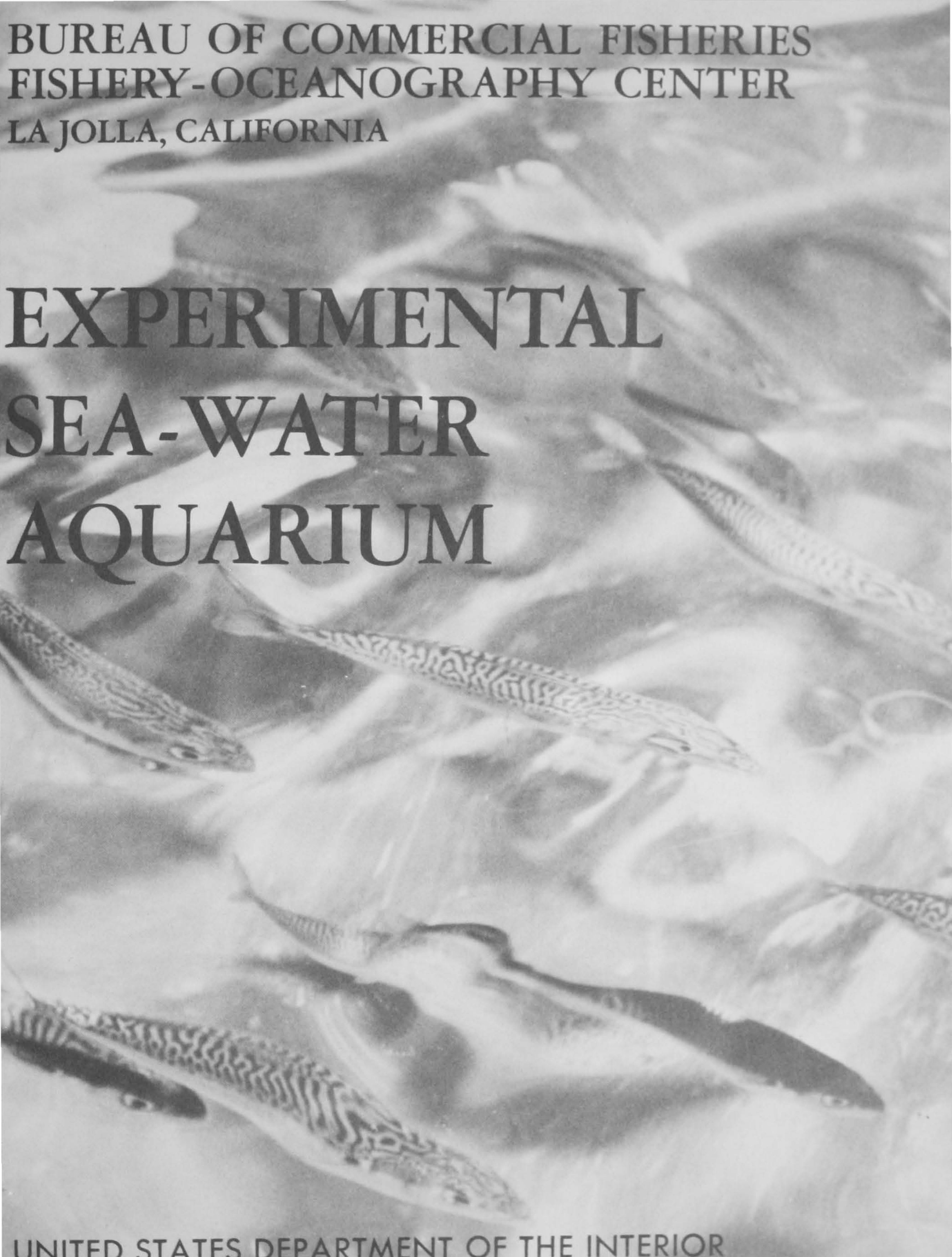
BUREAU OF COMMERCIAL FISHERIES
FISHERY-OCEANOGRAPHY CENTER
LA JOLLA, CALIFORNIA

EXPERIMENTAL SEA-WATER AQUARIUM



UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

Circular 334

Cover. Pacific Mackerel (Scomber japonicus) *about six months old and eight inches long were raised in the BCF experimental aquarium from eggs collected at sea. Photo by George Mattson.*

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EXPERIMENTAL SEA-WATER AQUARIUM

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By REUBEN LASKER and LILLIAN L. VLYMEN

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ABSTRACT

This illustrated paper describes the equipment, design, and operation of the 9,300 $ft.^2$ sea-water experimental aquarium. The Appendix lists the research reports resulting from work performed since this facility began operation in 1965.

CONTENTS

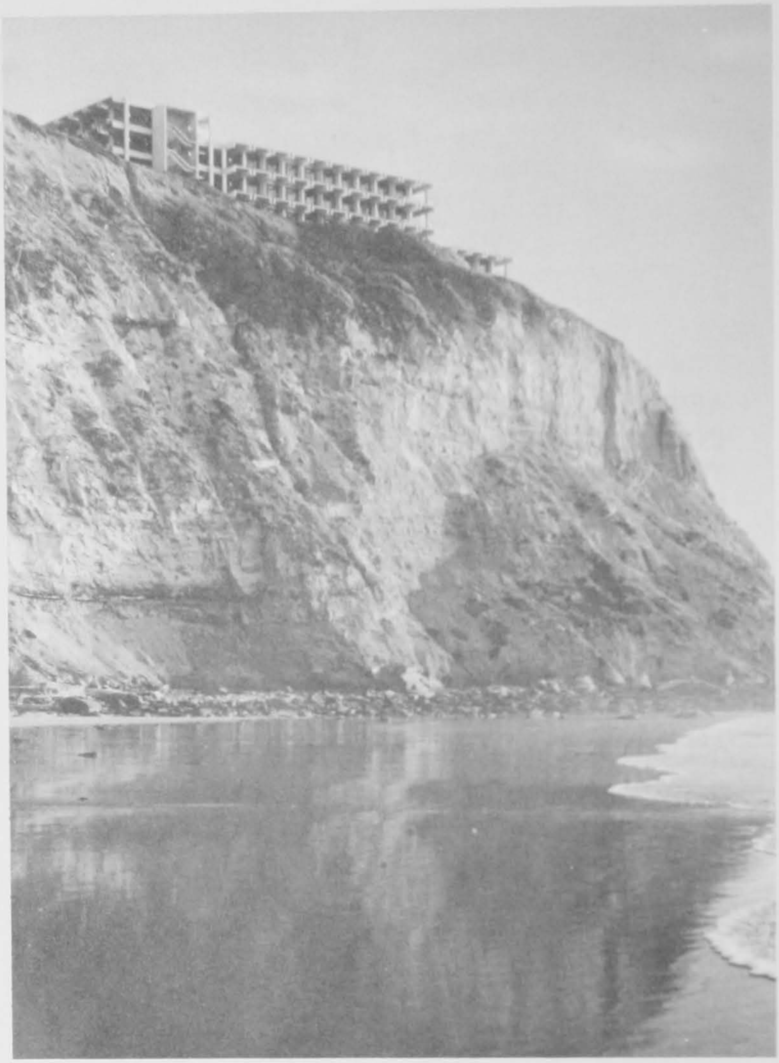


Figure 1. Bureau of Commercial Fisheries Fishery-Oceanography Center, La Jolla, Calif.

INTRODUCTION

Among the facilities at the BCF (Bureau of Commercial Fisheries) Fishery-Oceanography Center in La Jolla, Calif., is a 9,300 ft.^{2} sea-water experimental aquarium, in operation since 1965. The aquarium has a number of important features not usually incorporated into the design of other sea-water systems (see Clark and Clark, 1964, for a review). It is the purpose of this paper to present detailed information on the innovations in equipment, design, and operation that have made this aquarium outstanding for fishery and marine biological research.

The Fishery-Oceanography Center is located at the top of a cliff (fig. 1), 210 ft. above the Pacific Ocean, to the north of SIO (Scripps Institution of Oceanography), University of California, San Diego. Because it was too costly to construct facilities to bring sea water up the cliff face, the University upgraded and extended an existing sea-water pumping, filtering, and delivery system to provide BCF and the expanded SIO facilities with water.

The system, owned and operated by the University of California, extends from the end of the SIO pier to the BCF property line and consists of pumps, a flume on the SIO pier, sand and gravel filter beds, storage tanks, and piping.

The experimental aquarium occupies the entire basement in two of the four buildings (3,600 ft.^{2} in Building C and 5,700 ft.^{2} in Building D) which constitute the Fishery-Oceanography Center (fig. 2). Fixed spaces supplied with running sea water in this area include four completely enclosed and isolated environment rooms, six adjoining cubicles, water tables and workbenches, a small food-preparation room, and a storage space for gear. The remaining area is essentially in two large rooms with no fixed tanks or cross walls, permitting tank sizes, types, and locations to be changed at will. All utility pipes and conduits are exposed and hung from the ceilings. The pipes carry sea water, gas, and compressed air; the conduits carry 120-v. and 205-v. electricity. Large industrial-type heaters and ample fluorescent lighting are hung throughout the aquarium. Ceiling height in the aquarium is 12 ft. between supporting beams and 10 ft. at the bottoms of the beams. The floor is plastic-sealed concrete, sloped and crowned to drain water into gutters that run north to south for 100 ft. in each building. The gutters are 10 ft. from the walls to prevent salt-water contact with the building's foundations.

The area in Building D has no windows. Overhead fiberglass ducts and heavy-duty fans move the moist air out of the aquarium. The aquarium extension in Building C has cross ventilation with many louvered, floor-to-ceiling windows (figs. 3A and B).

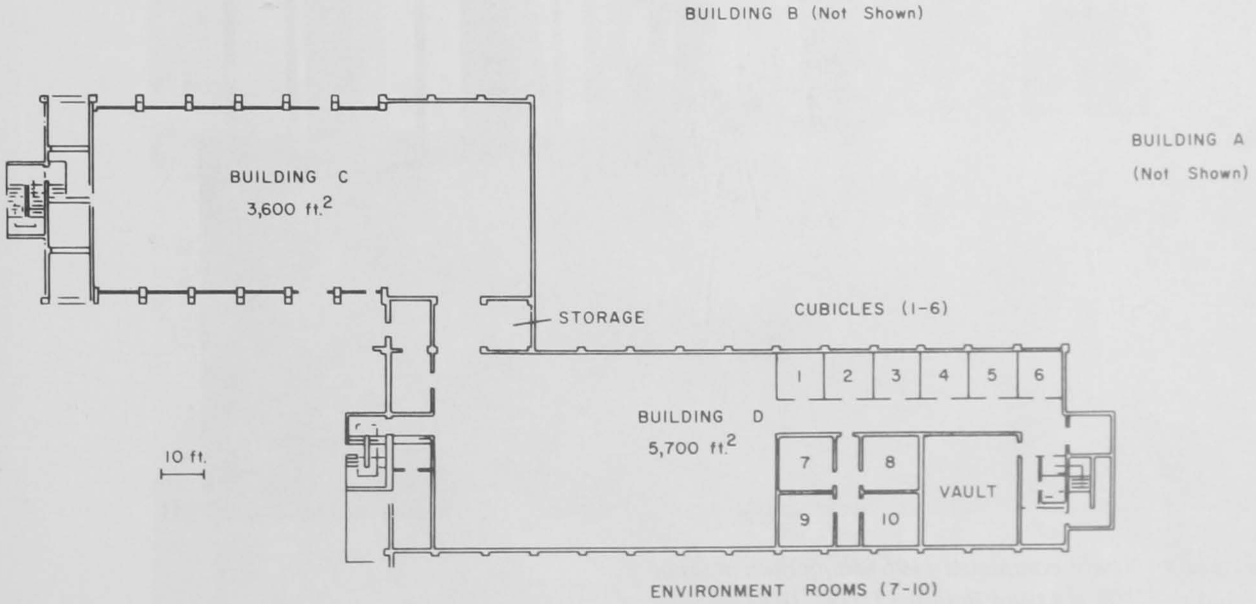
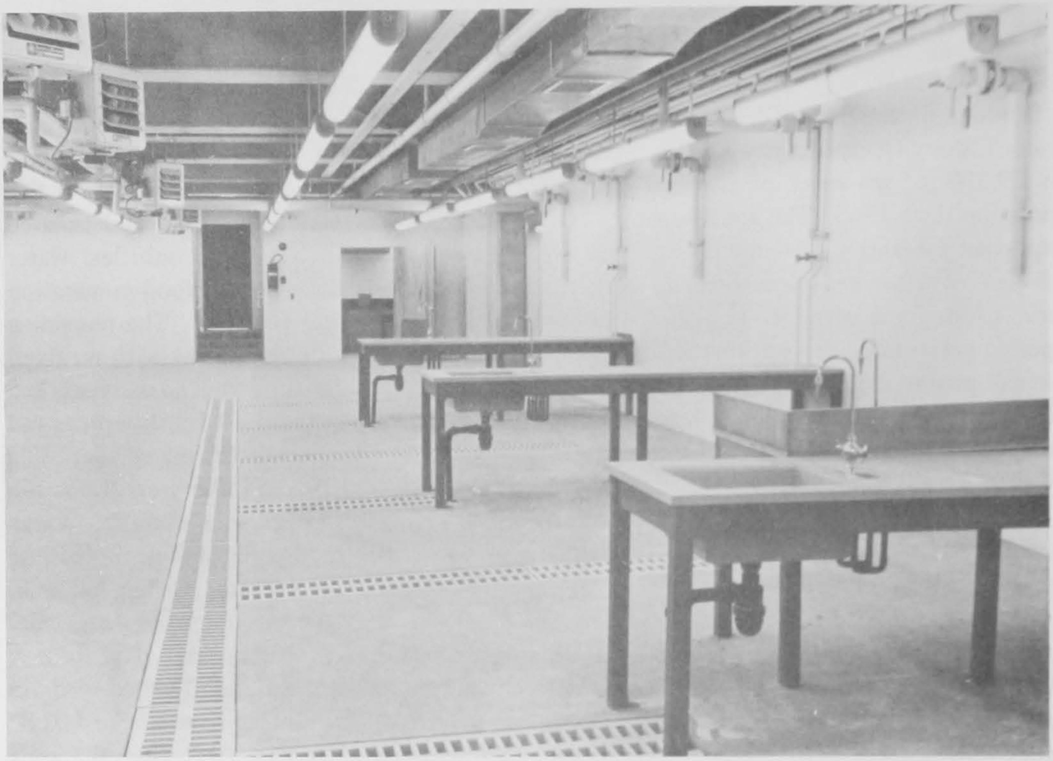


Figure 2. Floor plan of the experimental aquarium.



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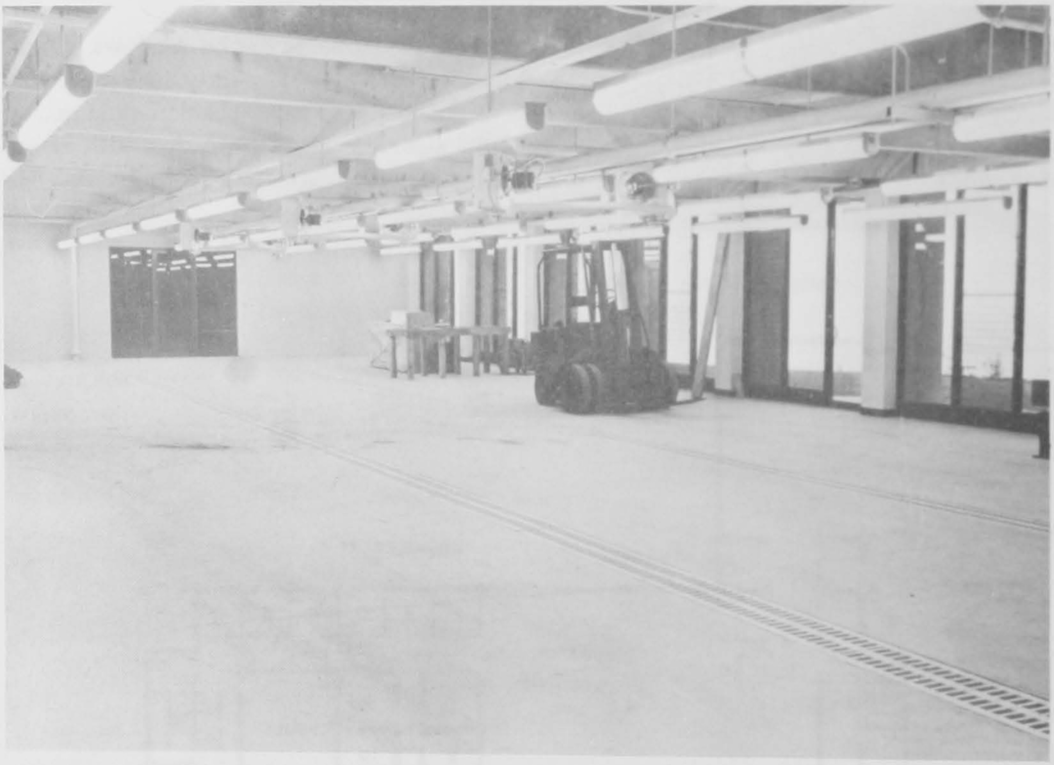


B

Figure 3. Newly completed (1964) aquarium areas in Building C (fig. 3A) and Building D (fig. 3B). Wooden grates cover the drainage troughs.

THE SEA-WATER SUPPLY

The sea-water intake (fig. 4) is at the end of the SIO pier, 900 ft. offshore, 7 ft. above the seabed and 13 ft. below the lowest low-tide level. Pacific Ocean water temperatures off the pier range from about 57° F. (14° C.) in winter to a maximum of 70° F. (21° C.) in summer. Salinity normally is from 33.56 to 33.70 parts per thousand. The sea water is usually saturated with oxygen.

Two 15-hp. suction pumps (Worthington Model 6CNG 104)*, with stainless steel impellers have been used since 1962 to bring sea water into the delivery system. One pump is used while the other is serviced or acts as a standby. Normally the pumps are interchanged on a weekly basis but in the event of a breakdown, three men can replace a pump in less than 8 hours.

*Use of a trade name does not imply endorsement by the Bureau of Commercial Fisheries.

Sea water is pumped from the ocean into a covered redwood flume (fig. 4) that extends almost the length of the pier (900 ft.) to the filter beds. The flume, 15 by 15 inches, is lined with 1/16-inch gray PVC (polyvinyl chloride) sheeting. At weekly intervals, a brush-studded box, with stiff bristles on the sides and bottom and built to fit tightly in the flume, is dropped into the trough at the seaward end of the pier where the rush of the swiftly moving sea water carries it the length of the flume and effectively sweeps away accumulated organisms and debris.

At this point, the raw sea water enters a system of filter beds, storage tanks, transport pipes and reservoir, culminating in delivery of water to the basement sea-water aquarium at the Fishery-Oceanography Center. Water brought in by the flume empties at about

Figure 4. Redwood flume on Scripps Institution of Oceanography *pier.*

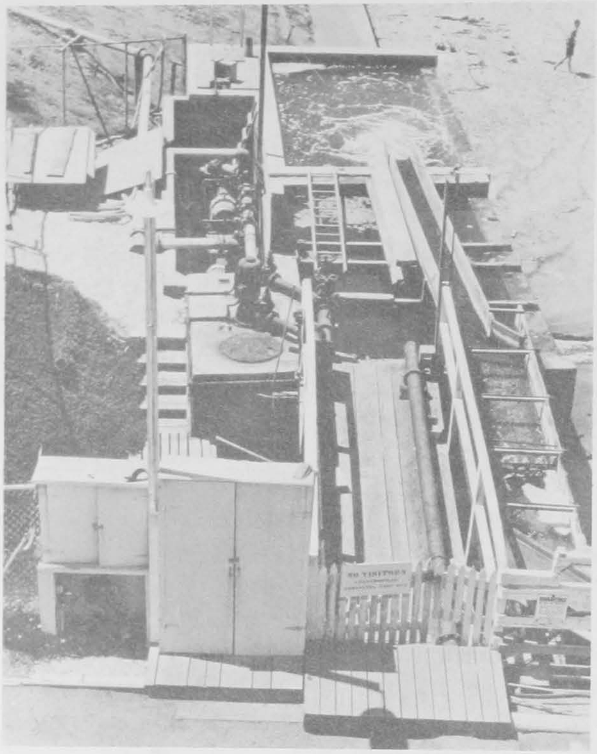
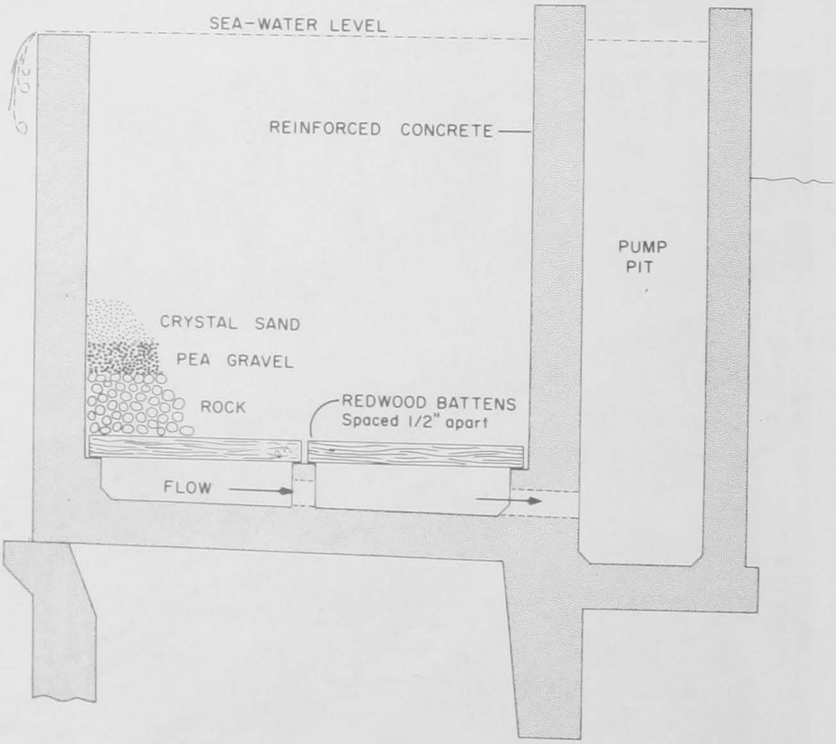


Figure 5. Flume terminal, concrete filter beds, and pumps at the head of the Scripps Institution of Oceanography *pier.*

600 gallons per minute (2,271 liters per minute) into the top of two 10- by 20-ft. concrete filter beds (fig. 5). Each filter bed contains 12 inches of No. 12 crystal sand at the top, succeeded by 8 inches of pea gravel, and 18 inches of rock, laid across wooden battens, with 1/2-inch gaps so that the sea water can drop into a pump pit (fig. 6). From the pump pit, two pumps (40-hp. Worthington Model 4CNG 84) move the filtered sea water through dual, 6-inch epoxy-lined transite pipes (Johns-Manville Co.) to a 40,000-gallon (151,412-liter) concrete holding tank, 90 ft. above the filter bed.

Dual piping is used throughout the sea-water delivery system after it leaves the filter beds. The pipes (Johns-Manville Co.) are epoxy-lined asbestos cement whose smooth, glasslike lining permits easy cleaning. Delivery is alternated at weekly intervals from one pipe to the other; any settled organisms in the drained pipe desiccate and die. When water once again is delivered through the dry pipe, the first flush is usually sufficient to break away dead animals. The dual system also permits emergency repairs to be made without stopping the sea-water delivery.

Figure 6. Cross section of a filter bed and pump pit. The bed is 12 ft. deep.



Sea water is diverted by gravity feed from the 40,000-gallon storage tank to the nearby SIO public and experimental aquariums and to its Physiological Research Laboratory where large concrete pools often hold captive porpoises and other sea mammals for experiments (fig. 7).

Two 30-hp. pumps (Worthington Model CNG 104) at the large storage tank push sea water uphill for a distance of about one-half mile through 6-inch underground pipes to a dual concrete reservoir of two 15,000-gallon (56,880-liter) tanks which directly supply the Fishery-Oceanography Center's experimental aquarium (fig. 8). Access openings and cleanouts are located at intervals along the path of the pipeline to facilitate cleaning and repair.

Figure 8. Storage tanks on a hill directly above the experimental aquarium. Two pipes enter the tanks from above, but only the one to the large deaerating tower is used at present after water arrives by either of the two pipes emerging from the ground on the right.

Figure 7. Diagram of the sea-water supply system. Scripps Institution of Oceanography, University of California, San Diego, *owns and operates all parts of the system to the* BCF *property line.*

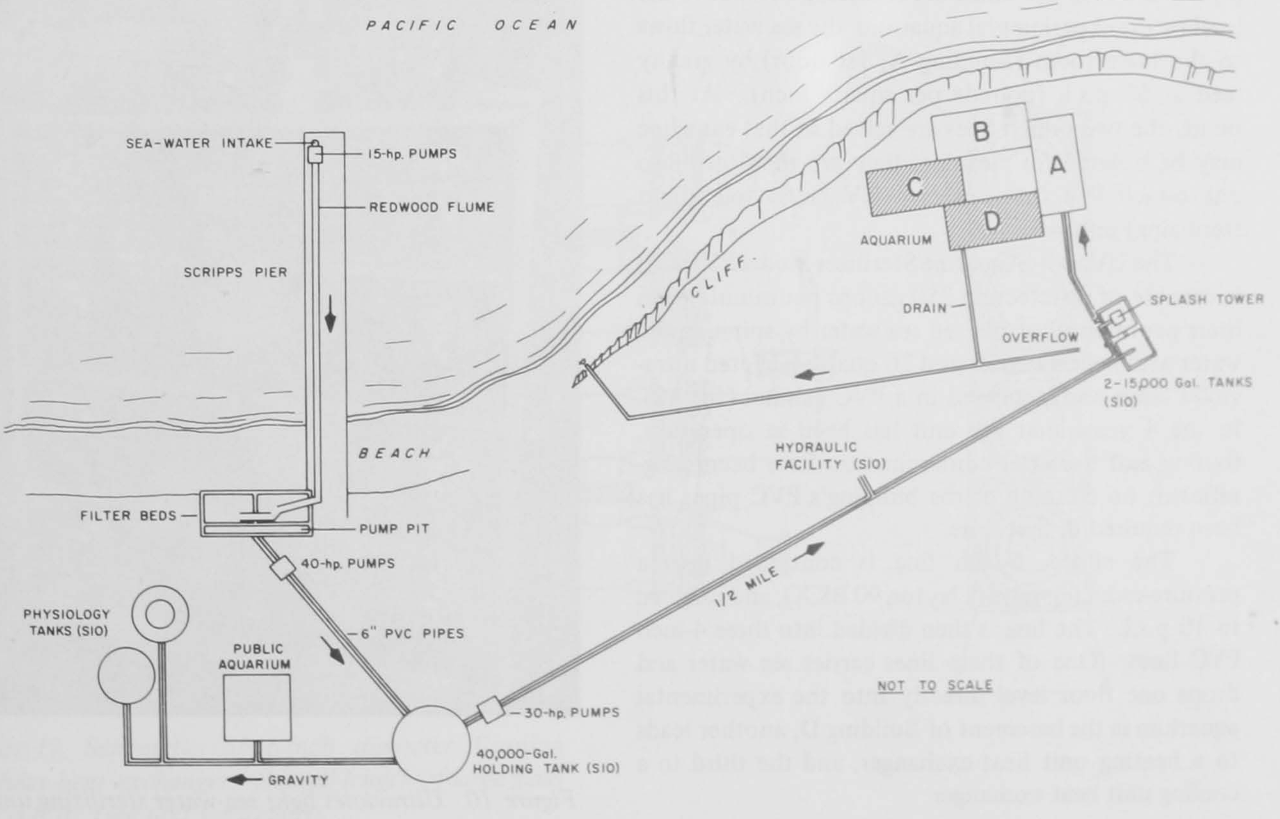


Figure 9. Interior of the splash tower for deaerating sea water.

At the reservoir, the sea water cascades through a splash tower before going into one of the tanks (fig. 9). This tower is an 8- by 8- by 5-ft. structure of redwood siding with stepped wooden baffles that help to dissipate the excess air in the sea water through mechanical action. Each of the concrete tanks is a self-contained unit, so that either one may be cleaned without interrupting the flow of water to the aquarium.

Sea water is heated about 3 to 4° F. (2° C.) as it travels uphill to the Fishery-Oceanography Center. This slight heating supersaturates the water with oxygen and nitrogen. Gas embolism killed some fish in our aquarium during early experiments. The splash tower alleviated this problem although individual scientists make cascades for their own tanks, particularly if they use warmed sea water (see section on Special Facilities for detailed discussion).

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The filtered, air-saturated sea water enters the Center through one or the other of two 6-inch PVC pipes. Because the tanks are located 50 ft. above the level of the experimental aquarium, the sea water flows to the boilerroom (Building A, 1st floor) by gravity feed at 50 p.s.i. (pounds per square inch). At this point, the two 6-inch lines are valved so that each line may be isolated for cleaning; they are then teed into one 6-inch line that enters a UV (ultraviolet light sterilizing) unit.

The UV unit (Aquafine Sterilizer Model PVD-24) is capable of disinfecting 250 gallons per minute (946 liters per minute) of filtered sea water by spinning the water with helical baffles past 26 quartz-jacketed ultraviolet lamp units, encased in a PVC cabinet (fig. 10). In the 4 years that the unit has been in operation, fouling and bacterial contamination have been insignificant; no cleaning of the building's PVC pipes has been required in that time.

The single, 6-inch line is continued into a pressure-reducing valve (Clayton 90 BKX), and reduced to 10 p.s.i. The line is then divided into three 4-inch PVC lines. One of these lines carries sea water and drops one floor level directly into the experimental aquarium in the basement of Building D, another leads to a heating unit heat exchanger, and the third to a cooling unit heat exchanger.

Figure 10. Ultraviolet light sea-water sterilizing unit.

The modular heat exchangers (Corning Glass)—fig. 11—are a shell-and-tube unit, consisting of a bundle of thin-walled (0.030-inch) glass tubes within a 6-inch-diameter glass shell. The sea water enters the tubes and is heated or cooled to the desired temperature through transfer of heat from the surrounding jacket of fresh water. The heating unit requires two horizontal tube bundle assemblies specified to warm 150 gallons per minute (568 liters per minute) to 68° F. (20° C.) when 180° F. (82.2° C.) water from the hot-water boiler of the Center's heating system is used. The cooling unit requires four horizontal tube bundle assemblies specified to chill 50 gallons per minute (189 liters per minute) to 50° F. (10° C.) with a refrigeration unit (Bell and Gossett Hydro-Flow Package Liquid Cooler Model EPCIN 60). The glass units are insulated with a styrofoam casing. In addition, a cooling tower at ground level at the south end of Building D is required to dissipate the heat accumulated by the refrigeration unit. Because the heat exchangers are glass and subject to breakage, the maximum working pressure is limited to 20 p.s.i.—hence the need for the pressure-reducing valve earlier in the line.

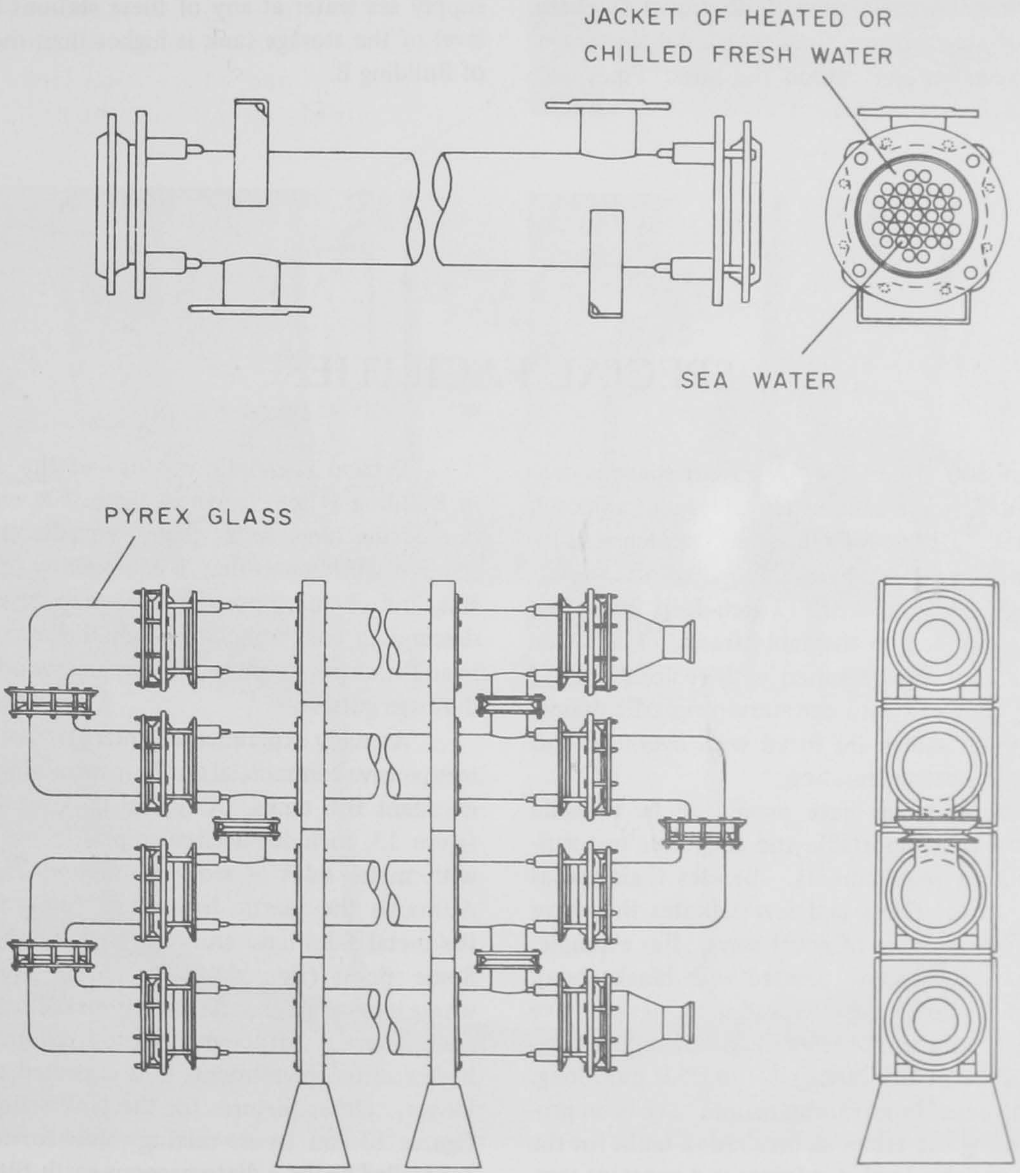

Figure 11. Schematic of 6-inch diameter Corning *modular heat exchanger. Overall length of large glass unit is 8 ft. (see text for details).*

From the heat exchangers the "warmed" and "chilled" sea-water lines drop one floor to the experimental aquarium where the "chilled" line is divided to service the east and west sides of Building D with 3-inch asbestos-insulated pipes; ambient temperature water is similarly piped but not insulated. The warmed sea water is carried through a 3-inch single pipe. Feeder lines, mostly 1-inch, lead out wherever needed in the aquarium. Cleanouts, usually screw-in adapters, are placed at all bends, tees, crosspieces, and ends. To reduce the possibility of clogging and to facilitate the cleanout, straight runs of pipes are used wherever possible.

Cast iron butterfly valves with monel discs are located at strategic places to allow partial shutdown to repair, clean out, or extend the lines. Pipes and fittings are everywhere exposed and readily accessible.

The 3-inch pipes with ambient and chilled water on the west wall of Building D extend around the corner at the south end of Building D and along the north end of Building C. Then they are divided to extend the length of Building C along the east and west sides. The "warmed" sea-water pipe, a single line down the middle of Building D, is extended to run in a single line down the middle of Building C.

Sea water is also delivered from single taps at each level of Building B. These installations have been provided to avoid frequent trips to the aquarium for small amounts of sea water. No pumps are needed to supply sea water at any of these stations because the level of the storage tank is higher than the top story of Building B.

SPECIAL FACILITIES

About 500 ft.^{2} of the open floor space is currently devoted to movable water tables and adjacent workbenches. The water tables have dimensions of 14 by 3 ft. or 8 by 3 ft. and are constructed of 3/4-inch exterior-type plywood with 12-inch-deep fiberglass-tray inserts, bonded to the table frame. The water level in the tray can be varied with removable PVC standpipes, which fit into countersunk plastic drains. The long water tables are fitted with overhead and end shelves for instrumentation.

The water tables have proven to be valuable aquarium tools, semiportable and adaptable to a variety of research requirements. Besides their use as holding tanks for fishes and invertebrates they have been used in a number of novel ways. For example, the smaller water tables, painted with black epoxy and provided with strong overhead illumination, have been used to hold and observe the behavior and feeding of transparent fish larvae, 3.0 to 25.0 mm. long. Large quantities of brine shrimp nauplii have been produced by using the tables as incubation tanks for the eggs. With variable level standpipes and constant temperature sea water the tables have often been used as large constant-temperature baths.

Typical installations south of the cubicle area in Building D are shown in figure 12, which depicts one of the large water tables, an adjacent Formica-covered workbench that is equipped with a fiberglass sink and chemical-proof plastic trap, sea-water lines descending and branching from the main line, overhead fluorescent lights, a heater, and wood grates over drainage gutters.

As many experimental aquarists have discovered, inexpensive commercial outdoor swimming pools make excellent fish tanks. A typical tank setup, shown in figure 13, includes a circular plastic swimming pool with metal sides of steel, aluminum, or wire mesh. Although the plastic liners last almost indefinitely, the metal sides have an average life of about 2 years. Some pools (fig. 14) have marine plywood sides where long-range experiments or special configurations are planned. Although plywood requires a slightly higher initial investment, it is expected to last years longer. Other features for the tank setups shown in figures 13 and 14 are mixing valves for temperature-controlled water, a diatomaceous earth filter (installed at the discretion of the researcher), fluorescent lights, overhead electric conduit, and workbench.

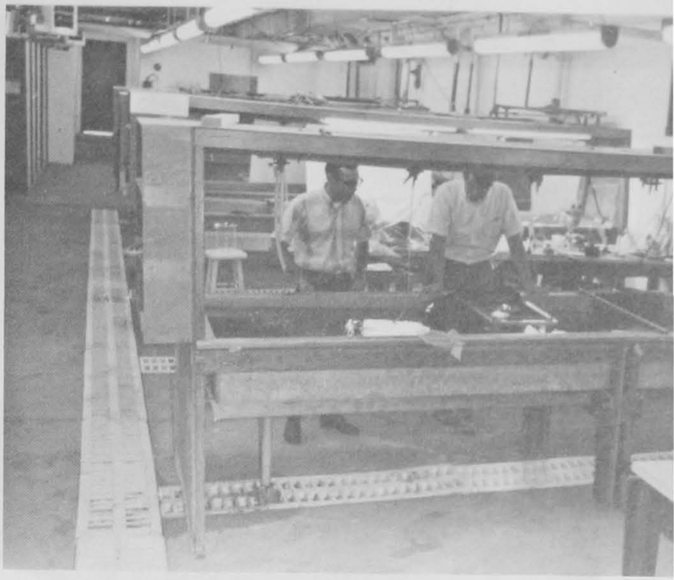

Figure 12. Typical water table installation. Compare this photo with figure 3A (see text for details).

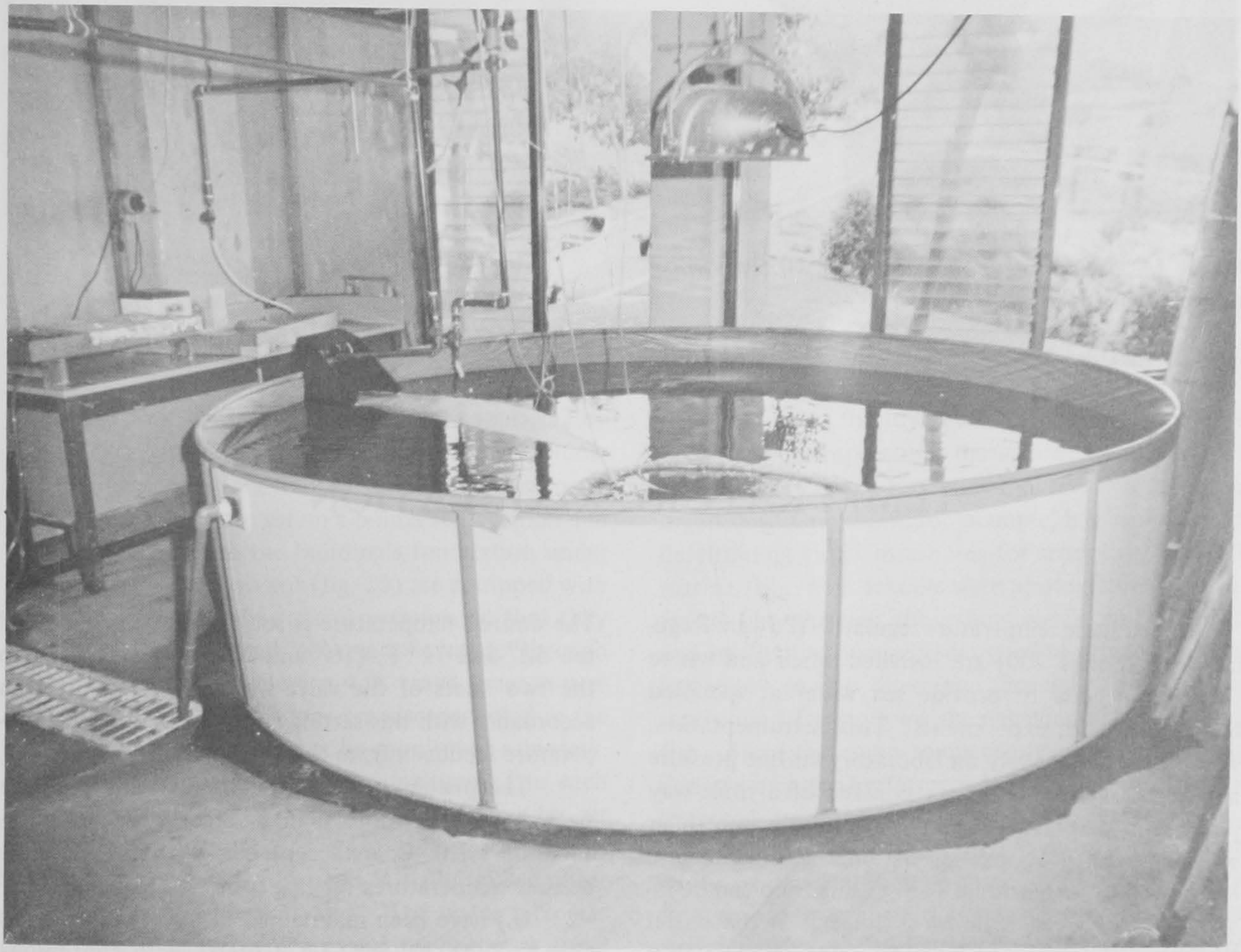

Figure 13. Plastic swimming pool used as an inexpensive fish tank. For deaeration the water is run over a wooden cascade attached to the rim of the tank.

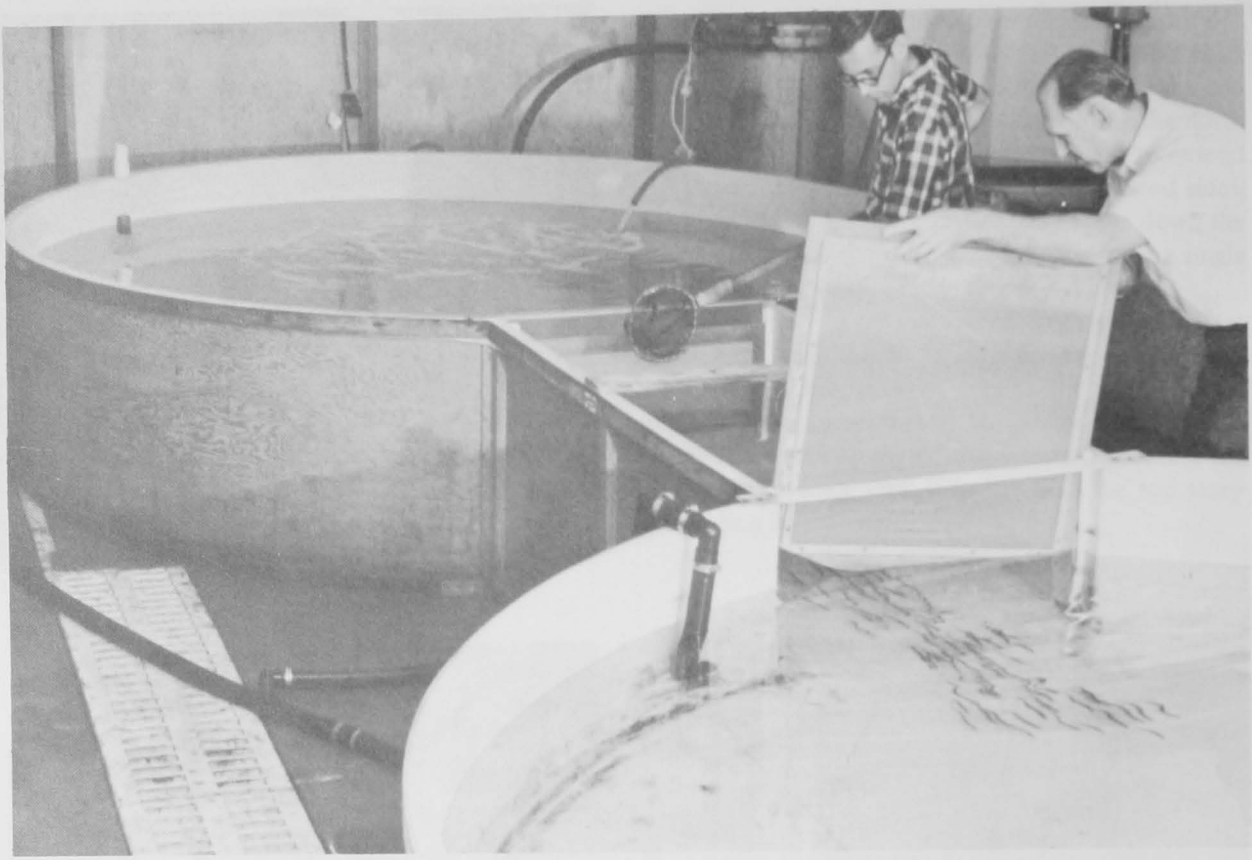

Figure 14. Swimming pool modified with plywood sides for long-term experiments.

TEMPERATURE REGULATION

Pneumatic temperature regulators (Powers Regulator Co., Series 200) are installed when and where they are needed to provide sea water at specified temperatures for experiments. This instrumentation, which operates entirely on laboratory air-line pressure and requires no electricity, consists of a three-way pneumatic diaphragm mixing valve and a controller with a gas-filled copper sensing bulb at the end of a long capillary extension. The sensing bulb can be inserted in a special cylindrical housing in the outlet line from the mixing valve. Some researchers have coated the sensing bulb with a silicone rubber compound (Dow Corning Building Sealant 781), making the copper impervious to corrosion in sea water. The desired temperature is set on the controller, and the 50° and 72° F. (10° and 22° C.) water piped to the two inlets of the valve where they are mixed in accordance with this setting and regulated by the temperature feedback from the sensing bulb.

The pneumatic regulators, in 1/2- and 3/4-inch sizes, have been more than satisfactory where tolerances of ± 1.0° C. are acceptable. Within these limits desired temperatures ranging from 54° to 72° F. (12° - 22° C.) have been maintained in bodies of water as large as 2,000 gallons (7,571 liters), with continuous replacement as low as 5 gallons per minute (19 liters per minute).

One disadvantage of the system is that the ordinary mixing valves are made of cast bronze, which may be harmful to small organisms. No ill effects have been detected, however, with partially grown or mature fish. Where larval fish are involved, the temperature-regulated water has been used only as a water bath.

The greatest danger with this system, where water is heated and cooled under pressure in closed heat exchangers and then mixed by temperature regulators, is nitrogen supersaturation. In the past excessive nitrogen has caused mortalities from gas embolism.

If water is heated several degrees the nitrogen solubility decreases with respect to temperature but the nitrogen remains in solution because of the elevated pressure. If the temperature being maintained is high, the cold water introduced by the mixing valve is insufficient to ameliorate the situation, and the water can be supersaturated for a time after it enters the experimental pool where atmospheric pressure prevails. As a result, the dissolved nitrogen entering the circulatory system of the fish may exceed its solubility in the blood; some of it then comes out of solution to cause embolism. This danger has been eliminated by the simple expedient of placing inlet lines in small wooden splash boxes just above pool surfaces (fig. 13). The combination of pounding and spraying immediately reduces the dissolved air concentration to 100 percent saturation.

ENVIRONMENT ROOMS

The four controlled environment rooms, 12 by 12 by 8 ft., are built of concrete and cement block. To eliminate vibration, the four rooms and their common concrete base are set on a 6-inch felt cushion and thus separated from the building's foundation under the cushion. These rooms (fig. 15) are equipped with temperature- and light-control systems, so that they can be sealed off and observations made through ports in the ceiling where a 4-ft. crawl space is provided. Through-hole fittings are also provided in the walls so that equipment can be monitored remotely. A constant temperature can be maintained in each room from 61° to 77° F. (16° - 25° C.) by air conditioning.

Each room was furnished initially with a water table and a dry table with sink. The water table has fresh water, compressed air, and sea water at three temperatures, 50° F. (10° C.), 72° F. (22° C.), ambient. A drainpipe connects with the general drainage system. Electrical strip outlets are available around all walls.

Owing to the low level of noise and the control of light and temperature, the environment rooms are an excellent facility for behavioral research on marine organisms. One room, for example, has been used for determining visual thresholds for schooling in pelagic marine fish. Fish schools were photographed with infrared film through the ceiling hatch, and the room and its illumination were designed to provide uniform luminance in any direction. Several rooms are currently used for studying the behavior of larval marine fish. Here the room temperature control and isolation are of great importance because the fish must be sustained in static but constant-temperature water and are very sensitive to external disturbances. Currently, one room is being equipped with an automatic data recording system that will permit observers to record aspects of fish behavior directly on perforated paper tape to be analyzed by computer.

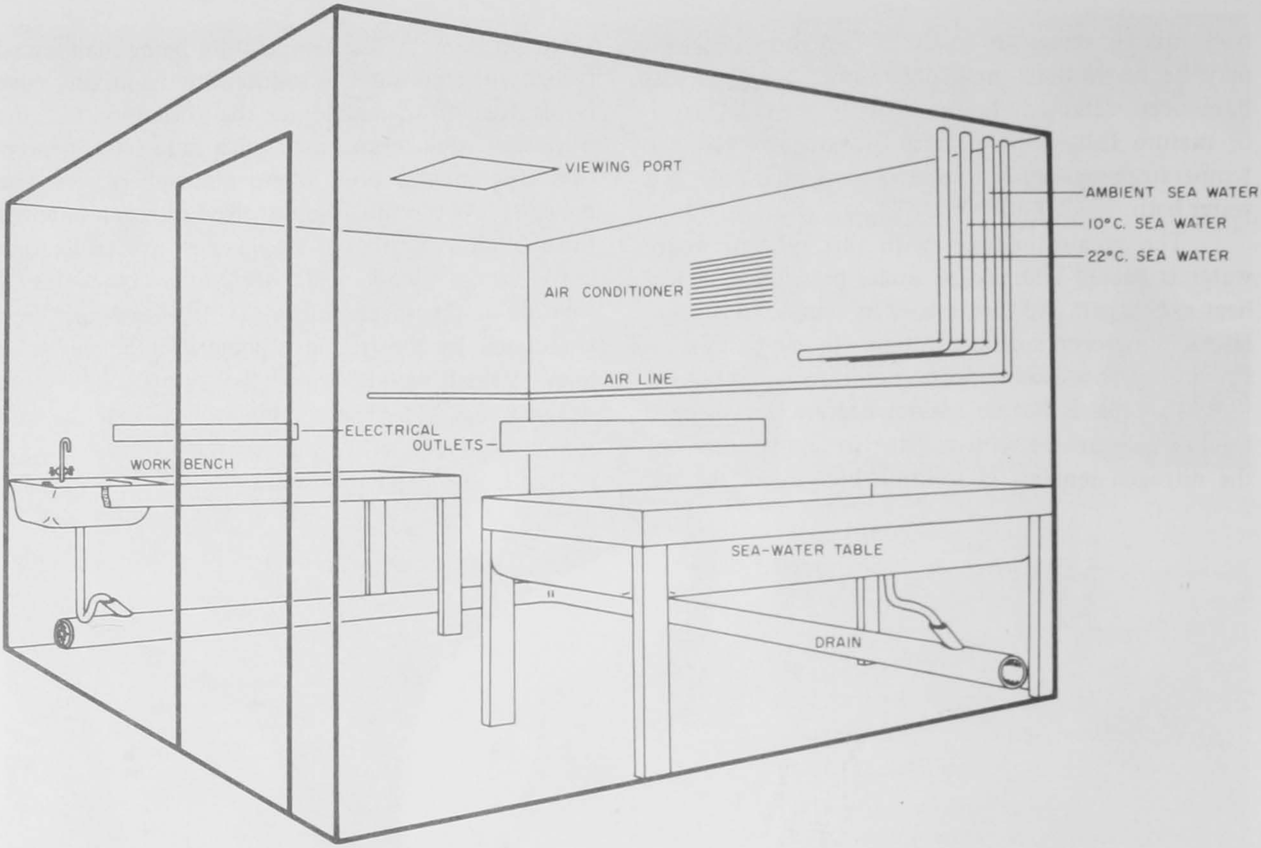

Figure 15. Diagrammatic outline of environment room and facilities.

CUBICLES

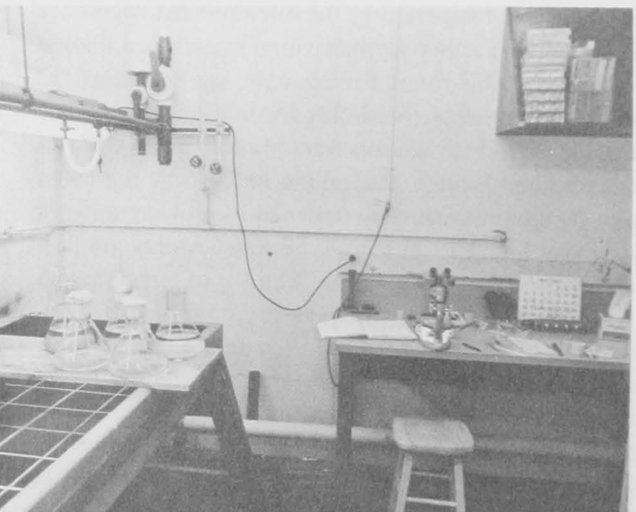

Figure 16. Cubicle showing sea-water table and other facilities.

Six cubicles, each with 10- by 10-ft. floor space, in the basement of Building D occupy about 600 $ft.^2$ and are used for individual experiments where partial, but not total, isolation is desired. None of these rooms has a ceiling. Each room was originally furnished with a wet table, dry table, fresh water, sea water at 50° F. (10° C.), and ambient, compressed air, and electrical outlets at intervals of a few feet around all walls (fig. 16).

Floor drains were omitted from the cubicles because experience with small floor drains in other research aquariums indicated that they often clogged, and were often responsible for flooding and wet floors. We have found that separate drainage pipes in the cubicles offer no significant advantage over floor drains in preventing flooding and that they greatly increase the difficulty in cleaning up when a flood does occur. Therefore we recommend that in any similar installation, floor drains—perhaps 2-inch PVC in short straight runs—be provided in all wet areas.

MAINTENANCE

Virtually all sea-water systems have problems associated with fouling, corrosion, maintenance of good water quality, and temperature control. The design and construction of the Fishery-Oceanography Center aquarium have largely eliminated these problems.

Cleaning the Sea-Water System

The two halves of the main aquarium can be separated from one another by valving; therefore, sea water does not have to be turned off entirely in cleaning. Each half may be cleaned separately with industrial fresh water, at 60 lbs. pressure connected to the sea-water pipes entering the building's boilerroom. With this arrangement, one man can operate the valving necessary to flush and fill the sea-water pipes with fresh water; hence no scouring of pipes is needed. In 4 years the pipes have required no flushing because fouling has been insignificant. Occasionally accumulations in the shorter pipes are released by flushing them out with sea water.

Temperature Failure Alarm

To ensure that sea water will be at the desired 72° F. (22° C.) when it leaves the heating unit heat exchanger, a temperature controller is used to modulate a motorized three-way bypass valve. When the temperature of the heated sea water falls below 68° F. (20° C.), a second temperature control triggers a bell-alarm relay, alerting maintenance personnel.

Cleaning the UV Unit

The UV unit is cleaned once a month to remove accumulations of minerals on the exterior surfaces of the quartz sleeves. To avoid the necessity of dismantling the system and removing the sleeves, the sterilizer is flushed with a dilute solution of hydrochloric acid.† The sterilizer is bypassed, and the acid is added directly to the unit, where it remains in contact with the sleeves for about 1 hour. At the end of this time, the acid solution is drained and the unit thoroughly flushed with water before it is reconnected to the sea-water system.

Dielectric probes are mounted in the tray installed at the bottom of the UV cabinet to catch water. If a leak occurs, the probes short out and trip a relay which shuts off electricity to the lamps and sounds a bell alarm.

†Murphy, W.K. 1969. Ultraviolet sterilization of water and its relation to maintaining aquatic organisms. Contrib. Underwater Technology Conference, San Diego, Calif., 9-12 Mar. 1969. American Society of Mechanical Engineers, 4 pp.

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APPENDIX

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