CHAPTER 196

Steep Slope Seawater Supply Pipeline

Dr. Lloyd F. Lewis[1] Dr. Joseph Van Ryzin[2] Dr. Luis Vega[3]

Abstract

The State of Hawaii's Ocean Science and Technology (HOST) Park, the U.S. Oepartment of Energy (OOE), and the Pacific International Center for High Technology Research (PICHTR) sponsored the construction and installation of an expanded seawater supply system at the Natural Energy Laboratory of Hawaii (NELH). This effort included the installation of a 1.0m diameter high density polyethylene pipe capable of delivering 840 l/s of cold seawater, representing the longest (2,060m) large diameter pipe traversing the steepest slope ever spanned. Acceptance testing of the system was completed in June 1988 and the design service life is 10 years.

Introduction

Since 1975, the State of Hawaii, OOE, and others have sponsored projects using relatively pristine seawater found adjacent to NELH at Keahole Point, Hawaii (Towill, 1976). Figure 1 illustrates the location of the NELH site. With the successful installation in 1981 of a bottom-mounted 0.3m diameter polyethylene pipe (PICHTR, 1988), experiments have had a constant supply of cold (7-8^{o}C), nutrient-rich, pollution- and pathogen-free seawater as a resource. The State of Hawaii and others supported research in both warm and cold water mariculture (Daniel, 1985) and DOE has focused its support on both closed- and open-cycle ocean thermal energy conversion (OTEC) research (Penney, 1987). 8y 1985, with the formation of the High Technology Oevelopment Corporation and HOST Park adjacent to NELH, the State of Hawaii developed plans to increase the existing 130 l/s cold seawater supply and to install a 0.7m diameter pipeline to pump up to 430 l/s of cold seawater to several large-scale mariculture demonstration projects (HTDC, 1985). At the same time, DOE began designing a similar size line to supply up to 410 l/s of cold seawater (as well as a 0.7m line for 600 l/s of warm water) to a planned OOE-PICHTR net-power producing open-cycle OTEC experiment at NELH (SERI, 1985; Lewis, 1987). As plans and funding availability were evaluated, it became clear that a cost-effective solution would be to install a single line of 1.0m diameter to supply the required 840 l/s of cold seawater along with a 600 l/s warm seawater line.

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1. U.S. Department of Energy, Washington, O.C. 20585
2. Makai Ocean Engineering, Kailua, HI 96734
3. Pacific Int'l. Ctr. for High Tech. Research, Honolulu, HI 96814

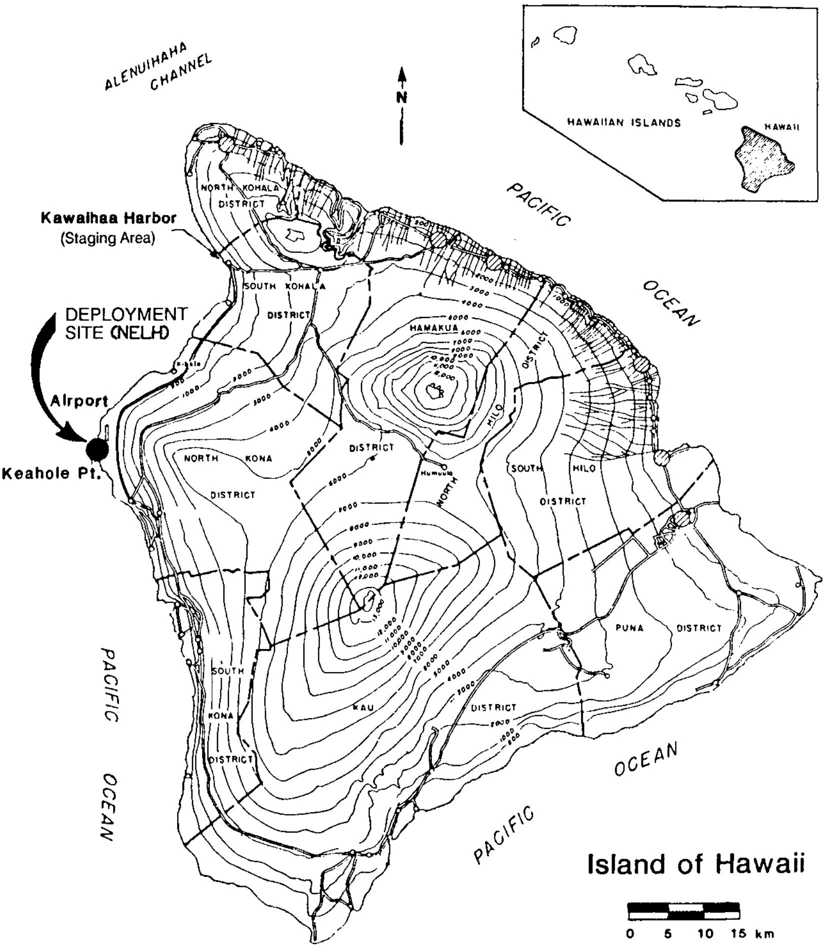

Figure 1. Seawater Supply System Deployment Site

Keahole Point Seawater Pipelines

The 0.3m diameter bottom-mounted cold ocean water pipe has been operating since 1981. In addition to the 1.0m seawater system described here, three other bottom-mounted polyethylene pipelines were installed at Keahole Point. Hawaiian Abalone Farms installed two 0.4m lines and the State of Hawaii installed a 0.5m line (PICHTR, 1988), all in 1987. These lines were small enough to be installed by a direct pull from shore. Pump installation and final inspection for all three lines were recently completed.

Site Conditions

Site-specific oceanographic, bathymetric, and environmental studies have been conducted at and near Keahole Point since 1975 in anticipation of OTEC and mariculture research (Bathen, 1975). Although Keahole Point is located on the leeward side of the Big Island of Hawaii relative to the predominant trade winds, during the November-March time frame there is a strong possibility of Kona storms (i.e., from the unprotected south and west) at the site (Rocheleau, 1979). Waves from those storms break suddenly on the very narrow island shelf and are known to move large boulders in the shoreline area. In addition, tsunami runup has been recorded at 3.7m (Cox, 1982) causing significant site inundation. Open ocean waves for the 100-year event have been estimated to exceed 14.3m (Bretschneider, 1978). Ocean currents off Keahole Point have been monitored by several researchers since 1975 (Bathen, 1975; Noda, 1979; Frye, 1981; Lobel, 1985; Noda, 1986). In the presence of a large-scale eddy often formed west of the Big Island, local currents can reach 2.6 m/s at the surface, 1.1 m/s at 150m depth, and 0.4 m/s at 300m depth. The bathymetry and sediment cover off Keahole Point have been studied in detail both with surface supported (Campbell, 1979) and submersible supported (Noda, 1979; Makai, 1983; Fornari, 1984) geophysical and geotechnical equipment. Although the distance offshore and therefore the pipe length to the cold water resource is less than 1.5 km, the slopes are very steep, occasionally exceeding 50°. In places, large outcroppings of irregular lava occur. Fig. 2 schematically illustrates the bottom slope and thin sediment condition. Environmental studies have pointed out that although there are no resident threatened or endangered species near Keahole Point, endangered marine mammals and sea turtles are known to migrate nearby in the winter months (HTDC, 1985; MSG, 1986; NELH, 1987).

Pipe Design

Considering the site-specific and environmental conditions described above, the design chosen for the 1.0m pipeline was the partially bottom-weighted and partially inverted buoyant catenary configuration shown in Figs. 2 and 3 (Horn, 1980; State of Hawaii, 1986; Vuillemot, 1988). Table 1 lists the principal design requirements of the pipeline for the DOE-PICHTR OTEC experiments (Lewis, 1987). In addition to the 410 l/s of cold seawater supplied to the OTEC experiments, another 430 l/s are simultaneously pumped to HOST Park for mariculture projects (Table 2). Additional design requirements included having only relatively inert surfaces contacting seawater and a design service life of 10 years.

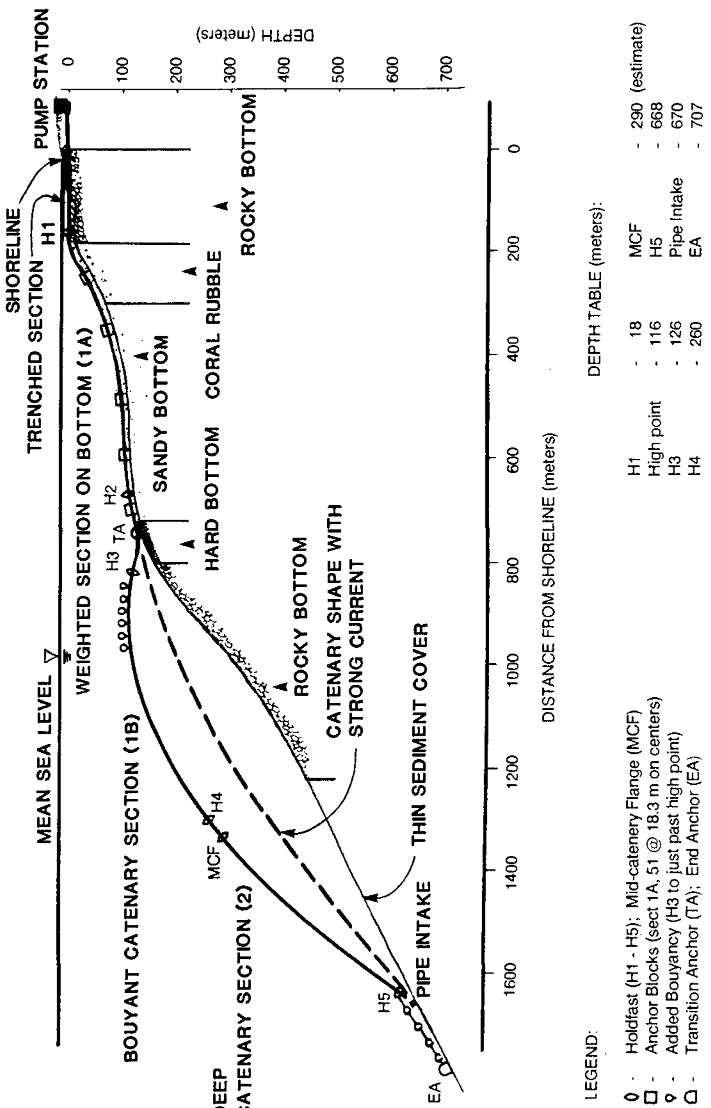

Figure 2. Profile View of Seawater Supply System

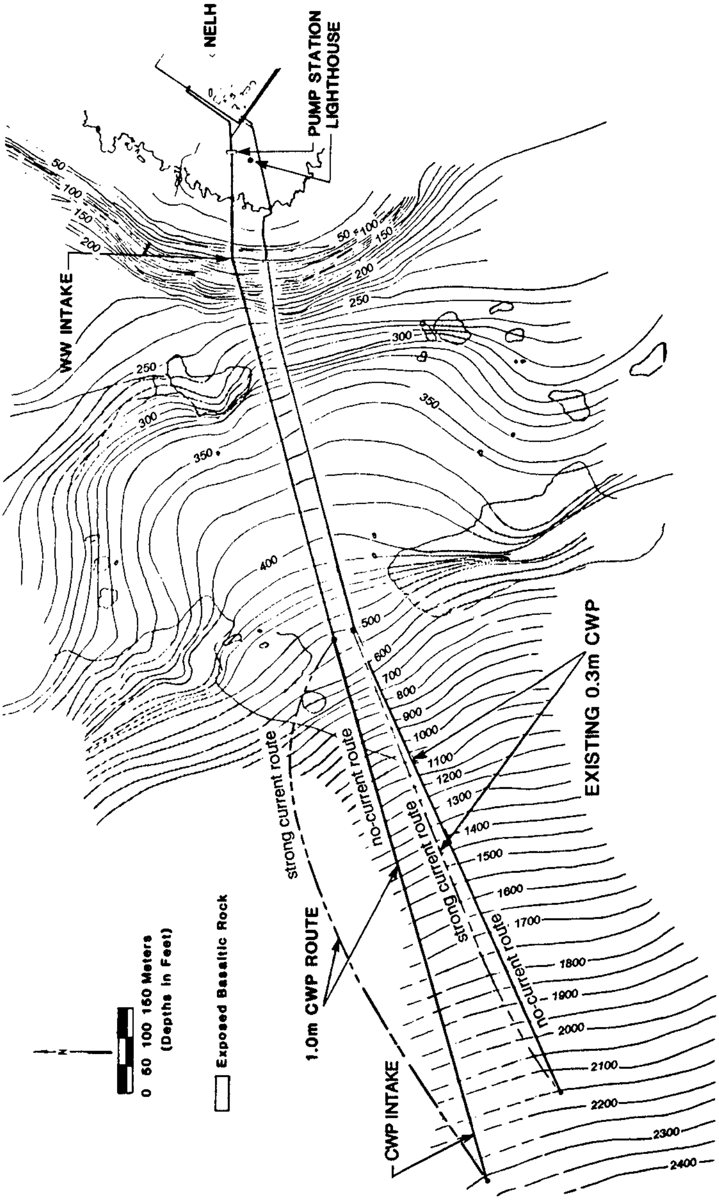

Figure 3. Plan View of Seawater Supply System

High density polyethylene was chosen as the pipe material for several reasons. Its natural buoyancy in seawater offers the option of reversibility in the deployment scenario. Its inertness satisfies the user requirements. It is sufficiently flexible yet strong in tension and bending in the chosen diameter and wall thickness to facilitate towing, controlled submerging, and long-term flexure in the deployed configuration. Fabrication is facilitated by thermal butt welding (Fig. 4) resulting in welds as strong as the extruded pipe. Finally, it has demonstrated success in prior bottom-laid configurations on steep and rugged slopes (PICHTR, 1988).

The buoyant, inverted catenary prevents the pipe from contacting the rough and steep ocean floor that it spans. As illustrated in Figures 2 and 3, however, the catenary does allow the pipe to sway in the locally strong currents (as much as 150m horizontally and 75m vertically). An 18,000kg gravity anchor below the cold water intake fixes the seaward end of the catenary as shown in Fig. 5. At a depth of about 150m, the pipe transitions from the floating catenary to a bottom-weighted configuration through bridles and a sliding sleeve (Fig. 6). Another gravity anchor (36,000kg) restrains the shoreward end of the catenary through these bridles. Shoreward of this transition section, the slope is less steep and generally sediment-covered with only minor outcrops along the route. The weighted section of pipe is restrained from downslope movement by chain bridles linked to rock-bolted anchor plates installed at the shore end of the pipe. At a depth of 15m (just above the warm water intake), the cold water pipe enters a trenched and backfilled section (Fig. 7) along with the warm water pipe and two spare conduits, all of which continue to the onshore pumphouse invert at approximately 5.5m below sea level. Submersible pumps draw warm and cold water from the pumphouse sump and force these supplies through a distribution network to the NELH and HOST Park sites.

Makai Ocean Engineering (MOE) designed the ocean portion of the pipe system. R. M. Towill Corporation designed the land portion of the system and, assisted by MOE, also served as the resident engineer for the State of Hawaii during construction. Construction of the seawater system was done by Kiewit Pacific Company under contract to the State of Hawaii.

Site Preparations

The principal site preparation for installing the seawater system involved trenching for the nearshore, surf zone, and onshore pipe route. Other predeployment activities included installing the nearshore rock anchors and clearing the chain bridle paths to the pipeway. Blasting and excavation were precluded during the winter marine mammal migration period. Pre- and post-construction surveys were conducted to assess the impact on, and recovery time of, local nearshore aquatic biota. In addition, these diver surveys were coordinated with the National Marine Fisheries Service and Hawaii Department of Land and Natural Resources. A shore-based navigation and positioning triangulation system was installed along with visual range markers. Numerous radio frequencies were selected for voice communications among the deployment vessels and shore-based personnel.

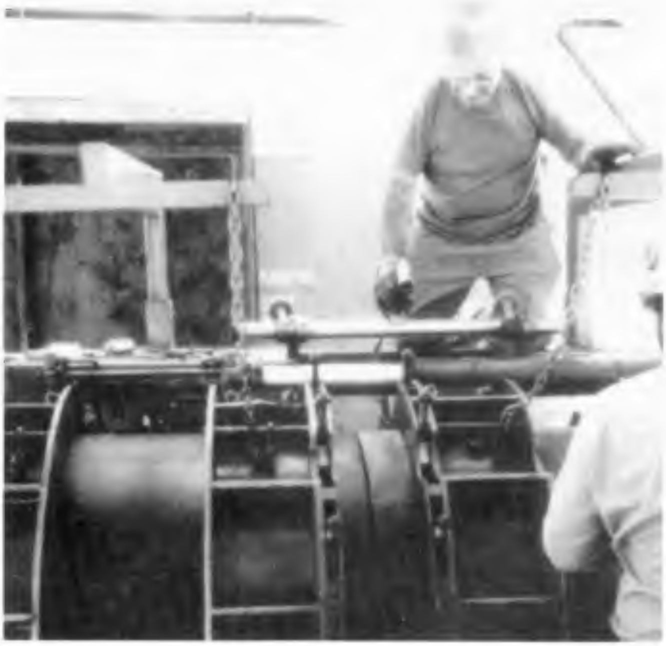

Figure 4. Polyethylene Pipe Thermal Butt Welding

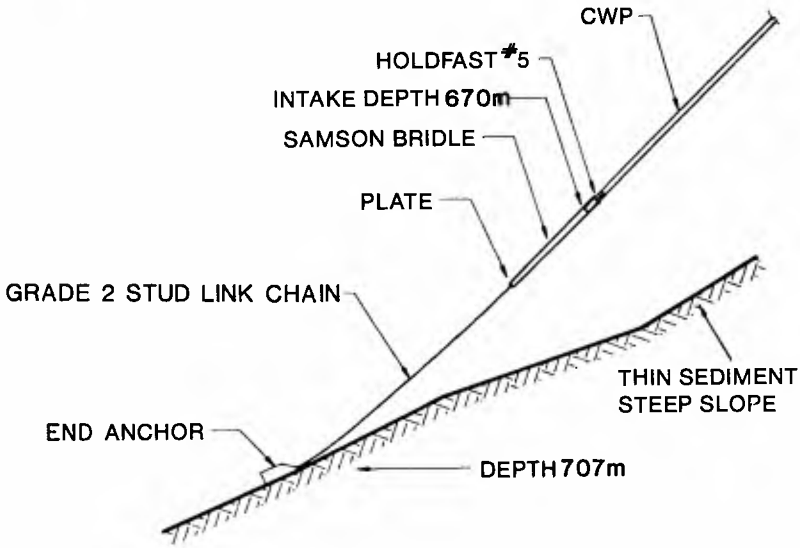

Figure 5. Pipe Intake Assembly

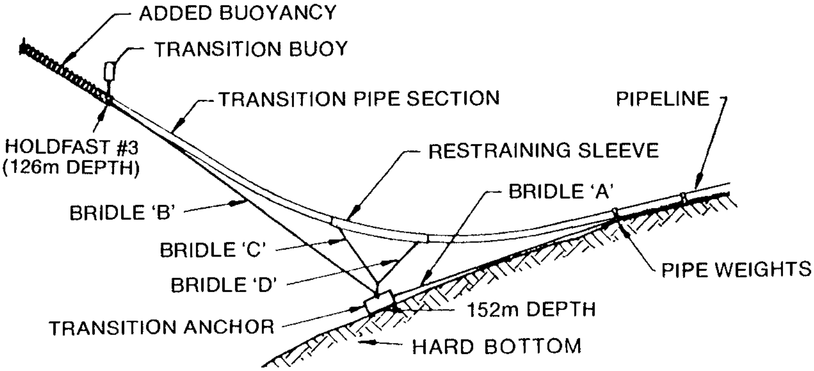

Figure 6. Pipe Transition Area

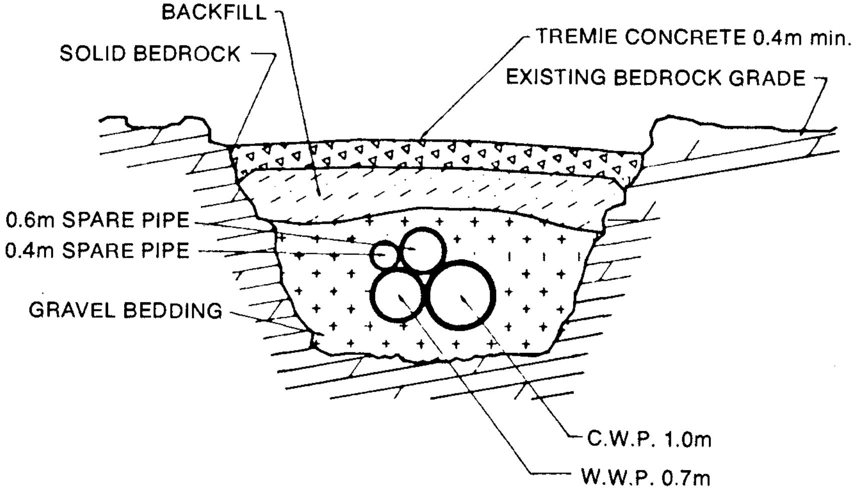

Figure 7. Section of Offshore Trench, Typical

Weather windows were selected with regard to each of the planned deployment operations. The deployment guideline (State of Hawaii, 1986) called for towing in sea states less than 4, pipe alignment in sea states less than 3 with surface currents less than 0.8 m/s, and pipe lowering in sea states less than 3 with currents less than 0.5 m/s. Weather conditions were monitored daily from the National Weather Service and by a Kiewit-employed meteorologist. An in situ telemetering current meter was monitored continually during critical phases of the deployment. None of the condition limits were exceeded during deployment.

Fabrication, Assembly, and Deployment

The high density polyethylene pipe was shipped by the manufacturer, DuPont of Canada, in 12m sections and off-loaded at the Kawaihae Harbor staging area. DuPont and Kiewit personnel then formed sections 1A, 1B, and 2 (Fig. 2) using a thermal welding machine (Fig. 4). Holdfasts, floats, weights, flanges, certain bridles, and other attachments (Fig. 2) were installed and the pipe sections floated into the harbor (Fig. 8) These sections were anchored to prevent movement due to winds and were also restrained to prevent twisting during holdfast installation. Sections 1A and 1B were pressure tested by running a pig through the pipe and pressurizing to 125% of the maximum expected deployment pressures (e.g. 620kPa) for 24 hours. Lights were attached at 60m intervals for night tows.

Deployment of the ocean portion of the seawater system off Keahole Point was initiated in late July, 1987. Sections 1A and 1B were mechanically flanged together (Fig. 9), pressurized to 140kPa, and towed as a unit to Keahole Point. The tow tug transferred holdfast 1 to the crane barge for controlled lowering and connection by divers to the nearshore anchor plate bridles. After aligning section 1 along its deployment corridor (Fig. 10), hoses were connected to the shoreward end, and the 36,000kg transition anchor and associated bridles were connected near holdfast 3 (Fig. 6). In order to cool the pipe and thus reduce bending strains, it was necessary to spray water on the floating pipe during this period. The pipe was pressurized to 350kPa to prevent pipe collapse during deployment. Then the pig was forced through the pipe by water pumped from the shore end, causing the pipe and concrete anchor blocks to sink; however, pressure equilibrium was maintained in case the pipe had to be raised during this period. The offshore tug, pulling up to 220kN tension, maintained the pipe alignment and acceptable bend radii. As the final anchor blocks were submerging, the crane barge lowered the transition anchor into place. After about 600,000 liters were pumped, lowering was stopped and holdfast 4 was kept on the surface.

The University of Hawaii's manned submersible PISCES V was launched to inspect the pipe from about anchor block 30 through the transition area to confirm placement of weights, condition of bridles, clearance from the existing 0.3m line, avoidance of rock outcrops, etc. After the inspection, pipe section 2 was towed from Kawaihae and connected to section 1 at the mid-catenary flange. The crane barge moved to the pipe intake, and the catenary end anchor and bridles were attached. Pumps were started again and the pig

Figure 8. Pipe Haul, Kawaihae Harbor

Figure 9. Connecting Pipe Sections 1A and 1B, Kawaihae Harbor

Figure 10. Aligning Pipe Section 1, Keahole Point

displaced air from the pipe while the barge lowered the end anchor. Since the distance between the two catenary anchors was critical in determining catenary shape, the end anchor was acoustically positioned into its touchdown location. A few days after this six-day pipe installation was completed, PISCES V made another dive to confirm the as-deployed condition of the pipe over its full length. The entire deployment was documented by helicopter-, surface-, and submersible-supported video taping and still photography.

Acceptance Testing

In June 1988, after completion of the surf zone and onshore pipes and pumphouse components, a full set of acceptance tests was successfully completed, including operation of the eight cold and four warm water pumps (Table 2). The stainless steel submersible pumps are rated for service to 20m depth. They have alarms and shutoffs for overheating, excessive motor current, vibration, and low water levels in the pumphouse sump. The pumps are rotated during low flow use periods to maintain uniform wear.

Additional Effort

The HOST Park portion of the system is presently operating with discharges into large capacity, deep injection wells. It is not anticipated that the NELH portion of the system will be fully used until 1990-1991 when the DOE-PICHTR large-scale, net-power producing open-cycle OTEC experiment is operational. Presently, a shallow trench is being designed and, when constructed, will serve to collect and disperse the OTEC discharges.

The pipe will be instrumented at holdfast 3 with recording depth gauges to monitor depth changes as a function of ocean currents, which will also be monitored on a separate nearby mooring. It is expected that this data will assist in verifying predictive pipe motion models and in designing future catenary pipe systems.

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TABLE 1

OPEN-CYCLE OTEC SEAWATER
SUPPLY SYSTEM CHARACTERISTICS

Characteristic	Cold Water	Warm Water
Primary Flow (l/s)	410	600
Secondary Flow (l/s)*	19	19
Head at Test Pad (m)	6.1	6.1
Intake Depth (m)	670	20
Particulates Screened (cm)	1	1

*continuous flow

TABLE 2

SEAWATER PUMP CHARACTERISTICS

User	Type	Number*	Power (kW)	Flow (l/s)	Head (m)
HOST	Cold	5	66	110	37
DOE/NELH	Cold	3	57	205	19
DOE/NELH	Warm	4	57	200	19

*each use has one redundant pump