavior near an offshore power plant.

Estimates of the micronekton and gelatinous organism biomass impinged each day on the warm- and cold-water intakes of the Pilot Plant (Table 3-2) were made using data from Maynard et al. (1975). Micronekton were assumed to be attracted by both platform presence and lights. At night impingement will be a greater problem at the warm-water intake than at the cold-water intake because of the micronekton population's nocturnal migration to the upper layers of the water column, and their presumed attraction to surface lights (Appendix B). However, the actual impinged biomass on Pilot Plant screens may be slightly less, since gelatinous organisms (salps, ctenophores, coelenerates) are impinged on intake screens for only a short time before breaking up and being extruded through the screen (Coles, 1980).

TABLE 3-2
PILOT PLANT IMPINGEMENT RATES
(kg wet weight)

Intake		Micronekton	Gelatinaus Organisms	Total
Warm-water (15m)	Day	3	3	6
	Night	123	5	128
	Total	126	8	134
Cold-water (1,000m)	Day	56	4	60
	Night	28	3	31
	Total	84	7	91

Impingement may reduce the population slightly in a localized area downstream of the plant. For example, the biomass impinged in 1 day is 3% of the population in the reference water parcel (Appendix B). The impact of this loss on the oceanic ecosystem is unknown, because little data is available on the replacement ability of the micronekton population in the surrounding oceanic region. Many commercially important species of nekton (e.g., tuna) rely on the micronekton as a major food source. These nekton species may also be affected by impingement at the warm-water intake screen of the Pilot Plant. The effect of impingement on commercially important species, either directly or through food-chain interactions, cannot be fully evaluated with the available data.

3.3.3.2 Entrainment - Small marine organisms will be withdrawn from the water column and entrained in the seawater, which flows through the heat exchangers. The entrained organisms at the warm-water intake will be subjected to chlorine and the physical abuse (acceleration, impaction, shear forces, and abrasion) associated with passage through the plant. Although mortality rates for organisms entrained at the warm-water intake are expected to be high, survival after discharge is possible. Organisms entrained at the cold-water intake will be exposed to chlorine, physical abuse, a temperature change of approximately 20°C, and a pressure change of nearly 100 atmospheres, all within a few minutes. Organisms entrained at the cold-water intake will probably suffer 100% mortality. If organisms survive to the discharge, they will be exposed to increased turbidity, light levels, and predation.

The daily entrainment rates of phytoplankton, microzooplankton, and macrozooplankton at the warm- and cold-water intakes of the Pilot Plant are given in Table 3-3. These estimates are based on biomass averages presented in Section 2. In addition to organisms withdrawn from the water column and entrained through the Pilot Plant, a large number of planktonic organisms may be entrained into the discharge plume along with ambient waters and displaced deep into the water column. The effects from displacing organisms from the surface layers to deeper depths cannot be adequately assessed with the available information; however, organism mortality resulting from this displacement would be an additional effect of organism entrainment.

TABLE 3-3
PILOT PLANT DAILY ENTRAINMENT RATES

Intake	Phytoplankton (kg C)	Microzooplankton (kg C)	Macrozooplankton (kg C)
Warm-water (15m)	114	2	46
Cold-water (1,000m)	0	0	6
Total	114	2	52

Entrainment at the cold-water intake will be relatively low, primarily affecting macrozooplankton. The phytoplankton and microzooplankton biomasses at 1,000-m depth are expected to be zero (Lawrence Berkeley Laboratory, 1980; Beers, 1978). Entrainment at the warm-water intake is high, affecting phytoplankton, microzooplankton, and macrozooplankton.

Phytoplankton and microzooplankton entrainment is not expected to seriously affect the populations because the majority of the biomass is concentrated below the depth of the warm-water intake. For instance, the phytoplankton biomass entrained each day is only 1.3% of the total phytoplankton biomass in the reference water parcel. In terms of productivity, the amount of phytoplankton entrained each day is comparable to the biomass produced in the reference water parcel during a 6-hour period (Appendix B). The entrained microzooplankton biomass is only 0.6% of the total microzooplankton biomass in the reference water column.

Entrainment of macrozooplankton at the warm-water intake may be the most serious biological impact that will result from Pilot Plant operation. The macrozooplankton biomass entrained each day is approximately 5% of the total macrozooplankton population in the reference water parcel; however, the biomass entrained by the warm-water intake is 12% of the biomass in the mixed layer of the reference water parcel. A high proportion of the macrozooplankton population in the mixed layer is likely to be composed of larvae of nearshore organisms. Around islands, the maintenance of a larval population near the spawning site is vital to adult population existence.

Assumming the average fish larvae abundance in surface waters is 0.1 individuals m^{-3} during the day and 0.2 individuals m^{-3} at night (King and Hida, 1957; Miller et al., 1979), the Pilot Plant will entrain 1.7×10^6 fish larvae each day. No fish larvae are expected to be entrained at the cold-water intake. The entrained fish larvae are comparable to 34% of the fish larvae in the mixed layer of the reference water column. Depending on the importance of the Pilot Plant site as a spawning grounds, the entrainment of ichthyoplankton may cause a significant impact on the adult population of ecologically or commercially important fish.

Estimates of meroplankton (planktonic eggs and larvae of nearshore invertebrates) abundance are extremely speculative, because larval abundance varies greatly according to species dominance, seasonal spawning patterns, and various other factors. In order to obtain an order-of-magnitude estimate of effects, it is necessary to make four general assumptions: (1) meroplankton are not attracted to structures and lights, (2) 10% to 20% of the zooplankton biomass is composed of meroplankton (Owen, 1980; Youngbluth, 1975), (3) all meroplankton are within 5 km of shore, and (4) the meroplankton biomass within 2.5 km of shore is equal to 10 times the biomass of the outer 2.5-km region (Hirota, 1979). Thus, the nearshore larvae entrained by the warm-water intake of the Pilot Plant each day is between 0.007% and 0.03% of the total biomass around the candidate islands (Appendix A). Entrainment of the larvae of nearshore organisms by the Pilot Plant may eventually reduce the adult population downstream of the plant.

3.3.4 Discharge

3.3.4.1 Ocean Water Mixing - The Pilot Plant will displace large quantities of ocean water, and potentially cause disturbances of natural thermal structures, salinity gradients, and levels of dissolved gases, nutrients, trace metals, carbonates, and turbidity, among others. An estimate of the downstream behavior of water discharged from the Pilot Plant is essential for assessing the effects of these disturbances. This subsection presents a general summary of Pilot Plant discharge plume behavior, based on results of DOE-funded physical model studies.

As the Pilot Plant discharge effluent enters the ocean, it will have a different density than the surrounding ambient water. The behavior of the discharge plume will be dominated by the initial discharge momentum and buoyancy forces resulting from the initial density difference. Within several hundred meters from the point of discharge, the Pilot Plant discharge plume will: (1) be diluted by the ambient ocean water, (2) sink (or rise) to reach an equilibrium level within the water column where the average density difference between the diluted plume and surrounding ambient water vanishes, and (3) lose velocity until the difference between the plume's velocity and the ambient current velocity is small. This initial region is referred to as the near-field regime (Ditmars and Paddock, 1981).

When the discharge effluent from the plant has reached its equilibrium depth, it has lost its jet-like characteristics and has a velocity only slightly different than the ambient current; this region is referred to as the intermediate-field regime. The intrusion of the effluent into the stratified ocean results in the plume collapsing vertically due to residual buoyancy forces and spreading laterally due to gravity forces. The interaction of the spreading layer and the ambient current in the far-field produces a plume that extends upcurrent of the plant and grows in width downcurrent of the plant due to gravity spreading until gravity forces become small and turbulent diffusion takes over as the dominant mixing process (Ditmars and Paddock, 1979).

Mixing in the intermediate-field is greatly reduced compared to the near-field region. The magnitude of the ambient current dominates the behavior of the discharge plume in the intermediate-field, although local ambient density stratification and initial near-field dilution will have some influence on the width and thickness of the resultant plume. Further downstream, buoyancy-driven motions become small and diffusion (by means of ambient turbulence in the ocean) becomes the dominant mixing and spreading mechanism. This region of passive turbulent diffusion is referred to as the far-field regime.

Predicting the detailed external flow field in the near-field region of the Pilot Plant discharge plume is complicated by the strong dependence the discharge structure design, ambient currents, and water column proximity of the warm-water intake to the outfall have on plume behavior. Schematic laboratory-scale experiments on OTEC discharge plume behavior have been conducted by Sundaram et al. (1977, 1978) and Jirka et al. (1977); detailed physical model tests are currently underway (Adams et al., 1979; Coxe et al., 1981). These studies indicate that in the case of separate evaporator and condenser discharges the density of the evaporator effluent will be only slightly above ambient if discharged into the mixed layer. The plume will therefore reach its equilibrium level within the mixed layer if discharged horizontally, or slightly below the mixed layer if initially directed downward. The condenser effluent will be strongly negatively buoyant, but mixing with ambient water in the mixed layer will cause the condenser effluent to reach an equilibrium level only slightly below the mixed layer (within the thermocline). If discharged vertically below the thermocline, mixing will prevent the condenser effluent from sinking more than 50 to 100m below the point of discharge. In the case of a combined or mixed discharge, the effluent will behave much like the effluent from the condenser alone, except that the equilibrium depth will probably be slightly higher due to the smaller initial density difference.

To provide estimates of the geometry and dilution of the Pilot Plant discharge plume, modified versions of the near-field model of Koh and Fan (1970) and the far-field model of Brooks (1960) were used. Mixing due to gravity-spreading in the intermediate field, as defined by Jirka et al. (1979), is not included in Brooks' far-field model. The Brooks model considers horizontal, but not vertical, mixing due to turbulent diffusion. Low flows magnify impacts, therefore a net current velocity of 12 cm sec^{-1} was used for plume calculations as a conservative estimate. Details of the models and input parameters are presented in Appendix B.

Plume behavior from several discharge configurations were evaluated. A Land-Based Pilot Plant will probably discharge the warm and cold water separately out of single discharge structures. Tower or moored Pilot Plants will discharge the warm and cold waters, either separately or mixed, out of multiple discharge structures. Therefore, the discharge configurations that were evaluated include: (1) one warm-water and one cold-water discharge structure, directed horizontally, (2) four mixed discharges directed vertically downward, and (3) four separate warm-water and cold-water discharges directed vertically downward. Results of model estimates are presented in Table 3-4. Far-field calculations indicate that the discharge plume will spread to a width between 550m and 750m at 10 km downstream of the plant, dependent on the season, discharge structure configuration, and discharge orientation.

If, as expected, an offshore Pilot Plant discharges vertically at or near the thermocline, the discharge plume will stabilize between 160m and 270m (Table 3-3). Although separate discharge structures will be used, mixing between the separate plumes will occur rapidly in the near-field region. Land-Based Pilot Plants will use separate warm- and cold-water pipes to discharge horizontally near the bottom. The warm-water discharge plume will stabilize at approximately 100m, while the cold-water discharge plume will sink along the bottom to approximately 200m. At 10 km downstream the total estimated dilution is approximately 15 to 1 (Table 3-5).

3.3.4.2 Nutrient Redistribution - Pilot Plant discharge plume predictions indicate the mixed- or cold-water plume will stabilize below the 1% light penetration depth, where light is a limiting factor. Therefore, enhanced productivity resulting from nutrient redistribution is not an environmental issue. However, if the Pilot Plant discharges horizontally at the surface, rather than vertically near the thermocline (as presently projected), part of the cold-water discharge plume may remain within the photic zone, resulting in enhanced primary production.

Primary production in oceanic and neritic waters is limited by the availability of usable nitrogen compounds (Ryther and Dunstan, 1971; Thomas, 1970). Nitrogen is usually available in regenerated form as ammonium nitrogen or as "new" nitrate-nitrogen from deep waters (Dugdale and Goering, 1967).
The Pilot Plant will discharge nutrient-rich deep water and nutrient-poor surface water into the mixed layer of the ocean. The discharged water should have a nitrogen: phosphorus ratio close to that of Redfield's (1963).

TABLE 3-4
DISCHARGE PLUME MODELING RESULTS

Modeling Conditions		Near-Field Results			Far-Field Plume Width (m)									
Discharge Orientation	Discharge Description	Stabilization Depth (m)	Width (m)	Near-field Dilution	Downstream Travel (km)									
					1	2	3	4	5	6	7	8	9	10
Horizontal	One warm-water discharge pipe; summer conditions	90	80	2.4	120	160	200	250	300	350	410	470	530	590
	One warm-water discharge pipe; winter conditions	100	70	1.9	100	140	180	230	280	330	380	440	500	560
	One cold-water discharge pipe; summer conditions	200	140	4.1	180	220	270	320	380	440	500	560	620	690
	One cold-water discharge pipe; winter conditions	190	90	3.5	120	160	210	260	310	360	420	480	540	600
Vertical	One of four mixed-discharge pipes; summer conditions	260	130	3.6	170	220	260	320	370	430	490	550	610	680
	One of four mixed-water discharge pipes; winter conditions	270	100	4.3	140	180	230	270	330	380	440	500	560	630
	One of four warm-water discharge pipes; summer conditions	160	100	1.3	140	180	230	270	330	380	440	500	560	630
	One of four warm-water discharge pipes; winter conditions	170	120	1.7	160	200	250	300	360	410	470	530	600	660
	One of four cold-water discharge pipes; summer conditions	250	100	6.5	140	180	230	270	330	380	440	500	560	630
	One of four cold-water discharge pipes; winter conditions	260	160	7.5	200	250	300	360	410	470	530	600	660	730

TABLE 3-5
DISCHARGE PLUME DILUTIONS

Discharge	Downstream Travel (km)									
Configuration	1	2	3	4	5	6	7	8	9	10
One horizontal warm-water discharge; 100m depth; winter conditions	2	3	4	5	6	7	8	9	10	12
One horizontal cold-water discharge; 100m depth; winter conditions	4	5	6	7	9	11	12	14	16	18

phytoplankton uptake ratio of 16:1. Before the increased productivity from the discharge of these waters can be assessed, many simplifying assumptions must be made:

- The discharge of chlorine from the Pilot Plant will inhibit phytoplankton growth rates; however, chlorination will be intermittent and will not be considered.
- The degree of expected mixing is estimated to be the average of the dilution values shown in Table 3-5.
- The average growth rate for phytoplankton in nutrient-enriched oceanic waters is 2 doublings per day (Parsons and Takahashi, 1973).

A 1-meter-long portion of the plume was followed downstream as the plume widened due to entrainment of diluting water (Appendix B). The amount of nutrients dissolved in the 1-meter-long portion of the plume was estimated at various downstream distances as phytoplankton uptake decreased the nutrient concentration, and increased the phytoplankton biomass. Under optimal conditions, the nutrients released from the Pilot Plant will increase the phytoplankton biomass in the plume approximately fivefold after 10 km (1 day) travel. A fivefold increase in the phytoplankton biomass concentration downstream of the Pilot Plant is greater than the environmental variability at the sites and may increase the number of organisms in higher trophic levels. Therefore, nutrient redistribution may be a significant environmental effect resulting from Pilot Plant operation.

3.3.4.3 <u>Chlorine Release</u> - Chlorine used to prevent biofouling on the seawater side of heat exchanger surfaces will be released along with the Pilot Plant's discharge waters. Chlorine is expected to adversely affect the local marine environment because of its toxicity to nontarget organisms and the large volumes that must be released to maintain heat-exchanger efficiency. Chlorine, in conjunction with the working fluid (ammonia), may have synergistic effects. In order to assess the impact of discharging chlorinated effluents, it is necessary to obtain information on chlorine reactions in seawater, toxicity, expected release rate, and decay/dilution rates.

a. Reactions in Seawater - The chemistry of chlorine in seawater is complex (Opresko, 1980; Macalady et al., 1977; Block et al., 1976; Davis and Middaugh, 1975), and it is not possible to confidently predict the chemical products generated by chlorinating natural seawater (Block et al., 1977). In general, chlorine decays rapidly in seawater exposed to sunlight, forming various inorganic and organic compounds that may persist for long periods of time. The inorganic reactions of chlorine are somewhat predictable, but the organic reactions are not.

The principal expected inorganic products of seawater chlorination are hypobromous acid, hypobromide ions, and possibly tribromamine (DOE, 1979c). Ultimately, the hypobromous acid will appear as bromate. The principal organic compounds are bromamines, bromoforms, and trihalomethanes; however, many compounds remain unidentified (DOE, 1979c).

Macalady et al. (1977) studied the disappearance of residual oxidants (chlorine, hypochlorous acid, hypochlorite ions, inorganic and organic chloramines, and other compounds) in chlorinated seawater exposed to sunlight. Samples exposed to full midday sunlight underwent 80% degradation in less than 1 hour and 95% degradation after 2 hours. When subjected to overcast conditions (less than 20% full sunlight) samples underwent 80% degradation after 2 hours; after 3 hours approximately 15% of the initial chlorine dosage remained (Figure 3-3). Approximately 50% of the chlorine added to seawater produces bromate; however, it is not clear what other compounds are formed, nor is it predictable what their toxicity will be.

b. Toxicity Data - A review of the toxicity of chlorine reaction products to oceanic organisms was presented in the OTEC Preoperational Platform Environmental Assessment (DOE, 1979b). This review indicated that phytoplankton are the organisms most sensitive to chlorine, and that organic compounds formed from chlorine-seawater reactions may be more toxic than either the inorganic forms or the initially introduced

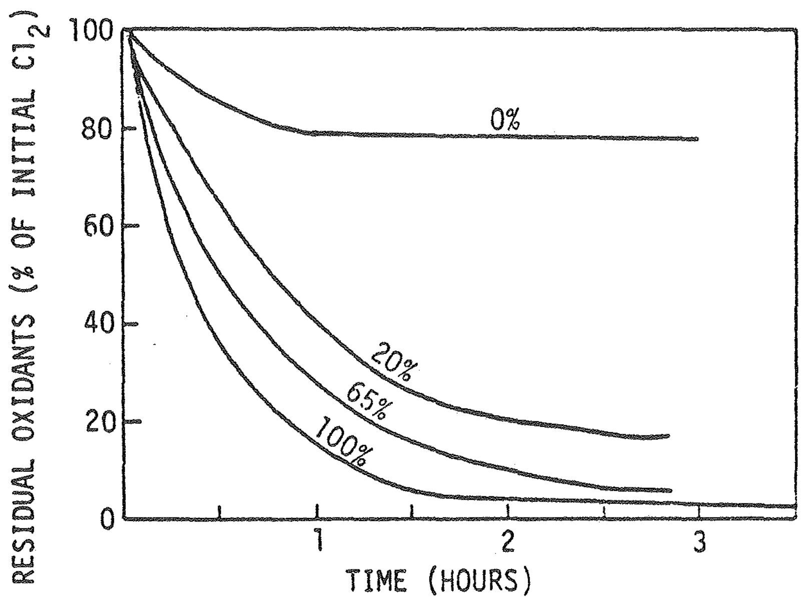


Figure 3-3. Disappearance of Residual Oxidants in Chlorinated Seawater with Exposure to Sunlight (in percent). Source: Macalady et al., 1977

chlorine. Several investigators (Carpenter et al., 1974; Eppley et al., 1975) reported severe and irreversible (50% to 83%) decreases in phytoplankton photosynthesis at chlorine concentrations that were below the analytical detection limit (less than 0.1 mg $liter^{-1}$). Estuarine and coastal zooplankton species demonstrate significant mortality rates when exposed to chlorine concentrations greater than 1.0 mg $liter^{-1}$ for more than 1 hour (DOE, 1979b).

Studies are presently underway at the Gulf Coast Research Laboratories (GCRL) to examine chlorine toxicity in oceanic invertebrates and fish. Preliminary studies on mullet (Mugil cephalus) have shown that chlorine is lethal at concentrations above 1.4 mg $liter^{-1}$, with sublethal effects occurring at 1.0 mg $liter^{-1}$ and below (Venkataramiah, 1979). Since salinities in the inshore waters where the test organisms were taken range from 5 to 25 g kg^{-1} (Venkataramiah, 1979), the results may not be indicative of the effects of chlorine to oceanic organisms. Oceanic organisms have adapted to a stable, predictable environment and may be more vulnerabl to environmental stress than coastal organisms, which have adapted to unstable, unpredictable environments. Further chlorine toxicity studies are planned using an oceanic crustacean, the Sargassum shrimp (*Latreutes fucorum*).

c. Release Rate - The permissible discharge concentration for a 2-hour chlorination schedule must average 0.2 mg $liter^{-1}$ during a 30-day period, with a maximum of 0.5 mg $liter^{-1}$ (EPA, 1974). However, OTEC-1 received permits to continuously release chlorine along with its discharge waters at a concentration of 0.1 mg $liter^{-1}$. Therefore, the Pilot Plant could discharge a minimum and maximum of 375 and 2,250 kg day^{-1} of chlorine. For perspective, the minimum expected daily chlorine discharge rate from the Pilot Plant is over four times the chlorine discharged daily into marine waters by all the power plants on Oahu.

d. Expected Effects - The centerline residual oxidant concentration downstream of the Pilot Plant is given in Table 3-6. The chlorine concentration in the discharge plume is less than the analytical detection limit (0.1 mg $liter^{-1}$) before the end of the near-field. Chlorine concentrations of this magnitude may affect only phytoplankton in a localized area immediately downstream of the plant, and not cause significant environmental impacts if the Pilot Plant is sited away from ecologically sensitive areas.

The most significant environmental effect of chlorine release may be the formation of organic and inorganic compounds that are resistant to degradation and can be acutely toxic or chronically bioaccumulated. Bromate will be used as an example of the effects of chlorine reaction products that persist downstream of the Pilot Plant discharge, because bromate is one of the few chlorine-seawater reaction products that can be predicted. During the day chlorine decays rapidly, with 50% of the

TABLE 3-6
RESIDUAL OXIDANTS AND BROMATE CONCENTRATIONS
DOWNSTREAM OF THE PILOT PLANT †

Downstream Distance (km)	0	0.2	1	2	3	4
Centerline Dilution	1	2	3	4	5	6
Day Percent Concentration of Residual Oxidants at 100m (from Figure 3-4)	100	100	40	25	20	20
Day Concentration of Residual Oxidants (mg $liter^{-1}$)	0.200	0.100	0.027	0.013	0.008	0.007
Day Bromate Concentration (mg $liter^{-1}$)*	0.000	0.000	0.020	0.019	0.016	0.013
Night Percent Concentration of Residual Oxidants at 100m (from Figure 3-4)	100	100	80	80	80	80
Night Concentration of Residual Oxidants (mg $liter^{-1}$)	0.200	0.100	0.053	0.040	0.032	0.027
Night Bromate Concentration (mg $liter^{-1}$)*	0.000	0.000	0.007	0.005	0.004	0.003

† Dilutions based on discharge conditions given in Table 3-5
* 50% of initial chlorine concentration produces bromate

initial concentration forming bromate. As the chlorine decays and is diluted by ambient waters, the concentration of bromate increases, potentially reaching levels toxic to downstream organisms (Table 3-6). The lack of information on the toxicity of chlorine-seawater reaction products to marine organisms (Macalady et al., 1977) restricts the further assessment of chlorine discharges; however, the sublethal effects of these compounds could potentially have a significant effect.

3.3.4.4 Working Fluid Leaks - The Pilot Plant will have heat exchangers with extensive surface areas that will be exposed to constant physical and chemical stresses. Leaks may develop in the working fluid transport system, resulting in ammonia release. The effect of ammonia-working fluid leakage on marine organisms is a function of ammonia's chemistry in seawater, the release rate, and the organisms in the vicinity of the plant. A small accidental release of ammonia may increase primary productivity downstream of the plant. A catastrophic spill would result in total ammonia release to the receiving waters and may adversely affect the local environment.

Limited ammonia toxicity data is available for marine organisms indigenous to candidate Pilot Plant sites. Natarajan (1970) reported concentrations of 55.0 to 71.1 mg liter^{-1} of ammonia inhibited photosynthesis in unspecified marine phytoplankton. Toxicity studies by the Gulf Coast Research Laboratory on Sargassum shrimp (*Latreutes fucorum*) and filefish (*Monocanthus lispidus*) are underway and preliminary results indicate that the lethal ammonia concentration for both species is approximately 1.0 mg liter^{-1} (Venkataramiah, 1979).

Approximately 140,000 kg of ammonia will be stored on the Pilot Plant, and may be released into the environment by slow leaks or a catastrophic spill. During a large ammonia surface spill, 40% would be released into the atmosphere and the remaining 60% would dissolve (EPA, 1977). In order to obtain a concentration of 1.0 mg liter^{-1} (the concentration found to be lethal to oceanic shrimp and fish), the dissolved ammonia released after a major Pilot Plant spill would have to be distributed through the mixed layer over a 1.4 km^2 area (Appendix B). Destruction of zooplankton and fish stocks over such a large area would result in a significant short-term environmental disturbance. The increased concentration of organisms near the plant due to the attractive force of the platform and lights will compound the significance of this potential disturbance.

3.3.4.5 Trace Constituent Releases - Trace constituent releases from the Pilot Plant will occur from the seawater corrosion and erosion of structural elements within the plant (e.g., heat exchangers, pump impellers, metallic piping). The discharge or release of trace constituents from these sources could prove to be toxic or sublethal to many marine organisms.

The major source of trace constituent release is from the heat exchangers. The condenser and evaporation heat exchangers will be constructed of aluminum, titanium, or stainless steel. The pump impellers and metallic piping are comparatively minor sources; however, they include copper-bearing alloys and lead-bearing materials which have high toxic potentials.

A review of the limited data on aluminum and titanium toxicity indicates that toxicity of these metals is very low (DOE, 1979b). Aluminum concentrations below 10 mg $liter^{-1}$ had no effect on marine fish and shrimp (Pulley, 1950), while concentrations below 0.2 mg $liter^{-1}$ did not significantly inhibit marine algae (Kylin, 1946). The potential for bioaccumulation of titanium and aluminum in tissues of marine organisms has not been assessed; however, bioaccumulation rates are expected to be extremely slow.

Design projections indicate that the Pilot Plant will have approximately 300,000 m^2 of heat exchanger surface, all subject continuously to the erosive and corrosive actions of seawater. To obtain an aluminum concentration of 0.2 mg $liter^{-1}$ (the lowest concentration found to inhibit marine algae) at the point of discharge, about 15 g m^{-2} of heat exchanger surface would have to be lost each day (Appendix B). The heat exchanger erosion and corrosion rate is not known, but is expected to be several orders of magnitude less than this. Thus, concentrations of trace metals will be extremely low and no significant impacts are expected.

3.4 SOCIOECONOMIC ISSUES

The socioeconomic impacts associated with Pilot Plant construction, deployment, and operation are specific to each site and platform design being considered and, therefore, can only be generically assessed. In general, the candidate island communities are almost totally dependent on foreign imported oil, with few viable alternatives available. Since their future economic development is tied to oil prices, the candidate island communities are increasingly vulnerable to oil price increases and future oil embargoes. The OTEC Pilot Plant will be a positive influence on island economies by initiating a process for obtaining total energy independence; thereby creating long-term price stability for economic development.

At least some of the Pilot Plant components will be manufactured in the selected island community; the remaining plant components will be constructed at existing shipyard or industrial facilities around the world and transported to the site for assembly. The construction and assembly of the Pilot Plant will have a positive impact on island employment and income, by providing building, road construction, and utility installation opportunities to local contractors and laborers.

The projected job impact of Pilot Plant construction is very significant for large depressed city areas, where most major shipyards are located (Francis et al., 1979). Pilot Plant construction will require a period of 2 to 3 years between initial construction crew and equipment mobilization and the completion of the plant. Francis et al. (1979) estimated that approximately 2,000 worker-years of shipyard employment would be required for the construction of a 40-MW Pilot Plantship.

There may be significant short-term (2 to 3 years) impacts on the population characteristics of the communities near the construction and assembly sites during building of the Pilot Plant. Temporary housing and community services (water, electricity, sewage) may have to be provided for the construction crews. Population impacts would probably be reduced to minimal levels after Pilot Plant construction is complete and operation begins.

3.5 PILOT PLANT ENVIRONMENTAL STUDIES

A complete description of environmental and engineering data requirements for the OTEC Pilot Plant Program were summarized in the OTEC Pilot Plant Data Priorities Report (Sullivan and Sands, 1980). After the Pilot Plant deployment site has been selected, the ecological, geological, physical, and chemical conditions of the site must be determined. An engineering test plan for evaluation of plant design and operation, and an environmental monitoring plan for evaluation of plant operational effects, must be prepared prior to deployment. After Pilot Plant deployment, ocean engineering and environmental monitoring data must be periodically obtained and analyzed. The collected data should be compared with engineering and environmental predictions made prior to deployment, in order to calibrate theoretical results. The environmental monitoring data can be used for determining the long-term environmental effects associated with Pilot Plant operation.

Due to several potentially significant environmental impacts associated with Pilot Plant deployment and operation which cannot presently be fully assessed, the Pilot Plant will require the preparation of an Environmental Impact Statement (EIS) specific to the selected platform design and deployment site. The potential environmental impacts and data requirements for assessing their magnitudes are described in the following subsections.

3.5.1 Biota Attraction

The Pilot Plant will serve as an artificial reef and provide a habitat for a large number of organisms. The increased population near the plant will compound environmental impacts by exposing greater numbers of organisms to operational effects. In addition, attraction of organisms to the Pilot Plant may potentially deplete populations in other areas. In order to evaluate attraction to the Pilot Plant and its resultant effects on impacts, monitoring studies on OTEC-1 and Mini-OTEC (second-deployment) should concentrate on obtaining data on attraction rates, the species attracted to the platforms, and the concentration of organisms with distance from the plants. Results from these studies can be used for evaluating Pilot Plant impacts prior to deployment; after deployment, monitoring studies can validate attraction predictions.

3.5.2 Entrainment of the Larvae of Oceanic and Nearshore Organisms

Entrainment of the larvae of oceanic and nearshore organisms by the Pilot Plant may reduce the adult population downstream of the plant. Around islands, the maintenance of a larval population near the spawning site is vital to adult population existence. In order to evaluate meroplankton entrainment and the resultant effects on adult populations, the entrainment and mortality rates of the species affected by OTEC-1 operation must be monitored and the results extrapolated to the Pilot Plant. Estimates of meroplankton and ichthyoplankton concentrations in the water column around candidate islands must be collected so that the estimated loss of larvae due to Pilot Plant operation can be compared to the population available for recruitment. After plant operation begins, adult invertebrate and fish stocks must be monitored downstream of the Pilot Plant to ensure population depletions do not occur.

3.5.3 Impingement of Ecologically or Commercially Important Species

Information necessary to assess the effects of Pilot Plant impingement includes: (1) species potentially affected by Pilot Plant impingement (by mortality and food-chain interactions), (2) impingement and mortality rates, and (3) platform attraction rates. Such information, obtained from monitoring the OTEC-1 platform, can be used to evaluate the effect of Pilot Plant impingement and the resultant standing stock changes. To facilitate this evaluation, data from OTEC-1 environmental monitoring studies should be combined with plant operational records in order to correlate the numbers and types of organisms impinged with physical, biological, and plant-operation parameters.

3.5.4 Redistribution of Ocean Properties

If nutrient-enriched discharge waters remain in the photic zone, enhanced primary production may occur. Increases in phytoplankton biomass may have either beneficial or detrimental effects downstream of the plant: increased primary productivity may increase the number of organisms in higher tropic levels, but could also increase turbidity, potentially affecting the aesthetic quality of an area. Data necessary for evaluating nutrient redistribution effects on the ecosystem includes physical-model predictions, physical and chemical measurements, phytoplankton uptake rates, and food-chain investigations. Results of physical models will provide estimates of the plume-stabilization depth, downstream nutrient concentrations, and the area affected. Photic-zone depth and nutrient profiles at the site are necessary for estimating the potential for increased productivity. Phytoplankton uptake rates and food-chain investigations are important for estimating the increase in biomass and its resulting effect on trophic-level structures.

3.5.5 Discharge Plume Releases

The Pilot Plant will release waters containing chlorine and sodium hydroxide used for biofouling control. In addition, working fluid (ammonia) could potentially be released from large power system leaks or spills. Little bioassay and toxicity data is available for assessing acute or chronic effects of chlorine and ammonia releases on oceanic organisms. Preliminary results are available on the effects of ammonia on oceanic organisms (Venkataramiah, 1980); however, a broad range of studies must be performed for assessing and predicting effects of discharge plume releases from the Pilot Plant, including:

- Descriptive studies on the seawater chemistry of released substances, emphasizing chlorine

- Calibration of physical-model estimates of OTEC-1 plume behavior, in order to accurately predict the Pilot Plant discharge plume stabilization depth and downstream concentrations

- Acute and chronic toxicity and bioassay studies using varying concentrations of chlorine (and its reaction products) on typical oceanic organisms

- Food-chain investigations in order to assess the trophic levels affected by potential biota losses

3.5.6 Protective Hull Coating Release

Toxic substances released from protective hull coatings may accumulate in the tissues of biofouling organisms, be passed up the food chain, and concentrate in recreationally and commercially important fish species. Investigations of food-chain dynamics should begin prior to Pilot Plant deployment for assessing trophic levels potentially affected by bioaccumulation. After deployment, ecologically and commercially important species should be periodically sampled and their tissue trace metal concentrations monitored.

3.5.7 Oil Discharges

If a catastrophic accident occurs during cold-water pipe deployment, the resulting oil discharges could significantly impact the marine environment. However, since estimates of the volume of oil required for deploying and operating the Pilot Plant range from zero to 10,000 m^3, the environmental impacts from oil releases could range from insignificant to adverse. In addition to information on the volume of oil to be carried aboard the Pilot Plant, a characterization of the pelagic, benthic, and avian populations within range of effects and the predominant circulation characteristics of the site are required for evaluation of the potential effects of a Pilot Plant oil spill. The risk of an accident occurring during cold-water pipe deployment should be assessed, and a spill contingency plan prepared.

3.5.8 Pipe and Cable Implantation

Environmental impacts may result during dredging operations for the implantation of the cold-water pipe or submarine electrical cable. Environmental impacts will be severe if the dredging occurs in ecologically sensitive areas. The environmental impacts from pipe and cable implantations can be assessed, once the installation route and its proximity to coral reefs, spawning grounds, and other ecologically sensitive areas have been determined.

3.5.9 Land Issues

Construction of a Land-Based Pilot Plant necessitates the total destruction of the existing local terrestrial habitat. Since the location of a Land-Based Pilot Plant has not been designated, and the flora and fauna at candidate sites is extremely diverse, the availability of terrestrial data is not known. After the Pilot Plant design and deployment site is determined, sufficient terrestrial data must be obtained, in order to evaluate the impact of a Land-Based Pilot Plant.

3.6 UNAVOIDABLE ADVERSE EFFECTS

There is insufficient information to determine whether there are significant environmental impacts associated with Pilot Plant deployment and operation. However, preliminary (order-of-magnitude) estimates have demonstrated that the OTEC Pilot Plant could possibly cause unavoidable adverse effects on the marine and terrestrial environments. The potential impacts associated with Pilot Plant activities include:

- Biota attraction, as it compounds impacts
- Entrainment of nearshore organisms
- Impingement of ecologically or commercially important species
- Redistribution of ocean properties
- Discharge plume releases (biocide and working fluid)
- Protective hull coating release
- Oil discharges
- Pipe and cable implantation
- Terrestrial habitat destruction

The magnitude of these potential impacts must be assessed before Pilot Plant development begins. To do so will require preparation of an Environmental Impact Statement (EIS) for the Pilot Plant.

3.7 RELATIONSHIP BETWEEN SHORT-TERM USE AND LONG-TERM PRODUCTIVITY

Construction and deployment of the OTEC Pilot Plant is a long-term (30-year) commitment to evaluate the technical, economic, and environmental feasibility of the commercial OTEC system. No short-term uses are associated with the Pilot Plant Program. Deployment of a Bottom-Resting Tower or moored Pilot Plant may enable the site to be returned to its natural state after use; construction of a Land-Based Pilot Plant may require permanently altering the site.

The significant long-term positive impact of OTEC operation will be the development of an energy-independent island community. The long-term productivity of the site will be increased, due to the utilization of the thermal gradient for energy production. Recreational and commercial fish catches in the vicinity of the site will probably increase after Pilot Plant deployment, due to fish attraction and concentration around the platform.

3.8 IRREVERSIBLE AND IRRETRIEVABLE RESOURCE COMMITMENT

The marine biota at candidate Pilot Plant sites will be subjected to several alterations in the environment. The extent of impact, or magnitude of environmental change, cannot be fully assessed because of the lack of data on attraction, food-chain dynamics, and chlorine-derived reaction product toxicities. Specific data are required on platform designs and the environment where the Pilot Plant will be sited. Significant resource commitments can be avoided, or minimized, provided that further investigations of key problem areas are performed early in the Pilot Plant design phase.

Several raw materials, consumables, and construction materials will be used during the construction, deployment, and operation of the Pilot Plant. The magnitudes of committed materials depends on the platform design, deployment site, and other factors, and therefore cannot be projected.

Section 4
RISK OF CREDIBLE ACCIDENTS

Operations in the marine environment present several unique hazards or potentials for occurrence of accidents. Collisions, extreme meteorological conditions, military or political terrorism, and human error may endanger the safety of the platform crew. The risk of credible accidents associated with Pilot Plant deployment and operation is site-specific, and can only be fully evaluated after the platform design and deployment site are identified. This section provides a brief overview of considerations for evaluating the risk of credible accidents.

The potential for occurrence of credible accidents must be carefully and thoroughly reviewed prior to the deployment of the Pilot Plant. The Pilot Plant will be adjacent to population centers, where vapors from operating fluid leaks could pose serious health threats. The Pilot Plant will serve as a baseload electrical-generating facility and potentially expose the community which it serves to power outages resulting either from acts of man or nature. Thus, the population affected by the Pilot Plant includes: (1) the platform crew, (2) the adjacent population within range of effects, and (3) the population center served by the plant.

Potential threats to health and safety for all three communities must be quantified for possible accidents, based on site and platform design data. Specific elements necessary for a risk evaluation include a complete account of the accidents that may occur to the platform as a result of human error, storms, or sabotage. From these data, appropriate plans can be prepared for mitigating or reducing the probability of occurrence of these accidents.

4.1 POTENTIAL EMERGENCY SITUATIONS

4.1.1 Acts of Man

4.1.1.1 Collision - The frequency of collisions and incidents at sea increases logarithmically with proximity to shore (Washom, 1977). More than

85% of navigational accidents occur within 8 km of shore, primarily near harbor approaches, or within international straits. If the Pilot Plant is situated in a high-traffic area, the probability of collision is greatly increased.

Coastal traffic is primarily small craft, whereas major ship traffic is prevalent around harbor entrances and on the open ocean. Military submarine traffic is a potential hazard to the cold-water pipe and mooring cables of the Pilot Plant. In addition, the submarine transmission cable route could transect anchoring areas.

Specific items to be considered in collisions include detailed evacuation procedures, fluid flammability and fire fighting procedures, and communication procedures. The location and boundaries of the Pilot Plant deployment site should be clearly marked on navigational charts and be internationally recognized. Ship traffic near the Pilot Plant must be strictly controlled and monitored to avoid catastrophe.

4.1.1.2 Accidents - Accidents of many types requiring firefighting or other emergency operations may occur on the Pilot Plant. A complete appraisal of accident potentials must be performed and probability indices assigned. The Pilot Plant crew must be composed of experienced and skilled individuals. It is imperative that a detailed safety program be developed, which documents both the potential for accidents and the corrective steps if an accident occurs.

4.1.1.3 Military/Political Terrorism - The Pilot Plant will be susceptible to takeover by political dissenters of various persuasions. The potential for takeover will be influenced by the community served, its dependency on the plant, and the degree of protection provided for the platforms.

4.1.2 Acts of Nature

During its operational lifetime, the Pilot Plant may have to endure several hurricane- and sub-hurricane-force storms. As a matter of safety and practicality, the Pilot Plant will be designed to survive a 100-year storm at the operational site. Since the Pilot Plant is not motile, site evacuation is not a reasonable consideration. Thus, it is imperative to design platform survival limits, with contingency plans around the worst possible situations. A contingency plan must be prepared to ensure the safety of the crew and to maintain platform integrity throughout irregular events.

The seriousness of a major storm is determined by the st ength of the storm and the durability of the platform. To endure a storm within the limits of survival, procedures necessary for preparation must be familiar to all personnel. Accordingly, a section in the safety manual and training program must be dedicated to these concerns. In addition, procedures for platform evacuation must be described in the safety manual. Training program for platform evacuation must be implemented to prepare for storms exceeding platform survival limits.

4.2 MITIGATING MEASURES

4.2.1 Considerations for a Risk Assessment Model

In compliance with DOE Executive Order 5481.1 (Safety Analysis and Review [SAR] System for DOE operations), a Risk Assessment Model will be prepared by the Pilot Plant contractor. The Risk Assessment Model will describe the probability of events that may jeopardize health or safety of the individuals affected by the plant. No single model is available or applicable which considers all aspects of Pilot Plant operations. At a minimum, the following data for platform characteristics and operational site characteristics must be compiled in order to accurately assess Pilot Plant risk potentials:

a. Platform Characteristics

(1) The operational and survival limitations of overall platform design and construction must be assessed. Several different designs and construction materials are being considered for the Pilot Plant. The operational and survival limitations of each component must be collectively examined for abilities to withstand the stresses imposed by the marine environment.

(2) The operation and maintenance hazards associated with each Pilot Plant design must be assessed and rated.

(3) The potential for a major spill of fluids stored onboard the Pilot Plant must be assessed. Of particular concern is the toxicity of the constituents and potential reaction products formed.

(4) The characteristics (e.g., boiling point, melting point) and volumes of fluids onboard must be evaluated with respect to accident potential. For example, it may be preferable to resupply the platform more frequently, rather than have large holding capacities.

b. Site Characteristics

(1) The historical meteorological conditions of the site (including wind speed and direction; precipitation; wave height; air/water temperature; and tropical cyclone or hurricane path, duration and strength) are critical to Pilot Plant operation and survival. Frequencies of occurrence of meteorological events at the deployment site are important for designing both minimum and maximum operational and survival limits. Prevailing wind speed and direction can be used to determine the projected travel of vapors originating from a major leak.

(2) The origin, type, frequency, and cargo of ship traffic through the region are important, as is the servicing Port Safety Index (Schneider and Lambert, 1978), for determining the potential for credible accidents and hazardous spills.

(3) Evacuation times for removal of platform personnel and the adjacent shore-based population.

(4) The frequencies of fog or variable-visibility days that may limit supply vessel loading and unloading.

(5) The hazardous spill cleanup crew response times.

(6) Adequacy of available platform protection from harassment or outside takeover.

These data must be compiled in a handbook from which a Risk Assessment Model can be developed. As a starting point the USCG has developed several methods for Marine Safety Risk Assessment that can be applied to Pilot Plant evaluations (Schneider and Lambert, 1978). This Risk Assessment Model is a fundamental component of the DOE-required SAR.

4.2.2 Traffic Control

Traffic control around the Pilot Plant is required since the platform will attract curious onlookers and fishermen. To protect these individuals and prevent them from interfering with Pilot Plant operations, approach boundaries must be established. A security buffer zone should be established around the plant to prevent access by unauthorized individuals. Knight et al. (1977) suggest that the USCG border of 500m be applied. The safe-approach radius around the Pilot Plant will depend on the area of activity associated with platform movements, safety operations, cables, and monitoring.

4.2.3 Spill Contingency Plans

In addition to the large volumes of working fluid (ammonia) necessary for Pilot Plant operation, large quantities of oil may be required during deployment of the cold-water pipe. The release of small volumes of ammonia or oil into the environment will not endanger the local population. However, if all or most of these fluids are released into the surface waters at one time, serious episodes may ensue.

In a study performed by the USCG to evaluate ammonia spills, the partitioning value (the fraction by weight that goes into solution) was estimated to be 0.6; the remaining fraction (0.4) will vaporize, rise rapidly, and be transported away from the site (EPA, 1977). In subsurface ammonia spills, the partitioning value was estimated to be 0.85 to 0.90 with no vapor liberation; however, the expected effects from instantaneous versus continuous releases of ammonia were not resolved, nor were the possibilities of underwater explosions determined (EPA, 1977).

An ammonia and oil spill contingency plan should be prepared specifically for the Pilot Plant platform and site. The spill contingency plan should contain the following information:

- Notification list and telephone numbers of applicable government agencies

- List of spill cleanup companies including:

  - Emergency phone number of company and principal contact within the company

  - Main office location and phone numbers of branch offices

  - Emergency response radius to the site

  - Number of permanent employees and degrees of expertise

  - Spill contractor reliability, including training programs of employees and the number of years in operation

  - Inventory of available materials and equipment at manned locations of spill contractors

- Spill cleanup preparedness drills

Data from dispersion studies performed in advance would be useful to predict the speed, direction, and dispersion of the released materials at various water depths. Existing models may be modified to adjust to different characteristics of the released materials. Air transport models may be prepared to estimate expected transport of ammonia vapors formed during a large spill.

Section 5
RELATIONSHIP TO INTERNATIONAL, FEDERAL, AND STATE PLANS AND POLICIES

Pilot Plant deployment and operation will be influenced by various Federal and State regulations. Since the deployment site has not been selected and the Pilot Plant may be situated in either Federal or State jurisdictional areas, many legal issues remain unresolved. In addition, Pilot Plant development will require the resolution of several international, safety, and health issues. Within this section, the international, Federal, and State legal, health, and safety policies pertinent to the Pilot Plant are presented.

5.1 LEGAL CONSIDERATIONS

The intent of this discussion is to present an overview of the complex interworking of the laws which will affect the Pilot Plant. This overview is drawn principally from Sands (1980) and Knight et al. (1977, 1978). Sands (1980) summarized the international, Federal, and State legal, health, and safety policies pertinent to the siting and operation of OTEC platforms. Knight (1977) presented a comprehensive review of the legal, political, and institutional aspects of OTEC (under the auspices of the American Society of International Law). Knight (1978) discussed specific problems that have emerged in the development and demonstration of OTEC plants.

5.1.1 Jurisdictional Limits

International practice divides ocean jurisdiction outside internal waters into three areas: (1) the territorial seas, (2) the exclusive Economic Resource Zone (ERZ), and (3) the high seas (Knight et al., 1977). The United States presently claims 12 nmi as the limit of its territorial sea. State jurisdiction applies to the first 3 nmi at all candidate sites except Puerto Rico; Puerto Rico claims juridiction out to 10.8 nmi from its shores. Federal jurisdiction applies to the remaining area between State and U.S. limits (Knight et al., 1977).

The United States has established an ERZ extending from the baseline (from which the territorial sea is measured) to 200 nmi offshore. Within the ERZ the United States has sovereign rights over living and non-living resource uses, including such energy-producing activities as OTEC. There is, however, a duty to accommodate other legitimate uses of the ERZ, such as navigation and the laying and use of cables or pipelines. The United States, in unilaterally declaring a 200-nmi ERZ, may extend coastal State territorial seas to 12 nmi, thereby creating uncertainty as to State's rights over various acquired zones (Nanda, 1979).

The Pilot Plant will operate in either the territorial sea of the adjacent coastal state or in the United States ERZ, using surface and subsurface waters and the seabed. Figures 5-1 through 5-4 illustrate the potential siting locations for the Pilot Plant in relation to jurisdictional boundaries at each of the candidate sites. A moored or Bottom-Resting Tower Pilot Plant could potentially be located within State waters at each of the candidate sites except Key West. The Pilot Plant will not be located on the high seas or in the territory of foreign countries. The proximity of Cuba's jurisdictional limit to a Pilot Plant located off Key West, Florida will determine the extent of international legal considerations for Pilot Plant deployment and operation.

5.1.2 State Issues

Under the Submerged Lands Act Congress gave the States title and ownership of land and resources on the adjacent sea floor seaward to the territorial limit. However, the authority for navigation, flood control, and production of power was maintained under Federal control (Nanda, 1979). The Outer Continental Shelf Lands Act implemented the 1945 Truman Proclamation, and provides for (among other applications) the application of civil and criminal law of the coastal State to activities on the seabed of the Outer Continental Shelf (OCS), extending to artificial islands and fixed structures.

Coastal States have continued to claim a strong involvement in development of their coastal areas. In the recent case of United States vs. Maine, the Supreme Court affirmed its earlier decision that the Federal government had

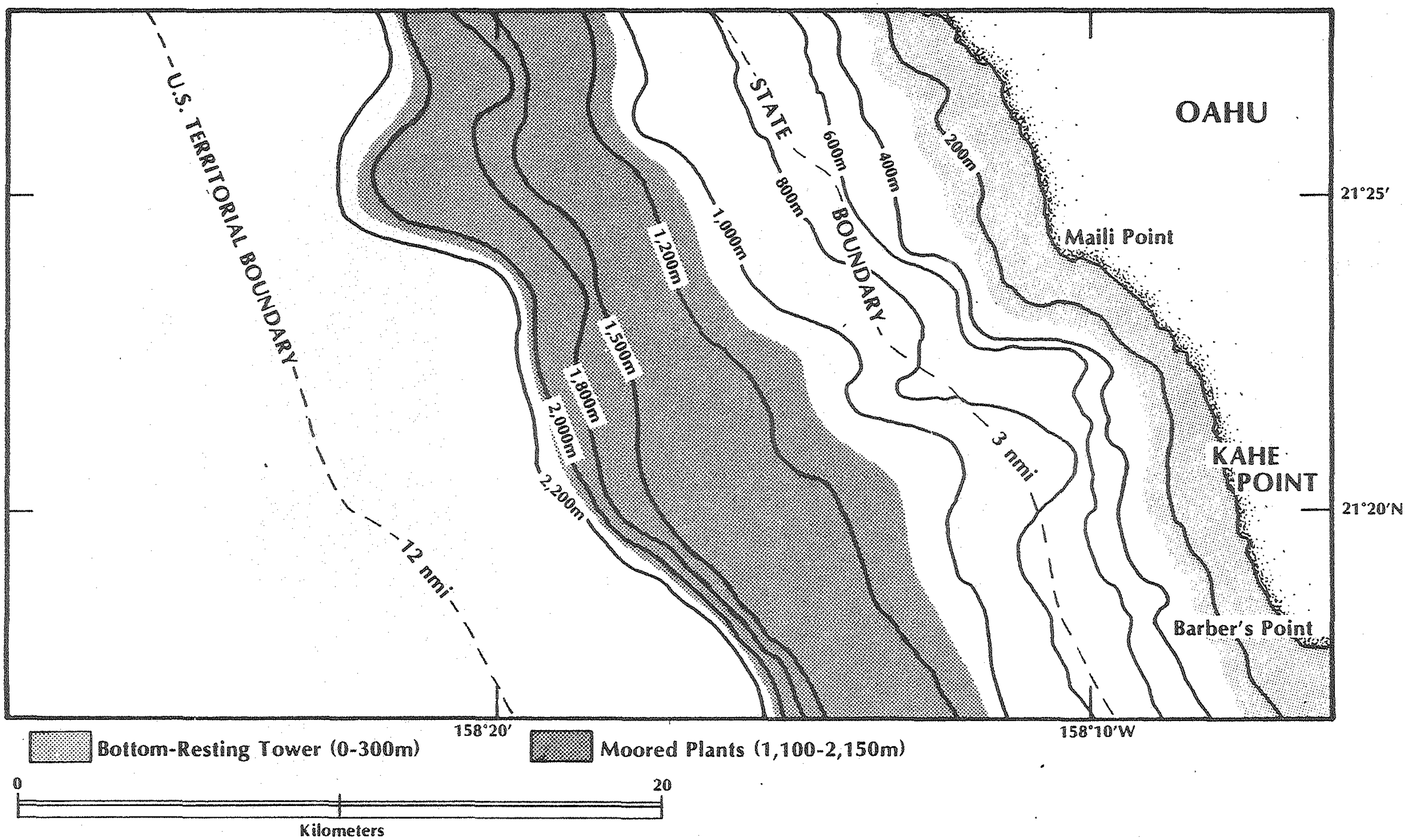


Figure 5-1. Jurisidictional Boundaries at Kahe Point, Oahu

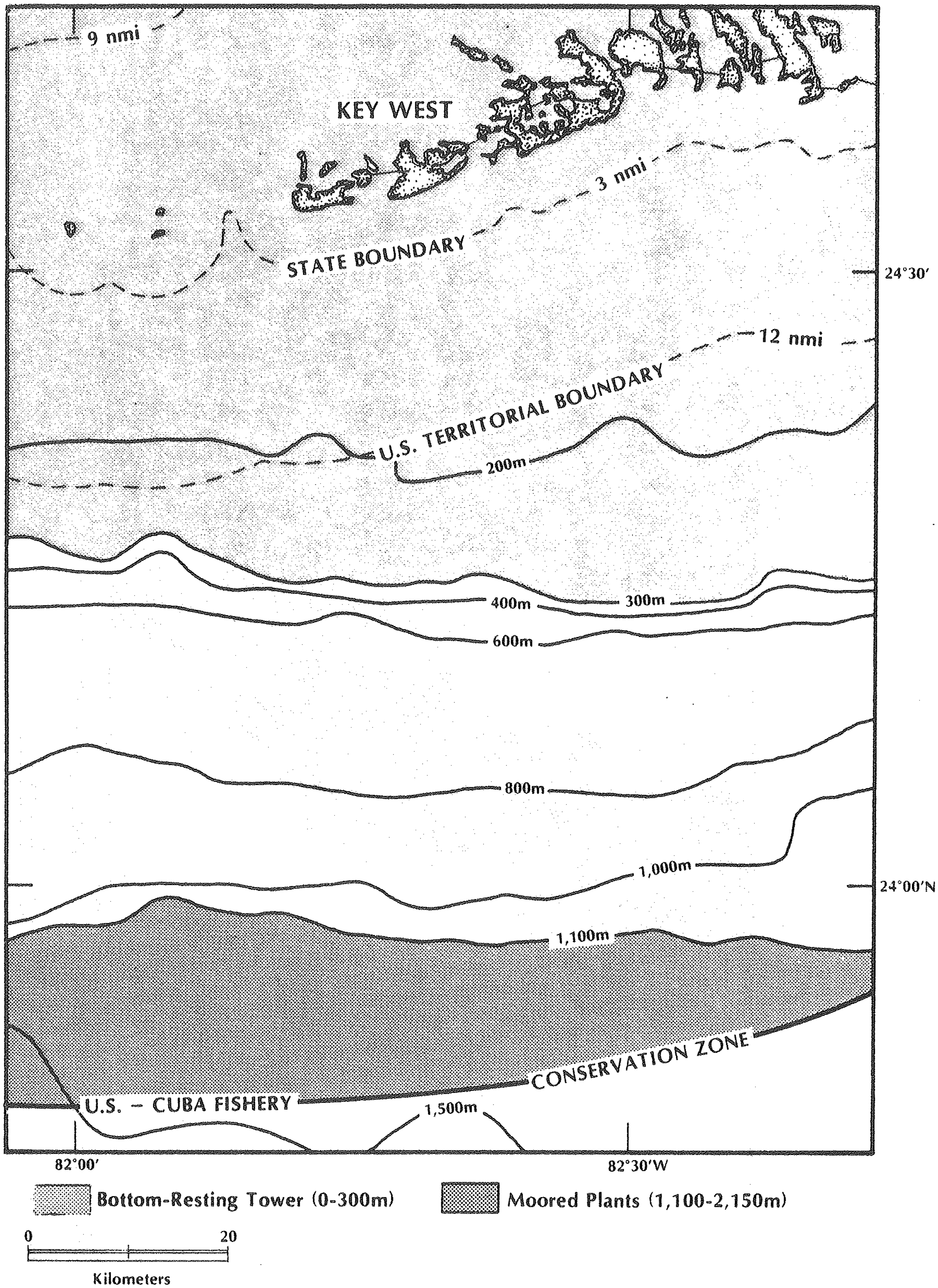


Figure 5-2. Jurisdictional Boundaries at Key West, Florida

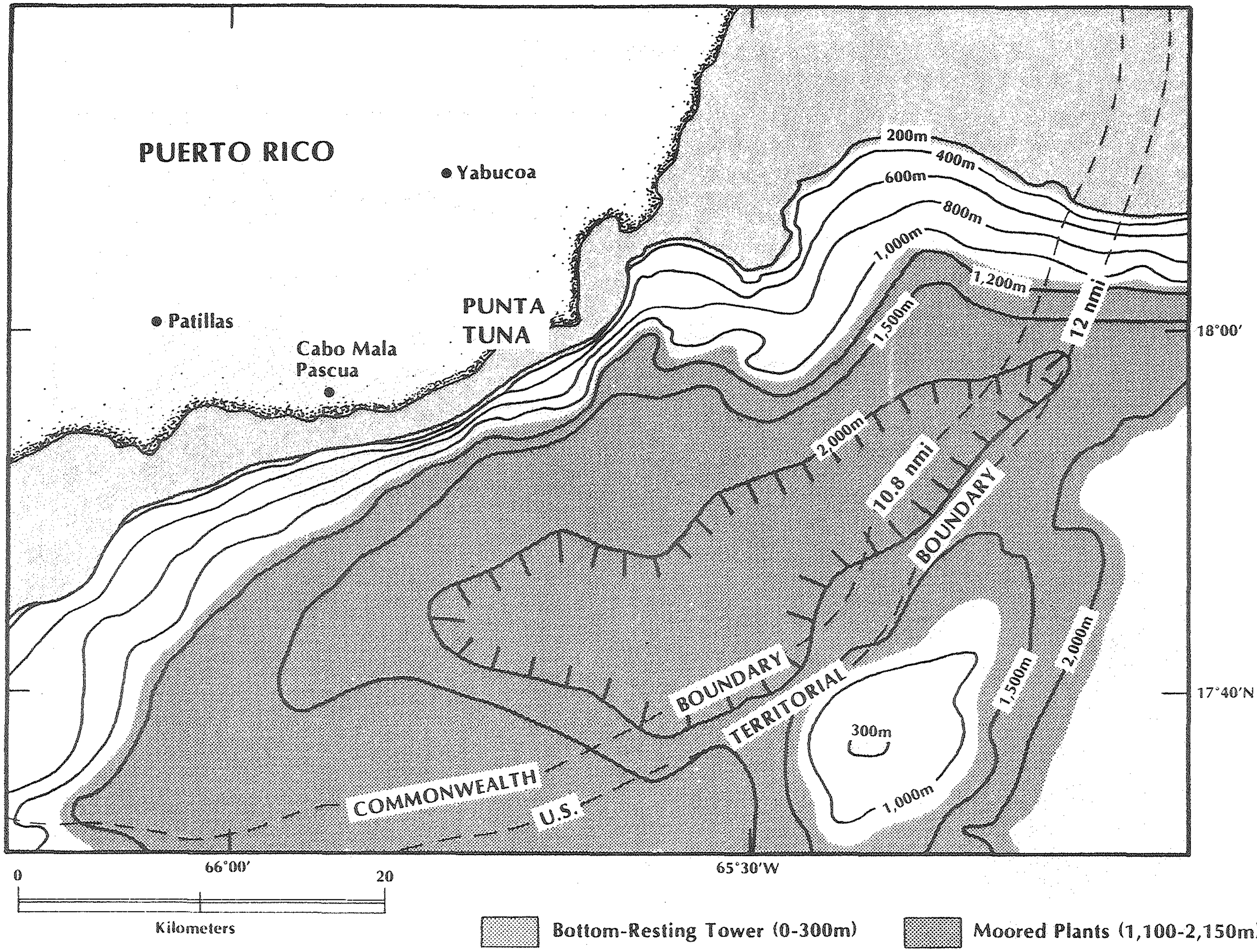


Figure 5-3. Jurisdictional Boundaries at Punta Tuna, Puerto Rico

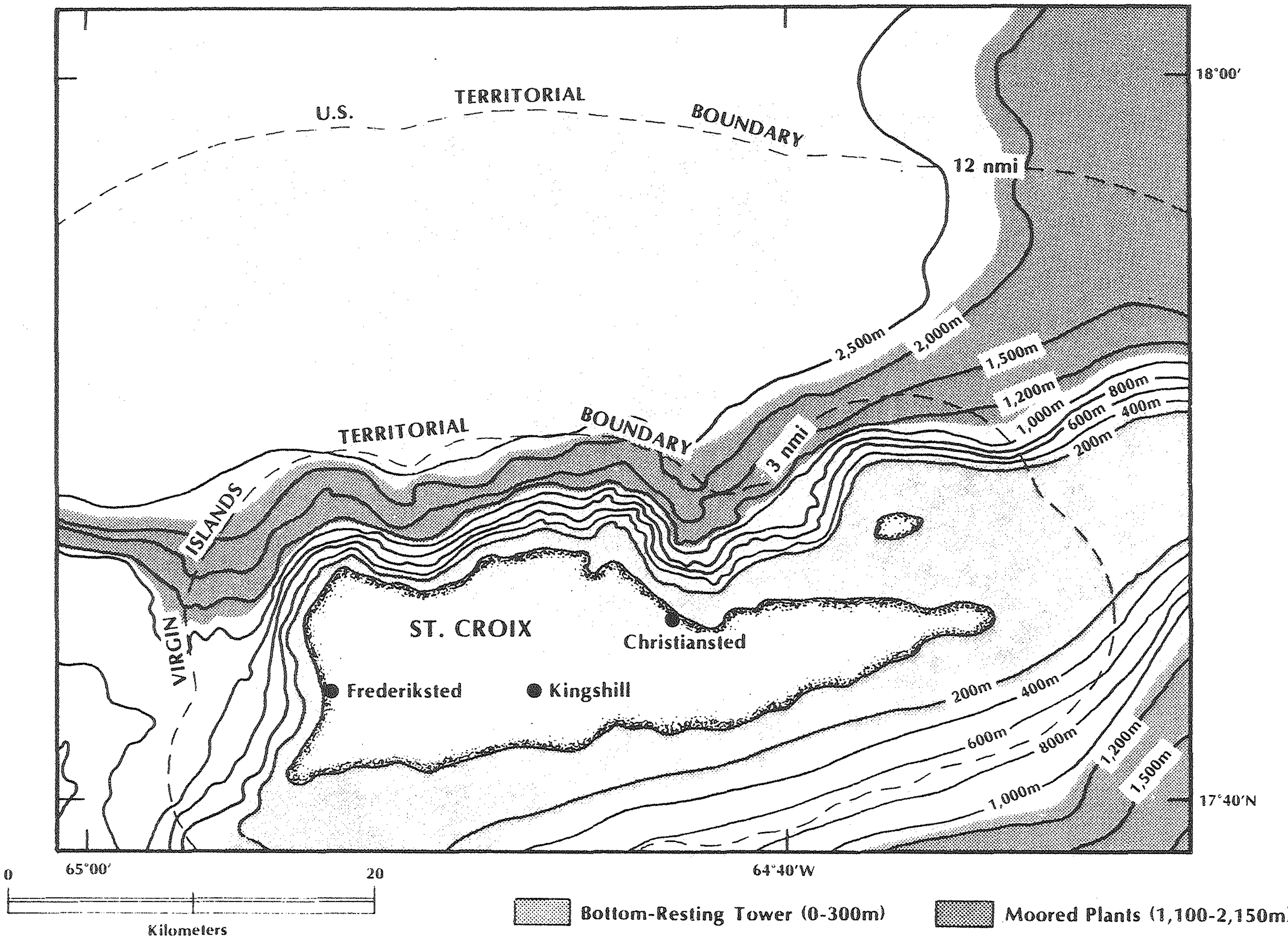


Figure 5-4. Jurisdictional Boundaries at Saint Croix, Virgin Islands

paramount rights in waters beyond the territorial seas (Nanda, 1979). The case of United States vs. California, in 1965, provided a determination of the Federal/State of California authority over submerged lands, mineral rights within inland waters, and the fixing of seaward territorial boundaries. However, questions still exist as to Federal paramount rights and State interests in the marginal seas beyond 3 nmi.

Nanda (1979) reported that recent acknowledgment of the State's role in activities conducted in its waters is evident by the following developments: (1) inclusion of States' representatives on regional OCS advisory boards, (2) development of a new leasing system by the Department of the Interior to include the States' participation, and (3) 1978 amendments to the OCS Lands Act giving States a role in decisionmaking processes for leased tracts.

Other laws that specifically encourage State participation in offshore activities include the Coastal Zone Management Act of 1972 (CZMA) and the Deepwater Port Act (DPA; Nanda, 1979).

Coastal Zone Management Programs established by the CZMA have been established at all candidate Pilot Plant sites except Florida. The goals of these programs are the preservation, protection, development, and where possible, restoration and enhancement of coastal resources (DOC, 1979). Coastal zone management generally means making a rational choice among competing objectives. The 1976 CZMA amendments created a fund for the establishment of a coastal energy impact program. The CZMA will play a key role in siting the Pilot Plant in State waters.

Under the DPA the Secretary of Transportation is given the responsibility and authority to license coastal facilities that may cause large-scale environmental impacts. The Governor of the adjacent coastal State has de facto veto power over the approval of the license (Linky, 1979).

A required permit for the Pilot Plant is the National Pollutant Discharge Elimination System (NPDES), which regulates the point source discharge of warm and cold waters. Normally, these permits are distributed by the appropriate regional office of the Environmental Protection Agency. However, for platforms within State waters, the appropriate State office may have authority to issue and enforce several permits, including the NPDES permit.

5.1.3 Federal Issues

Waters beyond 3 nmi (10.8 nmi for Puerto Rico) are under jurisdiction of the Federal government. Federal issues include platform siting, licensing, and operation. In addition, sources of liability, Federal regulatory law, and criminal and private law applicable to the Pilot Plant must be identified and resolved. These issues are described in the following paragraphs.

5.1.3.1 Licensing - The Federal agencies involved in Pilot Plant licensing are listed in Table 5-1. The regulations of each agency must be addressed prior to deployment of the Pilot Plant. Failure to comply with all specifications will result in denial of appropriate permits or approvals.

Federal regulations will ensure that the Pilot Plant does not (1) cause significant adverse environmental impacts, (2) endanger the health and safety of the operating crew or adjacent population, or (3) conflict with established or proposed site uses. Federal legislation, either existing or in draft form, which will significantly influence Pilot Plant development includes:

- The OTEC Act of 1980 (Public Law 96-320)
- The OTEC Research, Development, and Demonstration Act (Public Law 96-310)
- The Marine Protection, Research, and Sanctuaries Act (MPRSA)
- The National Environmental Policy Act of 1969 (NEPA)
- The Federal Water Pollution Control Act (FWPCA)
- The Clean Water Act

TABLE 5-1
FEDERAL AGENCIES INVOLVED IN OTEC LICENSING

AGENCY	AREA OF RESPONSIBILITY	LEGISLATION	RESOLUTION
Army Corps of Engineers	Implantation of mooring equipment	River & Harbor Act (1899)	Petition Corps of Engineers for approval
	Dredging to implant positioning equipment	Marine Protection, Research & Sanctuaries Act (1972) Federal Water Pollution Control Act (1972)	Petition Corps of Engineers and Environmental Protection Agency
	Siting	River & Harbor Act (1899)	Petition Corps of Engineers for approval
Department of Transportation ●U. S. Coast Guard	Enforcement of all Federal Laws on navigable waters	General Statutory Authority	Follow existing published guidelines and request approval for others
	Safety and health	General Statutory Authority	As above
	Navigation aids for safety	General Statutory Authority	As above
	Plant manufacture and construction	Section 395(a), Title 46 U. S. Code and others	Construction, inspection and approval by USCG and American Bureau of Shipping (also see Safety and Health, Section 5)
	Siting and emergency preparedness: Procedures Siting	Coast Guard is empowered to prescribe rules and regulations for vessel safety inspection and certification	Request/review applicable USCG documents and petition for approval
	Operation: Dangerous cargo Manning Sewage treatment	As above	As above
●Federal Aviation Administration	Heliport licensing	See Safety/Health Section 5	See Safety/Health Section 5
Environmental Protection Agency	Point source discharge	Federal Water Pollution Control Act (1972)/ Clean Water Act and Amendments (1977)	File application with EPA Regional Administrator of the Region for a National Pollutant Discharge Elimination System (NPDES) permit to discharge
	Hazardous substance control	Federal Water Pollution Control Act (1972)	Develop control plan for substance, develop spill contingency plan and submit to EPA
	Ocean disposal of materials	Marine Protection, Research and Sanctuaries Act (1972)	Request approval from EPA Regional Administrator
Department of Energy	The funding agency must prepare an Environmental Impact Assessment/Statement	National Environmental Policy Act 1969	Environmental Impact Assessment and Statement (if required)
Department of Defense	Siting	Congress has delegated responsibility to restrict use of seabed, waters and air space of the territorial sea, contiguous zone and outer continental shelf	Approval required by Deputy Asst. Secretary of Defense only if site is in a defensive sea area.
Department of Interior ●Bureau of Sport Fisheries and Wildlife	Jurisdiction over conservation, development, and management of fish and wildlife resources	Not applicable	Will be involved in NEPA Environmental Impact Evaluation
●U. S. Geological Survey	Jurisdiction over Federal lands for leasable minerals	Not applicable	Contact prior to siting to preclude use of area for mineral production
Department of Labor ●Occupational Safety and Health Administration	Enforce occupational Safety and Health Standards	Occupational Safety and Health Act of 1970	See Safety/Health Section 5
Department of Commerce	Siting	Marine Protection, Research, and Sanctuaries Act (1972)	Request approval
●National Oceanic and Atmospheric Administration	Enironmental Monitoring and Research	National Ocean Pollution Research Development Monitoring Planning Act of 1978	Interagency agreement with EPA

Source: Summarized from Knight et al., 1977

The OTEC Act of 1980 (Public Law 96-320) will have a significant influence on OTEC development. This widesweeping legislation will prohibit any person, whether or not a U.S. citizen, from engaging in the ownership, construction, or operation of an OTEC facility standing on or moored to the Continental Shelf beyond the U.S. territorial sea, unless a license has been granted. In order to receive a license, a facility will have to be documented under U.S. law. The OTEC Act of 1980 designates the National Oceanic and Atmospheric Administration (NOAA) as the licensing authority, which will reduce the lead time required for receiving permits. The OTEC Act of 1980 provides a firm legal base on which to resolve many uncertainties surrounding OTEC development.

The OTEC Research, Development, and Demonstration Act (Public Law 96-310) allows for the acceleration of the OTEC research, development, and demonstration program to achieve the early commercialization of OTEC systems. The Act establishes realistic national goals for OTEC commercialization, including: (1) the demonstration of an electrical and energy product equivalent capacity of at least 100 MW by 1986, (2) the demonstration of an electrical and energy product equivalent capacity of at least 500 MW by 1989, (3) the reduction of the average cost of an electricity and energy product equivalent produced by installed OTEC systems to a level competitive with conventional energy sources by 1993, and (4) a national goal of an electrical and energy product equivalent capacity of 10,000 MW by 1999.

The OTEC Research, Development, and Demonstration Act requires that the DOE estabish an aggressive demonstration program to meet these goals. The Secretary of Energy is required to transmit to Congress by 1983 a comprehensive plan and program for the conduct of the mandated research, development, and demonstration activities. He is required to initiate a program to design, construct, and operate facilities of sufficient size to demonstrate the technical and economic feasibility of utilizing the various forms of OTEC to displace nonrenewable fuels.

To facilitate development of a strong industrial basis for commercialization, the OTEC Research, Development, and Demonstration Act states that at least two independent, parallel demonstration projects shall be competitively selected to achieve the program goals.

Title III of MPRSA allows the Secretary of Commerce to designate marine sanctuaries in order to preserve their conservational, recreational, ecological, or aesthetic values. Marine sanctuaries near potential Pilot Plant sites must be identified and avoided.

NEPA requires the preparation of an Environmental Assessment (EA) or an Environmental Impact Statement (EIS) to consider the environmental consequences of all federally funded activities prior to the implementation of the proposed action. An EA is prepared to provide sufficient data and analysis to determine whether an EIS or a negative declaration (finding of no significant impact) is required. An EIS analyzes and resolves environmental issues associated with the proposed action. Involvement of the EA/EIS contractor early in the Pilot Plant design phase is important for reducing or mitigating potential adverse environmental impacts.

The FWPCA, as amended, established the National Pollutant Discharge Elimination System (NPDES) to regulate point-source dicharges to surface waters. An NPDES permit, required prior to Pilot Plant operation, will establish effluent guidelines based on toxicity data from representative oceanic organisms. The effluent guidelines for the Pilot Plant will be established by EPA.

In setting permit limits, EPA personnel may consider: (1) technology-based permit limits which apply at the discharge point, (2) water quality standards, (3) a discharge limitation based on toxicity data, or (4) use of the steam-electric industry effluent guidelines for the basis of an OTEC permit (DOE, 1979c). In developing the best available technology to control the release of certain effluents, EPA states that greater emphasis will be placed on toxicity-based limits, rather than on technology-based limits, particularly if the latter limits are inadequate for toxicity elimination (DOE, 1979c). There are no established toxicity guidelines for organisms which occupy the OTEC siting regions.

The Clean Water Act and Amendments (1977), Section 316(b), govern the cooling water intake structures for any facility which withdraws large volumes of cooling waters. Section 316(b) provides a means to demonstrate to EPA that the design of the intake represents the best available technology for minimizing adverse environmental impacts.

5.1.3.2 Liability - Gas and oil exploration and exploitation on the Continental Shelf were the first major technological advances into the ocean and expanded ocean use from transportation and fishing. It also created substantial problems with liability issues. Sources of liability for failure of the Pilot Plant to comply with existing or customized standards or regulations may be resolved through Federal regulatory law, U.S. civil and criminal law, U.S. maritime law, State law, and (least likely) international law. A more detailed discussion is given by Knight et al. (1977).

5.1.3.3 Federal Regulatory Law - Federal regulatory law furthers public safety, health, and welfare. Activities such as construction, layout and design, financing, initial and periodic certification and inspection, operational processes, systems safety, customs, navigation, and environmental controls fall within the Federal regulatory regime.

5.1.3.4 Criminal and Private Law - Tort, contract, and similar legal issues will likely be resolved by civil and criminal law in the Federal courts. However, Nyhart (1979) suggests that the extent to which Federal criminal law will apply to OTEC platforms located within the ERZ must be resolved. In terms of private law, there are two bodies of law available to OTEC policy planners: the maritime law the law of the adjacent State (Nyhart 1979). Maritime law is designed to respond to problems with legal solutions arising from the conduct of the sea-transport industry. Nyhart recommends that admiralty and maritime law be applied to OTEC platforms, with State law serving as a supplement only when necessary.

5.2 HEALTH AND SAFETY REGULATIONS

In March 1979 the DOE Order Number 5481.1, Safety Analysis and Review System for DOE Operations, established the uniform requirement to evaluate and review the safety of DOE operations and report the findings in a Safety Analysis Report (SAR). The SAR draft guidelines have been published to ensure a uniform and systematic approach to safety evaluation (DOE, 1979d). A SAR must be prepared for the OTEC Pilot Plant. Further details of the SAR are given in Subsection 5.2.1.2.

Various operational procedures are inherent for most ocean-going vessels. The health and safety aspects associated with these operational procedures, but related specifically to the Pilot Plant, are outlined in Subsection 5.2.2. In defining precautions, it was necessary to make certain assumptions (e.g., crew size and composition, system configuration). Some requirements, either between regulating agencies or within one agency, may overlap; however, this has been taken into account and requirements will be acceptable in all cases.

5.2.1 Safety Analysis Report

A brief overview is presented on the purpose, scope, basic document requirements, and updating schedule of the SAR (DOE, 1979d).

5.2.1.1 Purpose - The information contained in the SAR documents the safety analyses performed for the operation in accordance with DOE objectives. The objectives of the preparation and review of the SAR are to: (1) systematically identify potential hazards, (2) analyze potential impacts, (3) describe reasonable measures to eliminate, control, or mitigate the identified hazards, and (4) serve as a documentation of DOE management authorization based on an objective safety analysis assessment.

The SAR is completed in two phases: a preliminary SAR during the design phase and a final SAR submitted prior to operation.

5.2.1.2 Scope - The DOE is responsible for implementing the SAR guidelines; the analyses must be conducted by the organization with direct operating responsibilities. SAR must be completed for all health, safety, or environmental protection activities for which DOE has assumed responsibility, with the exception of: (1) safety of nuclear weapon designs, (2) construction-related work activities, and (3) operations with hazards of a type and magnitude routinely encountered and/or accepted by the public.

5.2.1.3 Basic SAR Requirements - An SAR must address the following topics: (1) description and evaluation of the site, (2) description of the facility and/or operations, (3) design criteria for systems, components, and structures, (4) identification of hazards, (5) physical design features and administrative controls providing for prevention and mitigation of potential accidents, (6) potential accidents, including those resulting from natural phenomena, (7) probability of occurrence and predicted consequences of accidents (expressed in qualitative or quantitative terms), (8) normal and emergency operating procedures to be used, and operational limitations.

5.2.1.4 Updating - The alteration or significant modification of a facility requires the update to the Safety Analyses Documentation.

5.2.2 General Safety Considerations

5.2.2.1 Platform Considerations - There are risk differences between moored, Bottom-Resting Tower, and Land-Based Pilot Plant designs; however, the hazards are generally the same. Due to the innovative nature of the moored and Bottom-Resting Tower designs, the nearest parallel that can be made is to the risks and safety of offshore drilling platforms. By reviewing drilling platform accidents, it is apparent that careful consideration and planning are needed for all eventualities.

Safety considerations and responsibilities for a Land-Based Pilot Plant, with the exception of marine/vessel considerations, should not differ from an offshore plant. The personnel safety requirements will be totally under OSHA authority. Other certifying authorities for equipment and plant safety should remain the same (i.e., National Fire Protection Association [NFPA]). The U.S.

Army Corps of Engineers (CE) will have involvement as to plant siting safety and safe construction of outflows, berms, and breakwaters, as required. Additionally, State and local authority and regulation may take precedence over Federal authority (i.e., in California, the Cal-OSHA act takes precedence over Federal OSHA authority).

a. **Platform Classification** - The preoperational platform (OTEC-1) is classified as an "Oceanographic Research Vessel" under Title 46, Subchapter U; however, the Pilot Plant may be classified differently. Current regulations such as the USCG's "Requirements for Mobile Offshore Drilling Units" or "Rules and Regulations for Cargo and Miscellaneous Vessels" may be applied or rewritten to accommodate the Pilot Plant (USCG, 1973, 1978). The USCG is currently proposing rules for "Unregulated Hazardous Working Conditions on the Outer Continental Shelf" (USCG, 1979). The rulemaking efforts will significantly impact platform and personnel safety.

b. **Regulating Agencies** - The following list of U.S. government agencies will be involved in regulatory or advisory capacities during Pilot Plant deployment and operation. In many cases a specific agency's recommendations have been incorporated into a senior agency's requirement.

- Army Corps of Engineers (CE)
- Department of Commerce
  - National Oceanic and Atmospheric Administration
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Interior (DOI)
  - U.S. Geological Survey (USGS)
  - Bureau of Sport Fisheries and Wildlife (BSFW)
- Department of Labor (DOL)
  - Occupational Safety and Health Administration (OSHA)
- Department of Transportation (DOT)
  - Federal Aviation Administration (FAA)
  - U.S. Coast Guard (USCG)
- Environmental Protection Agency (EPA)
- Federal Communications Commission (FCC)

- Individual State or Locality Regulations (dependent on Pilot Plant geographical location)
  - U.S. Navy Military Specifications (MILSPEC)
  - The United States Code (USC), as it governs the conduct of and is referenced by any of the above agencies.

Other non-Governmental organizations that may be involved in standardization are listed below. These organizations may offer advice or guidelines, but will not issue permits:

- American Bureau of Shipping (ABS)
- American Boat and Yacht Council, Inc. (ABYC)
- American National Standards Institute (ANSI)
- American Society of Mechanical Engineers (ASME)
- American Society of Testing and Materials (ASTM)
- American Welding Society (AWS)
- Compressed Gas Association (CGA)
- Fluid Controls Institute, Inc.
- Manufacturers' Standardization Society of the Valve and Fittings Industry (MSS)
- Marine Department, Underwriters' Laboratories, Inc.
- National Fire Protection Association (NFPA)
- National Fluid Power Association (NFPA)
- Tubular Exchanger Manufacturers' Association (TEMA)
- Underwriters' Laboratories Inc. (UL)

The contractor(s) constructing the Pilot Plant must be familiar with all publications pertinent to the regulation of marine operations and those which specifically apply to OTEC systems. The regulatory agencies listed above continually update and publish regulations. Government agencies publish updates, when appropriate, in the Federal Register.

c. <u>Hospital</u> - As outlined in Vessel Rules and Regulations (USCG-257, Subpart 92.20, Section 35), the Pilot Plant must be provided with a hospital. The hospital must have at least one berth for every 12 members of the crew. Due to the size and inherent hazards of the equipment on the

Pilot Plant, the hospital should be prepared to handle major injury cases. It must also be able to treat acute respiratory problems, burns, and diving diseases. Surgical and treatment (examination) rooms should be provided, as outlined in USCG-257. Hospital staffs, whether medical or paramedical, must be adequately trained to cope with anticipated problems. If paramedical personnel work independent of physicians, they must carry Merchant Marine Documentation (Licensing of Personnel USCG-191, Subpart 10.25, Sections 9 and 11). A physician qualified in the pertinent problems must be retained on 24-hour call to advise and, if required, be available to treat emergency cases. Apart from specific paramedical or medical skills required for the Pilot Plant, medical and paramedical personnel should (1) be familiar with general operations of OTEC systems, (2) be capable of defining hazards before they cause injury, and (3) contribute to the development and implementation of additional safety procedures.

To implement vessel safety programs, aside from those established or required by the USCG, a system safety analysis should be established for each OTEC platform. A report entitled "System Safety Analysis of a Commercial Vessel" is an excellent guideline (Cheaney and Coyle, 1977).

5.2.2.2 **Personnel** - There are no universally applicable regulations concerning personnel safety and training requirements for offshore operations. The USGS administers some training procedures for offshore drilling operations. OSHA covers some offshore industrial safety, and the USCG covers marine safety.

The USCG bimonthly publication, "Proceedings of the Marine Safety Council, USCG-129", documents the need for adequate training programs and lists the dates and location of such programs, with outlines of training requirements and procedures. The Pilot Plant will present some unique personnel risks and safety requirements. A careful evaluation of all problems will facilitate formulation of a composite safety training program.

a. Operational Crew - The Pilot Plant will be a production-intensive facility. Major tasks will be stationkeeping (for the moored designs) and marine platform maintenance. Requirements are presented in IMCO (1978) for the training of seafaring personnel.

All personnel on the Pilot Plant must have a thorough understanding of the personnel risks of at-sea operations. Correct action by personnel must be strictly adhered to and fully understood for the following typical marine occurrences:

- Man overboard
- Firefighting
- Collision
- Severe weather
- Grounding
- Flooding
- Acts of war or sabotage
- Lifeboat use
- Lifejacket use
- Respirator use
- Weather-related difficulties
- First aid
- Diver accident aid
- Any combination of the above

It should be understood that the dividing line between marine platform and personnel safety and risks is very fine. Often the events which cause a vessel accident involve personnel errors. Therefore, an integrated training program of marine safety must be established for all OTEC personnel, and continual drills should be conducted per USCG regulations (USCG 257). To facilitate daily routine operations, detailed procedure manuals must be prepared, defining individual responsibilities for operation, safety, or emergency activities.

b. Divers - Both offshore and Land-Based Pilot Plants will have intensive underwater repair and inspection requirements (Brown and Root Development Inc., 1980). This effort will be performed by either divers, small manned submarines, or remotely operated vehicles (ROV). Generally, this type of inspection and repair work is routine in the o fshore oil industry and safety aspects are well regulated (U.S. Department of Labor, 1977; American Bureau of Shipping, 1978; Pritzlaff, 1979). Some degree of hazard to divers and submersibles may exist with underwater electrical cables (National Academy of Sciences, 1976; Mole, 1978). Based on this and the additional routine underwater hazards, a System Safety Analysis and Safety Procedures Plan must be formulated for submersible and diving operations, in conjunction with the USCG, OSHA, American Bureau of Shipping, and the Marine Technology Society.

5.2.2.3 Process System - A variety of chemical systems and subsystems will be present onboard the Pilot Plant. The various chemical systems, their potential hazards, and the required safety equipment are summarized in Table 5-2 and described in detail in the following paragraphs.

a. Chemical Systems - There have been a number of chemicals discussed in OTEC literature; however, this discussion is limited to those chemicals likely to be carried in bulk aboard the Pilot Plant: anhydrous ammonia, chlorine, and sodium hydroxide. Personnel with responsibility for these chemicals must be familiar with USCG-388, "Chemical Data Guide".

Chlorine will likely be generated as needed on the Pilot Plant, rather than stored in bulk quantities, since ammonia will be stored on the platform and these two chemicals will explode if combined (NFPA, 1978). The relative location of each chemical must be carefully considered. The potential release of ammonia into the atmosphere must be evaluated. The minimum safety distances from residential buildings are listed in Table 5-3.

The following listed data are pertinent to anhydrous ammonia, chlorine, and sodium hydroxide. Recommended specification precautions and procedures will be outlined in pertinent process systems discussions.

TABLE 5-2
POTENTIAL HAZARDS SUMMARY

Agent	Source	Physical State	Handling Procedures	Crew Hazard Level	OTEC Hazard Level	Type of Hazard	Neutralizing Agent	Hazard Maintenance	Comments
Anhydrous Ammonia	1	1,2	1,2,3	1-2	3	1,2,3	Water	1,2,3,4,5,6	Protective clothing and breathing equipment may be required
Carbon Dioxide	3	2	6	3	4	4	Air circulation	1	Breathing equipment may be required; diver hazard
Chlorine	3	1,2	1,2,3,5,6	1-2	3	3,7	Ventilation	1,2,3,4,5,6	Protective clothing and breathing equipment may be required
Electrical connections	2,3	--	3	1	4	6	Insulation	2,3,4,5	Protective clothing and devices required
Lubricating oils	3	1	2,3	3-4	3	1	Containment boom-absorbents	3,4,5,6	Spill hazard
Oxygen	5	1,2,4	1,2,3,6	1	1-2	2	Ventilation	1,2,4,5,6	Supports combustion

Source	Physical State	Handling Procedure	Crew Hazard Level	OTEC Hazard Level	Type of Hazard	Hazard-Level Maintenance
1. Working fluid	1. Liquid	1. Containment	1. High	1. High	1. Flammable	1. Circulation
2. Process product	2. Gas	2. Storage	2. Medium	2. Medium	2. Oxidant	2. Sensor monitoring
3. Process requirement	3. Solid	3. Transfer	3. Low	3. Low	3. Toxic/ irritant	3. Visual monitoring
4. Fuel	4. Cryogen	4. Shipment	4. None	4. None	4. Sufficant	4. Special precaution
5. Support requirement		5. Controlled application			5. Explosive	5. Personnel training
		6. Ventilation			6. Shock	6. Containment
					7. Corrosive	

Note: Other hazardous materials such as acetylene, paints and thinners, etc., will be carried aboard; however, they have not been listed above due to their being carried in minimal quantities, and their hazards should be readily discernible.

Source: Adapted from Mallinckrodt Inc. (1976)

TABLE 5-3
SAFE LOCATION OF AMMONIA CONTAINERS

	Minimum Distances (m) from Container to:		
Nominal Capacity of Container (m^3)	Line of Adjoining Property	Place of Public Assembly	Institution Occupancy
1.9 to 7.6	7.6	46	76
7.6 to 114	15.0	91	152
114 to 379	15.0	137	229
379 or greater	15.0	183	305

Source: EPA, 1977

(1) <u>Anhydrous Ammonia</u> (Mallinckrodt Inc., 1976) - Ammonia, in high concentrations, is an irritating and corrosive compound that can damage eyes, mucous membranes, and skin; and (on inhalation) inhibit respiration. Upon removal from an ammonia atmosphere, an exposed individual usually recovers in a few days; in extreme cases, eye damage can be permanent. Severe lung exposures can be fatal.

- Incompatible with mercury, halogens, calcium hypochlorite, hydrogen fluoride

- Physical state: gas

- Solubility: extremely high, greater than 500 g $liter^{-1}$ water

- Boiling Point: -33.33°C (-28°F)

- Vapor Density: 0.6 units (ratio of volume of vapor or gas to equal volume of air)

- Ignition Temperature: 651.11°C (1,204°F)

- Flammability limits (percent volume in air): Minimum concentration at which explosion cannot occur: 16%. Maximum concentration at which explosion cannot occur: 25%.

- Hazard Rating

  - Health: Short exposures could cause serious temporary or residual injury, even if promptly treated.

  - Flammability: Must be preheated before ignition can occur.

  - Type of Hazard: Flammable material, gas, or vapor rapidly toxic or extremely irritating on exposure for a short time or to low concentration

  - Life Hazard: Primary skin irritant, can cause severe eruptions or burns. Respiratory threshold limit value = 50 ppm

  - Precautions: Keep away from heat, sparks, open flame; avoid spilling, contacting skin, eyes, or clothing. May require gloves, goggles, aprons, etc. Use adequate ventilation, avoid breathing fumes, mists, gases or vapors. Personal respiratory protection may be required

  - Fire Extinguishing Method: water spray

(2) Chlorine (Mallinckrodt Inc., 1976) - Chlorine is a product carried in large tonnages, and is fairly typical of the more hazardous gas cargos. When sufficient concentration of chlorine gas is present, it will irritate the mucous membranes, the respiratory system, and the skin. Large amounts cause irritation of the eyes, coughing, and labored breathing. Symptoms of exposure to high concentrations are gagging and vomiting, followed by difficult breathing. In extreme cases the difficulty of breathing may result in death by suffocation. Liquid chlorine in contact with the eyes or skin will cause local irritation and/or burns.

- Incompatible with ammonia, acetylene, butadiene, benzene and other petroleum fractions, hydrogen, sodium carbides, turpentine, and finely divided powdered metals

- Physical state: gas

- Solubility: Fairly high, nearly 50 g $liter^{-1}$ water

- Boiling point: -34.4°C (-30°F)

- Vapor density: 2.5 units

- Type of hazard: Gas or vapor highly toxic or extremely irritating on exposure for short time or to low concentrations. Oxidizing material: contact with other combustible may cause fire. Irritant, sensitizer, corrosive; causes skin irritation or burn.

- Hazard rating: Short exposure could cause serious, temporary, or residual injury even if promptly treated; not flammable

- Reactivity: Normally stable except in combination with certain other materials or at elevated temperatures and pressures

- Life hazard: Primary skin irritants can cause burns and skin eruptions. The respiratory threshold limit value = 1 ppm.

- Precautions: Not to be handled unless safety precautions are understood. Use adequate ventilation, avoid breathing fumes, mists, gases, or vapors. Personal respiratory protection may be required. Avoid contact with acids, combustibles, and moisture.

● <u>Sodium Hydroxide</u> (Mallinkrodt, Inc., 1976) - Sodium hydroxide (NaOH) reacts vigorously when in contact with aluminum or water, giving off heat and hydrogen gas (NFPA, 1975; Sax, 1979). Sodium hydroxide is a dangerous personnel hazard and a plant hazard.. All USCG, NFPA, and OSHA precautions and procedures shall be followed.

- Physical State: Solid

- Solubility: Extremely high, greater than 500 g liter^{-1} of water

- Specific Gravity: 2.1

- Type of Hazard: Sodium hydroxide dust is hazardous when inhaled or touched. It is an irritant-sensitizer causing skin and membrane irritation and burns.

- Health Hazards: Short exposure could cause serious temporary or residual injury even if promptly treated

- Reactivity Hazards: Normally stable, except in combination with certain other materials or at elevated temperatures and pressures

- Skin Hazards: Primary skin irritant, can cause severe eruptions and burns

- Oral Hazard: Moderately toxic

- Precautions: Avoid spilling, contacting skin, eyes, and clothing. May require gloves, goggles, aprons, etc. Use adequate ventilation. Avoid breathing dust, fumes, mists, gases or vapors. Personal respiratory protection may be required.

The effects of a spill of these chemicals on personnel, equipment, or facilities in the immediate environment are evident; however, the effects on a condensed population downwind would, of course, be dependent on environmental factors (e.g., wind speed and direction, precipitation, and distance of the Pilot Plant from populated areas). All of these factors have a possible diluting effect on the chemicals. Routine reports of population evacuations in the immediate area of railroad-tank-car or barge spills of ammonia and chlorine are evident in the news media and other publications.

There is a need for an intensive training program specific to the hazards of the chemicals used on the Pilot Plant. The systems personnel must as a matter of course, be well versed in these hazards, as must the marine crew.

b. <u>Personnel Safety Equipment for Hazardous Chemicals</u> - Due to the hazards to personnel by various chemicals proposed for use on the Pilot Plant, careful attention must be paid to the training of personnel and the selection and use of protective clothing and respiratory equipment. Therefore, the following requirements are presented:

- An emergency air-breathing system should be incorporated into the Pilot Plant design. Emergency oxygen systems should not be used since they are expensive and difficult to maintain. Additionally, oxygen in the presence of flammable chemicals (e.g., ammonia, fuel oils) is a severe explosive hazard. The emergency air system must be maintained at certain levels of purity. The air system should be tested daily for contaminants. The compressor intakes will be outboard or upwind of any possible sources of contamination (e.g., ammonia, chlorine, engine exhausts). If the platform is fixed (e.g., Tower or Land-Based), the location of intakes may be a problem during a spill because the wind may shift. The air quality during a spill will be monitored. Large-volume tanks (air reservoirs) will provide the necessary air volume for diving and recompression chamber operation, as well as emergency breathing purposes. This system must be dedicated to breathing air only and will require compressors separate from those required for plant or ship-service (utility) air uses.

- Choice of emergency breathing devices will be regulated by USCG Equipment Lists, 160.011 gas masks, self-contained breathing apparatus, and supplied-air respirators. Breathing equipment (e.g., air supplies, gas masks) should be compatible with those chemicals or hazardous situations encountered aboard the Pilot Plant. Air breathing apparatus must be capable of connection to the divers' emergency breathing air systems.

- Protective clothing (as defined by the USCG and OSHA) must be worn when handling chemical contaminants on the Pilot Plant.

- An emergency rescue team and plan must be developed to handle chemical casualties. This team will be capable of aiding personnel injured in chemical accidents and be capable of shutting down equipment in critical situations, such as chemical spills.

Section 6
ALTERNATIVES

A discussion of the alternatives associated with deployment and operation of the OTEC Pilot Plant is important since the plant represents a permanent structure that will be on site for up to 30 years. The alternatives in the Pilot Plant Program are in the environmental and engineering categories, each considered from the point of reducing or eliminating potential environmental impacts. The environmental alternative is the selection of the deployment site. The engineering alternatives include the type of platform, choice of power cycles, design of the warm-water intake structure, and design of the discharge structure.

6.1 NO ACTION

The no-action alternative would indefinitely postpone Pilot Plant deployment and operation. The OTEC Research, Development, and Demonstration Act (Public Law 96-310) states that at least 100 MW of OTEC electrical capacity or energy product equivalent be demonstrated by 1986, and 500 MW of OTEC power be demonstrated by 1989. The goal of the Act is to achieve an OTEC electrical and energy product equivalent capacity of 10,000 MW by 1999. The Pilot Plant will serve as a subscale prototype of a large-scale commercial plant and test various heat-exchanger design components, verify submarine electrical energy transmission systems, and perform other equipment analyses. Postponement of the Pilot Plant would delay development of OTEC technology and subsequently reduce the contribution ocean thermal energy can make to the energy needs of the United States.

6.2 SITE SELECTION

Achieving maximal usage from the Pilot Plant at minimal economic cost and environmental disturbance requires selection of the optimal deployment site. The economic viability of the Pilot Plant will be enhanced if it is sited in an area having an expensive baseload-electricity market. Furthermore, costs for the Pilot Plant and submarine transmission cable can be reduced if the site is close to construction facilities, harbors, and the existing electrical grid. Environmental disturbances can be minimized by selecting a site with no ecologically sensitive or commercially important areas within range of effects, and by designing the p ant to the geological, physical, chemical, and biological characteristics of the site.

The DOE is considering Kahe Point (Oahu), Key West (Florida), Punta Tuna (Puerto Rico), and Saint Croix (Virgin Islands) as candidate sites for the OTEC Pilot Plant. These candidate sites, which are representative of the island communities where the Pilot Plant will be sited, are quite different economically and socially. Careful consideration of present populations, economies, power production capabilities and needs, and environmental characteristics of these candidate island communities will determine the optimal Pilot Plant deployment site.

6.3 PLATFORM ALTERNATIVES

The Pilot Plant may be Land-Based, situated on a Bottom-Resting Tower, or moored offshore in a Spar or Plantship configuration. Land-Based plants are restricted as to location; the availability of a cold deep-ocean resource at minimal distance from shore is required, as is an acceptable bottom topography and shore zone for cold-water pipe installation and plant construction activities. A Land-Based plant has the advantage of being a safer working environment, and more accessible to operation and maintenance crews than the offshore designs.

Moored platforms are limited to water depths between 1,000 and 2,150m. It is difficult to moor platforms in ocean areas having irregular bottom topography or shifting substrates. The Bottom-Resting Tower can be located in water up to 300m deep. Installation and maintenance of the Bottom-Resting Tower is a proven technology, as demonstrated by existing offshore oil facilities. Offshore towers should be able to be designed to operate and survive in conditions exceeding those of moored platforms.

6.4 HEAT-EXCHANGER ALTERNATIVES

The primary choice of heat-exchanger designs for the Pilot Plant is between plate-type and tube-in-shell heat exchangers. Plate-type heat exchangers are expected to be situated horizontally; therefore, the plant must have a large area reserved for the evaporators and condensers. The Land-Based Tower or Moored Plantship designs could be designed for plate-type heat exchangers. The tube-in-shell power cycle can be situated vertically or horizontally. The Spar platform design requires vertically oriented tube-in-shell heat exchangers, due to the limited amount of heat-exchanger space onboard.

The environmental differences between the two types of closed-cycle heat exchangers include differences in impingement and entrainment rates, trace-constituent release, and cleaning methods. The plate-type heat exchanger will require a smaller mesh size for the warm- and cold-water intake screens than does the tube-in-shell heat exchanger. The smaller intake-screen mesh size for plate-type heat exchangers results in a greater number of organisms being impinged and suffering 100% mortality. Some of these organisms, which would otherwise pass through the screen will be entrained through the plant and discharged back into the environment, potentially surviving. The surface area in plate-type heat exchangers is larger than in tube-in-shell heat exchangers, and implies a greater amount of trace constituents will be eroded and corroded from the power cycle and released to the environment. Heat exchanger cleaning alternatives have differences which influence the environmental effect of plant operation. Mechanical cleaning methods, only usable in tube-in-shell heat exchangers, may cause increased heat exchanger erosion rates and trace constituent release rates. Chemical cleaning methods will release biocides into the environment, which may adversely affect nontarget organisms.

6.5 INTAKE ALTERNATIVES

The engineering alternatives associated with the warm- and cold-water intakes of the Pilot Plant include intake depths, intake screen designs, and intake velocities. In order to obtain the temperature differential required for Pilot Plant operation, the warm- and cold-water intakes must be positioned near the surface and between 800 and 1,000m, respectively. The available biological data indicate that there is little difference in the vertical distribution of organisms within the upper 50m of the water column, and between 800 and 1,000m (Sullivan, 1979). Thus, the intake depth selection will not significantly influence the potential environmental impact that may result.

Although mortality rates are expected to be high, entrained organisms have a chance of survival after being discharged from the Pilot Plant. In contrast, impinged organisms will probably suffer 100% mortality. Once an organism is within the sphere of influence of the intake, its size and shape in relation to the intake-screen mesh size determines whether it will be impinged or entrained. Selection of the largest intake-screen mesh size that will allow adequate protection of the Pilot Plant power system will permit the greatest number of organisms to be entrained, rather than impinged, thereby decreasing the mortality rate due to impingement and entrainment.

Proper design of the warm- and cold-water intakes could reduce impingement rates significantly. The use of velocity caps, which produce a horizontal flow field that can be more readily sensed and avoided by fish than a vertical flow, will reduce impingement rates. Bell-shaped or multiple intake structures can reduce the intake current velocity, thus potentially enabling certain motile organisms to avoid being withdrawn along with the entrained water.

6.6 DISCHARGE STRUCTURE ALTERNATIVES

Impact assessment of the discharge involves a variety of factors, among which are plume dilution and location after near-field mixing. The evaluation of these factors must not be passive, since plume geometry and dilution are governed by the environmental characteristics of the site and the engineering criteria of the plant. Plume geometry and dilution can be controlled within specified limits by proper design of discharge configurations. The design criteria include mixed and separate discharges; the velocity, angle, and depth of discharges; and the number of discharge ports. It is not possible to consider a diffuser in the traditional sense; however, the advantages of multiport discharges should be considered.

Section 7
GLOSSARY, ABBREVIATIONS, AND REFERENCES

GLOSSARY

ABUNDANCE	Relative degree of plentifulness.
ABYSSAL PLAIN	Flat area of the ocean floor extending from the base of the Continental Rise seaward to the abyssal hills.
ABYSSAL HILLS	Submarine geomorphic features rising from the ocean basin floor at 3,000 to 6,000-m depths.
ADVECTION	The process of transport of water or of an aqueous property by the mass motion of the oceans, most typically via horizontal currents.
AESTHETICS	Pertaining to the natural beauty or attractiveness of an object or location.
AMBIENT	Pertaining to the existing conditions of the surrounding environment.
ATMOSPHERE	A unit of pressure equal to the air pressure at mean sea level, comparable to a 760-mm column of mercury, 14.7 pounds $inch^{-2}$, or 1013 millibars.
BAR SCREENS	Heavy gauge bars which prevent damage to static or traveling screens by large objects.
BATHYMETRY	Measurement of ocean depths, usually used to determine sea floor topography.
BATHYPELAGIC ZONE	The biogeographic realm of the ocean lying between depths of 1,000 and 4,000m.
BENTHOS	A category of marine organisms which live on, in, or near the bottom of the ocean.
BIOACCUMULATION	The uptake and assimilation of substances, such as heavy metals, leading to a concentration of these substances within organism tissues, blood, or body fluids.
BIOCHEMICAL OXYGEN DEMAND (BOD)	The amount of dissolved oxygen used in a specified time period (usually 5 days) during the oxidation of organic material.

BIOASSAY — Exposure of a sample of polluted water to a test organism to determine the concentration lethal to the organism. Bioassays are quantitative measurements of the responses of test organisms to natural water impacted by toxicants.

BIOCIDE — A substance that is capable of destroying living organisms.

BIOFOULING — The adhesion of various marine organisms to underwater structures.

BIOTA — Collectively, the plants and animals of a region.

BIOTIC — Pertaining to life and living organisms.

BIOTIC GROUPS — Organisms that are ecologically, structurally, or taxonomically grouped.

BIOMASS — The weight of living matter (including stored food) present in a population and expressed in terms of a given area of the water column or volume of habitat.

BLOOM — An enormous concentration of plankton in an area, caused either by sudden or gradual multiplications of organisms.

BOTTOM-RESTING TOWER — A Pilot Plant design in which the plant is placed on a tower resting on the ocean bottom, at a depth of 300m or less.

BOUSSINESQUE APPROXIMATION — The assumption that a fluid is incompressible, except insofar as contractions and expansion due to thermal fluctuations change buoyancy.

CALANOID COPEPODS — Minute, planktonic copepods with the principal point of trunk articulation located between the thorax and abdomen. First antennae are long, at least half the length of the body; second antennae have two branches.

CALCAREOUS — Consisting of or containing calcium carbonate.

CALCAREOUS OOZE — A fine-grained pelagic deposit which contains more than 30% calcium carbonate, derived from the skeletal material of various planktonic animals and plants.

CARIDEAN SHRIMPS — Decapod crustaceans in the suborder Natantia, which includes the abundant and diverse shrimps and prawns.

CATCH RATE PER UNIT EFFORT — Measurement used in commercial fisheries to describe the efficiency of equipment or the abundance of desired organisms in an area.

CATHODIC PROTECTION — Protection of a metal from electrochemical corrosion by using it as the cathode of a cell with a sacrificial anode.

CENTIGRADE DEGREE (CELSIUS DEGREE) — Unit of thermometric scale on which the interval between the freezing point and boiling point of water is divided into 100 degrees, with 0° representing the freezing point and 100° is the boiling point; also called Celsius degree.

CEPHALOPODS — A subgroup within the phylum Mollusca. Typical members include the squid and the octopus.

CHAETOGNATHS — A phylum of small, elongate, transparent, wormlike invertebrates, known as arrow worms, which are important carnivores in the zooplankton community. These planktonic organisms are abundant worldwide and occasionally multiply into vast swarms.

CHLORAMINE — A chemical compound formed when chlorine in the free, available form reacts with nitrogenous organic materials.

CHLOROPHYLL — A group of green pigments which occur chiefly in intercellular bodies called chloroplasts, active in photosynthesis.

CHLOROPHYLL a — A pigment used in photosynthesis which serves as a convenient measure of phytoplankton biomass.

CLOSED-CYCLE SYSTEM — A power-plant system in which the working fluid does not enter or leave the system but is used repeatedly.

COLD-WATER PIPE — That component of the OTEC plant extending down to approximately 1,000m in the sea, through which the cold water is drawn to condense the working fluid.

COMPENSATION DEPTH — The depth at which oxygen production by photosynthesis equals that consumed by plant respiration during a 24-hour period.

CONDENSER — The portion of a heat exchanger which conducts heat from the gaseous working fluid to the cold water drawn from the cold water pipe. In this process the vapor is changed, or condensed, from a gas to a liquid.

CONTINENTAL MARGIN — The zone separating the emergent continents from the deep-sea floor; generally consists of the Continental Shelf, Continental Slope, and Continental Rise.

CONTINENTAL SHELF — The zone bordering a continent extending from the line of permanent immersion to the depth (usually about 180m) where there is a steep descent toward the great depths.

CONTINENTAL SLOPE	A declivity from the outer edge of a Continental Shelf, extending from the break in slope to the deep-sea floor.
COPEPODS	Minute, planktonic crustaceans, mostly between 0.5 and 10 mm in length. These shrimp-like crustaceans are abundant worldwide and are an important link in the oceanic food chain.
COPEPODID STAGES	Copepod larvae that have passed through the naupliar stage, but have not reached the adult stage.
CORROSION	The gradual erosion of a surface, especially by chemical means.
CRUSTACEANS	Animals with jointed appendages and a segmented external skeleton composed of a hard shell or crust. The group includes barnacles, crabs, shrimps, and lobsters.
CTENOPHORES	Spherical, pear-shaped, or cylindrical animals of jelly-like consistency, ranging from less than 2 cm to about 1m in length. The outer surface of the body bears eight rows of comb-like structures. These planktonic organisms are commonly called comb jellies or sea walnuts.
DELTA t	(1) Difference in temperature between ocean depths. (2) Difference in temperature between incoming warm water and incoming cold water.
DENSITY	The mass per unit volume of a substance.
DETRITUS	Loose material (organic or inorganic) which results directly from disintegration.
DIATOMS	Minute, free-floating algae with external skeletons of silica; abundant worldwide.
DIEL CYCLE	Pertaining to or occurring within a 24-hour cycle.
DIEL MIGRATION	The cyclical pattern of vertical migration which occurs within a 24-hour period. Usually, organisms which display this pattern migrate toward the surface during the night and away from the surface during the day.
DIFFUSION	Transfer of material (e.g., salt) or a property (e.g., temperature) by eddies or molecular movement. Diffusion causes dissemination of matter under the influence of a concentration gradient, with movement from the stronger to the weaker solution.

DILUTION	A reduction in concentration through the addition of ambient waters.
DINOFLAGELLATES	Microscopic, planktonic organisms that may possess characteristics of both plants (photosynthesis) and animals (ingestion of food); abundant worldwide.
DISCHARGE PLUME	The fluid volume, derived from the discharge pipe, which is distinguishable from the surrounding water.
DISPERSION	Dissemination of discharged water over large areas by the natural processes of ocean turbulence and ocean currents.
DISSOLVED OXYGEN	Amount of oxygen dissolved in a unit volume of water; usually expressed in ml $liter^{-1}$ at standard temperature (0°C) and pressure (1 atmosphere).
DIVERSITY	A measure of the variety of species in a community, which takes into account the relative abundance of each species.
DOWNWELLING	Downward movement of water, usually associated with a convergent zone.
ECONOMIC RESOURCE ZONE (ERZ)	The ocean zone within 200 nmi from shore in which the adjacent coastal state possesses exclusive rights to the living and nonliving ocean resources.
ECOSYSTEM	An ecological community, together with its physical environment, considered as a unit, each influencing the properties of the other, and each necessary to the maintenance of life.
ENHANCED HEAT EXCHANGER	Heat exchanger with increased surface area, either by addition of fins or surface coating.
ENDEMIC	Restricted or peculiar to a locality or region.
ENTRAINMENT	(1) The process by which organisms are drawn into the intake pipes of an OTEC power plant. (2) The process by which ambient waters are mixed with the discharge plume.
EPIPELAGIC	Pertaining to the ocean zone ranging from the surface to 200-m depth.
EROSION	The group of natural processes (including weathering, dissolution, abrasion, and corrosion) by which the surface is removed from a metal.

EUPHAUSIIDS	Shrimp-like, planktonic crustaceans, commonly called krill, widely distributed in oceanic waters. These organisms grow to 8 cm in length and are important links in the oceanic food chain.
EVAPORATOR	The chamber in which the working fluid is vaporized to a gas prior to passing through the turbine.
EXTINCTION COEFFICIENT	A measure of the attenuation of downward-directed light.
FAR FIELD	A somewhat arbitrary cutoff point between regions, where the mixing of discharge is governed by the discharge momentum; the region where natural ocean turbulence becomes the dominant factor in further mixing of the discharge waters.
FAUNA	The animal population of a particular location, region, or period.
FLORA	The plant population of a particular location, region, or period.
GALVANIC CORROSION	The corrosion, above normal corrosion of a metal, associated with the flow of electric current to a less active metal in the same solution and in contact with the more active metal.
GELATINOUS ORGANISMS	Generally, the large organisms composed of a jelly-like substance, including the cnidarians, salps, siphonores, and ctenophores; jellyfish.
HEAT EXCHANGER	A material (usually metal) with a high coefficient of thermal conductance that is used to exchange heat between the working fluid and the heat source or sink.
HEAVY METALS OR ELEMENTS	Elements which possess a specific gravity of 5.0 or greater.
ICHTHYOPLANKTON	Fish eggs and weakly motile fish larvae.
IMPINGEMENT	A situation in which an organism is forced against a barrier, such as an intake screen, as a result of the intake of water into a facility, such as a power plant.
INDIGENOUS	Having originated in and being produced, growing, or living naturally in a particular region or environment.
INITIAL MIXING	The dispersion or diffusion of liquid, suspended-particulate, and solid phases of a material, which occurs within 4 hours after dumping.

IN SITU	In the natural or original position; pertaining to samples taken directly from the environment in which they occur.
INSULAR SHELF	The zone surrounding an island extending from the line of permanent immersion to the depth (usually 100 fathoms) where there is a marked or rather steep descent towards the great depths.
INVERTEBRATES	Animals without backbones.
LAND-BASED DESIGN	A design in which the Pilot Plant is built on land, with the intake and discharge pipes projecting into the water.
LARVACEANS	Minute, transparent, planktonic animals having a globular or cylindrical shape, many of which are covered by a tough, flexible material. A tail is present and the body has a U-shape.
LC_{50}	A bioassay, or toxicity study, in which the concentration of a pollutant which causes 50% mortality in the population of test organisms during a unit time is determined.
MACROZOOPLANKTON	Planktonic organisms with lengths between 200 and 2,000 micrometers, composed mainly of copepods, chaetognaths, and larval forms.
MACROFOULING ORGANISMS	Sessile organisms visible to the naked eye (e.g, barnacles, mussels, and sea anemones) which affix themselves to exposed surfaces.
M.A.N.™ BRUSHES	Machinefactory Augsburg-Nurenberg brushes which travel through heat-exchanger tubes for removal of microfouling organisms.
MASS ANCHOR	A large amount of concrete or other material placed on the sea floor that is heavy enough to resist all vertical forces exerted on it by the structure to which it is attached.
MEGAWATT (MW)	One million watts.
MEROPLANKTON	Organisms which spend only a portion of their life cycle as plankton; usually composed of floating developmental stages (i.e., eggs and larvae) of benthic and nektonic organisms. Also known as temporary plankton.
MESOPELAGIC	Relating to the oceanic depths between 200m and 1,000m.

MICROFOULING ORGANISMS	Organisms too small to be seen with the naked eye which accumulate on exposed surfaces and appear as a slime film.
MICROGRAM-ATOM (μg-at)	Mass of an element in micrograms, divided by its atomic weight.
MICRONEKTON	Organisms commonly collected in an Isaac-Kidd Midwater Trawl. This group consists of weak-swimming nekton, such as mesopelagic fish, small squid, gelatinous organisms, and fish larvae.
MICRO-ORGANISMS	Microscopic organisms, including bacteria, protozoans, yeast, viruses, and algae.
MICROZOOPLANKTON	Planktonic animals with lengths between 20 and 200 micrometers, composed mainly of protozoans and juvenile copepods.
MIXED LAYER	The upper layer of the ocean which is well-mixed by wind and wave activity. Within this layer temperature, salinity, and nutrient concentration values are essentially homogeneous with depth.
MOLLUSCS	Any of a large phylum (Mollusca) of invertebrate animals (e.g., clams) with a soft, unsegmented body, usually enclosed in a calcareous shell.
MONEL	A corrosion-resistant alloy of nickel, copper, iron, and manganese.
MONITORING	As considered herein, the observation of environmental effects of disposal operations through biological and chemical data collection and analyses.
MOORED PLANTSHIP	An OTEC plantship that is moored on the water by means of single- or multiple-anchor systems.
MOTILE	Exhibiting or capable of spontaneous movement.
MYCTOPHIDS	Commonly called lantern fish; this family of mesopelagic fish are typically 7 to 15 cm in length, possess neatly arranged photophores along the sides, and undergo large-scale diel migrations.
MYSIDS (Mysidae)	Elongate shrimp-like crustaceans which generally inhabit deep waters and are nearly transparent.
NANNOPLANKTON	Minute planktonic plants and animals which are 50 micrometers or less in size and include algae, bacteria, and protozoans. Individuals of this size will pass through most nets and are usually collected in centrifuges.

NAUPLIAR STAGES	A larval stage characteristic of many groups of Crustacea; the oval, unsegmented body has three pairs of appendages: uniramous attennules, biramous antennae, and mandibles.
NEAR FIELD	The region in which the plume momentum is the dominant factor, controlling entrainment and mixing of the plume with the ambient receiving waters.
NEKTON	Free-swimming aquatic animals, essentially moving independent of water movements.
NERITIC WATERS	Shallow waters in the marine environment.
NEUSTON	A community of minute organisms which are associated with the surface film of water; mainly composed of pontellid copepods and the eggs and larvae of fish.
NUTRIENT	Any substance which promotes growth or provides energy for biological processes.
ONE-PERCENT LIGHT DEPTH	The depth at which light has been attenuated to 1% of its surface value; used to define the photic zone; that depth above which net productivity of phytoplankton may occur.
OPEN-CYCLE SYSTEM	A power plant system in which the coolant and/or working fluid passes through the plant only once and is then discharged.
OPERATING CONDITIONS	The maximum values of winds, waves, or currents below which the Pilot Plant is able to operate.
ORTHO-PHOSPHATE	One of the possible radicals of orthophosphoric acid; one of the components in seawater of fundamental importance to the growth of marine phytoplankton.
OTEC	Ocean Thermal Energy Conversion.
OTEC-1	A 1-MW OTEC test platform which is presently testing power system designs, materials, and cleaning methods at Ke-ahole Point, Hawaii.
OXIDATION	The combination of a substance with oxygen, sulphur, or nitrogen; a reaction in which the atoms in an element lose electrons and the valence of the element is correspondingly increased. Examples of oxidation are the rusting of iron, the burning of wood in air, the change from cider to vinegar, and the decay of animal and plant material.
OXYGEN MININUM LAYER	The portion of the water column in which the lowest concentration of dissolved oxygen exists.

PARAMETERS — Any of a set of arbitrary physical properties whose values determine the characteristics or behavior of something (e.g., temperature, pressure and density); a characteristic element.

PARTS PER THOUSAND (ppt, $^{o}/oo$) — A unit of concentration of a mixture which denotes the number of parts of a constituent contained per thousand parts of the entire mixture (e.g., g kg^{-1}, ml $liter^{-1}$). For example, the average salinity of seawater is usually reported to be $35^{o}/oo$, indicating 35 parts total salts per 1,000 parts seawater (including the salts).

PELAGIC — Pertaining to the open sea or organisms not associated with the bottom.

PENAEID SHRIMPS — A group of crustaceans which live on sand bottoms in shallow water; important to commercial fisheries.

PHOTIC ZONE — The layer of the ocean from the surface to the depth where light has been attenuated to 1% of the surface value. The zone in which primary production shows a net increase.

PHOTOSYNTHESIS — Synthesis of chemical compounds in light, especially the manufacture of organic compounds from carbon dioxide and a hydrogen source, with simultaneous liberation of oxygen by chlorophyll-containing plant cells.

PHYTOPLANKTON — Minute, passively floating plant life of a body of water; the base of the food chain in the sea.

PLANKTON — Organisms whose movements are determined by the currents and not by their own locomotive abilities.

PRIMARY PRODUCTION — The amount of organic matter synthesized by organisms from inorganic substances in unit time, in a unit volume of water, or in a column of water of unit area extending from the surface to the bottom.

PROTOZOA — Single-celled, microscopic organisms which include the most primitive forms of animal life.

PTEROPODS — The sea butterflies, an order of pelagic gastropod molluscs in the subclass Opisthobranchia, in which the foot is modified into a pair of large fins and the shell, when present, is thin and glass-like.

REACTIVITY — The tendency of a substance to combine (react) with another substance.

RECRUITMENT — Addition to a population by reproduction of new individuals.

REFERENCE OR AFFECTED WATER COLUMN	The volume of ocean water passing the Pilot Plant in 1 day, which is affected in some manner by plant operations. The depth of the parcel ranges from the surface down to 1,000m, just below the cold-water intake. The parcel width is the distance over which the discharge plume is estimated to spread in 1 day.
SALINITY	A measure of the quantity of dissolved salts in seawater. It is formally defined as the total amount of dissolved solids in seawater in parts per thousand by weight, or grams per kilogram, when all the carbonate has been converted to oxide, the bromide and iodide to chloride, and all organic matter is completely oxidized.
SALPS	Planktonic chordates with translucent, somewhat flattened, keg-like bodies, common in warm seas. These organisms often form chains, and are asexual and sexual, the former budding the latter.
SARCODINE PROTOZOANS	Members of a superclass of Protozoa in which movement involves protoplasmic flow.
SIGNIFICANT WAVE HEIGHT	The average height of the one-third highest waves of a given wave group.
SPAR	A long, thin, typically cylindrical structure ballasted at one end so that it floats in an approximately vertical position.
SPECIES	A group of organisms having similar characteristics and capable of interbreeding and producing viable offspring; a taxon forming basic taxonomic groups which closely resemble each other structurally and physiologically and in nature, interbreed and produce fertile offspring.
SPONSON	Any structure projecting from the side of a ship or hull.
STANDING STOCK	The biomass or abundance of living material per unit volume or area of water.
STATIC SCREENS	Intake screens which are fixed in position.
STRATIGRAPHY	A branch of geology concerned with the form, arrangement, geographic distribution, chronological succession, classification, correlation, and mutual relationships of rock strata, especially sedimentary.

STERNOPTYCHIDS	Small (less than 8 cm) mesopelagic fish having photophores along the lateral margins of the underside of the body. Commonly called hatchet fish, they are distributed worldwide, and undergo large-scale diel migrations.
STRESSED	A state caused by factors which tend to alter an existent equilibrium, or normal state.
SURFACTANT	A soluble compound which reduces the surface tension of liquids or reduces interfacial tension between two liquids, or a liquid and a solid.
SURVIVAL CONDITIONS	The maximum intensities of winds, waves, and currents which a structure must endure without sustaining permanent damage.
SUSPENDED SOLIDS	Finely divided particles of a solid temporarily suspended in a liquid (e.g., soil particles in water), expressed as a weight per unit volume.
SYNERGISTIC EFFECTS	The action where the total effect of two active components of an action is greater than the sum of their individual effects.
TAXA	Two or more of a hierarchy of levels, in the biological classification of organisms, which best reflect the totality of similarities and differences.
TERRIGENOUS	Being or relating to oceanic sediment derived directly from the destruction of rocks on the earth's surface.
TERRIGINEOUS SEDIMENT	Shallow marine sedimentary deposits composed of eroded terrestrial material.
THERMAL CONDUCTIVITY	The heat flow across a surface per unit area per unit time, divided by the negative of the rate of change of temperature with distance in a direction perpendicular to the surface.
THERMAL EFFICIENCY	The ratio of the work done by a heat engine to the heat energy absorbed by it.
THERMOCLINE	The region of the water column where temperature changes most rapidly with depth.
TOTAL RESIDUAL CHLORINE (TRC)	The summation of the concentrations of various chlorine compounds in water, including hypochlorous acid, hypochlorite ion, chloramines, and other chloro-derivatives.
TOXICITY STUDY	The addition of a specific pollutant to a sample of natural waters containing a number of test organisms to determine the toxicity of the pollutant to the organisms.

TRACE CONSTITUENT	An element or compound found in the environment in extremely small quantities.
TRADE WINDS	The wind system which occupies most of the tropics and blows from the subtropical highs towards the equatorial trough; the winds are northeasterly in the northern hemisphere and southeasterly in the southern hemisphere.
TRAVELING SCREENS	Mesh screens attached to the Pilot Plant intakes for the prevention of intake of materials which could clog the heat exchangers.
TROPHIC LEVELS	Any of the feeding levels through which the passage of energy of an ecosystem proceeds. Typical marine trophic levels include phytoplankton, zooplankton, and fish.
TROPICAL CYCLONE	A type of atmospheric disturbance, originating between 25° north and south latitudes, characterized by masses of air rapidly circulating (clockwise in the southern hemisphere and counterclockwise in the northern hemisphere) around a low-pressure center. Tropical cyclones are usually accompanied by stormy, often destructive weather.
TURBIDITY	A reduction in transparency, as in the case of seawater, caused by suspended sediments or plankton.
TURNOVER RATE	The time necessary to completely replace the standing stock of a population; generation time.
UPWELLING	The rising of water toward the surface from subsurface layers of a body of water. Upwelling is most prominent where persistent winds blow parallel to a coastline so that the resultant wind current sets away from the coast. The upwelled water, besides being cooler, is rich in nutrients, so that regions of upwelling are generally areas of rich fisheries.
VELOCITY CAP	Restriction plate placed over intake ports to change direction of inflow.
VERTICAL DISTRIBUTION	Frequency of occurrence in relation to depth.
WARM-WATER PIPE	That component of the OTEC plant through which the warm surface water used to vaporize the working fluid is drawn.
WATER MASS	A body of water usually identified by its temperature-salinity (T-S) curve or its chemical content.

WET WEIGHT	The weight of a sample of organisms determined before the interstitial water is removed.
WORKING FLUID	The medium in an OTEC plant that is vaporized by warm ocean water, passed over a turbine to generate electricity, and finally condensed by cool ocean water to be recirculated through the closed system.
ZOOPLANKTON	The passively floating or weakly swimming animals of an aquatic ecosystem.

ABBREVIATIONS

As	arsenic
BOD_5	biochemical oxygen demand
C	carbon
CE	United States Army Corps of Engineers
CFR	Code of Federal Regulations
CZMA	Coastal Zone Management Act
cm	centimeter(s)
cm sec^{-1}	centimeter(s) per second
COD	chemical oxygen demand
Cu	copper
°C	degrees Celsius
DOC	United States Department of Commerce
DOE	United States Department of Energy
DPA	Deepwater Port Act
EA	environmental assessment
ED	extruded dialectric cable
EDP	Environmental Development Plan
EDTA	ethylenediaminetetraacetic acid
EIS	environmental impact statement
EPA	United States Environmental Protection Agency
ERZ	Economic Resource Zone
FRP	fiberglass-reinforced plastic
FWPCA	Federal Water Pollution Control Act
GCRL	Gulf Coast Research Laboratories
GNP	gross national product
Hg	mercury
ICNT	Informal Composite Negotiating Text
IMCO	Inter-governmental Maritime Consultative Organization
kg	kilogram(s)
kg day^{-1}	kilogram(s) per day
kg hr^{-1}	kilogram(s) per hour
km	kilometer(s)
kW	kilowatt(s)
kWh	kilowatthour(s)

MPRSA	Marine Protection, Research, and Sanctuaries Act
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
$m\ sec^{-1}$	meter(s) per second
μg-atom N $liter^{-1}$	microgram-atom(s) of nitrogen per liter
$\mu g\ liter^{-1}$	microgram(s) per liter, or millionth(s) gram per liter
μm	micrometer(s) = 0.001 millimeter
mi	mile(s)
mg C	milligram(s) carbon
mg	milligram(s), or thousandth gram
$mg\ liter^{-1}$	milligram(s) per liter
ml	milliliter(s), or thousandth liter
mm	millimeter(s), or thousandth meter
MSD	marine sanitation device
MW	megawatt(s)
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NPDES	National Pollution Discharge Elimination System
nmi	nautical mile(s)
NOAA	National Oceanic and Atmospheric Administration
OCS	Outer Continental Shelf
OF	oil- or gas-filled laminated dielectric cable
OSHA	Occupational Safety and Health Administration
OTEC	Ocean Thermal Energy Conversion
ppt	parts per thousand
PSAR	Preliminary Safety Analysis Report
RCN	rubber-coated nylon
SAR	Safety Analysis Report
sec	second(s)
SST	sea-surface temperature
USCG	United States Coast Guard
USGS	United States Geological Survey
WAPA	Water and Power Authority
Zn	zinc

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Appendix A

NAVIGATION AND ENVIRONMENTAL INFORMATION FROM THE U.S. COAST PILOT

KEY WEST, FLORIDA

4. KEY WEST TO TAMPA BAY

This chapter describes the W coast of Florida from Key West to Tampa Bay, and the ports of Key West, Naples, Fort Myers, Port Boca Grande, Venice, and Sarasota, and many of the smaller ports and landings. Also described are the Ten Thousand Islands, Big Marco Pass, Gordon Pass, Estero Island, Matanzas Pass San Carlos Bay, Caloosahatchee River, Sanibel Island, Charlotte Harbor, Peace River, Myakka River, Gasparilla Sound, Gasparilla Island, New Pass, Venice Inlet, Big Sarasota Pass, Lido Key, Longboat Key, Longboat Pass, and Anna Maria Key.

The section of the Intracoastal Waterway from Caloosahatchee River, Fla., to Tampa Bay passing through the waters described in this chapter and places along its route is discussed in chapter 12.

COLREGS Demarcation Lines.–The lines established for this part of the coast are described in 82.740 through 82.750, chapter 2.

Chart 11420.–The coast, for nearly 115 miles, from Key West to San Carlos Bay is low, sandy, and generally wooded. Innumerable small islands and keys, interlaced by many small rivers and bayous, make up Everglades National Park and the Ten Thousand Islands. From San Carlos Bay N to Tampa Bay the coast is made up of nearly straight sandy beaches of the barrier islands.

The **Florida Keys** comprise a chain of low islands along the SW coast of the Florida Peninsula extending W in a wide arc to the Dry Tortugas. The keys are mostly of coral formation and are generally covered with dense mangrove, though some have stands of pine and a few have coconut groves.

On the straits side of the keys, and at an average distance of 5 miles, are the **Florida Reefs**, a dangerous line of shoals which extend along the entire length of the chain. The reefs are particularly hazardous because they do not break in smooth weather and few of them are exposed. The water shoals abruptly between the reefs and along their outer edges.

When approaching the reefs from seaward, their proximity usually is indicated by a change in color of the water from deep blue to light green or by the bank blink, described in chapter 3. However, too much reliance should not be placed on such indications. Lights and daybeacons facilitate navigation along the reefs in clear weather, but soundings should be resorted to in thick weather. Depths of 50 fathoms indicate a distance of 2 to 3 miles from the reefs, and great caution should be used in approaching closer. Fogs are infrequent in this area.

The water always becomes milky following windy weather. The usual color is bluish green on the reefs, while the rock patches are dark, shading through brown to yellow as they approach the surface. Sand patches are bright green. Grass patches at depths of 10 to 15 feet have the appearance of rocks. With the sun astern, the line marking deep water and the edges of reefs is surprisingly clear from a position aloft.

Charts 11447, 11441, 11445.–**Key West Harbor** is 134 miles and 151 miles SW of Miami Harbor via the inside and coastwise routes, respectively. The harbor proper is in front of the city of Key West, protected on the E side by the island and on the other sides by submerged reefs and sand flats. The harbor is entered through breaks in the reef by four principal channels with depths of about 13 to 33 feet, and several minor channels.

Key West, on the island of the same name near the W end of the Florida Keys, is a winter resort. Commercial fishing is one of the leading industries, but commerce is mostly in crude and refined oils. Occasionally cruise ships call here.

Prominent features.–Easy to identify when standing along the keys is the 300-foot-high radio tower at the former U.S. Naval Station, N of Fort Taylor, the hotel cupola, the U.S. Naval Hospital cupola, and a 110-foot-high abandoned lighthouse, 0.5 mile ENE of Fort Taylor. Numerous tanks, lookout towers, and masts are prominent but difficult to identify. The stacks of the city's electrical plant on the S end of Stock Island are prominent from the S. Also conspicuous are three white radar domes and an aerobeacon on Boca Chica Key, and the white dome of the National Weather Service station and the aerobeacon at Key West International Airport. From S, a six-story apartment complex on the S shore just W of the airport is prominent; it is lighted by yellow lights at night.

Sand Key Light (24°27.2'N., 81°52.7'W.), 109 feet above the water, is shown from a 120-foot brown square pyramidal skeleton tower, enclosing a stair cylinder and square dwelling on pile foundation on **Sand Key.**

Channels.–**Main Ship Channel** is the only deep-draft approach to Key West. Federal project depth is 34 feet from the Straits of Florida to a turning basin off the former U.S. Naval Station and inside the basin, thence 30 feet to an upper turning basin off Key West Bight, and then 12 feet to and including a turning basin in the bight. (See Notice to Mariners and latest editions of the charts for controlling depths.) The channel from the entrance to the upper turning basin is marked by lighted ranges and other aids to navigation. Spoil areas are W of the channel.

Northwest Channel is a medium-draft passage between Key West Harbor and the Gulf of Mexico.

In January 1974, the reported controlling depth was about 15 fee'. Vessels can pass directly across the reefs from the Gulf to the Straits of Florida by way of Northwest Channel and Main Ship Channel. The Gulf end of the channel is shifting W.

The jetties on either side of the Gulf entrance to Northwest Channel are 0.3 to 0.5 mile from the centerline of the channel, and only the outer part of the E jetty shows above low water. The channel is marked by lighted ranges and lighted and unlighted buoys. The inner range is hard to identify until within about a mile of the front light. The steel pilings and platform of a former Coast Guard lighthouse are about 0.3 mile SW of the S end of the W jetty.

Smith Shoal (chart 11439), about 4.5 miles N of the N entrance to Northwest Channel, is covered 11 feet and marked on its NE end by **Smith Shoal Light** (24°43.2'N., 81°55.0'W.). The light also marks the N approach to the channel and is shown 47 feet above the water from a small black house on a white, hexagonal, pyramidal skeleton tower on piles. A relatively flat-topped coral head, covered by a least depth of 11 feet, is about 3.3 miles WSW of the light.

Southwest Channel, a convenient approach to Key West from SW, has been swept to a depth of 23 feet, and is marked by buoys. In 1961, this depth was confirmed for midchannel. A general course following the aids leads to the outer anchorage and Main Ship Channel. Strangers should not attempt passage at night.

West Channel, a passage leading W from Key West between the keys and outer reefs, is deep and fairly well marked. It is used by small boats bound toward the Dry Tortugas.

Calda Channel leads N from Man of War Harbor to the open waters of the Gulf. The channel is narrow and crooked, but is well marked by daybeacons and a light at the N end. The reported controlling depth was 4 feet in June 1975. The channel should be used only with local knowledge and during good visibility.

Garrison Bight Channel, well marked, leads from Man of War Harbor around the N end of Fleming Key, thence S for about 1.8 miles, thence E to Trumbo Point, thence into a turning basin just inside the entrance of Garrison Bight. In October 1976, the centerline controlling depth was 7 feet. An overhead power cable crosses the entrance and the N part of the bight; clearances are 50 feet at the entrance and 34 feet elsewhere. A privately dredged channel leads from the turning basin to a basin in the SW part of the bight. In 1972, the privately dredged channel had a reported controlling depth of 5 feet. A causeway bridge, with a 44-foot span and a clearance of 19 feet, crosses the SW part of the bight.

Garrison Bight can also be reached via an unmarked channel that leads from Man of War Harbor E between Fleming Key and the N shore of Key West to a junction with Garrison Bight Channel at Trumbo Point. A depth of about 6 feet can be carried to the junction. The channel is crossed by a 42-foot fixed span highway bridge with a clearance of 18 feet which connects Fleming Key with Key West. Garrison Bight has excellent small-craft facilities; these are described later in the chapter.

The Intracoastal Waterway from Miami to Key West joins Garrison Bight Channel off the N end of Fleming Key.

Measured course.-S of Sand Key is a measured course 6,510 feet long on course **089°38'-269°38'.** The W front range marker is 140 yards N of Sand Key Light; and the E front marker is 50 yards N of **Rock Key,** to the E of the light. The rear markers are about 600 yards N of the front markers. All are slatted white daymarks with vertical black trim.

Anchorages.-The best anchorage for medium draft vessels is N of the city in **Man of War Harbor** where depths are 14 to 26 feet. Mariners should exercise caution to avoid the visible and submerged wrecks in the harbor. It is protected against heavy seas by **Frankfort Bank** and **Pearl Bank,** on the W and **Fleming Key** on the E. Small craft usually anchor in **Key West Bight** or at the Municipal Marina or Key West Yacht Club in **Garrison Bight** on the N side of the city.

Vessels can anchor W of the city in depths of 20 to 26 feet, taking care, however, to avoid the reefs which rise abruptly in some places along the edges of the channels. The outer anchorage, SW of **Fort Taylor,** is favored by deep-draft vessels. It is somewhat exposed, but has depths of 22 to 36 feet and is safe for vessels with good ground tackle. The anchorage area at Key West is one of the best for large vessels S of Chesapeake Bay.

A **naval explosives anchorage** is about 2.5 miles SW of Key West. (See 110.189a, chapter 2, for limits and regulations.)

Dangers.-A **naval restricted area** is off the S side of Key West near its SW end. (See 207.173, chapter 2, for limits and regulations.)

The waters near the former naval facilities at Key West are **restricted.** (See 207.173a, chapter 2, for limits and regulations.)

A **naval operational training area,** aerial gunnery range, and bombing and strafing target **danger zones** are in the Straits of Florida and the Gulf of Mexico in the vicinity of Key West. (See 204.95, chapter 2, for limits and regulations.)

Caution.-Craft approaching Key West, Boca Chica, and Safe Harbor from the E through Hawk Channel should be mindful that submerged rocks and reefs extend up to 0.6 mile off the keys and give little or no indication of their presence under certain conditions.

Fishermen operating out of the Florida Keys, particularly Key West, routinely use stakes to mark otherwise unmarked channels that they use as short cuts or for safe passage in rough weather. When the channels change or fall into disuse, these stakes are not removed. Visitors to the keys should not rely on them as channel markers without local knowledge.

Tides.-The mean range of tide is 1.3 feet at Key

West, and 2.5 feet at the Northwest Channel jetties. (See the Tide Tables for daily predictions.)

Currents.–In the S approaches to Key West within the 10-fathom curve currents are weak and variable. In the main channel W of Fort Taylor, the flood (NNE) and the ebb (SSW) currents at strength average 1.0 knot and 1.7 knots, respectively. In the upper turning basin, the flood sets NE and the ebb SW with averages at strength of 0.8 and 1.1 knots, respectively. In Northwest Channel about 2.5 and 5.5 miles from Key West, the tidal currents average 1.3 knots and 0.6 knot, respectively. (See the Tidal Current Tables for daily predictions.) However, both the time and velocity of the tidal current are influenced by winds.

Weather.–Because of the nearness of the Gulf Stream in the Straits of Florida, about 12 miles S and SE, and the tempering effects of the Gulf of Mexico to the W and N, Key West has a notably mild, tropical-maritime climate in which the average temperatures during the winter are only about 14°F. lower than in summer. Cold fronts are strongly modified by the warm water as they move in from N quadrants in winter. There is no known record of frost, ice, sleet, or snow in Key West. Prevailing E tradewinds and sea breezes suppress the usual summertime heating. Diurnal variations throughout the year average only about 10°F.

Precipitation is characterized by dry and wet seasons. The period of December through April receives abundant sunshine and slightly less than 25 percent of the annual rainfall. This rainfall usually occurs in advance of cold fronts in a few heavy showers, or occasionally 5 to 8 light showers per month. June through October is normally the wet season, receiving approximately 53 percent of the yearly total in numerous showers and thunderstorms. Early morning is the favored time for diurnal showers. E waves during this season occasionally bring excessive rainfall, while infrequent hurricanes may be accompanied by unusually heavy amounts. Humidity remains relatively high during the entire year.

The National Weather Service maintains an office at the Key West International Airport. **Barometers** can be compared and weather information obtained by telephone. (See appendix for address.)

(See page T-1 for **Key West climatological table.**)

Pilotage is compulsory for all foreign and U.S. vessels under register in the foreign trade drawing more than 7 feet (including tugs, barges, and tows) bound for Key West, Safe Harbor, Stock Island, Boca Chica Channel or the Gulf of Mexico through Key West channels. Pilotage is optional for U.S. coastwise mechanically-propelled vessels that have on board a pilot properly licensed by the Federal Government for the waters which that vessel travels. Vessels are boarded day or night at Key West Entrance Lighted Whistle Buoy (24°27.7'N., 81°48.1'W.). Various boats are used by the pilot to meet vessels. Pilots may be arranged for through the Key West Bar Pilots; telephone (305-296-5512), cable address, KPILOT, or through the Key West marine operator on VHF-FM channels 16 (156.80 MHz) and 26 (157.30 MHz), or through the ships' agents. The marine operator telephone number at Key West is (305-294-6655). The pilots request a 24-hour notice of time of arrival.

Towage.–A 440-hp tug, available at the port, is equipped with VHF-FM channel 16 (156.80 MHz). Key West is the regular station for a large 3,800 hp salvage tug. General equipment is available for heavy salvage work.

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Key West is a **customs port of entry.**

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See U.S. Public Health Service, chapter 1.) The quarantine anchorage is in Man of War Harbor if size and draft of vessel permit. Larger vessels anchor in the outer harbor. In addition to the county and naval hospitals, a private hospital and a public clinic are available.

Coast Guard.–The **Captain of the Port** maintains an office at the Coast Guard Station. The marine inspection office at Miami maintains a **vessel documentation office** at Key West. (See appendix for address.)

Harbor regulations.–The harbormaster has direct supervision of the port, of anchoring and mooring all vessels, and collection of port dues. The harbormaster can be contacted through City Hall or the Key West Bar Pilots. Harbor regulations are enforced by the Pilot Commissioners and the Board of Port Wardens.

Wharves.–Municipal Wharf (24°33'35"N., 81°48'28"W.), also known as Mallory Wharf, is 870 feet long and has a deck height of about 7 feet. The N half is owned by an oil company, and the S half is owned and operated by the city of Key West as a general cargo facility. In June 1975, depths of about 20 feet were reported along the N half and 18 to 23 feet along the S half. Water and electrical shore power connections are available at the wharf.

Pier D-3 (24°34.0'N., 81°48.0'W.), S side has two 375-foot berths with roll-on/roll-off ramps at the end of each berth. In 1974, 24 feet was reported alongside the inner berth and 26 feet reported alongside the outer berth. Covered storage space of 6,000 square feet and 45,000 square feet of open storage is available. Water is available at the pier. The pier is operated by the Key West Port and Transit Authority. The only other deepwater wharves are those at the former U.S. Naval Station. Commercial fish wharves are in Key West Bight and Safe Harbor. Charter boats and yachts use Garrison Bight.

Supplies.–Gasoline, diesel fuel, water, provisions, and marine supplies can be obtained in Key West.

Repairs.–There are no commercial drydocks or major repair facilities for deep-draft vessels in Key West; the nearest such facilities are at Tampa and Jacksonville, Fla. There are two repair yards at

Key West; one is just W of the W end of the Key West Bight breakwater, and the other is on the W side of Garrison Bight. Marine railways to 110 feet long or 90 tons, lifts to 25 tons, and engine, hull, electrical, radio, and electronic repair facilities are available. Above-the-waterline repairs can also be made to larger vessels.

Small-craft facilities.–Berths, electricity, water, ice, and some marine supplies are available at Key West. Gasoline and diesel fuel are available at the Municipal Wharf and in Garrison Bight; diesel fuel is available in Key West Bight. Hull, engine, electrical, and electronic repairs can be made. Small craft moor in Key West Bight, and in Garrison Bight at the Municipal Marina, or at the Key West Yacht Club, which are at the SW and E ends of the bight, respectively. A causeway across the SW part of Garrison Bight has a small-craft opening. The highway bridge over the opening has a 44-foot fixed span with a clearance of 19 feet at the center. An overhead power cable crossing the N part of Garrison Bight and the entrance has a clearance of 50 feet over the entrance channel and 34 feet elsewhere. Anchorage in 6 to 8 feet is available at the Municipal Marina and Key West Yacht Club. Anchoring or mooring elsewhere in Garrison Bight, except in an emergency or as a shelter during bad weather, is not permitted. Public launching ramps are in Garrison Bight and at the foot of Simonton Street.

Communications.–There are no rail connections at Key West. Movement of freight in and out of the port is by vessel or truck. The Overseas Highway (U.S. Route 1) connects the city with Miami and points N, and there is air service to Miami. Bus service is available to mainland points.

Safe Harbor, 4 miles E of Key West, is a medium-draft harbor on the S side of Stock Island. Conspicuous objects include the stacks and tanks at a powerplant and desalination plant on the E side of the harbor, and a large red dry storage building at a marina on the SE end of Stock Island. A privately dredged channel leads from Hawk Channel into the harbor. A light marks the approach; private daybeacons mark the channel. In January 1974, the controlling depth in the entrance channel was reported to be 18 feet, with greater depths inside the harbor.

Piers with dolphins on the E side of the harbor near the entrance are used by barges to unload petroleum products for the power and desalination plants. Depths of 18 feet are reported alongside the piers.

The piers on the E and W sides of the harbor are used by cold storage and seafood packing plants; numerous shrimp boats tie up alongside the finger piers.

Small-craft facilities in Safe Harbor can provide berths, electricity, gasoline, diesel fuel, water, ice, marine supplies, a launching ramp, and open storage; hull and engine repairs can be made. The largest haulout facility is at a yard at the head of the harbor N of the fish piers; craft to 100 tons or 85 feet long can be handled.

Cow Key Channel, between Stock Island and Key West, is a narrow channel privately marked by daybeacons to the fixed highway bridges about 0.8 mile above the entrance. In June 1975, the reported controlling depth was 4 feet. The channel is narrow, and a shoal that bares, extends about 100 yards S from Daybeacon 1 on the W side of the channel. Shallow-draft boats can pass through the highway bridges between the keys. The bridges have 16-foot spans with a clearance of 8 feet. In June 1977, a fixed 17-foot span highway bridge with a design clearance of 10 feet was under construction at the site of the S bridge. When completed it will replace the existing bridge. N of the highway bridges the channel is unmarked and difficult to follow. A drive-in movie screen E of the channel and three radio antennas on the E side of the channel are prominent. A small marina just S of the bridges has gasoline, water, ice, and some marine supplies. Scuba tanks can be filled at a diving facility on the E side of the channel at the bridges. About 0.5 mile N of the bridges, on Stock Island, a marina has gasoline. Boats up to 25 feet can be hauled on trailers for engine repairs.

Charts 11439, 11434.–The area from Key West for 63 miles W to Dry Tortugas is a continuation of the keys with their intervening reefs and shoals. The keys are low, small in extent, and, except for the Dry Tortugas, generally covered with dense growths of mangrove.

About 5 miles S of the main chain of keys and reefs is a line of reefs, shoals, and generally broken ground which rises abruptly from the deep water of the Straits of Florida. Buoys, lights, and daybeacons mark the outer reefs. Deep-draft vessels standing along the keys should avoid this broken ground and also the areas with depths less than 10 fathoms, S and W of Rebecca Shoal and the Dry Tortugas.

Currents are variable along the edge of the reefs, being influenced by winds, by differences of barometric pressure in the Gulf and the Straits of Florida, and by the tides. At times there are strong tidal currents through the passages between the keys.

Between Key West Harbor and Boca Grande Channel there is an extensive shoal area in which are several small scattered keys. The white sand beaches of the southernmost keys are easily discernible from seaward.

A **danger zone** in a Navy restricted area surrounds Woman Key and Ballast Key. (See 204.90, chapter 2, for limits and regulations.)

Boca Grande Channel, between Boca Grande Key and the Marquesas Keys, is about 15 miles W from Key West. The channel has a controlling depth of about 11 feet from the Straits of Florida to the Gulf of Mexico and is marked by daybeacons and a buoy, but is seldom used except by local boats of 6 feet or less draft. The channels through Key West Harbor are deeper and better marked, and offer a shorter passage from the Gulf to the Straits of Florida. Good anchorage is available 1 mile NE of

PUNTA TUNA, PUERTO RICO

13. PUERTO RICO

This chapter describes the islands of the Commonwealth of Puerto Rico, which includes Puerto Rico, Mona, Vieques, Culebra, and a few smaller islands. Port information is provided for San Juan, Fajardo, Radas Roosevelt (Roosevelt Roads), Yabucoa, Laguna de Las Mareas, Bahia de Jobos, Ponce, Guayanilla, Guanica, Mayaguez, Arecibo, Isabel Segunda, Ensenada Honda, and other smaller ports.

Nine hundred miles ESE of Key West, Fla., is the island of **Puerto Rico,** which was ceded to the United States in 1898. Puerto Rico is the smallest and easternmost of the **West Indies** group known as the **Greater Antilles;** the larger islands are Cuba, Jamaica, and Hispaniola. To the N of Puerto Rico is the Atlantic Ocean, and on the S is the **Caribbean Sea.**

Puerto Rico formerly was administered under the Jones Act of March 2, 1917, which extended United States citizenship to all Puerto Ricans. On July 25, 1952, the island was formally proclaimed a free Commonwealth, voluntarily associated with the United States. Under the Constitution of Puerto Rico, the people of the Commonwealth elect a governor and a legislature for 4-year terms. The Legislature has an upper house, or senate, and a house of representatives. The people also elect a Resident Commissioner who speaks in the U.S. House of Representatives but does not vote.

Puerto Rico, the big island, is about 96 miles long, W to E, and about 35 miles wide. The interior of Puerto Rico is mountainous and very rugged. The highest mountains are nearer the S and E coasts and have elevations up to 4,400 feet. There are many fertile valleys, and along the coasts are more or less narrow strips of lowland from which the higher land rises abruptly.

The sea bottom is similar to the land. Close to the island are narrow banks from which the bottom pitches off rapidly to great depths. Under favorable conditions, the shoals frequently are marked by a difference in the color of the water.

Caution.–Mariners are advised that local fishermen commonly mark the position of their fish nets and fishtraps with plastic bleach bottles. Care should be taken to avoid destroying this fishing gear.

Puerto Rico has several hundred streams, some of good size, but none are navigable for anything but small boats. The mouths of the streams generally are closed by bars except during short periods of heavy rainfall. From the location of the mountain divides, the streams on the S and E sides of the island are short and fall rapidly to the sea, whereas those on the N and W sides are longer and slope more gently.

COLREGS Demarcation Lines.–The lines established for Puerto Rico are described in 82.738, chapter 2.

Control over movement of vessels.–(See **Part 124,** chapter 2, for regulations requiring advance notice of vessel's time of arrival to Captain of the Port.)

Anchorages.–Under ordinary conditions, the first requirement for anchorage is shelter from the E trade winds. Anchorages are numerous except along the N coast. Strong N winds and heavy seas may occur from November to April. During the hurricane season gales may strike from any direction. The best hurricane harbors are Bahias San Juan, Guanica, Guayanilla, and Jobos, and Ensenada Honda (on Isla de Culebra).

Tides.–The periodic range of tide around Puerto Rico is only about 1 foot. The actual fluctuations in the water level consequently depend largely upon the winds and other meteorological conditions. The tide is chiefly semidiurnal along the N and W coasts of Puerto Rico, whereas it is more or less diurnal along the Caribbean coast.

Currents.–Along the Atlantic and Caribbean coasts of Puerto Rico, the currents are greatly influenced by the trade winds. In general, there is a W drift caused by prevailing E trade winds; the velocity averages about 0.2 knot and is said to be strongest near the island. A decided W set has been noted near the 100-fathom curve along the Caribbean coast from Isla Caja de Muertos to Cabo Rojo. Offshore of Bahia de Tallaboa a current of 0.5 knot has been observed setting NE across and against the E wind. With variable winds or light trade winds it is probable that tidal currents are felt at times along the Atlantic and Caribbean coasts of Puerto Rico. Currents are weak in the passage N of Isla Caja de Muertos and Cayo Berberia.

Predictions of the tidal current in Canal Guanajibo and at three locations off the E coast of Puerto Rico may be obtained from the Tidal Current Tables. The times of slack water and of maximums of flood and ebb in the middle of Canal de la Mona are 2 to 3 hours later than in Canal Guanajibo. The times of S and N currents in the passages E of Puerto Rico, as far as Isla Culebrita, are believed to be about the same as the times of W and E currents, respectively, in Pasaje de Vieques.

In Canal de la Mona, on the NW end of the bank about 13 miles W of Punta Guanajibo, there is a current velocity of about 1 knot; slacks and strengths occur about 15 minutes later than in Canal Guanajibo.

In Sonda de Vieques, there are strong tidal currents over the shoals in the W part and around Isla Cabeza de Perro. In Pasaje de San Juan and Pasaje de Cucaracha, estimated velocities of about 2 knots have been reported. In the wider passages between Cayo Icacos and Cayo de Luis Pena, it is estimated that the current velocity is less than 1 knot. From Isla de Culebra the S current sets toward Punta Este, Isla de Vieques, around which tidal currents are strong.

In Canal de Luis Pena, the SE current is deflected N of Bahia Tarja and thence sets toward the S end of Cayo de Luis Pena; the current is weak off the entrance to Bahia de Sardinas. The NW current sets directly through the channel. The current velocity is about 2 knots.

Weather.–The following description of general weather conditions in Puerto Rico was prepared by the National Weather Service. (See page T-7 for **San Juan and Santa Isabel climatological tables.**)

Climate.–Puerto Rico is a tropical, hilly island which lies directly in the path of the E trade winds throughout the year. Because of island characteristics, daily temperature ranges are relatively small, at least near the coast where there is a tempering effect from the nearby waters. The hilly terrain of the island causes rather sizable variations in temperature over relatively short distances with precipitation largely mountain-related in nature. The rugged terrain also causes wide local variations in wind speed and direction due to sheltering and channeling effects.

Winds.–The prevailing winds over Puerto Rico are the E trades, which generally blow fresh during the day. The center of the Bermuda High shifts a little N in summer and S in winter changing the direction of the winds over that island from NNE in winter to E in summer.

Factors which interrupt the trade wind flow are frontal and E wave passages. As the cold front approaches, the wind shifts to a more S direction, and then as the front passes there is a gradual shift through the SW and NW quadrants back to NE. The E wave passage normally does not bring a W wind but is usually characterized by an ENE wind ahead of the wave and a change to ESE following the passage.

Over most of the ocean area near Puerto Rico the strength of the winds increases in midsummer, with lighter winds in the spring and autumn seasons. There are also somewhat higher average winds in the NW part of the area in the late autumn and winter. Mean wind speeds over the Atlantic in this area range from 9 to 10 knots during the autumn to a high of 12 to 15 knots in midsummer.

Since the island lies in the path of tropical storms and hurricanes, occasional winds of extreme force are experienced. At San Juan, during the passage of the hurricane known locally as "San Felipe" in September 1928, the National Weather Service's anemometer blew away after recording an extreme wind speed of 160 m.p.h. This is the highest value recorded in Puerto Rico to date.

Precipitation.–The greatest part of Puerto Rico's rainfall is mountain-related and showery in nature. Duration of rain is usually brief and amounts vary greatly from place to place. The distribution of rainfall over the year shows only a relatively dry season and a relatively wet season. The length of the dry season varies somewhat with the location on the island. In the S portion of Puerto Rico the dry season normally lasts from about December to April, while in the N portion it runs from about February to April. In both the N and S the wet season commences in May. The geographical distribution of the rainfall over the island shows that the heaviest is centered over El Yunque in the Luquillo Mountains in the NE section. The annual rainfall there is approximately 150 inches greater than at San Juan, about 23 miles distant.

Temperature.–Temperatures are normally steady over the tropical island of Puerto Rico. For the San Juan-Isla Verde Airport area, the highest temperature of record is 96°F and lowest, 60°F at the airport. These conditions are in significant contrast to those prevailing in the mountain and valley regions of the interior, where much greater daily and annual ranges of temperature occur. The highest temperature that has been reported in Puerto Rico is 103°F. at San Lorenzo, and the lowest is 40°F. at Aibonite.

Tropical cyclones of the North Atlantic are usually called West Indian Hurricanes, but many of these storms form, move, and die hundreds of miles from the West Indies. The hurricane season generally begins in June and closes with November. (See chapter 3 for more detailed discussion of hurricanes.)

Storm warning display locations are listed on the NOS charts and shown on the Marine Weather Services Charts published by the National Weather Service.

Routes.–Vessels bound from Straits of Florida (24°25'N., 83°00'W.) to San Juan can proceed by rhumb lines through the following positions: 23°34'N., 80°26'W.; 22°34'N., 78°00'W.; 22°07'N., 77°24'W.; 20°50'N., 73°43'W.; 19°45'N., 69°50'W.; 18°29'N., 66°08'W.

From the E coast of the United States, the route to San Juan is direct by great circle.

Distances from San Juan are 1,017 miles to Straits of Florida, 1,252 miles to Norfolk, 1,399 miles to New York, and 1,486 miles to Boston.

Pilotage is compulsory for all foreign vessels and U.S. vessels under register when entering or leaving the harbors of Puerto Rico. Coastwise vessels, vessels owned or controlled by the United States or foreign governments, and all pleasure yachts are exempt from pilotage unless a pilot is actually engaged. The pilot service at each port is under the supervision and direction of a Commonwealth Captain of the Port; ships' agents should notify his local office in advance so a pilot will be available at the expected time of arrival of a vessel. Pilots provide 24-hour service and board vessels from motorboats. Detailed information on pilotage procedures is given in the text for the ports concerned.

Towage.–Large tugs are available at San Juan, Puerto Yabucoa, and Bahia de Guayanilla; smaller tugs are available at some of the other ports. Arrangements for tugs should be made in advance by ships' agents. (See the text for the ports concerned as to the availability of tugs.)

the nearest point of the E coast of Puerto Rico, forms the S side of Sonda de Vieques. It is 18 miles long E and W and 3.5 miles wide near its middle. A range of hills extends the entire length of the island with a prominent hill at each end–**Monte Pirata** near its W end and **Cerro Matias Jalobre,** 3 miles from the E end. The island is wooded in places, especially its E half and around Monte Pirata.

Principal products are horses and cattle. Vegetables and tropical fruits are grown for local consumption. The rainy season lasts from May to October, but the rainfall is less than in adjacent parts of Puerto Rico. The island is subject to drought; the principal watersource is rainfall stored in cisterns.

Boats carrying supplies and passengers dock at Isabel Segunda on Bahia de Mulas on the N coast. When the trade wind is N of E a heavy surf runs and landing is difficult on the open N coast.

Naval restricted areas extend 1,500 yards offshore around the W part of the island. (See 207.815, chapter 2, for limits and regulations.)

Pasaje de Vieques is the strait lying between Puerto Rico and Isla de Vieques. **Radas Roosevelt** is the open-water portion of the passage lying within the shoals and banks N of the W end of Isla de Vieques and between that island and Puerto Rico. The current velocity is 1.2 knots in the passage and floods SW and ebbs E.

Punta Arenas, at the NW end of Isla de Vieques, is low and covered with a scrubby growth, with a white spit at its end. The point changes shape continually; at times the outer coconut trees are in the water.

At the W end of Isla de Vieques, S of Punta Arenas, there is a smooth anchorage with E winds but exposed to the S and W.

Escollo de Arenas is a continuation NW of a shoal which fringes the N side of Isla de Vieques to a distance of about 1 mile and extends E nearly to Punta Mulas. The W edge of the shoaler part of the bank extends 3.3 miles NNW from Punta Arenas to its outer end, where it is marked by a lighted buoy. Spots with depths of 5 feet are on the bank for 0.8 mile N of Punta Arenas, and thence to the lighted buoy, the bank is steep-to with about 40 feet on each side. The bank sometimes shows by discolored water and rips.

Currents.–A strong SW set is noted frequently N of Escolla de Arenas. The bank itself is generally indicated by the tide rips.

A 1.2 mile causeway extends from shore at **Desembarcadero Mosquito,** 3.9 miles E of Punta Arenas. A pier, marked on the outer and inner ends by Navy-maintained lights, is on the W side of the causeway about 350 yards from the seaward end. In 1965, a depth of 37 feet was available on either side of the pier; however, there are spots with lesser depths in the approaches, and the chart is the best guide.

Arrecife Mosquito, a reef awash, is 1.9 miles to the NE of Desembarcadero Mosquito. The reef is steep-to, and the sea always breaks on it. A shoal with a depth of 17 feet is about 0.5 mile WNW from the reef. During ordinary weather a fairly smooth anchorage is 0.3 mile S of Arrecife Mosquito, in 40 feet, sandy bottom. Several spots with a least depth of 9 feet are in the approaches to the anchorage, and vessels drawing more than that depth should use it only with local knowledge.

Arrecife Corona, a reef awash, is about 0.3 mile long and about 0.3 mile E of Arrecife Mosquito. Several shoals are around the reef, including a 9-foot spot 0.2 mile S. **Bajo Merail,** a shoal with least depth of 2 feet lies 0.8 mile S of Arrecife Corona.

Caballo Blanco, a low grassy islet is 1.7 miles NW of Punta Mulas. Several shoals surround the islet, the outer of which are 0.6 mile N and 0.2 mile S. **Bajo Comandante,** a shoal about 600 yards in extent with a least depth of 7 feet, lies about midway between Caballo Blanco and the shore. There are spots with a least depth of 23 feet in the channel between Caballo Blanco and Bajo Comandante.

Bahia de Mulas, 8 miles E of Punta Arenas and 10 miles W of Punta Este, is an open bight on the N coast of Isla de Vieques. **Isabel Segunda** (P.O. Vieques), the principal town on the island, is on the SE side of the bay.

Punta Mulas Light (18°09.4′ N., 65°26.6′ W.), 68 feet above the water, is shown from a 32-foot white octagonal tower on a dwelling on a low bluff point on the NE side of the bay. An old Spanish brick fort and building is prominent on a hill 0.5 mile SE of the light. A depth of 12 feet can be taken to the 300-foot pier on the E side of the bay. Depths of 4 to 12 feet are along the pier.

Small vessels and schooners anchor N and S of the pier at Isabel Segunda according to draft. Large vessels anchor 0.5 mile or more offshore in the bay. The outer anchorage is exposed, but the small-boat anchorage affords fair shelter during ordinary weather. With N winds a heavy sea makes into the bay causing small craft to drag anchor. The nearest hurricane anchorages are Ensenada Honda (Isla de Culebra) and Ensenada Honda (E coast of Puerto Rico).

The approach to Bahia de Mulas is obstructed by shoals with depths of 5 to 30 feet. Caballo Blancho and Arrecife Corona can be avoided in approaching from the NW by staying in the white sector of Punta Mulas Light until inside the bay.

A local person is designated to handle insular immigration and customs traffic. Supplies and passengers are landed at the pier. Some cattle are exported. Available supplies include gasoline in drums and groceries. Telephone and telegraph communications are available. A ferry carries passengers and supplies between Isabel Segunda, Isla de Culebra, and Fajardo; the mail is delivered by airplane.

A **danger area** of a bombing and target area is off the NE and SE coasts of Isla de Vieques. (See 204.234, chapter 2, for limits and regulations.)

Schedules of all operations by the U.S. Marine Corps and the Navy on Isla de Vieques and vicinity are promulgated weekly and distributed to local

A **267°31'-087°31' measured nautical mile** is off Punta Vaca; the front and rear markers are shown from poles.

Punta Boca Quebrada, 2.9 miles WNW of Punta Vaca, is a low wooded point which terminates in a dry ledge outside of a white sand beach. From Punta Boca Quebrada the coast trends N for 1 mile to Punta Arenas.

Charts 25650, 25663.–The E **coast** of Puerto Rico extends 10 miles S from Cabo San Juan to Punta Puerca and then 22 miles SW to Punta Tuna. The coast is very irregular with projecting rocky bluffs separating the numerous small shallow coves and bays, and with grass-covered or mangrove hills within a mile of the shore. Reefs awash or bare at low water and shoals with less than 10 feet over them extend more than a mile offshore in places. A depth of 24 feet can be carried through a partially buoyed channel from 2 to 5 miles off the E coast, but entrance caution is necessary to avoid the shoals near the route. The principal ports on the E coast are Fajardo and the private oil-handling facilities at Puerto Yabucoa. Ensenada Honda is the site of the Roosevelt Roads Naval Station ship base.

Chart 25667.–Playa Canalejo, 0.2 mile SSE of Cabo San Juan Light, is a shallow indentation leading to the ruins of a small pier.

Punta Gorda, 1.4 miles S of Cabo San Juan Light, is a conspicuous high head. A 360-foot hill, 0.4 mile WNW from the point, is the N end and highest part of a high ridge which extends SW nearly to Playa de Fajardo.

Punta Bateria, 2.2 miles S of Cabo San Juan Light, is a rocky 70-foot cliff from which a grassy ridge makes inland.

Bahia de Fajardo, 2.5 miles S of Cabo San Juan Light, affords good shelter for medium-draft vessels. It is somewhat protected on the E and S by two islands and surrounding reefs. Ferry service for both passengers and cargo operates between Playa de Fajardo, Isla de Culebra, Isla de Vieques, and the Virgin Islands. Commercial air transport is available to the Virgin Islands. Small interisland vessels trade in general cargo, building materials, and livestock.

Prominent features.–Cabo San Juan Light is the principal landmark in making the approach to Bahia de Fajardo. A hotel with two cupolas, each marked by a red light, just S of Punta Gorda, and two stacks of a sugar central, and a radio tower near Fajardo are prominent.

Storm warning signals are displayed. (See chart).

Channel.–The principal entrance to Bahia de Fajardo is from N through the channel marked by buoys W of Bajo Laja, although small vessels can enter from E and S with local knowledge. The N entrance has a controlling depth of 23 to 30 feet to Buoy 5, thence 11 feet to the public pier. The controlling depth from E is 17 feet to Buoy 5, and from S, 9 to 11 feet to the public pier.

Anchorages.–Large vessels anchor NE of Punta Bateria according to draft. During ordinary weather the protection is fair and the holding ground is good. Small vessels anchor inside the bay on either side of the entrance channel.

The hurricane anchorages for large vessels are Ensenada Honda (Isla de Culebra) and Ensenada Honda, 10 miles S of Fajardo. Small vessels can anchor S of Isla Marina.

Dangers.–The approaches to Bahia de Fajardo have reefs that usually show breakers and shoals with 7 to 18 feet over them. Inside the bay depths range from 3 to 24 feet.

Bajo Laja, with least depths of 7 to 10 feet over it, lies on the E side of the N entrance and is marked with buoys.

Isla Marina, with surrounding reefs up to 0.5 mile, is on the E side of the bay.

Storm warning signals are displayed. (See chart.)

Arrecife Corona Carrillo and a long reef to the W obstruct the S entrance to the bay. **Bajo del Rio,** a bank with depths of less than 5 feet, extends more than 0.2 mile offshore along the S entrance to the bay.

Currents.–The current velocity is 0.3 knot in the SSE direction on the flood and 1 knot in a NNW direction on the ebb in the channel in Bahia de Fajardo.

Pilotage.–A local pilot is available. (See Pilotage for harbors of Puerto Rico at the beginning of this chapter.)

Towage.–Tugs are not available at Fajardo.

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.)

Fajardo is a **customs port of entry.** A deputy collector of customs handles customs matters and acts as immigration inspector. The customhouse is on the waterfront at Playa de Fajardo.

Harbor regulations.–Local regulations are enforced by a Commonwealth Captain of the Port.

Wharves.–The landing facilities are at **Playa de Fajardo** on the SW side of Bahia de Fajardo. The westerly 300-feet public pier has 12 feet at the outer end and 8 feet alongside; two private white lights are off the outer end of the pier. An 80-foot bulkhead pier with 12 feet alongside for the ferry boat is 100 yards W of the public pier.

A privately owned pier 125 yards E of the public pier is 400 feet long with 5 feet at the outer end. The former limestone pier to the E is in ruins.

Storm warning signals are displayed. (See chart.)

Supplies and repairs.–Water is available and gasoline can be trucked in. Groceries can be obtained from **Fajardo,** 1.5 miles inland. Limited facilities are available for repairs. The principal source of marine supplies is San Juan, 38 miles by highway from Playa de Fajardo.

Small-craft facilities.–A marina on Isla Marina, on the E side of Bahia de Fajardo, has facilities for small craft. Depths of 8 to 14 feet can be taken to the marina. Berths, electricity, gasoline, diesel fuel, water, ice, and covered storage are available at the finger piers. Lifts can haul out vessels up to 200 tons for hull and engine repairs. Vessels up to 65 feet in length can be accommodated at the marina.

A private marina 0.3 mile NE of Playa Sardinera, N of Playa de Fajardo, has facilities for small craft. A depth of 12 feet can be taken to the berths inside a 700-foot breakwater that is marked on the seaward end by a fixed red light. Berths, electricity, gasoline, diesel fuel, water, and ice are available.

A marina at the hotel just S of Punta Gorda has berthing facilities inside a manmade basin. A depth of 12 feet can be taken through the lighted entrance and then 12 to 7 feet to the berths. Berths, electricity, gasoline, diesel fuel, water, and ice are available.

Chart 25663.–Isla de Ramos, 4 miles S of Cabo San Juan Light, is 0.2 mile in diameter and covered with palm trees except on its summit which is a grassy 35-foot knoll with a house on top. A reef surrounds the island to a distance of 200 to 300 yards. A buoyed shoal with a least depth of 16 feet is 0.6 mile ESE of the island.

Cayo Largo, 1.5 miles E of Isla de Ramos, consists of a narrow 1.8-mile-long ridge steep-to on all sides. The S half is awash at low water, and the sea always breaks on it; the N half has depths of 4 to 15 feet. Buoys mark the W side. The velocity of the current is 0.5 knot in the channel W of Cayo Largo; it floods S and ebbs NW.

Isla Pineros, 8 miles S of Cabo San Juan Light, is a 1-mile long wooded island with a 249-foot peak near the middle. **Isla Cabeza de Perro,** just E of Isla Pineros, has a large detached rock off the rocky bluff NE end. **Cabeza de Perro Light** (18°15.1'N., 65°34.6'W.), 90 feet above the water, is shown from a 30-foot red skeleton tower with a red and white diamond-shaped daymark on the E point of the island. **Pasaje Medio Mundo,** W of Isla Pineros, is foul, but a depth of 15 feet can be taken through the narrow crooked channel by small boats with local knowledge.

Punta Puerca, 10 miles S of Cabo San Juan, is a prominent bold wooded head with a high rock bluff at the shoreline. The highest point, 0.3 mile inland, is the site of several large white dish-shaped radar tracking units. The units show up well from offshore.

Chart 25666.–Ensenada Honda, 11 miles S of Cabo San Juan, is the site of the **Roosevelt Roads United States Naval Station.** The harbor is well protected by the circular shore and the reefs which constrict the entrance to 0.3 mile. The harbor is included in a **restricted area** which extends from **Punta Figueras** (see chart 25663), 3.5 miles N of Ensenada Honda, to 2 miles W of the entrance. (See 207.815, chapter 2, for limits and regulations.)

Bahia de Puerca, a mile NE of Ensenada Honda, has depths of 37 feet or more, leading to a pier with 37 feet alongside at the head of the bay. A 26-foot spot is 150 yards SW of the pier. The 1,000-foot pier consists of a series of caissons connected by walkways; a large inactive graving dock is inshore of the pier.

Isla Cabras, on the E side of the entrance to Ensenada Honda, has a rocky bluff on the E side. **Vieques Southwest Channel Range Front Light** (18°12.9'N., 65°36.0'W.), 70 feet above the water, is shown from a skeleton tower with a rectangular white daymark with a central red stripe near the E end of the island. The island is connected to the mainland by a causeway. **Cabra de Tierra** is the southernmost point of a low neck covered with mangroves and palms separating Ensenada Honda from Bahia de Puerca.

Punta Cascajo, the W point at the entrance to Ensenada Honda, has rock cliffs on the S side and a bare reef 250 yards off the SE side. Many houses are on the high part of the point, and trees fringe the shoreline. An unnamed cove just NW of the point is blocked at the entrance by a permanent shark net.

The SW approach to Ensenada Honda is marked by a **025°24'** lighted range. (The front range light is on Isla Cabras and the rear range light is on Punta Puerca.)

Channels.–A dredged channel, marked by lighted and unlighted buoys and a **315°** lighted range, leads to a large turning basin in Ensenada Honda. Vessels anchor inside the harbor according to draft; the holding ground is soft mud, which may cause some dragging during a hurricane. In 1965-68, a controlling depth of 40 feet was available in the channel and turning basin.

Wharves.–Pier 1, U.S. Navy fuel pier, the more W pier on the NE side of Ensenada Honda, is 450 feet long with 32 feet along the W side and 36 feet along the E side; water is available. A small boat landing with about 15 feet alongside is inshore of the E side of the fuel pier.

Pier 2, U.S. Navy cargo pier, SE of Pier 1, is 398 feet long with 32 feet alongside; water is available. An LST landing ramp is about 400 yards SE of the cargo pier.

Pier 3, a 1,200-foot-long U.S. Navy aircraft carrier pier marked at its seaward end by fixed red lights, is 0.25 mile S of Pier 2. Depths of about 39 feet are alongside.

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.)

Customs and **immigration,** services are handled by representatives from Fajardo.

An **agricultural quarantine** official is at the Roosevelt Roads Naval Station.

Chart 25665.–Puerto de Humacao, 19 miles S of Cabo San Juan, affords some shelter for medium-draft vessels. The port is exposed SE and S, and a heavy sea sometimes makes in with SE winds. The port is inactive and the piers and cargo handling facilities of Playa de Humacao are in ruins. Small boats can make a landing at the ruins of the old sugar central pier during good weather.

Prominent features.–**Punta Lima,** 3 miles NE of Puerto de Humacao, is a projecting wooded hill with low land back of it. A reef 0.5 mile E of the point usually shows breakers on it.

Cayo Santiago, 0.7 mile SE of the waterfront at **Playa de Humacao,** is the most prominent feature when approaching the port. The island is low at the N end, rising to 162 feet at the S end. The Caribbean Primate Research Center maintains a monkey colony for experimental purposes on the island; no visitors are permitted.

El Morrillo, 1.8 miles SW of the port, is a small rocky hill which rises abruptly from the water and the lowland around it.

Morro de Humacao, 3.5 miles SW of the port, is a 100-foot rocky point with higher ground inland. Grass-covered **Cayo Batata** is 0.4 mile off the point. A bare ledge, with five rocks and a reef, awash and steep-to, extends up to 0.2 mile E and S of Cayo Batata.

Channels.–The principal entrance to Puerto de Humacao is from S through an unmarked channel leading W of **Bajo Parse** and **Bajo Evelyn;** small vessels can enter from N.

Anchorages.–Large vessels can anchor inside the entrance lighted buoy, 2.3 miles S of Cayo Santiago, as close inshore as draft permits.

Ensenada Honda, 10 miles NE, is the nearest hurricane anchorage.

Small vessels anchor in depths of 3 to 10 feet in the NE part of **Puerto de Naguabo,** 2 miles NE of Puerto de Humacao. Good anchorage is afforded except with SE or S winds. A boat landing in about 7 feet of water can be made at a small pier SE of Puerto de Naguabo. Gasoline is available nearby.

Dangers.–Several shoal spots with depths of 12 to 18 feet are in the approaches to Puerto de Humacao. The 12-foot shoal 1.2 miles E of Cayo Santiago and the shoals at the S entrance are unmarked. The chart is the best guide. A shoal area with depths of 1 to 6 feet extends for 0.4 mile from Cayo Santiago towards the waterfront at Playa de Humacao. A wreck reportedly covered 8 feet is 300 yards SE of the ruins of the long pier.

Supplies and repairs.–Some groceries are available at Playa de Humacao, but most supplies must be obtained from **Humacao,** 6 miles inland. (See chart 25650.) The principal source of marine supplies is San Juan, 44 miles by highway from Playa de Humacao.

Humacao is a **customs port of entry.**

Chart 25661.–**Puerto Yabucoa,** 23.5 miles SW of Cabo San Juan Light and 6 miles NE of Punta Tuna Light, is an open bay with numerous reefs and sunken rocks with depths of less than 5 feet between rocky **Punta Guayanes** on the N and **Punta Quebrada Honda** on the S. The port is the site of a deep-draft oil-handling facility. Large tankers call here to deliver crude petroleum and load petroleum and petrochemical products.

Channels.–A privately dredged 500-foot channel leads from deepwater to a turning basin and petroleum wharf. A jetty extending about 200 yards from the NE side of the basin entrance is marked by a light. The channel is marked by private lighted aids and a 296°50′ lighted range. In April-May 1971 controlling depths were 49 feet in the entrance channel, thence 50 feet in the main basin except for depths of 34 to 36 feet along the S edge; 25 feet was available in the smaller basin to the W of the main basin. In September 1976, severe shoaling of an unknown extent was reported in the N half of the entrance channel between the breakwater light and Light 10.

The storage tank farm and several tall stacks are conspicuous NW of the turning basin.

Anchorages.–A suitable anchorage is available for several deep-draft vessels SE of Punta Guayanes.

Dangers.–The area seaward of the dredged channel is relatively open and free from dangers, but care should be exercised in approaching the channel as depths shoal extremely rapidly at the channel entrance. Outcrops of hard seafloor material exist close to the edges of the channel; give the edges of the channel a good berth. A shoal area that is partially bare with breakers is 0.5 mile SW of the channel. Prevailing winds from ESE cause a good swell in the basin most of the time.

Pilotage.–(See Pilotage for harbors of Puerto Rico at the beginning of this chapter.) Local pilots are available. Pilots board in-bound vessels about one mile seaward of the channel entrance.

Towage.–The use of a tug is compulsory for arriving and departing vessels. Tugs up to 3,800 hp are available.

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.)

Harbor regulations.–Local regulations are enforced by the local Commonwealth Captain of the Port.

Wharves.–The petroleum wharf on the N side of the main basin is 450 feet long with turning and berthing dolphins extending off the ends. Depth alongside is 50 feet. The barge and dry cargo wharf on the S side of the basin just inside the entrance is 200 feet long with a depth of 10 feet reported alongside.

A pipeline trestle pier in ruins, formerly used for loading molasses, is at **Playa de Guayanes** in the N part of Puerto Yabucoa.

Supplies and repairs.–Bunker C, diesel oils, and water are available at the petroleum wharf. Limited marine supplies are available in Puerto Yabucoa. Stores and supplies can be ordered through the ship agents for delivery to the vessel with at least 48-hours advance notice.

No repair facilities are available.

Chart 25659.–**Punta Yeguas,** 1.2 miles S of Punta Quebrada Honda, is a low point with a rocky bluff at the end, which rises gradually in a smooth grassy ridge that joins the E end of Cuchilla de Panduras.

Punta Toro, the point 1.4 miles WSW of Punta Yeguas, is a 500-foot-high spur of **Cuchilla de Panduras,** which has elevations of over 1,800 feet to the N.

Punta Tuna Light (17°59.4'N., 65°53.1'W.), 110 feet above the water, is shown from a 49-foot white tower on dwelling, near the end of the point. A radiobeacon is at the light. Storm warning signals are displayed. (See chart.) The point projects as a high cliff; a 400-foot hill 0.5 mile N is prominent.

Arrecife Sargent, 0.5 mile SE of Punta Tuna is 1.8 miles long and 0.3 mile wide at its widest point. Because it breaks the force of the SE swell, the reef affords some protection from the SE for vessels anchored well in by Punta Tuna where the reef is from 0.3 to 0.2 mile from shore. A bare part of the reef, 0.7 mile E of the light, has the appearance of a rowboat and black can buoy. Other parts of the steep-to reef have depths of 5 to 17 feet. The break on the reef does not show well except when there is considerable sea, and on parts of it the sea rarely breaks. The natural channel between the reef and the shore is not recommended for strangers.

Charts 25671, 25677.–The S coast of Puerto Rico from Punta Tuna to Cabo Rojo extends in an almost W direction for 75 miles. The coast is very irregular with projecting brush-covered points between shallow coves and bays; fringing reefs close to shore make landing difficult and often dangerous in most places. Except at the E and W ends of Puerto Rico, the land is generally low near the shore with prominent high hills in the interior. Many reefs and islands are from 2 to 5 miles offshore, then the bottom increases rapidly to great depths, making soundings of little use to indicate danger or distance from shore. Numerous lights and other prominent features along the coast can be used for position determination. Safety will be ensured by giving a berth of at least 3 miles to the coast and to Isla Caja de Muertos. Small vessels with local knowledge sometimes hug the coast inside the outer reefs to avoid heavy seas outside.

In 1967, a rock pinnacle, covered 6 fathoms, was reported about 12.5 miles ESE of Isla Caja de Muertos Light in 17°50'35"N., 66°18'14"W.

Chart 25689.–Puerto Arroyo, 11 miles W of Punta Tuna Light, is an open bay exposed to S winds. The harbor is used only by small fishing vessels that anchor near Arroyo in the NE part of the bay.

Punta Figuras, a projecting point on the E side of Puerto Arroyo, is marked by a light. **Cerro Range,** 3 miles N of the light, is a distinct sharp conical hill. The stacks of several sugar centrals are also prominent.

The principal entrance channel is from SW; a lighted buoy is on the E side of the approach. Several shoals with depths of 24 to 30 feet are in this approach, and the bottom is irregular. There is a small- boat passage from E between Punta Figuras and Arrecife Guayama; the passage should be used only with local knowledge. Depths of 24 to 30 feet can be taken to the anchorage area, thence about 5 feet to the private pier at Arroyo. The E passage has depths of 13 to 30 feet to the anchorage.

The best anchorage is in 23 to 30 feet a mile WSW of Punta Figuras Light. The prevailing SE wind is always felt in the anchorage, although the force is somewhat broken by the outlying reef. Some small fishing vessels anchor near Arroyo according to draft. Bahia de Jobos, 10 miles W, is the nearest hurricane anchorage.

Arrecife Guayama, 1 to 1.5 miles off Punta Figuras, is nearly 3 miles long and is dangerous to approach. Its E part is awash, and the sea usually breaks on it; the middle part has little water on it with patches awash on which the sea breaks. **Arrecife Corona,** 1.4 miles W of Punta Figuras, has a least depth of 5½ feet.

Arrecife Algarrobo, 2.3 miles W of Punta Figuras, has 1 foot or less over it. Several shoals with depths of 6 to 18 feet extend up to 2 miles offshore S of **Punta Barrancas,** a point on thw W side of Puerto Arroyo 3.8 miles W of Punta Figuras.

Local harbor regulations for Puerto Arroyo are enforced by a Commonwealth Captain of the Port.

Chart 25677.–Laguna de Las Mareas about 6.5 miles W of Punta Figuras is the site of a deep-draft oil-handling facility. Large tankers call here to deliver crude petroleum products and load petrochemicals and motor fuels.

Channels.–A privately dredged channel and landcuts lead through the reefs from deepwater to the facilities' basin and pier in Laguna de Las Mareas. The breakwater extending from the E entrance point, **Punta Ola Grande,** is marked at the seaward end by a light. The channel is marked by private lighted aids and a 025°04'36" lighted range. In October 1977, the controlling depth was 33 feet in the entrance channel, thence in 1976, 37 feet in the basin except for shoaling along the edges.

The 1,100-foot pier in the basin extends from the N shore and consists of a series of connected mooring and breasting dolphins with a 90-foot loading platform (pierhead) near its center. In 1968, depths of 38 feet were reported alongside.

Pilotage.–(See Pilotage for harbors of Puerto Rico at the beginning of this chapter.) Pilots board vessels 1 mile off the entrance to the harbor. A 48-hour and a 24-hour notice of time of arrival are requested.

Towage.–Tugs up to 1,800 hp are available for docking vessels. The tugs monitor 2182 kHz and VHF-FM channel 16 (156.80 MHz).

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.)

U.S. Public Health Service doctors are available for attendance on vessels upon receipt of notice 48 hours prior to arrival. A hospital is at nearby Guayama.

Repairs.–The nearest port for major repairs is San Juan; limited emergency above-the-waterline repairs are available at Ponce.

Supplies.–No bunkers are available; in emergencies bunkers and lube oils may be delivered from Ponce. Limited quantities of water and facilities for offloading waste water are available at the pier. Marine supplies are available on 48-hour notice.

Tides.–The reported mean range of tide is 0.8 foot.

Chart 25687.–**Bahia de Jobos,** 20 miles W of Punta Tuna Light, is a good hurricane anchorage. The harbor is formed by **Punta Pozuelo,** a projecting point on the E side, and many islands on the S and SW sides. The shore and islands are low and are covered with thick brush and mangroves. **Central Aguirre,** on the NW side of the bay, is one of the largest sugar centrals of Puerto Rico. The E part of the bay is shoal and is used only by local fishing boats.

A privately dredged and marked channel leads E from **Punta Rodeo,** the NW extremity of Punta Pozuelo, along the N side of Punta Pozuelo to a private basin and barge receiving wharf of an oil company. In 1967, the channel and basin were reported dredged to a depth of 15 feet.

Prominent features.–A light on the E end of **Cayos de Ratones** marks the entrance to Bahia de Jobos. The stacks at Central Aguirre and the water tank at **Salinas** show up well from offshore.

Channels.–The principal entrance to Bahia de Jobos is from the W between **Cayo Morrillo** and Cayos de Ratones, and thence through a marked dredged channel that leads to a turning basin and facilities of a powerplant, and to a 1,000-foot-long pier at the head of the channel at Central Aguirre. In June 1974, the dredged channel had a controlling depth of 25 feet for a midwidth of 150 feet to the turning basin and 1,000-foot-long pier. In March 1977, the basin, marked by private lighted buoys, had depths of 26 feet except for shoaling to 18 feet on the N and W sides.

Boca del Infierno, a small-boat entrance into Bahia de Jobos between **Cayos Caribes** and **Cayos de Barca,** has a depth of 11 feet over the bar which breaks with a heavy sea. This passage should be used only with local knowledge.

Anchorages.–Vessels sometimes anchor just inside the entrance between Cayo Morrillo and Cayos de Ratones to await daylight. There is a good anchorage in depths of 26 to 35 feet with grassy bottom NE of **Cayos de Pajaros.** The anchorage inside the bay is S of the pier at Central Aguirre in depths of 19 to 24 feet with soft mud bottom. A slight swell makes in through Boca del Infierno with S winds.

Dangers.–Numerous wooded islands with reefs awash and steep- to surround the S and SW part of Bahia de Jobos up to 1.5 miles from the mainland. There are passages between some of the island groups, but only the principal entrance E of Cayos de Ratones should be used by large vessels and small boats without local knowledge.

Pilotage.–Pilots from Ponce serve this harbor. (See Pilotage for harbors of Puerto Rico at the beginning of this chapter.) Vessels are boarded off Cayos de Ratones.

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.)

Puerto Jobos is a **customs port of entry.**

Wharves.–The 1,000-foot-long pier at the head of the dredged channel at Central Aguirre was reported, in 1975, to be in poor condition and not usable. The fuel oil barge loading platform of the powerplant, on the NW side of the turning basin, has about 300 feet of berthing space with dolphins.

Supplies and repairs.–Supplies have to be obtained from inland towns; San Juan is 67 miles by highway. Some above-the-waterline emergency repairs can be made by the machine shop at Central Aguirre.

Small-craft facilities.–A private yacht club is 0.3 mile NE of the pier at Central Aguirre. A depth of 4 feet can be taken to the pier where water is available. Gasoline can be brought in from nearby Central Aquirre. A small-craft facility is on the S side of Bahia de Jobos about 0.7 mile E of Punta Rodeo and another is on the N side of the bay at the town of **Puerto Jobos.** The entrance channel to the facility on the S side is very narrow and should be navigated with caution.

Bahia de Rincon, 26 miles W of **Punta Tuna** Light, is a 5-mile-wide bay used only by local fishing boats that anchor near **Playa de Salinas** in the NE part. There is a good anchorage in depths of 25 to 28 feet in the E part of the bay during ordinary weather. The bay shoals to 18 feet and less within a mile of the shore in some places. A covered crash boat wharf, marked by fixed red lights, is at the head of the cove just E of Playa de Salinas. The wharf is under control of the Puerto Rico Air National Guard. In 1975, it was reported that the fixed lights marking the crash boat wharf were no longer in use, and that a private, 25-foot-high, red occulting light over a fixed white light had been established near the NE side of the cove. This aid can be seen by craft entering the mouth of the cove and is used in navigating the middle of the cove. A small boat launching ramp is adjacent to the light structure, and a small-craft facility, on the W side of the cove, can make limited repairs.

Arrecife Media Luna and **Cayo Alfenique** obstruct the entrance to Bahia de Rincon from S. The reefs are partly bare or awash, steep-to, and the sea breaks on them. The W side is obstructed by Cayos de Caracoles and **Cayos Cabezazos.** Reefs awash or bare and nearly steep-to surround the islands, and the sea always breaks on their S sides. Foul ground with depths of 3 to 8 feet extends N to **Punta Petrona,** the W point of the bay.

Depths of 23 to 28 feet can be taken to anchorage in Bahia de Rincon on either side of Arrecife Media Luna; avoid the 11-foot shoal 0.4 mile W of Cayos de Ratones. Small vessels with local knowledge also use the narrow channel N of Cayos de Ratones.

In 1967, a rock pinnacle, covered 6 fathoms, was reported in about 17°50.6'N., 66°18.3'W., about 5 miles S of the light on the E end of Cayos de Ratones. (See chart 25677.)

Chart 25685.–The 15-mile indentation in the coast between Bahia de Rincon and Bahia Ponce is obstructed by islands and shoals up to 5 miles offshore. The stacks of several sugar centrals and several water tanks are prominent along the coast line. Anchorage in depths of 15 to 30 feet can be found within 0.5 mile of the shore during ordinary weather. Small local fishing boats anchor near the settlements along the shore.

Playa Santa Isabel, 31 miles W of Punta Tuna Light, is a small settlement near the beach where water can be obtained. A depth of 4 feet can be taken to the landing. Gasoline, groceries, and some supplies are available at **Santa Isabel,** 0.7 mile inland.

Cayo Berberia, 33 miles W of Punta Tuna Light, is 2 miles offshore and is surrounded by a reef and shoals. The fringing reef, on which the sea breaks on the S and E sides, extends up to 0.4 mile from the island. A shoal with depths of 2 to 12 feet extends for 0.2 mile N of the island and over a mile W of it. In ordinary weather, a good anchorage in 45 to 60 feet of water 1 mile NW of the island was reported by the NOAA Ship MT. MITCHELL. Care must be taken when approaching the area because of shoals with depths of 16 to 18 feet, 2 miles NW of the island.

Isla Caja de Muertos, about midway of the 75-mile stretch of coast between Punta Tuna Light and Cabo Rojo, is 5 miles offshore and prominent. The SW end is low except for a 170-foot steep hill at the extreme SW end. When viewed from a distance the 170-foot hill appears to be a separate island. At such times the hill is easily mistaken for Isla Morrillito. Care should be taken when shooting tangents to these islands. Landings can be made on the W side of the island during ordinary weather. **Isla Morrillito** is a small 31-foot flat-topped island 200 yards off the SW point.

Isla Caja de Muertos Light (17°53.7'N., 66°31.3'W.), 297 feet above the water, is shown from a 63-foot gray tower on the summit of the island.

Shoal water with depths of 3 to 18 feet extends up to 0.5 mile from the shore of Isla Caja de Muertos and Isla Morrillito. A reef is reported to extend about 0.4 mile seaward in all directions from a point on the NE end of Isla Caja de Muertos in 17°54.0'N., 66°30.6'W. A bar with a least depth of 15 feet extends NE from Isla Caja de Muertos gradually curving E and joins the shoal area W of Cayo Berberia. The sea rarely breaks on the bar; it is dangerous to approach.

A passage N of Cayo Berberia and Isla Caja de Muertos is used in the daytime by small coasting vessels with local knowledge. There are several shoals with depths of 14 to 17 feet along the route.

A good anchorage in ordinary weather in 90 to 120 feet of water about 0.8 mile NW of the center of Isla Caja de Muertos was reported by the NOAA Ship MT. MITCHELL. The island offers a good lee.

Isla del Frio (see chart 25683), 4.3 miles NNW of Isla Caja de Muertos and 0.4 mile offshore, is surrounded by a 0.4-mile-long reef that is steep-to on the S edge.

Chart 25683.–**Bahia de Ponce,** 43 miles W of Punta Tuna Light and 32 miles E of Cabo Rojo Light, is the most important commercial harbor on the S coast and one of the three leading ports of Puerto Rico. The harbor is protected from the prevailing E trade winds by Punta Penoncillo and Isla de Gata with their surrounding reefs, but it is exposed to the S causing a swell at times in the anchorage. The port facilities are in the E part of the 3.5-mile-wide bay, which is surrounded by shoals and reefs; the N part of the bay shoals to less than 18 feet within 0.4 mile of the shore in places.

Ponce, the second largest city in Puerto Rico, is 2 miles inland from the port at **Playa de Ponce,** and 71 miles by highway from San Juan. Most cargo is landed at the municipal pier and bulkhead on Punta Penoncillo. The principal imports include foodstuffs, textiles, building materials, and machinery. Exports include sugar, cement, and canned fish.

Prominent features.–(See also chart 25677.) Isla Caja de Muertos with the light on its summit is the most prominent feature in the approach. The stacks of the cement factory W of Ponce, the large microwave tower in Ponce, the hotel on the hill back of Ponce, and the radio towers and stacks surrounding the bay can be seen from well offshore. Also prominent is the aerolight at Mercedita Airport, about 2.5 miles E of Ponce.

Isla de Cardona, in about the middle of the entrance to Bahia de Ponce, is marked by a light shown from a white tower near the middle of the island. **Isla de Gata,** S of the municipal pier on **Punta Penoncillo** is connected by a dike to **Punta Carenero.**

Channels.–The principal entrance is E of Isla de Cardona, where in March 1977, the controlling depth was 22 feet in the buoyed approach to the municipal pier and bulkhead except for shoaling to 6 feet at the NE end of the municipal pier. Lesser depths exist N of the inner harbor basin buoys and NE of the municipal pier and bulkhead. The channel is also marked by a **015°** lighted range; do not confuse the rear range light with the flashing red radio tower lights back of it. A 0.2-mile-wide channel between Isla de Cardona and Las Hojitas is sometimes used by small vessels with local knowledge.

Anchorages.–The usual anchorage is NE of Isla de Cardona in depths of 30 to 50 feet, although vessels can anchor in 30 to 40 feet NW of Las

Hojitas. A small-craft anchorage is NE of Las Hojitas in depths of 18 to 28 feet. (See 110.1 and 110.255, chapter 2, for limits and regulations.) A well-protected anchorage for small boats in depths of 19 to 30 feet is NE of the yacht club on Isla de Gata. A comfortable anchorage with little swell during ordinary weather in depths of 18 to 30 feet can be found in **Caleta de Cabullones,** the bight E of Isla de Gata.

Bahia de Ponce is not safe as a hurricane anchorage because it is exposed to the S. The nearest hurricane anchorages are at Bahia de Jobos, 28 miles E, Bahia de Guayanilla, 8 miles W, and Bahia de Guanica, 16 miles W.

Dangers.–**Bajo Tasmanian,** an extensive bank on the E side of the principal harbor entrance, is about a mile long with several spots of 16 to 18 feet. Vessels should pass 200 yards or more W of the buoy to clear the W limit of the bank.

The bank on the W side of the entrance extends almost to Isla de Cardona and has general depths of 28 to 48 feet, but there are several spots of 18 to 23 feet within an area 0.5 mile SW of the island.

Bajo Cardona extends 600 yards ESE from Isla de Cardona with depths of 12 to 17 feet. A bare reef on which the sea breaks extends 300 yards NE of the island; depths of 11 to 14 feet continue in the same direction for 200 yards.

A reef bare at low water and steep-to extends 300 yards W and SW from Isla de Gata. The sea always breaks on the outer side of this reef.

It is reported that with an E wind of 25 knots or more, the mud from the reef off Isla de Gata discolors the water across the channel to Isla de Cardona and beyond making the channel off the piers at Punta Penoncillo appear shoal.

Other unmarked shoals and reefs are dangerous in approaching Bahia de Ponce through any of the inshore passages. A reef with four islets extends 0.4 mile from shore to Punta Cabullones, 2.5 miles E of Isla de Cardona. The reef is steep-to, and the sea breaks on the S side. **Roca Ahogado,** a bare rock in the middle of Caleta de Cabullones, has shoal water of 4 to 18 feet extending up to 0.2 mile from it.

Las Hojitas, NW of Isla de Cardona, is 0.8 mile long in a NE direction with a small patch awash near the SW end. The reef has depths of 4 to 11 feet and is steep-to E and NE of this patch.

Cayo Viejo, 0.8 mile W of Isla de Cardona, is about 0.3 mile in diameter and awash at its shoalest point.

Isla de Ratones, on the W entrance to Bahia de Ponce and a mile offshore, is a low island with a reef that bares at low water extending a mile ESE of it. **Cayo Arenas,** 0.5 mile E of Isla de Ratones, is surrounded by a reef and shoals that extend up to 200 yards from its shore. Crooked channels with a least depth of 10 feet are between these islands and the shore; they should be used only with local knowledge.

Storm warning signals are displayed. (See chart.)

Routes.–From E: When 3 miles S of Isla Caja de Muertos Light steer **303°** for 8 miles until Isla de Cardona Light bears 005°, distant 2.5 miles, then head in on the lighted range bearing **015°**. From W: When 5 miles S of Guanica Light steer 079° for 15.4 miles to the position off the entrance of Bahia de Ponce.

Pilotage.–(See Pilotage for the harbors of Puerto Rico at the beginning of this chapter.) Pilots board vessels at the entrance buoys.

Towage.–Vessels enter and clear the harbor under their own power. Two tugs are available in emergencies and may be contacted by calling the Coast Guard station at Ponce.

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.)

Ponce is a **customs port of entry.** The customhouse is at Playa de Ponce. The deputy collector of customs and his inspectors act as immigration inspectors.

Harbor regulations.–A Commonwealth Captain of the Port with an office at Playa de Ponce enforces the local rules and regulations for Bahia de Ponce.

Wharves.–The municipal pier and wharf on Punta Penoncillo are administered by a board with a dock superintendent in charge. The municipal pier on the SE side is 450 feet long and has depths of 26 to 30 feet along both sides; transit sheds and pipelines for water, molasses, and bulk cement are on the pier. Immediately NW of the pier is a 63-foot-wide loading ramp which slopes to about 1 foot above the water.

On the N side of Punta Penoncillo is a 1,900-foot bulkhead wharf, locally known as Alcoa Pier and has depths of 17 to 28 feet alongside; transit sheds and pipelines for water and diesel oil are on the wharf; general cargo is received.

About 350 yards E of the municipal pier is a L-shaped pier with a 350-foot face which in 1972 had reported depths of 30 feet alongside and 31 feet in the approach. Pipelines on the pier handle water and vegetable oil, and unload polluted water from fishing vessels.

A maneuvering basin extends 250 yards N of the municipal wharf, the northerly limits marked by buoys. In September 1971, the basin had depths of 24 to 30 feet with shoaling to lesser depths in the E end.

Supplies.–Most supplies are available at Ponce. If necessary, additional supplies can be brought in by truck from San Juan in a few hours. Freshwater, bunker C oil, and diesel oil are available at the municipal pier; gasoline is available by truck.

Repairs.–Above-the-waterline repairs and minor electrical and small-engine repairs are available in Ponce. There is no drydock or large marine railway available at the port.

Small-craft facilities.–The Ponce Yacht and Fishing Club has mooring facilities with depths of about 8 feet alongside on the N side of Isla de Gata. A 20-ton marine railway can haul out craft

SAINT CROIX, VIRGIN ISLANDS

14. VIRGIN ISLANDS

This chapter describes the United States Virgin Islands, which include the islands of St. Thomas, St. John, and St. Croix, and 40 small islets or keys. Information is given on the ports and harbors of the islands including Charlotte Amalie, Christiansted, Krause Lagoon, and Frederiksted. A general description of the British Virgin Islands is also included; more complete information is given in H.O. publication 22, Sailing Directions, The West Indies, Volume II, published by the United States Defense Mapping Agency Hydrographic Center, and West Indies Pilot, Volume II, published by the United Kingdom Ministry of Defense Hydrographic Department.

The **United States Virgin Islands,** separated from the easternmost island of the Puerto Rico group by 8-mile-wide Virgin Passage, were purchased from Denmark in 1917, and United States citizenship conferred upon the islanders in 1927. Under the revised Organic Act of 1954, legislative powers are vested in a Senate, whose members are elected by the islanders for 2-year terms. The Governor, who has certain veto powers, is elected by the people of the U.S. Virgin Islands. The capital is Charlotte Amalie, on the island of St. Thomas.

The **British Virgin Islands** are N and E of the United States group. The United States-Great Britain boundary extends SE between Hans Lollik and Little Tobago Islands, thence through the narrows between St. John and Tortola Islands, and thence S through Flanagan Passage between Flanagan and Norman Islands.

Prominent features.–Making the Virgin Islands from the N, Virgin Gorda (British) will be seen on the extreme left, rising in a clear, well-defined peak about 1,400 feet high. Next to Virgin Gorda, Tortola (also British) will appear most conspicuous; the highest mountain appears flattened and elongated from N but rises to an elevation of about 1,800 feet. Immediately W of Tortola will be seen the rugged, pointed peaks of Jost Van Dyke (British), rising to about 1,100 feet, and behind them the irregular small peaks rising from the tableland of St. John (U.S.) to heights of 800 to 1,300 feet.

From about 20 miles N of the islands, a separation will be observed between St. Thomas and St. John, but St. John, Jost Van Dyke, Tortola, and Virgin Gorda will appear to be one large island. St. Thomas is less rugged in outline than the other islands, but it may be recognized from its large midisland saddle which has horns nearly 1,600 feet high; the saddle is equally conspicuous from the S.

COLREGS Demarcation Lines.–The lines established for the Virgin Islands are described in 82.738, chapter 2.

Control over movement of vessels.–(See Part 124, chapter 2, for regulations requiring advance notice of vessel's time of arrival to Captain of the Port.)

Routes.–From Charlotte Amalie to the Straits of Florida, proceed through Virgin Passage and thence as direct as safe navigation permits along the N coasts of Puerto Rico and Hispaniola, and then along the N coast of Cuba through Old Bahama and Nicholas Channels to destination. The distance is 1,086 miles.

Bound to Baltimore, New York, or Boston, pass W of Sail Rock and, when clear of Virgin Passage, take a great circle course direct to destination. Distances from Charlotte Amalie are 1,418 miles to Baltimore, 1,435 miles to New York, and 1,517 miles to Boston.

Tides.–The range of tide around the Virgin Islands is only about 1 foot. Along the coasts bordering the Atlantic Ocean the tide is chiefly semidiurnal, and along the Caribbean shores it is mostly diurnal.

Currents.–The currents among the Virgin Islands, although of considerable importance to navigators, are not well established by observation. The tidal current is said to set SE and NW. In the general vicinity of the islands there is an oceanic current with a velocity of about 0.2 knot that sets in a direction varying from NW to W.

Weather.–The following description of weather conditions in the Virgin Islands was prepared by the Office of Climatology, Environmental Data Service. (See page T-8 for **St. Croix climatological table.**)

Wind.–One of the outstanding features of the climate in the Virgin Islands is the steadiness of the trade winds. They blow almost without exception from an E direction, or between NNE and SSE. The highest mean maximum wind speeds usually occur in July. Superimposed on the trade winds are the land and sea breezes, which are important in most coastal areas. Night winds are lighter than the daytime winds. About daybreak the wind speed begins to pick up, reaching a maximum late in the morning or early afternoon. A return to the lighter nighttime winds begins during the late afternoon, usually about 1600. It must be remembered that these islands are located in the path of occasional tropical storms or hurricanes and extremely high winds may be experienced during such passages.

Precipitation.–The time of maximum rainfall expectancy is roughly from May through November or December, with showers providing most of the rain. The heavier rains have usually been associated with tropical cyclones and hurricanes that are most likely to reach the area during the months of August, September, and October; or with frontal systems or E waves which may reach the area in small vessels. A shoal with rocks awash extends out 100 yards on the W side of Hurricane Hole.

Coral Harbor, the NW arm of Coral Bay, is narrow, and the deep part of the bay is restricted to a width of 100 yards or less by encroaching shoals from the side and head of the harbor. The anchorage ground, although smooth with ordinary winds, is narrow, and being on a lee shore it is available only for small vessels. A small-boat wharf with 3 feet alongside is at the head of the bay.

Coral Bay is a **customs port of entry.**

The S coast of St. John is very irregular with bold projecting points terminating in cliffs over 100 feet high between the small bays and coves that have fringing reefs and shoals near the shores. The dangers are within 0.5 mile of the coast.

Lameshur Bay, 1.5 miles NW of Ram Head, is divided into three smaller bays by projecting points. The easterly one affords good shelter for small vessels in 6 fathoms about 0.2 mile offshore. The middle bay has a good anchorage generally used by sailboats, and a sand beach.

The shore for 0.6 mile W of Lameshur Bay consists of very prominent 150-foot white cliffs.

Chart 25647.–Reef Bay, 2.7 miles W of Ram Head, is a large open bight, but the shores are fringed by coral reefs. A passage leads through the reefs to a protected small-boat harbor in **Genti Bay.**

Great Cruz Bay, 5.5 miles W of Ram Head, affords good shelter for small vessels. The depth is 24 feet in the entrance, decreasing to less than 10 feet in the middle of the bay.

Chart 25641.–St. Croix Island, 32 miles S of St. Thomas and St. John Islands and 50 miles SE of the mainland of Puerto Rico, is the largest of the U.S. Virgin Islands. The island is 19 miles long and averages about 3.5 miles wide. The N side is somewhat mountainous, particularly in the W part. **Mount Eagle,** 1,165 feet high and about 5 miles from the W end, is the highest point on the island. Southward from the mountains, the land is composed of fertile undulating valleys. The S side is nearly straight and generally low.

Water commerce with St. Croix Island is handled through Christiansted on the N coast, Frederiksted on the W coast, and the industrial complexes in Krause Lagoon and Limetree Bay along the central S coast. Tourism accounts for a good part of the commerce on the N and E coast; a petroleum refinery and a bauxite refinery are the major commerce on the S coast. Some cattle are raised for export to nearby islands.

Tides and currents.–The tides are chiefly diurnal and are small, the mean range being about 0.5 foot and the diurnal range less than a foot. There is usually a slight W current between St. Croix Island and St. Thomas Island. No perceptible current has been observed at Christiansted Harbor, but a moderate W flow is reported outside Fort Louise Augusta Light.

National Ocean Survey parties have reported that off East Point tidal currents of about 1 knot set NW and SE in calm weather. Close to East Point strong currents set N and S. Trade winds increase the NW flow and decrease the SE flow. A very strong W current setting around East Point and through Buck Island Channel was noted when the trade wind was blowing. A strong NW current was noted off Southwest Cape.

Weather.–Rainfall is irregular causing droughts at times. For a 37-year period annual rainfall varied from 26 to 70 inches.

There is no regular land breeze at St. Croix Island, but when the trade wind is light during the day it generally falls calm in the night. From June to September, when the trade wind is usually light, occasionally strong winds from the SW blow across the island, with much rain. Northers, with the accompanying heavy ground swell, do not appear to reach the island.

Storm warning display locations are listed on NOS charts and shown on Marine Weather Services Charts published by the National Weather Service.

Hams Bluff, the NW extremity of St. Croix Island, is a conspicuous 100-foot cliff with the land back of it rising to high hills. **Hams Bluff Light** (17°46.3'N., 64°52.3'W.), 394 feet above the water, is shown from a white tower.

From Hams Bluff the N coast of St. Croix Island has slightly jutting rocky points with sandy beaches between for 5.5. miles to Baron Bluff.

Baron Bluff is the sea front of the triple spurs of a 395-foot hill. From Baron Bluff E to **Salt River,** the shore consists of low rocky cliffs.

Salt River Point is 1.7 miles E of Baron Bluff. W of the point a narrow passage with depths of 6 feet leads through a reef to **Salt River Bay.** The shores of the bay are mostly mangrove swamps with several openings leading to boat landings.

White Horse, 400 yards N of Salt River Point, is a rock over which the sea always breaks. A boat channel with a depth of about 11 feet leads between the rock and the shore.

From Salt River Point the coast turns abruptly SE for 3 miles to Christiansted. In this area the hills near the coast are covered with grass and low bushes, and the low shoreline has a narrow sand beach.

Chart 25645.–Christiansted Harbor, on the N coast of St. Croix Island 10 miles E of Hams Bluff and 7.7 miles W of East Point, is a port of call for vessels drawing up to 16 feet. The harbor is protected by a reef and bank that extends clear across the entrance, except for the channel opening. **Gallows Bay** is in the SE part of the harbor. Most of the harbor is shoal.

Christiansted, on the S shore of the harbor, is the largest town on St. Croix Island. The principal imports include foodstuffs, building materials, petroleum products, and clothing. Exports include rum, cattle, and scrap iron.

Storm warning signals are displayed. (See chart.)

Prominent features.–Fort Louise Augusta, on the

E side of the harbor entrance, is an old battery on a projecting point. Christiansted Harbor Channel Entrance Front Light, 45 feet above the water, is shown near the fort. The radio tower adjacent to the front range light is prominent.

Protestant Cay, an islet in the harbor, is surmounted by an old stone building and a hotel. The ruins of Fort Sofia Frederika are at the N end of the cay.

Channels.–The entrance is N of Fort Louise Augusta through a crooked dredged channel marked by buoys, lights, and a **164°** lighted entrance range, thence E and S of Protestant Cay to a turning basin and to Gallows Bay Dock. In March 1977, the controlling depth was 14 feet except for shoaling to 12 feet along the SE limit of the basin. Shoaling has occurred close to the edges of the marked channel into Christiansted Harbor; extreme caution is advised in transiting the channel.

Inside the harbor, a privately dredged channel with private aids leads W of the main channel to facilities in the SW part of the bay. In 1972, a depth of 17 feet was reported in the channel and alongside the berthing facilities.

A 15-foot passage over the S portion of Scotch Bank is used by small vessels coming from E; local knowledge is necessary. A 13-foot channel E of Round Reef is sometimes used by schooners and small boats with local knowledge.

Anchorages.–Vessels anchor NE of Protestant Cay in depths of 9 to 30 feet according to draft. Holding ground in this area is reported to be hard; caution is advised to ensure against dragging. Small boats anchor in Gallows Bay and along the E side of the harbor. During a hurricane or gale vessels anchor in Gallows Bay and small boats sometimes anchor in Salt River Bay.

Dangers–Scotch Bank, a 1.8-mile-long sand shoal extending NE from Fort Louise Augusta, is on the E side of the harbor entrance. Depths of 2 to 20 feet are on the shoal, which is easily seen except when the sun is ahead.

Long Reef, a 2-mile-long strip nearly awash in places, forms the NW side of the harbor. Shoal water extends E from the reef to the channel marked with buoys.

Round Reef, W of Fort Louise Augusta, is circular with a spot bare at low water near its center and several spots with depths of 1 foot.

The harbor is shoal with depths less than 6 feet outside the circuitous channel marked by buoys.

Routes.–Approaching Christiansted Harbor from NE, give Buck Island a berth of 2 miles or more to avoid the bar N of it. From W all dangers will be avoided by staying a mile or more off the N coast. The entrance is marked by a lighted **164°** range, and buoys mark the entrance channel into the harbor.

Pilotage.–(See Pilotage for U.S. Virgin Islands at the beginning of this chapter.) Vessels are boarded from a motorboat just outside the sea buoy (Buoy 1, 17°45.9'N., 64°41.8'W.). Strangers are advised to take a pilot and should not attempt to enter at night without one.

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.) A municipal hospital is at Christiansted.

Christiansted is a **customs port of entry.**

Harbor regulations.–Local rules and regulations for Christiansted harbor are enforced by the **harbormaster,** whose office is on the waterfront.

Wharves.–Gallows Bay Dock (17°44'57"N., 64°41'57"W.), in the E part of Gallows Bay, has berthing space of 400 feet on the W side and 300 feet on the E side; depths of 16 feet are reported alongside. A roll-on/roll-off ramp with 16 feet alongside is E of the dock. Forklifts, mobile cranes up to 70 tons, and covered and uncovered storage are available. General cargo is received and shipped.

Kings Wharf, the 600-foot bulkhead stone quay about 300 yards W of Gallows Bay Dock and W of the fort, has depths of about 8 feet alongside; this bulkhead is used occasionally by auxiliary powered schooners engaged in the interisland trade.

A 380-foot-long pier, 0.9 mile W of Gallows Bay Dock, is operated by the Virgin Island Cement Company. Pipelines for handling raw cement and fuel oil are on the pier. A reported depth of 17 feet is alongside.

An L-shaped pier, just W of the long pier, has about 200 feet of berthing space with 17 feet reported alongside and is operated by Masonry Products, Inc. A pipeline for handling raw cement is on the pier.

Supplies and **repairs.**–Some marine supplies and limited amounts of water are available at Christiansted. Gasoline and diesel fuel are available near the waterfront; bunkers can be trucked in from the S side of the island. Facilities for repairs to oceangoing vessels are limited to minor above-the-waterline repairs.

Small-boat facilities.–St. Croix Marine and Development Company, NE of Gallows Bay Dock, has four finger piers; three, 100 feet long, and one, 200 feet long; depths of 10 feet are reported alongside. A marine railway at the facility can haul craft up to 75 feet long, and 10-foot draft; a transfer lift can handle craft up to 40 tons, 60 feet in length, and 10-foot draft. Gasoline, diesel fuel, and water are available. Limited engine repairs can be made.

Chart 25641.–Beyond Fort Louise Augusta, the N coast trends E for 7.3 miles to East Point, the E end of the island. The coast is fringed by coral reefs, behind which in several places small vessels may find protection.

Punnett Point (chart 25645) 1.4 miles E of Fort Louise Augusta, forms the E side of **Punnett Bay,** a semicircular cove 0.2 mile wide. NE of Punnett Point, at a distance of about 0.4 mile, is Green Cay, an islet 55 feet high at its S end. S to the beach and between Green Cay and Pull Point, the area has depths of only 6 to 18 feet with numerous coral heads.

Pull Point, 2.3 miles ENE of Fort Louise Augusta, is a small projecting point terminating in cliffs 35 feet high. A house with a conspicuous green roof is visible at the point. **Chenay Bay** is the bight W of the point.

Buck Island, 340 feet high, is 4.3 miles ENE of Fort Louise Augusta and about 1.5 miles off St. Croix. The island is on the S edge of a coral bank which extends W about 0.8 mile, then sweeps around a mile N of the island. This forms **Buck Island Bar,** 1.5 miles long. Shoals extend about 1.8 miles E of Buck Island. The island lies on the route from E to Christiansted Harbor. A light, 360 feet above the water, is shown from a red skeleton tower on the summit of the island. Buck Island lies within the Buck Island Reef National Monument, the boundary of which is marked by private buoys.

Diedrichs Point, the S extremity of Buck Island, is low. Several spots with 12, 17, and 20 feet lie from 1 mile E of the island to 1.7 miles ESE of it. **Buck Island Channel** lies between Buck Island and the adjacent reefs and St. Croix. Moderate-draft vessels may approach it from either N or E. **Channel Rock,** awash, lies 1.8 miles W of East Point.

The N coast of St. Croix from Pull Point to East Point is fringed by a coral reef. Behind this reef are several anchorages for small boats, but local knowledge is necessary to use them. Entrance is made at **Coakley Bay,** a bight 0.8 mile E of Pull Point. The opening in the end of the reef can be entered by steering **180°** with Coakley Mill directly ahead.

Pow Point, 1.5 miles E of Pull Point, is rocky with a 130-foot hill 250 yards inland. **Tague Point,** 1.1 miles E of Pow Point, is sharp and rocky with a 155-foot hill 0.2 mile SSW. **Tague Bay,** 0.7 mile wide between the bluffs at Tague Point and **Romney Point** , has a curving beach of sand and shingle. The bay provides anchorage for light-draft vessels entering behind the reef through a break NE of Tague Point. A marina, a private yacht club, and the Fairleigh Dickerson University research pier are along the shore. A depth of 10 feet can be taken to the marina pier where gasoline, diesel fuel, water, and minor repairs are available.

Cottongarden Point, a prominent rocky point with a 55-foot knoll, is 1.6 miles E of Tague Point and opposite the E end of the long reef paralleling the coast. **Cramer Park,** a public beach and park operated by the Insular Government, is W of the point.

East Point, the E extremity of St. Croix, is a bluff. A 225-foot hill is 100 yards WNW, and **Morne Rond,** 380 feet high, is a conspicuous round hill near the point.

Lang Bank, an extensive bank 3 to 5 miles wide stretches 9 miles NE from the E end of St. Croix Island. Along its edge is a wall-sided narrow coral ledge which, commencing about 3 miles E of Buck Island, sweeps around in a convex form for about 14 miles, terminating 2 miles S from East Point. Its N part is from half a mile to 1 mile wide, with depths of 5½ to 10 fathoms. The S portion is about 100 to 600 yards wide, with 7 to 10 fathoms on it. The shoalest part of Lang Bank breaks in heavy weather and should be given a wide berth.

From East Point, the S coast of St. Croix Island trends WSW for 20 miles to Southwest Cape. This coast is bordered by a dangerous broken coral reef which extends from East Point to nearly abreast of Long Point, 3.6 miles E of Southwest Cape. Behind this reef are several anchorages suitable for small local boats. Along the coast are many small bights and indentations, but all are shallow and do not afford anchorage except for small craft. Many old mills and the aerolight on the SW part of the island are prominent.

Point Cudejarre, a sharp point with a 25-foot bluff and a 120-foot hill NNW, is 0.3 miles SW of East Point. **Grass Point,** 3 miles WSW of East Point, is a long narrow point marked by a 43-foot knob.

Mount Fancy, about 4.7 miles W of East Point, is a conspicuous double hill, 245 feet high, which forms the E point of **Great Pond Bay.** Good anchorage for vessels of 10-foot draft, in hard sand bottom, can be had in this bay. An entrance range is the E tangent of Milord Point in line with Sight Mill; when about 100 yards off the point haul around to **064°**, pass W of a 7-foot shoal 200 yards E of Milord Point, and run for 0.3 mile, anchoring in 13 to 14 feet. **Milord Point,** the west entrance point of the bay, is a promontory of **Fareham Hill,** 192 feet high and prominent.

Vagthus Point, sharp and rocky, is 9.5 miles WSW of East Point. **Canegarden Bay,** 1.2 miles wide, forms an irregular crescent to the W of Vagthus Point.

Limetree Bay, close W of Canegarden Bay, is the site of a private deep-draft oil-handling facility operated by Hess Oil Company. Large tankers call here to deliver crude oil and to load petroleum and petrochemical products.

Channels.–A privately dredged channel leads from deepwater to a large turning basin and oil-handling terminal. The channel is privately marked by a **334°** lighted range visible 4° on each side of the channel centerline and by an auxiliary **334°** lighted range, close E of the first range, visible 4° on each side of the channel centerline, and by lights and lighted buoys. In 1973, the reported controlling depth was 60 feet.

In 1976, Limetree Bay and vicinity was undergoing extensive modification and dredging. Mariners are advised to exercise caution while navigating the inner harbor area.

Pilotage.–(See Pilotage for U.S. Virgin Islands at the beginning of this chapter.) Pilots board vessels 1 mile S of the harbor entrance. Night entry is limited to vessels less than 85,000 dwt.

Towage.–Three tugs up to 2,400 hp are available for docking.

Quarantine, customs, immigration, and **agricultural quarantine** matters are handled by representatives from Christiansted who board vessels at their berths. Documents required are the same as at U.S. ports.

Wharves.-A total of seven oil-handling docks are on the E and W sides of a 0.7-mile-long causeway that extends into the basin from the N shore. Depths alongside range from 35 feet at the northernmost dock to 60 feet at the southernmost docks.

Supplies.-Emergency supplies of bunker fuels, diesel oil, and limited amounts of water are available.

Krause Lagoon indents the S shore of St. Croix Island immediately W of Limetree Bay and about 12.3 miles WSW of East Point. The bauxite ore refining facility at the head of the lagoon is known as **Port Alucroix** and is owned by the Martin Marietta Aluminum Corp. Large vessels call here to deliver bauxite ore and load alumina, a white powder that is the principal raw material for the manufacture of aluminum.

Channels.-Krause Lagoon Channel, a privately maintained dredged 35-foot channel with dikes paralleling it on either side in the N part, leads from deepwater through the reefs to a large turning basin and pier at the head of Krause Lagoon. The channel is privately marked by buoys, lights, a daybeacon, and a lighted range. In 1972, the reported controlling depth in the channel, turning basin, and to the pier was 35 feet. In 1974, it was reported that the maximum acceptable draft for this channel was 33 feet 3 inches.

Currents.-The current in Krause Lagoon is reported to set W and to vary in velocity with the wind. The current does not completely dissipate until inside Port Alucroix.

Pilotage.-(See Pilotage for U.S. Virgin Islands at the beginning of this chapter.) Vessels are boarded 1 mile S of the harbor entrance; daylight only.

Towage.-Two tugs, up to 1,200 hp, are available.

Quarantine, customs, immigration, and agricultural quarantine.-(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.)

Wharves.-The concrete bulkhead pier at the terminal has 1,000 feet of berthing space along both the E and W sides. Depths alongside are 37 feet; recommended berthing depth is 32 feet.

Supplies.-Emergency supplies of bunker fuels, diesel oil, and freshwater are available. The terminal has no ballast disposal facilities.

Dumping of waste oil in the harbor is prohibited. Masters are cautioned that the discharge of any oil, oily waste, or other refuse in the harbor can result in serious damage to the shore plant cooling water intakes and every precaution should be exercised to prevent such an occurrence.

Chart 25644.-Long Point, 3.6 miles E of Southwest Cape, is a low projecting point covered with grass. W of the point is Long Point Bay, which is shoal. **Southwest Shoal,** 1.2 miles S of Long Point, has only 6 feet of water over it, and E to Krause Point the outlying reefs are the most dangerous along the S coast. They generally break, but as several shoal spots are S, the area should be approached with caution.

Southwest Anchorage, between Long Point and Southwest Cape, offers temporary anchorage in 7 fathoms 2 miles offshore. Small vessels can anchor in 4 fathoms a mile from shore.

A channel, privately marked and entered about 1.5 miles 125° from Southwest Cape, leads in an E direction to mooring buoys about 1.1 miles E of Long Point; channel and mooring buoys are maintained by Texaco Antilles Ltd., St. Croix, Virgin Islands. The channel is primarily for the use of tankers arriving at the mooring buoys.

Southwest Cape, the SW extremity of St. Croix Island, is a low point projecting 1.2 miles in a SW direction. The point is covered by low bushes and trees. A coral reef extends S, with a least depth of 9 feet, at a distance of 0.8 mile from the shore. A buoy marks the SW extremity of this shoal. The 5-fathom curve is 1.6 miles S of Long Point and nearly a mile S of Southwest Cape, but W of the point it is only 200 yards off. The 100-fathom curve lies nearly 2.5 miles SW of Southwest Cape. **Southwest Cape Light**(17°40.8'N., 64°54.0'W.), 50 feet above the water, is shown from a red skeleton tower near the tip of the cape.

Caution is necessary in approaching Southwest Cape. The point, fringed by shoals, is low for some 3 or 4 miles to the high land of the interior. This may cause the mariner to overestimate his distance from the coast, especially at night.

Sandy Point, the W extremity of the island, is 0.5 mile NNW of Southwest Cape.

The W coast of St. Croix Island trends NNE from Southwest Cape for 2.4 miles to Frederiksted, thence NW for 2 miles, and then curves NE for 2 miles to Hams Bluff. The coast consists mostly of sand beach with the land back of it sloping gently upward in the S part and the hills gradually working W to the shore in the N part. The slopes are covered by grass and bushes. The beach is steep-to with the 10-fathom curve lying 0.5 mile or less offshore.

Frederiksted, on the W coast of St. Croix Island 2.4 miles N of Southwest Cape and 3.7 miles S of Hams Bluff, is a port of call for cruise ships and cargo vessels. Large vessels can dock at the long pier in the 4-mile-wide open roadstead. The principal imports include foodstuffs, building materials, petroleum products, and clothing. Exports include rum and scrap iron.

Prominent features.-Frederiksted Harbor Light (17°43.0'N., 64°53.1'W.), 42 feet above the water, is shown from a white skeleton tower with a white and red daymark on a small wharf at the N part of the waterfront. **Fort Frederik** is 125 yards NE of the light.

A radar tracking station (17°43'13"N., 64°51'18"W.), illuminated at night, is on St. George Hill about 1.5 miles E of Frederiksted. The station is reported to be prominent for many miles.

Storm warning signals are displayed. (See chart

Anchorages.–Vessels anchor in depths of 30 to 60 feet NW and SW of the long pier according to draft. Small boats anchor near the waterfront.

Restricted areas have been established off the W coast of St. Croix Island, N and S of Frederiksted Harbor. (See 207.817, chapter 2, for limits and regulations.)

Routes.–From S, the shoals S of Southwest Cape will be avoided by staying a mile or more offshore. At night stay in the white sector of Frederiksted Harbor Light on the approach to the pier.

Pilotage.–(See pilotage for U.S. Virgin Islands at the beginning of this chapter.) Vessels are boarded 1 mile off the long pier.

Quarantine, customs, immigration, and agricultural quarantine.–(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.) A municipal hospital is at Frederiksted.

Harbor regulations.–Local rules and regulations for Frederiksted harbor are enforced by a **dockmaster,** whose office is on the shoreward end of the long pier.

Wharves.–A 1,600-foot pier extends from the waterfront at Frederiksted. A 242-foot loading platform (pierhead) is about 250 feet inshore of the outer end. Depths along both sides of the pier decrease from about 42 feet at the outer end to 30 feet alongside the loading platform, thence to 24 feet, 350 feet inshore of the E end of the loading platform; breasting dolphins are along the N side of the pier. Warping buoys, three off the S side, and one off the N side of the pier are available to ships in maneuvering alongside.

A roll-on-roll-off facility with landing ramp is on the S side and about 400 yards E of the seaward end of the long pier. A line of dolphins extends about 65 yards SW from the ramp to an offshore platform. Submerged ruins are close N of the line of dolphins. Depths in the approach and alongside the ramp are about 17 to 20 feet. Covered and uncovered storage areas, and mobile cranes up to 20 tons are available at the facility.

A 125-foot-long by 20-foot-wide landing platform for ships' tenders is on the S side of the long pier about 90 yards E of the roll-on-roll-off facility. A small-boat stone landing pier is on the N side of long pier.

Currents at the pier are reported to be more influenced by the wind than the tide and are strongest about 0.25 mile from the pier.

Supplies and repairs.–Some marine supplies and water are available. Bunker fuels, diesel oil, and gasoline can be trucked in from nearby. Limited above-the-waterline repairs are available.

Submarine cables extend WSW to the 100-fathom contour from **Sprat Hole,** 1.6 miles N of Frederiksted. Mariners are requested not to anchor in this area.

Chart 25641.–A general description of the **British Virgin Islands** is included in this chapter for a convenient reference to both the United States and British groups. Complete information is included in H.O. Publication 22, Sailing Directions, The West Indies, Vol. II, published by the Defense Mapping Agency Hydrographic Center, and West Indies Pilot, Vol. II, published by the British Ministry of Defense Hydrographic Department.

Little Tobago Island, 3.5 miles NE of Hans Lollik Island, is nearly 0.5 mile long and 279 feet high. It is steep-to except on its SE side. **Tobago Island,** 1 mile NE of Little Tobago Island, is 0.8 mile long and about 538 feet high. A small rock, awash and steep-to, is about 100 yards off the N point. The SE side of the island is fringed with coral, but elsewhere the coastal cliffs are steep-to. A few rocks lie close off the NW point.

Watson Rock, steep-to and 89 feet high, is about 0.3 mile W of the SW point of Tobago Island. **King Rock,** 0.6 mile S of the SW point, is awash and steep-to. It is near the S end of a bank, over which are general depths of 6 to 9 fathoms, extending about 0.7 mile S of Tobago Island.

Mercurius Rock, 0.8 mile E of the N end of Tobago Island and the only danger between that island and Jost Van Dyke Island, is small and steep-to. It is covered 7 feet. When using the passage between Tobago and Jost Van Dyke Islands, the east side should be favored.

Jost Van Dyke Island, about 2 miles E of Tobago, is 3.5 miles long, lofty, rugged, and steep-to. Near the middle of the N part a summit rises to 1,070 feet. **Great Harbor** and **Little Harbor,** on the S side of the island, are suitable only for small vessels. Great Harbor is about 0.5 mile in extent, with depths of 4 fathoms to about 0.2 mile from its head, and Little Harbor has depths of about 8 fathoms inside the entrance.

Little Jost Van Dyke Island, connected by a shallow ledge to the NE end of Jost Van Dyke Island, is 367 feet high. **Green Cay,** 108 feet high, is a small islet close E of Little Jost Van Dyke Island. **Sandy Cay,** nearly 1 mile S of Green Cay, is 66 feet high at its E end. It is surrounded by shoal water, and foul ground extends 200 yards from the E and W ends. The channel between it and Jost Van Dyke Island is 0.6 mile wide; the island shore must be favored.

Tortola, the largest of the British Virgin Islands, is 10 miles in length and 3.5 miles wide. **The West End,** the W extremity, is about 2 miles NE of Mary Point, St. John. The highest summit in the Virgin Islands is 1,740-foot **Mount Sage** in the W part of the island; rugged hills rise somewhat abruptly from the shores on all sides.

Great Thatch Island, about 0.6 mile N of Mary Point from which it is separated by The Narrows, is 1.7 miles long, and near its center rises to a peak 613 feet high. The E point is bold and steep-to. **Thatch Island Cut,** the channel between Great Thatch and The West End, is deep. Sailing vessels should not attempt Thatch Island Cut from the N except with a S current, as the eddies and currents are very strong.

The Narrows, between St. John Island and Great

KAHE POINT, OAHU

14. HAWAII

Chart 540.–Hawaii, a Polynesian kingdom until 1893 and then briefly a republic, requested and was granted annexation to the United States in 1898 and was given a territorial form of government in 1900. By Presidential proclamation of August 21, 1959, Hawaii officially became the 50th of the United States.

The **Hawaiian Islands,** an archipelago, consist of eight large islands, plus many islets, reefs, and shoals, strung out from SE to NW for 1,400 nautical miles in the north-central Pacific Ocean. The archipelago extends from 18°55'N. to 28°25'N., and from 154°49'W. to 178°20'W., straddling the Tropic of Cancer. All the islands of the archipelago, except 2-square-mile Midway, are part of the State of Hawaii.

The capital and chief population center of the State is Honolulu on the island of Oahu; the port is 2,091 nautical miles from San Francisco, 4,685 miles from the Panama Canal, and 2,477 miles from Anchorage, Alaska. Land area of the State totals 6,425 square statute miles, of which the "Big Island" of Hawaii alone accounts for nearly 63 percent. The other seven large islands are, in order of size, Maui, Oahu, Kauai, Molokai, Lanai, Niihau, and Kahoolawe.

The major islands are mountainous and of volcanic origin; the Island of Hawaii has two volcanoes that are still active. Elevations range from sea level to nearly 14,000 feet, with many peaks in excess of 2,500 feet. Although coastal plains, valley floors, and certain plateaus are relatively flat, much of the surface is quite rugged, with high ranges and deep ravines or gorges.

Nearly all of the island streams may be classified as mountain torrents, although some of them can be navigated for short distances by small boats. Most of the streams are on the N and E coasts, where rainfall generally is heaviest.

The 20-fathom depth curve is seldom more than a mile from shore and usually is not far from the coral reefs that fringe much of the island coastline. The bottom generally pitches off rapidly to great depths from a narrow coastal shelf, and the few off-lying dangers usually are indicated by breakers or by a change in color of the water. Under normal conditions the color of the water changes from a deep blue in the open ocean to a blue-green between the 10 and 15-fathom curves; bottom features become visible at 6 to 7 fathoms.

Agriculture is Hawaii's bedrock industry. Sugar exports total over a million tons annually, and the State produces and exports well over half of the world's output of canned pineapple. Truck farming is intensive, particularly on the Island of Oahu, and cattle ranches range from small to very large (one of the largest cattle ranches in the United States is on the Island of Hawaii). Military expenditures and tourist trade are major sources of income.

Polynesian-English Geographic Glossary

Following are the English meanings of Polynesian words that occur frequently in Hawaiian geographic names:

Ana–cave	Loko–pond
Awa–harbor	Lua–crater
Hale–house	Mauna–mountain
Heiau–temple	Moana–ocean
Hono–harbor	Moku–islet
Kai–sea	Pali–cliff
Kapu–prohibited	Pele–volcano
Kona–south	Puu–hill
Koolau–north	Wai–water
Lae–cape	Wailele–waterfall
Lapa–ridge	

Emergency signal flag.–The State of Hawaii has adopted an emergency signal flag as one of the signals that may be used or displayed when a vessel is in need of assistance; the flag should be at least **2 feet square** and **international orange** in color. This distress signal is authorized by the Hawaii Boating Law.

Harbors and ports.–Honolulu is by far the largest commercial deepwater facility in Hawaii. Other commercial deepwater harbors are Hilo and Kawaihae on Hawaii Island, Kahului on Maui, and Nawiliwili and Port Allen on Kauai. These ports service both overseas and interisland shipping.

Hawaii has several commercial barge harbors engaged in interisland shipping. Some of the more important are at Kaumalaupau on Lanai, and Kaunakakai, Haleolono, and Kalaupapa on Molokai. These harbors service only light-draft vessels.

Marine radio communications.–Honolulu is the only port that maintains a commercial radio communication watch. Vessels desiring services at other Hawaiian ports must make arrangements in advance.

COLREGS Demarcation Lines.–The lines established for the Hawaiian Islands and United States Pacific Island Possessions are described in 82.1410 through 82.1495, chapter 2.

Control over movement of vessels.–Regulations require advance notice of vessel's time of arrival to Captain of the Port. (See Part 124, chapter 2.)

All vessels are requested to exercise caution when navigating through the charted U.S. Navy submarine transit lanes.

Anchorages are numerous except on the N and E sides of the islands where shelter from the trade winds is a major requirement. The anchorages on the S and W sides of the islands are unsafe during kona weather.

Tides.–The periodic tides around Hawaii average only 1 to 2 feet. The tides along the N coasts usually occur about 1 to 1½ hours earlier than the tides along the S coasts. (See Tide Tables for daily predictions of times and heights of high and low waters.)

The effect of strong winds added to normal tidal action may cause water level to fall considerably below chart datum and/or rise considerably above mean higher high water. A heavy surf, particularly from N, gives the impression of higher tides on the exposed beaches; there is usually little actual increase under such conditions. On the S side of Oahu, where the trades usually blow directly off the land, a shift to kona winds or to a calm has been observed to raise the tide level a few tenths of a foot.

Currents.–The variable oceanic currents in the vicinity of Hawaii are believed to depend mostly upon the velocity and direction of the wind, but there are many reports of strong NE currents setting against the prevailing trades. There is a prevailing W oceanic drift in the vicinity of the larger islands and as far W as Necker Island.

The tidal currents are generally rather weak and are influenced by winds and oceanic movements. Such currents are mainly reversing in the channels between the larger islands, but they are rotary in more open waters, particularly around the W islets, and shift direction continuously in a clockwise movement.

Tsunamis (seismic sea waves).–The Hawaiian Archipelago has been visited from time to time by tsunamis, which caused enormous destruction. Loss of life and property can be lessened by intelligent response to warnings that such waves are imminent. (See chapter 1 for basic discussion.)

The National Oceanic and Atmospheric Administration administers a tsunami warning system that alerts the Hawaiian Islands, other Pacific islands, and most of the countries bordering the Pacific. The system has an operating center at the Honolulu Observatory on Oahu and includes scattered seismograph stations for quick detection and location of submarine earthquakes, a network of wave-detecting and reporting stations throughout the Pacific, a high-priority communication setup, and an extensive international arrangement for broadcasting warnings of possible sea waves.

Military authorities in Honolulu will issue warnings to all military bases that might be affected. Local base commanders will put into effect any precautions deemed necessary. Elsewhere warnings will be broadcast by civilian authorities. Disaster committees have been set up on all the major islands to alert the population and to assist in evacuation and rescue as needed. In Honolulu and Hilo, former air raid sirens now operated by the police department will be used. On Oahu, Civil Air Patrol planes equipped with sirens will fly the shoreline and sound the alarm. This service will later be extended to the other islands. On all the major islands, police cars equipped with sirens will patrol the coastal areas. Local commercial broadcasting stations will interrupt all programs to give the latest information and instructions.

The National Weather Service will broadcast all warnings over its VHF-FM stations on 162.55 MHz, Honolulu and Hilo, and 162.40 MHz, Kauai and Maui.

Should a warning occur when a radio station is closed down, it will come on the air immediately and remain on until the all clear is sounded. When an alarm is given, all persons are warned to turn on their radios to a local broadcasting station for information and instructions. If they have no radio and cannot find access to one nearby, they should seek high ground. Telephones are apt to be flooded with calls and therefore cannot be relied on during a warning.

When a warning is received, persons should vacate waterfront areas and seek high ground. The safest procedure for ships will depend upon the amount of time available, and this may not always be known. A ship well out at sea would ride such waves safely, and hence, if time is available to put to sea, that would be the safest action. During the 1946 wave, the master of a ship lying offshore near Hilo felt no unusual waves, though he could see great waves breaking on the shore. Crews of fishing boats in the Hawaiian area also reported no unusual conditions at that time. On the other hand, the crew of a ship in the harbor may have a difficult time averting serious damage.

The destructive force is usually greater on the sides of the islands facing the oncoming waves, but this directional effect is frequently lacking and the waves may reach their greatest heights on the leeward sides of the islands. The waves may also attain great heights in funnel-shaped bays and at capes or other places where a submarine ridge projects seaward toward the oncoming wave. Unusual heights may be attained at any place where two waves traveling different paths arrive at the same time to reinforce each other. There is still much to be learned about these waves, and the best policy is to avoid them in any way possible.

Weather.–The tables following the appendix includes climatological tables for Honolulu, Hilo, and Lihue. The appendix lists National Weather Service offices, and radio stations which transmit weather information.

Storm warning display locations are listed on NOS charts and shown on the Marine Weather Services Charts published by the National Weather Service.

General.–The climate of the Hawaiian Islands is unusually pleasant for a tropical area, the result principally of the marked marine influence and the persistent trade winds. Considering the latitude of the islands, there is relatively little uncomfortable heat. The discomfort that is occasionally experienced usually occurs when the trades are temporarily displaced by light variable or S winds, which are accompanied by comparatively higher humidities. The outstanding climatic features of the islands are the dominant trade-wind influences throughout all seasons, the remarkable variation in rainfall over adjacent areas, and the uniform temperature regime which varies slightly throughout the year.

During the summer season the trades blow with a high degree of persistency. As a result, uncomfortable periods are usually delayed until fall, and thus follow by weeks or possibly as much as 2 months the period when the highest temperatures occur. Rains most frequently fall at night.

Thunderstorms are infrequent and practically never severe. Hail seldom occurs. Occasionally local storms are accompanied by winds of sufficient force to do limited damage, but severe storms such as hurricanes or tornadoes are rare. So-called thick weather is almost unknown to the extent of seriously interfering with shipping, and is usually confined to mist and rain, rather than being in the form of fog. Except for rare 1- or 2-day disruptions of interisland airplane schedules, interference to shipping or travel because of bad weather is almost unknown.

Pressure and general circulation.–The strongest influence in the pressure pattern underlying the general circulation of air over the Hawaiian Islands area is the persistent and semipermanent high-pressure cell known as the Pacific high. The clockwise circulation around this cell, coupled with a slight deflection of the surface winds away from the high pressure, result in the NE trades that are the dominant winds of the area.

Winds.–The trade-wind influence is dominant in all seasons throughout the greater part of all the islands. In some local areas, winds deviate from the general pattern because of topography. In coastal areas where mountains to the E project high above sea level, as they do in the kona districts of the Island of Hawaii, the trades are cut off, resulting in prevalent SW winds with land and sea breezes in evidence. Such effects may be rather general in some areas and extremely local in others.

Tropical cyclones.–The Hawaiian Islands lie on the extremities of both the W North Pacific typhoon area and the E North Pacific hurricane area. Therefore, a tropical cyclone from either region is rare.

Typhoons can form in any month, but they rarely cross 180°; when they do they are usually extratropical and well N of the islands. It is not impossible, but highly improbable, that a typhoon will move through the Hawaiian Islands.

It is more probable that an E North Pacific hurricane would hit the islands. These storms, prevalent from May through November, originate from the North American coast W between 10°N and 20°N. Most hurricanes either recurve or dissipate before reaching the Hawaiian Islands. August is the most favorable month for one of these storms to reach the area, though they have occurred from July through November.

Kona weather.–The word "kona" is of Polynesian origin and means leeward. It refers to the S winds and accompanying weather on the normally leeward slopes of the principal Hawaiian Islands which, because of the wind shift, have temporarily become the windward slopes.

The konas, which occur most frequently during October through April, provide the major climatic variations of the Hawaiian Islands. During these storms, heavy rainfall and cloudiness can be expected on the lee sides of coasts and slopes, which, under the usual wind pattern, receive less cloudiness and may have almost no rain. Near gales may occur, especially near points where the air tends to funnel into sharp mountain passes near the coasts. At such times leeward anchorages may become unsafe for smaller craft.

Precipitation.–The complicated rainfall pattern over the islands results chiefly from the effects of the rugged terrain on the persistent trade winds. Frequent and heavy showers fall almost daily on windward and upland areas, while rains of sufficient intensity and duration to cause more than temporary inconvenience are infrequent over the lower sections of leeward areas.

In the districts where the trade winds are dominant, rains are decidedly heavier at night than during the day. This applies generally to the greater part of the islands. Daytime showers, usually light, often occur while the sun continues to shine.

Considerably more rain falls from November through April over the islands as a whole than from May through October. It is not unusual for an entire summer month to go by without measurable rain falling at some points on the Maui isthmus; at times considerably longer dry periods may occur in that locality.

Temperature.–Elevation is the major control factor in determining temperatures, although location, whether in a leeward or windward position, is also a noticeable factor. The highest temperatures reached during the day in leeward districts are usually higher than those attained in windward areas. The daily range is also greater over leeward districts where, because of less cloudiness, the maximum temperatures are higher and the minimum temperatures usually lower.

August and September are the warmest months, and January and February are the coldest. At Honolulu there is an average monthly range between a low of 72.5°F in January and February, and a high of 79.4°F in August. The extreme range of temperature at Honolulu for the 5-year period of record is from a low of 56°F for January, to a high of 93°F recorded in September. This spread of only 37°F between the extreme high and extreme low temperatures is small when compared with ranges at Pacific coast ports.

Humidity.–All coastal areas are subject to the relatively high humidities associated with a marine climate. Humidities, however, vary considerably, with high percentages over and near the windward slopes to low percentages on the leeward sides of the higher elevations.

At Honolulu the normally warm months of August and September are usually comfortable because of the persistency of the NE trades which numerous high peaks; **Kaala,** 4,046 feet high, is the highest.

Between the two mountain ranges is an extensive plain which extends from Pearl Harbor on the S to Haleiwa on the N; the plain rises to an elevation of about 1,000 feet at Wahiawa. There are low, flat, coastal plains between Honolulu and Barbers Point, in the vicinity of Waianae, Haleiwa, and Kahuku Point, and between Kaneohe Bay and Waimanalo. The greater part of these plains is under cultivation, principally in sugarcane.

Prominent headlands on Oahu are Makapuu Point, Koko Head, Diamond Head, Kaena Point, Kahuku Point, Kualoa Point, and Mokapu Peninsula. The entire coast of the island is fringed with coral reefs 0.5 to 1 mile in width, except along parts of the W shore between Barbers Point and Kaena Point. From Kaena Point to Kahuku Point, the reefs are not so continuous as along other parts of the island.

Harbors and ports.–The largest harbors on Oahu are Kaneohe Bay and Pearl Harbor; the latter is a prohibited area. Honolulu is the only commercial deepwater harbor on the island. Small-craft harbors include Maunalua Bay, Honolulu's Ala Wai Boat Harbor and Kewalo Basin, Pokai Bay, and Waialua Bay. The NE coast is exposed to the trade winds during most of the year, and the only small-craft shelter available is in Kaneohe Bay.

Currents.–The currents around Oahu depend largely upon the winds and are variable in velocity and direction. The general tendency is a W or N flow along the coast. Tidal currents and eddies are noticeable in some places.

Weather.–Thanks largely to the marked marine influence and the persistent trade winds, the climate of Oahu is unusually pleasant for the Tropics. Records for downtown Honolulu, on the leeward side of the island, show a lowest temperature of 56° F and a highest of 93° F. In some parts of the Koolau Range the annual rainfall is as much as 300 inches; at Honolulu the average is 22 inches. The driest region is the SW where rainfall drops to below 20 inches a year.

Storm warning display locations are listed on NOS charts and shown on the Marine Weather Services Charts published by the National Weather Service.

Supplies and repairs.–All kinds of supplies are available at Honolulu, and medium-size vessels can be handled for repairs.

Communications.–Oahu has a good network of hard-surfaced highways. Air and sea transportation is available from Honolulu to the other islands and to the mainland.

Honolulu is the only port in the Hawaiian Islands that maintains a commercial radio communication watch.

Chart 19358.–**Makapuu Head,** the E extremity of Oahu, is a bold, barren, rocky headland 647 feet high. **Makapuu Point Light** (21°18.8' N., 157°39.1' W.), 420 feet above the water, is shown from a 46-foot white cylindrical concrete tower on the head.

The seaward side of Makapuu Head is a dark cliff; the inland side slopes rapidly to the valley which separates it from the Koolau Range. The headland is the landfall for vessels inbound to Honolulu from the mainland.

There is deep water close to the outer end of the headland, but shallower water is found along the N and E sides. Deep-draft vessels should give Makapuu Head a berth of about a mile and or stay in depths greater than 20 fathoms.

The **restricted area** of the Makai Undersea Test Range extends NW and NE from Makapuu Point. (See 207.805, chapter 2, for limits and regulations.)

Koko Crater, 2.6 miles SW of Makapuu Head and 0.5 mile from the beach, is a sharp, brown cone 1,204 feet high. The coast between Makapuu Head and Koko Crater is low sand, rock, and shingle; from Koko Crater to Koko Head the coast is rocky, precipitous, and somewhat irregular.

Hanauma Bay, 3.5 miles SW of Makapun Head, is 0.3 mile wide and extends 0.5 mile inland. The waters off the entrance are very choppy during E winds, but the bay does afford good shelter for small craft in all weather except during E winds. Across the head of the bay is a sand beach that is fringed by 150 yards of coral reefs. Back of the beach is a steep bluff up which a paved road leads to the highway. The bay is a popular camping, picnic, and bathing area. The State of Hawaii has established an underwater park in the bay.

Koko Head, 4 miles SW of Makapuu Head, is a bold promontory 640 feet high; the seaward side is precipitous, the top is flat, and it slopes off rapidly on the inland side. The headland is partly wooded on its lower W slopes, but its general appearance is mostly brown and barren. There is deep water close to Koko Head. Strong W currents have been reported offshore.

Maunalua Bay is an open bight that extends W from Koko Head to Diamond Head; coral reefs fringe most of the shore. On the W side of Koko Head, a dredged channel, marked by private buoys and daybeacons, leads through the reef to a private marina in Kuapa Pond and to a public launching ramp behind the reef. The channel has a least depth of 5 feet, except at the entrance where it shoals to a depth of 3 feet on the E side near Daybeacon 2. Behind the Koko Head reefs is one of the few anchorages that offer small-craft shelter in all weather except kona storms. Although depths are 13 feet, only small craft familiar with the area should venture behind the reefs. Tidal currents in Maunalua Bay flood W and ebb E; slack waters occur at about the times of high and low waters at Honolulu.

Wailupe, 2.7 miles W of Koko Head, is a residential area with a seawall and private piers. A channel, reported dredged to 12 feet, leads through the reefs to Wailupe.

Diamond Head, 9 miles WSW of Makapuu Head is an extinct crater 761 feet high. The steep slopes and the top of the crater are bare and brown; the base is brush covered. **Diamond Head Light** (21°15.5'N., 157°48.7'W.), 147 feet above the water large ships are moored at Berth 8. **Kalihi Channel** is marked by lights, buoys, and a 007° lighted range.

The Sand Island highway bridge over the harbor end of Kalihi Channel has a bascule span with a clearance of 15 feet. (See 117.900, chapter 2, for drawbridge regulations and opening signals.)

Anchorages.-Recommended anchorage, except during strong kona winds and within at least 600 yards on either side of an underwater sewer outfall line that extends from a point on Sand Island in 21°18'13.7"N., 157°53'14.0"W., thence to 21°17'00.6"N., 157°54'06.0"W., thence to 21°16'56.0"N., 157°54'31.0"W., and thence to 21°16'59.2"N., 157°54'43.1"W., is in depths of 12 fathoms, sand and coral bottom, in Mamala Bay between the seaward ends of the two deepwater channels. Anchorage is not practical in the harbor basins because of the limited swinging room. An **explosives anchorge** is 1.3 miles W of the entrance to Kalihi Channel. (See 110.235, chapter 2, for limits and regulations.)

Tides.-The diurnal range of tide is 1.9 feet at Honolulu. Daily predictions for Honolulu are given in the Tide Tables.

Currents.-It is reported that a tidal current floods W and ebbs E along the coast between Makapuu Point and Honolulu. In the vicinity of Honolulu and E counterflow along the edge of the reef is reported to accompany the W flood. Strong W currents have been reported off Honolulu. Currents setting toward all four quadrants and having velocities up to 1 knot have been noted about 3 miles SW of Diamond Head.

Tsunamis (seismic sea waves).-The size of a predicted tsunami cannot be estimated in advance. Most of them felt in Honolulu Harbor have been relatively small; the largest of record was 10 feet high, in 1960. However, it is prudent to anticipate that even greater ones may strike.

Honolulu Harbor authorities require all ships to vacate the harbor prior to the estimated time of arrival of a sea wave if possible. If a long engine-warmup is necessary, it should be started at the first alert so the vessel may be ready to proceed in time.

Telephone notification will be given by the Captain of the Port to vessel agents who must, in turn, notify their respective ships. Messengers will be used to the extent available to supplement the telephone warnings.

When ready to depart, each ship should obtain clearance from the harbormaster. The Aloha Tower, traffic control, may be contacted by telephone (808-548-2359), or voice radio on VHF-FM, call sign KFQ-907, channel 16 (156.80 MHz); after calling, the ship will be instructed to shift to the working frequency of channel 12 (156.60 MHz).

The **harbormaster** will assign the exit channel and time of departure, in accordance with assigned priorities and in consideration of the time each vessel becomes ready to move. The assigned priorities for vessels ready to depart are: Government vessels, passenger vessels, tankers, vessels with explosive cargo, and freighters.

Vessels unable to move in time should take adequate precautions against damage during the tsunami due to the expected rise and fall of the water.

(See discussions of tsunamis at beginning of this chapter and in chapter 1.)

Weather.-The climate of Hawaii is unusually pleasant for the tropics. Its outstanding features are (1) the persistence of the trade winds, where not disrupted by high mountains; (2) the remarkable variability in rainfall over short distances; (3) the sunniness of the leeward lowlands, in contrast to the persistent cloudiness over nearby mountain crests; (4) the equable temperature from day to day and season to season; and (5) the infrequency of severe storms.

The prevailing wind throughout the year is the NE trade wind, although its average frequency varies from more than 90 percent during the summer to only 50 percent in January.

Annual rainfall in the Honolulu area averages less than 30 inches along the coast (25 inches at the airport, 24 inches in the downtown area), but increases inland at about 30 inches a mile. Parts of the Koolau Range average 300 inches or more a year. This heavy mountain rainfall sustains extensive irrigation of cane fields and the water supply for Honolulu. E (windward) of the Koolaus, coastal areas receive 30 to 50 inches annually; cane and pineapple fields in central Oahu get about 35 to 40 inches. Oahu is driest along the coast W of the Waianaes where rainfall drops to about 20 inches a year. However, variations from month to month and year to year are considerable; more so during the cooler season, when occasional major storms provide much of the rain, than in the summer, when rain occurs primarily as showers that form within the moist trade winds as they override the mountains. Thus, March rainfall at Honolulu Airport has ranged from more than 20 inches to as little as 0.001 of an inch. In the mean, about half of the airport's annual total occurs during its 3 wettest months, December through February. Trade-wind rain fall is more frequent at night. Daytime showers, usually light, often occur while the sun continues to shine, a phenomenon referred to locally as "liquid sunshine."

Hawaii's equable temperatures are associated with the small seasonal variation in the amount of energy received from the sun and the tempering effect of the surrounding ocean. The range in temperature averages only 7° between the warmest months (August and September) and the coolest months (January and February) and about 12° between day and night. Daily maximums run from the high 70's in winter to the mid-80's in summer, and daily minimums from the mid-60's to the low 70's. However, the Honolulu Airport area has recorded as high as 93°F and as low as 52°F.

Average water temperatures at Waikiki Beach vary from 75°F in the morning to 77°F in the afternoon during March, and from 77°F in the morning to 82°F in the afternoon during August.

Because of the persistence and moderate humidity of the NE trade winds, even the warmest months are usually comfortable. But when the trades diminish or give way to S winds, a situation known locally as "kona weather" ("kona storms" when stormy), the humidity may become oppressively high.

Weather severe enough to interfere with shipping or travel is uncommon. Intense rains of the October to April "winter" season sometimes causes serious, but local, flash flooding. Thunderstorms are infrequent and usually mild, as compared with those of the midwestern United States. Hail seldom occurs, and when it does it is small and rarely damaging to crops. At great intervals a small tornado or a waterspout moving onshore may do some slight damage. Four hurricanes have struck Hawaii since 1950, but several times that many, and a number of less intense tropical cyclones, most of them drifting W from their breeding grounds off the Mexican coast, have approached near enough for their outlying winds, clouds, and rain to affect the islands.

The National Weather Service office is in downtown Honolulu; **barometers** may be compared there or by telephone. (See appendix for address.)

(See page T-11 for **Honolulu climatological table.**)

Storm warning display locations are listed on NOS charts and shown on the Marine Weather Services Charts published by the National Weather Service.

Pilotage is compulsory for all foreign vessels and U.S. vessels under register in the foreign trade. It is optional for U.S. vessels in the coastwise trade, provided they are under the control and direction of a pilot duly licensed by Federal Law.

Services of the State Pilots of the Harbors Division may be obtained by flag hoist, voice radio to Aloha Tower, VHF-FM channel 16 (156.80 MHz), call sign KFQ-907, or in an emergency, by signalling the Pearl Harbor Navy Control Tower, call letters H-1.

Vessels are boarded at the Honolulu Pilot Station (21°16.2'N., 157° 53.4'W.), 2 miles S of the Honolulu Channel.

In addition to the above, the State of Hawaii has established **special pilotage regulations** for all **tankers, tanker barges, and tankerlike vessels.** In general the regulations require these vessels to have on board a Honolulu Port Pilot when entering or departing Honolulu Harbor for any reason. Exempt from this requirement are tankerlike vessels and vessels towing tanker barges when under the control and direction of a person duly licensed as a pilot by the U. S. Coast Guard for the Port of Honolulu, and tankers when departing from anchorage. A copy of the rules and regulations affecting such vessels may be obtained from the Department of Transportation of the State of Hawaii, Harbors Division, Honolulu, or at the office of the harbormaster.

Towage.-Tugs up to 3,300 hp are available in Honolulu. Salvage equipment is also available.

Quarantine, customs, immigration, and agricultural quarantine.-(See chapter 3, Vessel Arrival Inspections, and appendix for addresses.)

Quarantine is enforced in accordance with regulations of the U.S. Public Health Service. (See Public Health Service, chapter 1.)

Honolulu is a **customs port of entry.**

The U. S. Public Health Service maintains an **outpatient clinic** in Honolulu. (See appendix for address.) The Public Health Service also has contract space at several hospitals in Honolulu.

Coast Guard.-The **Captain of the Port** maintains an office in Honolulu. A **marine inspection office** and a **vessel documentation** office are in Honolulu. (See appendix for addresses.)

Harbor regulations are established by the Harbors Division, Hawaii Department of Transportation, and are enforced by the harbormaster. **Traffic control** in Honolulu is controlled by means of orange ball and orange cone signals on the yardarm on Aloha Tower by day and by amber lights on the tower at night. The lower light, showing fixed, is 143 feet above the water; the upper flashing light is 152 feet above the water. The lights are visible 5 miles from 320° to 062°. Traffic signals are: by day, ball hoisted at yardarm, incoming traffic only; cone hoisted at yardarm, outgoing traffic only; ball and cone hoisted at yardarm, harbor closed to all traffic; by night, flashing light on, incoming traffic only; fixed light on, outgoing traffic only; both lights on or no lights showing, harbor closed to all traffic. When no day signals are shown the harbor is closed for traffic of vessels over 500 gross tons. It is the invariable custom to display the ball on the E, or Waikiki side of the yardarm and the cone on the W, or Ewa side of the yardarm. To pass visual messages, contact Pearl Harbor Navy Signal Tower, call H-1.

The **speed limit** in Honolulu Harbor is 5 knots for all vessels and tows and 10 knots for sampans, motorboats, and other small craft.

A flashing amber warning light, privately maintained and shown about 22 feet above the water from a pole about 70 yards SSW of Pier 38, is activated when there is a gas leak or the likelihood thereof. Anyone observing the light flashing should remain well clear and upwind, and sources of ignition should be secured.

Wharves.-Honolulu has over 60 piers and wharves around its harbor waterfront. Only the deep-draft facilities are described. (For a complete description of the port facilities, refer to the Port Series, a Corps of Engineers publication.) The alongside depths for the facilities described are reported; for information of the latest depths, contact the State of Hawaii, Department of Transportation, Harbors Division or the private operators. All facilities have direct highway connections. Water and electric shore power connections are available at most piers and wharves.

General cargo at the port is usually handled by ship's tackle; special handling equipment, if available, is mentioned in the description of the particular facility. A 140-ton mobile crane can be rented.

Offshore pipeline terminal **anchorage and nonanchorage areas** have been established off Barbers Point. (See 110.236, chapter 2, for limits and regulations.)

Currents.–There is a general W current along the coast between Honolulu and Barbers Point. Velocities up to 0.8 knot, setting W, have been measured off the point, and greater velocities have been reported.

Chart 19357.–The coast has a general NW trend between Barbers Point and Kaena Point, a distance of about 20 miles, and consists of alternating ledges of rock and stretches of white sand. Spurs of the Waianae Mountains extend to most of the points. Between the spurs and ridges are heavily wooded valleys that contrast with the rocky and bare mountains. A highway follows the coast from just N of Barbers Point to Kaena Point.

Much of the shoreline is fringed with rocks and reefs, but they are mostly close to the shore. The 3-fathom curve is within 0.5 mile of the shore, and the 10-fathom curve is within 1 mile. Vessels can avoid all outlying dangers by giving the coast a berth of 1 to 1.5 miles. There are no harbors or anchorages along the W coast that afford shelter in all winds. During E weather small craft anchor 0.5 mile offshore in Pokai Bay.

A private barge harbor is about 2 miles NW of Barbers Point. The entrance channel through the reefs and the basin have been dredged to 21 feet. The channel is marked at the entrance by buoys, and by a private unlighted 058° range. Small craft may take shelter in the harbor during an emergency.

A flashing amber warning light, privately maintained and shown from a pole about 22 feet high on the S side of the harbor, is activated when there is a gas leak or the likelihood thereof. Anyone observing the light flashing should remain well clear and upwind, and sources of ignition should be secured.

Kahe Point, 3.5 miles N of Barbers Point, is the seaward end of a mountain spur. A large powerplant is on the point. Two short boulder groins extending from the shore protect the intake of the plant's cooling system. A private light is off the W side of the point.

Nanakuli, 5.5 miles N of Barbers Point, is a homestead areas near the shore.

Puu o Hulu, about 7 miles NW of Barbers Point, is a narrow rocky, barren ridge, 1.5 miles long. A large water tank is on the saddle of the S slope. The ridge is on **Maili Point,** the S of the two important projecting points of this coast, and is the most conspicuous landmark in this vicinity. The W end of the ridge is close to the shore and has an elevation of 856 feet; it is precipitous on its seaward side.

Chart 19361.–Laulualei Homestead tracts are N and NE of Puu o Hulu. Two 1,500-foot radio towers are prominent in the valley. **Puu Mailiilii,** about 2 miles N of Puu o Hulu, is a narrow, rocky ridge, 723 feet high, near the shore and approximately at right angles with it.

Low **Kaneilio Point,** 10 miles NW of Barbers Point, projects 0.2 mile from the general coastline. A fish haven consisting of old auto bodies is a mile S of the point. Between Puu o Hulu and Kaneilio Point the light-colored buildings of a limekiln 0.3 mile inland show up against a dark background.

Pokai Bay, on the NW side of Kaneilio Point, is the seaward approach to **Waianae,** Shallow water extends 0.3 mile from the inner shore of the bay. The breakwater extending N from Kaneilio Point and marked at the end by a light, and the opposing boulder groin from the inner shore form a small craft shelter and moorage area in depths of 5 to 14 feet. Boats moor to pilings behind the breakwater. Repair facilities are not available; however, fuel can be trucked to a small service dock on the inside of the breakwater at about the midpoint. A launching ramp is available.

Local magnetic disturbance.–Differences of 2° or more from normal variation may be expected in Pokai Bay.

A deep valley extends about 4 miles inland between Puu o Hulu and Lahilahi Point and is the largest valley on this side of the Waianae Range. The broken ridge which makes down to Puu Paheehee divides the valley. **Puu Paheehee,** 652 feet high, is about 1 mile inland from Waianae.

Lahilahi Point, 1.7 miles NW of Kaneilio Point, is a detached, steep ridge of dark rock, 234 feet high. This narrow, conspicuous point, projecting seaward about 0.2 mile, has the appearance of an islet from a distance and is known to local fishermen as **Black Rock.** An apartment building on the beach 250 yards N of the point and a hotel about 1.2 miles NNE of the point are good landmarks.

Kepuhi Point, 13 miles NW of Barbers Point, is a few hundred yards from the seaward end of a bold, rocky, mountain spur.

Chart 19357.–The coastal bight between Kepuhi Point and Kaena Point, 7 miles to the NW, is backed mostly by ridges of the Waianae Mountains. Midway along the bight is a sand beach in front of a small valley; small boats can make beach landings when the sea is smooth and can anchor in depths of 4 to 6 fathoms about 0.2 mile offshore.

Kaena Point, the NW extremity of Oahu, is low and rocky and is only a few hundred yards from the foot of Kuaokala Ridge. **Kaena Point Light** (21°34.7'N., 158°16.9'W.), 65 feet above the water, is shown from a 20-foot white pyramidal concrete tower. Off the end of the point are several low, jagged rocks, over which the sea washes, and breakers extend about 0.4 mile from shore. The 10-fathom curve is 0.8 mile W of the point.

The **danger zone** of a firing area covers a wide sector N of Kaena Point. (See 204.224, chapter 2, for limits and regulations.)

Currents.–A continuous NW current and moderate tide rips are reported off Kaena Point. Observations over a 24-hour period at a location 0.8 mile S of Kaena Point Light show a NW current averaging 0.8 knot; the greatest velocity measured was 1 knot.

The N coast of Oahu trends E for 9 miles from Kaena Point to Waialua, thence NE for another 11 miles to Kahuku Point; rock ledges alternate with stretches of white sand beach. The broad valley back of Waialua spreads to the coastal plain, which narrows as it approaches Kaena and Kahuku Points; most of the valley is cultivated in sugarcane. From Kaena Point to Waialua the mountains have a rugged appearance; from Waialua to Kahuka Point the hills resemble a continuous plateau. A hard-surface highway parallels the coast.

Most of the N coast is fringed with reefs as much as 0.5 mile in width, but all dangers can be avoided by staying at least a mile from shore. Haleiwa Small-Boat Harbor is the only harbor along the N coast.

Kuaokala Ridge, back of Kaena Point, is high, and its seaward end breaks off rather abruptly. White domes and telemetry antennas are conspicuous along the ridge. The scattered beach houses between Kaena Point and Waialua are backed by cultivated fields that extend to the mountains.

Kaiaka Bay is a small coastal dent 9 miles E of Kaena Point; **Kiikii Stream** and **Paukauila Stream** empty into the head of the bay. Prominent from offshore is the mill stack in **Waialua,** a half mile back of the beach. A depth of 3 feet can be carried halfway into the bay by passing between the **Kaiaka Point** reefs, on the NE side, and the reef in midentrance.

Waialua Bay, a mile NE of Kaiaka Bay, is a small dent at the bend in the middle of the N coast. The bay shores are low, black rock, with sand patches in the bights and fringed by large algaroba trees. The low land back of the beach slopes gently to a tableland with mountain ranges on either side. **Haleiwa** is at the head of Waialua Bay.

Haleiwa Small-Boat Harbor, at the head of Waualua Bay, is protected by a breakwater on the W and a mole marked by a light on the E. In January 1974, the midchannel controlling depth in the entrance channel was 10 feet. The channel is marked by lighted and unlighted buoys and by a **129°** lighted range. Depths inside at the berths are reported to be 6 to 7 feet. Water is available at most berths, and a launching ramp is in the harbor. The harbor can be entered in all but the most violent storms, at which time good anchorage is found about a mile offshore in 20 to 30 fathoms.

Anahulu River empties into the SW corner of Waialua Bay. River navigation is restricted by the fixed bridge over the mouth; the clearance is 8 feet for a channel width of 14 feet.

The narrow coastal plain between Waialua and Kahuku Point is backed by a vegetation-covered tableland with steep seaward slopes that are cut by deep gorges.

Waimea Bay, 5 miles NE of Waialua, is a small coastal dent at the mouth of the **Waimea River** gorge. The highway bridge over the river can be seen from seaward. A yellow-brown tower and scattered buildings are visible on the N side of the bay.

Wananapaoa Islet, the outer of two ragged masses of black rock off the S point of Waimea Bay, has deep water close to its seaward sides. The submerged rocks near the point on the NE side of the bay are usually marked by breakers.

Waimea Bay affords little shelter, and beach landings can be made only in very smooth weather. There is a wide beach at the head of the bay, but both sides of the entrance are fringed with rocky ledges. Indifferent anchorage is available in depths of 9 or 10 fathoms, sand bottom, 0.3 mile W of the river mouth.

Waialee is 4 miles NE of Waimea Bay. A group of large conspicuous buildings is at the foot of a bluff a few hundred yards inland. Also prominent are two large dish antennas atop a ridge about 1.3 miles SW of Waialee and radome on Mount Kawela about 2 miles SE. Low **Kuilima Point,** 5.4 miles NE of Waimea Bay, has a resort hotel complex on the point.

Kahuku Point, the N extremity of Oahu, is low and sandy; the dunes are partly overgrown with vegetation, and there are few scattered trees. The coast rounds gradually at Kahuku Point, and there are several small black rocks close to shore. The land rises gently from the low bluffs near the point to the mountains of Koolau Range. The 10-fathom curve draws in to within 0.4 mile of the point. The breakers afford sufficient daytime warning of coastal dangers, but the low, unmarked point is difficult to locate at night. Currents off Kahuku Point set W or NW, but are sometimes negligible; tide rips have been reported a mile E of the point.

The coast between Kahuku Point and Makapuu Point, 30 miles to the SE, is known as **Windward Oahu** and is more productive than other parts of the island because of its greater rainfall. Paralleling this coast is the Koolau Range from which several spurs reach shore between Laie Bay and Kaneohe Bay. The shore is low and sandy with patches of black rock outcrop, particularly at the headlands and most of the points. Between the shore and Koolau Range is a narrow strip of cultivated land; this coastal area widens between Kaneohe Bay and Waimanalo and is one of the principal agricultural areas of Oahu. There are good highways along the entire coast.

Nearly all of this NE coast is fringed by coral reefs with little or no water over them at low tide, and the area is exposed throughout most of the year to the sea and swell built up by the NE trades. The numerous small openings in the reefs can be navigated by local craft; wider openings lead to Kahana, Kaneohe, Kailua, and Waimanalo Bays. The 10-fathom curve is no farther than 1.6 miles from shore except in Kaneohe Bay.

Kahuku, 3 miles SE of Kahuku Point, is marked by a mill stack which is a half mile from the beach.

Low **Makahoa Point** projects 0.2 mile from the general coast 3.5 miles SE of Kahuku Point. **Kihewamoku,** an islet 24 feet high, is 0.5 mile off

Appendix B
IMPACT CALCULATIONS

B.1 DISCHARGE PLUME GEOMETRY

This section describes the mathematical models used to investigate the downstream behavior of various Pilot Plant discharge configurations.

B.1.1 Near-Field Model

A modified version of the near-field model designed by Koh and Fan (1970) was used to estimate the near-field trajectory, geometry, and dilution for the OTEC Pilot Plant. The purpose of the near-field modeling effort is to provide estimates of plume behavior for evaluating plume related impacts. In addition, near-field results provide initial conditions for the far-field model. The assumptions made in the model include similarity in flow pattern, Boussinesque approximation, and entrainment mechanism depending only on local plume velocity. The near-field model does not consider the effects of the ambient currents on the plume behavior. Significant deviations from the model prediction could occur when the direction of discharge is with or angled into the ambient currents.

Plume behavior from several discharge configurations were evaluated under summer and winter environmental conditions at the candidate Puerto Rico OTEC Site (Lawrence Berkeley Laboratories, 1980). Temperature and density characteristics at Punta Tuna, Puerto Rico were assumed to be typical of the other candidate sites. Land-Based Pilot Plants were assumed to discharge the warm and cold water out of separate discharge structures. Tower or moored Pilot Plants discharged the warm and cold waters, either separately or mixed, out of multiple discharge structures. The discharge configurations considered include: (1) one warm-water and one cold-water discharge structure directed horizontally, (2) four mixed discharges directed vertically downward, and (3) four warm-water and four cold-water discharges directed vertically downward. Near-field model inputs are presented in Table B-1.

TABLE B-1
ENVIRONMENTAL CONDITIONS FOR MODELING DISCHARGE

Parameters	System Configuration	One of Four Discharge Pipes			One Discharge Pipe	
		Mixed	Cold	Warm	Cold	Warm
Warm-water intake	Depth (m)	15	15	15	15	15
	Temperature (°C) (winter/summer)	26.28/27.59	26.28/27.59	26.28/27.59	26.28/27.59	26.28/27.59
	Density (g ml^{-1}) (°C) (winter/summer)	1.02347/1.02302	1.02347/1.02302	1.02347/1.02302	1.02347/1.02302	1.02347/1.02302
	Temperature change across evaporator	-3.1	-3.1	-3.1	-3.1	-3.1
Cold-water intake	Depth (m)	1,000	1,000	1,000	1,000	1,000
	Temperature (°C) (winter/summer)	5.46/5.84	5.46/5.84	5.46/5.84	5.46/5.84	5.46/5.84
	Density (g ml^{-1}) (winter/summer)	1.02758/1.02756	1.02758/1.02756	1.02758/1.02756	1.02758/1.02756	1.02758/1.02756
	Temperature change across condenser (°C)	+3.1	+3.1	+3.1	+3.1	+3.1
Discharge	Discharge depth (m)	100	100	100	100	100
	Jet diameter (m)	12.0	8.5	8.7	17.1	17.3
	Discharge velocity (m sec^{-1})	0.56	0.56	0.56	0.56	0.56
	Jet temperature (°C) (winter/summer)	16.03/16.88	8.56/8.94	23.18/24.49	8.56/8.94	23.18/24.49
	Jet density (g ml^{-1}) (winter/summer)	1.02643/1.02623	1.02760/1.02755	1.02484/1.02443	1.02760/1.02755	1.02484/1.02443
	Discharge orientation	Vertical	Vertical	Vertical	Horizontal	Horizontal
	Current speed (m sec^{-1})	0.116	0.116	0.116	0.116	0.116
	MODEL SITE Winter/summer (Lawrence Berkeley Laboratories, 1980)	Puerto Rico winter/summer (Lawrence Berkeley Laboratories, 1980)	Puerto Rico winter/summer (Lawrence Berkeley Laboratories, 1980)	Puerto Rico winter/summer (Lawrence Berkeley Laboratories, 1980)	Puerto Rico winter/summer (Lawrence Berkeley Laboratories, 1980)	Puerto Rico (Lawrence Berkeley Laboratories, 1980)

B.1.2 Far-Field Model

An order of magnitude estimate of far-field dispersion was obtained using the method of Brooks (1960). This provided a reasonable estimate of far-field dilution for the OTEC Pilot Plant. The Brooks model solves the equation for Fickian diffusion using a diffusion coefficient which obeys the "4/3" law. The model does not treat vertical mixing.

The width of field (L) is given by the expression:

$$L = b\left(1 + \frac{2}{3}\beta\frac{x}{b}\right)^{\frac{2}{3}}$$

Where: $\beta = \frac{12\epsilon}{\mu b}$

L = field width

b = initial field width

x = downstream distance

ϵ = horizontal diffusion coefficient

μ = uniform current velocity

The centerline concentration is given by the expression:

$$C_{max} = C_o \,\text{erf}\left(\frac{\frac{3}{2}}{\left(1 + \frac{2}{3}\beta\frac{x}{b}\right)^3 - 1}\right)^{\frac{1}{2}}$$

where C_{max} is the concentration of a conservative element at the centerline of the plume at some point downstream and C_o is the initial concentration. These expressions were used to evaluate the dispersion and dilution of the far-field water mix.

The far-field model inputs and results are given in Chapter 3, Table 3-3. An ambient current speed of 11.6 cm sec^{-1} was used for all computations and results were calculated to a distance of 10 km.

The results are gross, considering the large flow volumes used and the boundary presented by the strong vertical stratification of the nearby thermocline. Furthermore, the model does not consider buoyancy spreading or vertical mixing.

B.2 CARBON DIOXIDE RELEASE

Carbon dioxide (CO_2) gas may be released from the cold resource water when it is brought to the surface and warmed. An estimate of the carbon dioxide potentially released from the Pilot Plant was made using the cold-water flow volumes. It was assumed the carbon dioxide released is equal to the difference in carbon dioxide content of the deep cold water over that of the warmer surface waters.

The carbon dioxide concentration in surface waters is approximately 1.947×10^{-3} moles kg^{-1} seawater (Takahashi et al., 1970). Water brought to the surface from 1,000m would contain approximately 2.328×10^{-3} moles carbon dioxide kg^{-1} seawater. Therefore, the excess carbon dioxide would be 0.381×10^{-3} moles kg^{-1} seawater, or 1.68×10^{-5} kg CO_2 kg^{-1} seawater. Since the Pilot Plant displaces 128 m^3 sec^{-1} (1.1×10^{10} kg day^{-1}) of cold deep-ocean water to the surface, approximately 1.9×10^5 kg of carbon dioxide would be released each day.

B.3 PROTECTIVE HULL COATING RELEASE

The purpose of this calculation is to estimate the greatest distance from the Pilot Plant hull where seawater would have a copper concentration of 0.1 mg $liter^{-1}$, one tenth the concentration found to inhibit marine dinoflagellate growth rates (Saifullah, 1978). A small parcel of water with a surface area of 1 cm^2 exposed to the Pilot Plant was assumed to pass along the length of the Pilot Plant. With a 12 cm sec^{-1} current speed, this parcel of water would require 16 minutes (960 seconds) to move 115m, the length of the

Moored Plantship. Assuming laminar flow and a cuprous oxide release rate of 30 $\mu g\ cm^{-2}\ day^{-1}$ from the protective hull coating (De et al., 1976), 0.33 μg copper would be released to the parcel of water as it moved along the length of the hull. This was calculated by:

$$\frac{115\ m \times 100\ cm\ m^{-1} \times 30\ \mu g\ cm^{-2}\ day^{-1}}{12\ cm\ sec^{-1} \times 24\ hr\ day^{-1} \times 60\ min\ hr^{-1} \times 60\ sec\ min^{-1}} = 0.33\ \mu g\ cm^{-2}$$

To obtain a concentration of 0.1 mg $liter^{-1}$ (0.1 $\mu g\ cm^{-3}$), the copper released in the parcel of water with a 1-cm^2 surface area exposed to the hull must have a volume of 3.3 cm^3. To calculate the greatest distance from the hull to have a concentration of 0.1 $\mu g\ cm^{-3}$, the copper released was divided by the copper concentration:

$$\frac{0.33\ \mu g\ cm^{-2}}{0.1\ \mu g\ cm^{-3}} = 3.3\ cm$$

B.4 MOORING AND CABLE SCOUR

Assuming that 300m of the mooring lines and submarine transmission cable will scour a 100-m section of the bottom (Figure B-1), the area affected can be estimated.

The area of the right triangle (half the area scoured) is calculated by multiplying one-half the base times the height:

$$1/2 \times 50\ m \times 300\ m = 7,500\ m^2$$

The area scoured is twice the area of the right triangle. Since up to 10 mooring lines and 1 electrical cable will be used for the Pilot Plant and each would scour 15,000 m^2 of ocean bottom, approximately 165,000 m^2, or 0.165 km^2, of ocean bottom is affected.

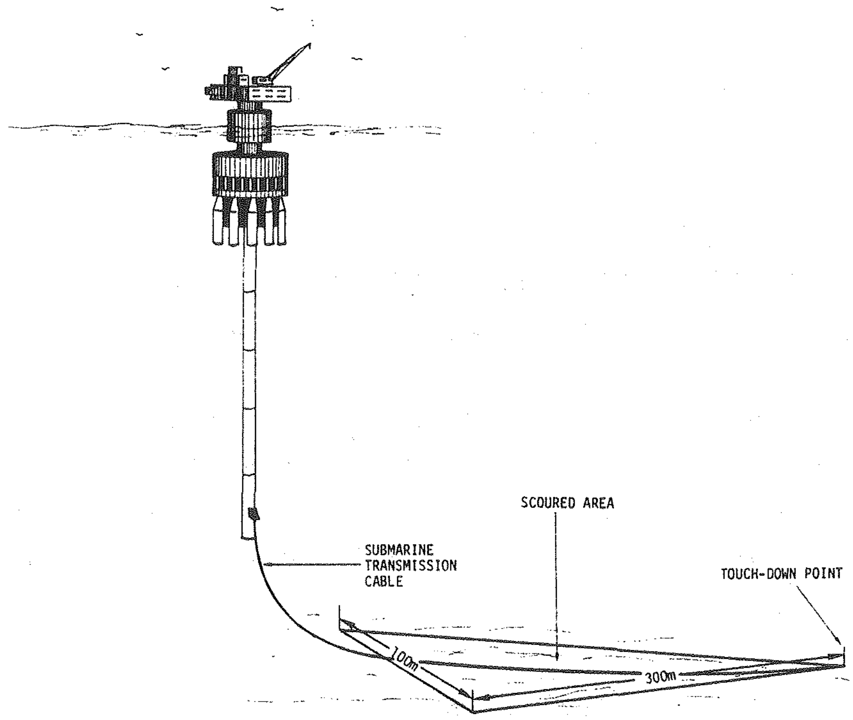

Figure B-1. Bottom Area Affected by Scouring

B.5 REFERENCE WATER COLUMN CALCULATIONS

The net surface velocity at each of the candidate Pilot Plant sites varies from 10 cm sec^{-1} to over 50 cm sec^{-1}. A 12 cm sec^{-1} flow was used in these calculations, since minimum velocities represent the most severe case. The velocity gradient decreases with depth, and subsurface currents were assumed to flow in the same direction as surface currents. Bretschneider (1977) reported the current flow at 1,000m was approximately 10% of surface velocity. Since the population biomass values utilized are only estimates, the net velocity for the entire water column was not integrated; instead it was broken into discrete layers, as listed.

Depth (m)	Surface Current (Percent)
0 - 60	95
60 - 350	50
350 - 1,000	15

The net surface velocity of 12 cm sec^{-1} was calculated through the water column to 1,000m by the percent velocity in each layer. The three-dimensional distribution of these various layers with a 12 cm sec^{-1} net current for 24 hours appears in Figure 3-2. The expected distance traveled by the plume is 10 km in 1 day.

Approximately 3.9 x 10^8 m^3 of water are in the surface to 60-m layer of the affected water column each day, and 9.4 x 10^8 and 6.3 x 10^8 m^3 of water are in the 60 to 350-m and 350 to 1,000-m layers, respectively. Multiplying the biomass concentration by the volume of water in each layer of the water column will provide the total biomass in the affected water column.

The warm- and cold-water flow rates for the Pilot Plant are 132 m^3 sec^{-1} and 128 m^3 sec^{-1}, respectively. Multiplying the biomass concentration at the warm- and cold-water intake depths by the volume of water utilized by the Pilot Plant provides an estimate of the biomass affected. The biomass affected can be compared to the total biomass in the reference water column for an evaluation of impact.

B.5.1 Impingement

Maynard et al. (1975) reported the average micronekton biomass on a wet weight basis to be 0.27 mg m^{-3} and 5.4 mg m^{-3} in the upper 400m during the day and night, respectively. The biomass increase due to attraction to the platform and to lights was assumed to be a factor of 2 each. Therefore, the expected micronekton biomass impinged on the warm-water intake screen is 0.54 mg m^{-3} during the day and 21.6 mg m^{-3} at night. The micronekton biomass near the cold-water intake will be twice the ambient biomass, due to attraction to the cold-water pipe; thus 10.2 mg m^{-3} is available for impingement during the day and 5.0 mg m^{-3} at night.

Gelatinous organisms will also be impinged, but will not be attracted by the structure or lights. Maynard et al. (1975) reported the biomass of "other invertebrates," which are primarily gelatinous organisms, to be 0.57 mg m^{-3}

and 0.86 mg m^{-3} above 400m during the day and at night, respectively. Below 400m the biomass average 0.7 mg m^{-3} during the day and 0.55 mg m^{-3} at night.

The impinged biomass was calculated by multiplying the biomass near the intakes by the volume of water withdrawn. Since 5.7×10^6 m^3 and 5.5×10^6 m^3 of water is withdrawn in 12 hours by the warm- and cold-water intakes, respectively, the following impingement rates were calculated:

IMPINGEMENT RATE (kg wet weight)

Intake		Micronekton	Gelatinous Organisms
Warm-water	Day	3	3
	Night	123	5
Cold-water	Day	56	4
	Night	28	3

The total biomass in the reference water column is calculated by separating the water column into three divisions. However, Maynard et al., (1975) reported data from two depth ranges; 0 to 400m and 400 to 1,200m. Correspondingly, the water column biomass calculations must be divided into four parts:

Depth (m)	Volume (m^3)
0 to 60	3.9×10^8
60 to 350	9.4×10^8
350 to 400	0.5×10^8
400 to 1,000	5.9×10^8

Dividing the calculations by water column layers and the day and night biomass values, the total biomass for the reference water column was estimated to be approximately 7,510 kg wet weight. The 225 kg of biomass impinged was equal to 3.0% of the biomass in the reference water parcel.

B.5.2 Entrainment

a. Oceanic Forms - Data summarized in Section 2 indicates that chlorophyll *a* averages 0.10 mg m^{-3} in surface waters of candidate sites. To convert chlorophyll *a* values to carbon biomass, a multiple of 100 was used (Steele, 1964). The phytoplankton biomass in the warm-water intake waters was calculated to be approximately 10 mg C m^{-3}. Microzooplankton biomass in surface waters is about 0.2 mg C m^{-3} (Gunderson et al., 1976). The phytoplankton and microzooplankton biomass at 1,000m (the depth of the cold-water intake) is expected to be near zero (Lawrence Berkeley Laboratories, 1978; Beers, 1978). Multiplying the expected biomass at the warm-water intake depth by the intake flow rate of the Pilot Plant produced an estimate of 114.0 kg C phytoplankton and 2.3 kg C microzooplankton entrained daily.

Assuming an average chlorophyll *a* concentration of 0.1 mg m^{-3} in the upper 60m and 0.2 mg C m^{-3} between 60 and 130m, and converting chlorophyll *a* biomass to carbon biomass by multiplying by 100 (Steele, 1964), the total phytoplankton biomass in the 0 to 60-m and 60 to 130-m regions of the reference water column were calculated to be 3,900 kg C and 4,600 kg C, respectively. Therefore, the phytoplankton biomass entrained was 1.3% of the total phytoplankton biomass in the reference water column.

Another means of comparison is to relate the amount of phytoplankton entrained by the Pilot Plant to the productivity of the surrounding waters. Since productivity at the sites is approximately 100 mg C m^{-2} day^{-1}, the average productivity was estimated to be 0.8 mg C m^{-3} day^{-1}. By using the previously calculated volume of the photic zone in the affected water column, it was estimated that 494 kg will be produced in the reference water column each day. Therefore, the phytoplankton biomass entrained by the Pilot Plant is comparable to the biomass produced during an average 5.5-hour period.

The average concentration of macrozooplankton in the surface layer is about 1.0 mg C m^{-3} during the day and 1.5 mg C m^{-3} at night. Attraction to lights and structure will increase the biomass near the warm-water intake by a factor of 2 each. Therefore, the macrozooplankton expected to be entrained at the warm-water intake is 2.0 mg C m^{-3} during the day and 6.0 mg C m^{-3} at night. The average macrozooplankton biomass at the depth of the cold-water intake is 0.25 mg C m^{-3}, but attraction to structure will double the biomass. By multiplying the average biomass by the intake flow rates, the daily macrozooplankton entrainment rate, 52 kg C, was estimated.

The water column biomass was estimated to be 1.0 mg C m^{-3} for the surface to 150-m layer and 0.25 mg C m^{-3} for the 150 to 1,000-m layer. To calculate the total macrozooplankton biomass in the reference water column, data from the following depths were summed: 0 to 60m, 60 to 150m, and 150 to 1,000m. This yielded a macrozooplankton biomass total of 1,000 kg carbon for the reference water column. The macrozooplankton biomass entrained was equal to 5.2% of the biomass in the reference water column.

b. <u>Nearshore Forms</u> - Approximately 10 to 20% of the macrozooplankton biomass within 5 km of shore at candidate Pilot Plant sites are composed of nearshore organisms (Owen, 1980; Youngbluth, 1975). The biomass in the outer region (2.5 to 5.0 km) was estimated to be 10% of the 0 to 2.5-km region (Hirota, 1979). The total biomass of nearshore organisms can be determined and compared to the nearshore biomass entrained by the Pilot Plant.

The areas of the inner and outer 2.5-km regions around Saint Croix, Oahu, and Puerto Rico are:

	0 to 2.5 km	2.5 to 5.0 km
Saint Croix	230 km^2	240 km^2
Oahu	450 km^2	550 km^2
Puerto Rico	950 km^2	1,100 km^2

Using Saint Croix as a worst-case estimate and assuming the maximum depth at which nearshore larvae occur is 60m, the total meroplankton biomass around Saint Croix was estimated. Since the macrozooplankton biomass in the outer 2.5-km region is 1.0 mg C m^{-3}, the meroplankton biomass was equal to 0.15 mg $C \cdot m^{-3}$. The meroplankton biomass within 2.5 km of shore was 10 times this concentration, or 1.5 mg C m^{-3}. Multiplying by the area in each region, the total meroplankton biomass around Saint Croix was estimated at 7.6 x 10^4 kg C. The Pilot Plant will entrain 6.9 kg C of meroplankton population each day (46 kg x 0.15), comparable to 0.03% of the total meroplankton population around Saint Croix.

B.6 EFFECTS OF OCEAN WATER REDISTRIBUTION

The discharge of nutrient-rich waters into the photic zone may increase the phytoplankton biomass downstream of the Pilot Plant. Data limitations prevent accurate predictions of the resulting enhanced productivity that will occur from these discharges. Therefore, it was assumed that the growth rate of phytoplankton in nutrient-enriched oceanic waters was two doublings per day. This assumption provided a conservative estimate, since growth rates of two doublings per day occur in oceanic waters only under optimal conditions (Parsons and Takahashi, 1973). The average phytoplankton standing stock at depths at which the discharge plume was expected to stabilize, was estimated to be 0.2 mg chlorophyll a m^{-3}, which can be converted to biomass carbon by multiplying by 100 (Steele, 1964).

A 1-meter-long portion of the plume (comparable to 8.6 sec of discharge with a current speed of 11.6 cm sec^{-1}) was followed downstream as the plume widened, due to the entrainment of diluting waters. Phytoplankton- biomass increase estimates were obtained at 5-km intervals by: (1) calculating the volume of water comprising that portion of the plume by taking the centerline dilution factor as an average; (2) summing the phytoplankton biomass in the previous plume interval with the biomass in the water entrained in the plume to obtain an estimate of the phytoplankton biomass required to double; (3) estimating the nitrate required to produce the increase in phytoplankton biomass, (4) subtracting the nitrate required for doubling the biomass from the total nutrients released from the plant; and (5) dividing the doubled phytoplankton biomass by the volume of water in that section of the plume to obtain the phytoplankton concentration.

The Pilot Plant will discharge water having a nitrate concentration of approximately 15 μg-atom liter^{-1}. In 8.6 seconds, approximately 2,240 m^3 of water, or 33,540 mg-atoms of nitrate will be discharged. The phytoplankton biomass in these discharge waters is 20 mg C m^{-3}. After 5 km (12 hours) downstream travel, this section of the plume has a total dilution of 7.5 and a volume of 16,800 m^3. In order for the phytoplankton biomass to double and reach a concentration of 40 mg C m^{-3}, 6.72 x 10^6 mg C is required. This was calculated from:

$$16{,}800\ m^3 \times 40\ mg\ C\ m^{-3} = 6.72 \times 10^5\ mg\ C$$

Subtracting the existing phytoplankton biomass, either already present in the plume or brought in with the entrained waters, from the biomass required for a concentration of 40 mg C m^{-3}, the biomass that must be produced was estimated:

$$6.72 \times 10^5\ mg\ C - (20\ mg\ C\ m^{-3} \times 16{,}800\ m^3) = 3.36 \times 10^5\ mg\ C$$

Using the phytoplankton uptake ratio for nitrogen and carbon of 16:106 (Redfield et al., 1963), the amount of nitrate required to produce this biomass was estimated.

$$3.36 \times 10^5\ mg\ C \times \frac{1\ mg\text{-}atom\ C}{12\ mg\ C} \times \frac{16\ mg\text{-}atom\ N}{106\ mg\text{-}atom\ C} = 4{,}230\ mg\text{-}atom\ N$$

Subtracting the nitrate required for the first doubling to occur from the nitrate discharged provided an estimate of the nitrate remaining for the next doubling.

$$33{,}600\ mg\text{-}atom\ N - 4{,}230\ mg\text{-}atom\ N = 29{,}400\ mg\text{-}atom\ N$$

The biomass that must be produced for another doubling to occur was estimated by multiplying the expected phytoplankton biomass concentration by the volume of water contained in the discharge plume after 1 day's travel, and subtracting the biomass already present.

Biomass required for second doubling	Biomass present from first doubling	Biomass entrained into plume

$$(2{,}240\text{m}^3 \times 15 \times 80 \text{ mgC m}^{-3}) - (6.72 \times 10^5\text{mgC}) - 20\text{mgCm}^{-3}[(2240\text{m}^{-3} \times 15) - 16{,}800\text{m}^3]$$

$$= 1.68 \times 10^6 \text{ mg C}$$

The phytoplankton biomass in the plume after 1 day's (10 km) downstream travel and the second doubling was 2.69×10^6 mg C; however, 6.72×10^5 mg C was already present from the previous doubling and 3.36×10^5 mg C was brought in with the ambient water entrained into the plume. Therefore, 1.68×10^6 mg C must be produced. The nitrate required to produce this biomass was calculated.

$$1.68 \times 10^6 \text{mg C} \times \frac{1 \text{ mg-atom C}}{12 \text{ mg C}} \times \frac{16 \text{ mg-atom N}}{106 \text{ mg-atom C}} = 21{,}100 \text{ mg-atom N}$$

Subtracting the nitrate required for the second doubling to occur from the nitrate remaining after the first doubling provided an estimate of the nitrate remaining for the next doubling.

29,400 mg-atom N - 21,100 mg-atom N = 8,300 mg-atom N

There is not enough nitrate remaining for another doubling to occur. To calculate the biomass that will be produced, the following equation was used:

$$8{,}300 \text{ mg-atom N} \times \frac{106 \text{ mg-atom C}}{16 \text{ mg-atom N}} \times \frac{12 \text{ mg C}}{1 \text{ mg-atom C}} = 6.6 \times 10^5 \text{mg C}$$

Adding this produced biomass to the biomass present in the plume after 1 day's travel, the phytoplankton biomass concentration was approximated:

$$\frac{\text{Biomass previously produced} + \text{Biomass produced}}{\text{Volume of plume}} = \text{Biomass concentration}$$

$$\frac{2.69 \times 10^6 \text{mgC} + 6.6 \times 10^5 \text{mgC}}{2{,}240 \text{ m}^3 \times 15} = 54 \text{ mg C m}^{-3}$$

Therefore, under optimal conditions, the phytoplankton biomass can increase to approximately 100 mg C m^{-3} (5 times the ambient concentration) due to nutrient redistribution.

B.7 HEAT EXCHANGER EROSION AND CORROSION

The daily discharge rate from the Pilot Plant is expected to be 22.5×10^6 m^3. The trace element concentration from structural erosion and corrosion would affect the marine biota if it reached concentrations above 0.2 mg $liter^{-1}$ (Kylin, 1946; Pulley, 1950). For this to occur 4,500 kg of trace elements would have to be released each day. Since the heat exchangers are the major source of trace element release and have a surface area of approximately 300,000 m^2, the release rate would have to be 15.0 g m^{-2}. This is several orders of magnitide higher than the expected release rate.

B.8 AMMONIA SPILL

Approximately 140,000 kg of ammonia will be stored in the Pilot Plant. During a large surface spill, 60% of the ammonia would dissolve and the remaining 40% would be released to the atmosphere. Therefore, 84,000 kg of ammonia would dissolve. To obtain an ammonia concentration of 1 mg $liter^{-1}$, the concentration found to inhibit oceanic shrimp and fish, the ammonia would have to be dissolved in 84.0×10^6 m^3 of water. This is equivalent to a 1.4 km^2 area of the mixed layer (60m).