HAWAII DEEP WATER CABLE PROGRAM

PHASE II-B

EXECUTIVE SUMMARY

Department of Planning and Economic Development

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Department of Planning and Economic Development

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INTRODUCTION

This Executive Summary for the Hawaii Deep Water Cable (HDWC) Program reviews work-to-date on the Program emphasizing the recently completed State-funded, Phase II-B tasks. This report also describes the interrelationships of the State-funded and Federally-funded portions of the Program and identifies the major accomplishments of these cumulative efforts.

Program Goal

The HDWC Program has the following major goal:

> "To determine the technical feasibility of deploying and operating a submarine power transmission cable between Kohala on the Island of Hawaii and the Makapuu area of Oahu over a service life of at least 30 years."

Background

The State of Hawaii depends almost completely on imported petroleum for its energy needs, and consequently is extremely sensitive to fluctuations of oil price and supply. Paradoxically, Hawaii has abundant, undeveloped geothermal, direct solar, wind, biomass, and ocean energy resources. Recognizing the potential of these undeveloped resources and the State's vulnerability to perturbations of world oil markets, Hawaii is committed to the full development of its renewable energy resources.

In terms of the potential magnitude of the resource and the maturity of existing technology, the most promising near-term, baseload alternative energy resource in the State is geothermal. The potential for development of this resource is greatest on the Island of Hawaii, but the demand for electricity is greatest on Oahu. It is estimated that the geothermal resource on the Big Island could supply at least half of Oahu's present electricity requirements if it could be transmitted. At present, it appears that the most feasible method of transporting geothermal electrical power to Oahu is by submarine, high-voltage, direct-current (HVDC) cables.

The current state-of-the-art in submarine cable technology is represented by the direct current cables linking Norway and Denmark (the "Skagerrak" cables). These cables are deployed over a distance of 78 miles at a maximum depth of 1,800 feet. Interconnection of Hawaii and Oahu will require the development of a submarine cable to span water depths to 7,000 feet and a distance of about 150 miles.

The HDWC Program will advance the state-of-the-art in submarine cable engineering to the benefit of future projects elsewhere by providing and testing designs for a HVDC cable and cable deployment/retrieval systems for applications in water depths to

7,000 feet. The at-sea tests in this Program will include deploying and retrieving a cable in the deepest waters to be encountered along the most likely route across the Alenuihaha Channel.

Program Funding

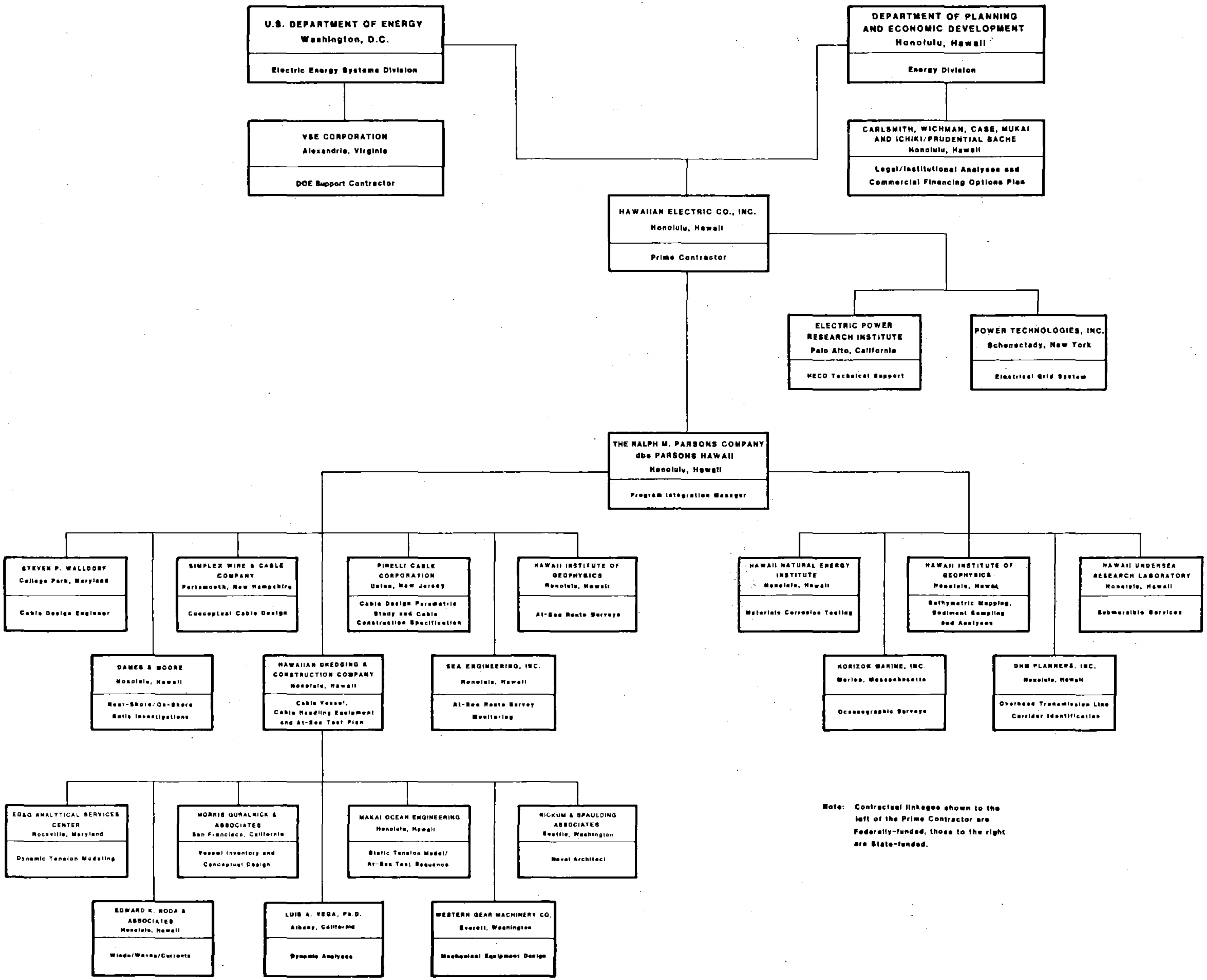
The HDWC Program is being funded by the U.S. Department of Energy (DOE), the State of Hawaii Department of Planning and Economic Development (DPED), and through cost-sharing by the Program's major team members. The Program consists of two phases: Phase I - Preliminary Program Definition, and Phase II - Final Program Definition and Cable, Cable Vessel and Cable Handling Equipment Design/Verification. During State Fiscal Year 81-82, the Hawaii State Government authorized, appropriated, and released funds for Phase I, Preliminary Program Definition. In October 1981, Phase I efforts began, augmented by additional funds provided by members of the Program team. Phase I efforts were completed in May 1982. Phase II is an extension of the preliminary definition work of Phase I. All Federally-funded activities are included in the designation Phase II, while the State-funded activities are divided into Phases II-A, II-B, and II-C.

Although the HDWC Program is being funded cooperatively by the State and Federal governments, each portion has its own focus. Generally, the Federally-funded portion of the Program is focused on generic aspects of the technologies involved, while the State-funded portion of the Program is considering more site-specific issues.

Participants

The HDWC Program draws from an international resource pool made up of private sector, government agency, public utility and university personnel. Participants include experts in the areas of oceanography, economics, engineering, manufacturing, computer modeling, utility system design, cable design, environmental analyses and program management. For both the State-funded and Federally-funded portions of the HDWC Program, Hawaiian Electric Company, Inc. (HECO) is the prime contractor with overall responsibility for the Program. The Ralph M. Parsons Company (Parsons), through its Honolulu office (Parsons Hawaii), is the Program Integration Manager with management and technical support responsibilities throughout the Program. In addition, the DPED has independently funded several studies of the cable system economics and potential financing methods. Figure 1 is an organizational chart showing all of the Program participants, contractual linkages and areas of responsibility.

FIGURE 1
PROGRAM ORGANIZATION/FUNCTIONS
(Through Phase II-B)



PHASE I: PRELIMINARY PROGRAM DEFINITION

As an aid to understanding the purposes and direction of the Phase II work, the following identifies the major accomplishments of Phase I. In Phase I, investigations were initiated into each of the major variables which will define the eventual commercial cable system, including cable design, cable laying vessels, electrical grid system integration and routing. Elements of the cable design evaluated included materials characteristics (type, composition and weight) and dimensions (diameter, area and thickness) of cable conductors, insulations, sheaths and armors. Identified were five basic cable designs that could possibly successfully operate in the deep ocean around Hawaii. These five designs were later evaluated in greater detail in the Federally-funded portion of the Program.

While cable designs were being evaluated, the characteristics, capabilities and availabilities of all known existing and planned cable laying vessels were surveyed. A preliminary conceptual design of a vessel for the HDWC Program at-sea test program was subsequently developed.

At the same time, a conceptual plan was developed for integration of the HVDC transmission linkage into the electrical grid systems of Hawaii and Oahu. Also accomplished was preliminary identification, mapping and environmental analyses of more than forty potential commercial cable system submarine and terrestrial route segments.

To inform interested agencies and organizations about the accomplishments of the Program, several methods were used. An Executive Summary was widely distributed to public and private organizations to provide a basic introduction to the Program. In addition, a narrated, 35 mm slide program was prepared and presented to private and public sector groups and agencies. This slide program described the goals and objectives of the HDWC Program and emphasized the HDWC Program's interrelationship with alternate energy resource development programs.

To manage and control the many diverse technical tasks in the Program, a Program Management Plan (PMP) was developed which defined the administrative, technical and fiscal functions and controls for the Program. The major components of the PMP included a Work Breakdown Structure (WBS), a Quality Assurance Plan (QA Plan) and a Program Mobilization Plan (Mob Plan).

PHASE II: FEDERALLY-FUNDED WORK

Following completion of the State-funded preliminary program definition in Phase I, Federal funding began for design of the three major hardware subsystems - the cable, the cable vessel and the cable handing equipment. At the same time, preliminary at-sea route surveys were performed and investigations of the thermal characteristics of near-shore and on-shore soils were conducted. Technical planning documents were prepared specifying cable laboratory and at-sea testing objectives and requirements, cable design selection methodology and technical report writing/formating requirements. A cable selection report was also prepared. The paragraphs below discuss in more detail the major accomplishments during this period.

Cable Design

Supplementing the prototype cable design information developed in Phase I, a comprehensive cable design parametric study was completed. Over 25,000 separate calculations were made, varying some sixteen different external and internal cable parameters. The results indicated that more than 251 cable designs met or exceeded all design criteria and, theoretically, were suitable for a commercial interisland cable system. Following a rigorous technical and economic analysis of all 251 candidate designs, one design was selected which is considered to be representative of an appropriate commercial cable. The selected cable is a +300 kVdc, 250 MW, "self-contained oil filled" (SCOF) cable. The conductor material is aluminum for maximum mechanical strength. The outer diameter of the cable is about 119.5 mm (4.70 in) and its weight (in air) is 36.4 kg/m (24.5 lb/ft). Following design selection, preparation of a cable construction specification began.

Cable Vessel and Cable Handling Equipment

In Phase I, a cable vessel and equipment survey was conducted, and a cable vessel and equipment conceptual design prepared. Early in Phase II, cable vessel and equipment availability and applicability were reassessed, and computer modeling of dynamic and static tensions on the cable as a function of different vessel sizes and equipment configurations was performed. The model integrated the cable, cable vessel and cable handling equipment design information with statistical data on sea conditions and expected ocean bottom conditions. Results of this work indicated that a 400-foot long by 100-foot wide vessel with a stern mounted overboarding sheave would satisfy the criteria established for a commercial cable deployment.

At-Sea Route Surveys

While design of the subsystems proceeded, detailed bathymetric mapping of the Alenuihaha Channel as well as deep water sediment sampling and bottom photography were performed. The data collected indicated that bottom conditions in the channel vary from ideal (i.e., flat, sandy bottoms) to hazardous (i.e., steep scarps and areas of underwater landslides). The bathymetric surveys conducted were the first detailed mapping of the Alenuihaha Channel and were later supplemented with additional surveys.

In order to adequately design the vessel propulsion system, the cable handling equipment and the integrated cable handling/vessel positioning system, it is necessary to understand the ocean currents which will act on the vessel and cable. Two programs investigating currents in the Alenuihaha Channel are in progress. Measurements of near-surface currents at a site on the Hawaii side of the channel began in 1984 and measurements of near-bottom currents at two stations farther offshore began in 1985. Data are being collected continuously over a period of one to two years at locations fixed geographically and in the water column. To determine that the data generated at these sites were representative of the entire channel, another type of measurement program was funded in Phase II-B. This program employed a new technology - expendable current probes. These devices, deployed from either an aircraft or surface vessel, fall through the water column transmitting current vector data back to the deployment vessel. On three occasions, a series of these probes were deployed in the Alenuihaha Channel over a short time period to give a nearly synoptic series of current profiles across the channel. These data were then compared with data from the moored meters to examine three-dimensional variability of water currents in the channel.

PHASE II-A, STATE-FUNDED WORK

In the State-funded Phase II-A portion of the Program the following were accomplished:

Environmental Analyses

A detailed environmental report, including an annotated bibliography of the electromagnetic field effects of HVDC systems, was prepared. Federal, State and County agencies were contacted regarding their environmental concerns about the HDWC Program, permitting requirements, environmentally sensitive areas, endangered and threatened species, and other environmental and regulatory considerations. A series of formal briefings of all County, State and Federal agencies with environmental and land use responsibilities was completed. No major environmental concerns were expressed about the HDWC Program, but a number of concerns were expressed relative to a potential commercial cable system. Issues included route selection and land use plans, wildlife and other natural resources, pollution, public health and socioeconomic impacts. The environmental impacts of the HDWC Program itself will be insignificant, limited to short-term ship operations and temporary disruption of small areas of marine benthic habitats during the at-sea tests. Because of their small-scale, transient and research nature, the operational aspects (at-sea testing) of the HDWC Program will face few permitting requirements. Implementation of a commercial interisland HVDC intertie, however, could have significant environmental impacts. Probable impacts include short-term negative impacts caused during construction of the system, long-term negative impacts in visual quality along some portions of the route and long-term positive impacts in the area of socioeconomics.

Significant impacts that could occur if the system were not carefully designed and the route not judiciously selected have also been identified. These potential impacts include both route-specific and system-specific impacts. Potential route-specific impacts include loss of wildlife habitat, interference with endangered and threatened species, destruction of historic and archaeological sites, electromagnetic field effects and indirect social and economic effects. Potential impacts in the marine environment include habitat destruction, interference with legally protected or otherwise sensitive species (especially the endangered humpback whale), interference with fisheries resources and harvesting, effects of cable oil leaks, interference with other cable systems and electromagnetic field effects. Potential electromagnetic field effects are system-specific and include noise, radio and television interference, air pollution, shock hazards, and health effects.

The level of significance of all of these impacts, both probable and potential, has not been determined. This will occur later in the assessment process. However, both State and Federal

Environmental Impact Statements (EIS's) as well as an extensive array of permits will be required prior to implementation of a commercial cable system.

Electrical Grid System Integration Studies

Using the grid system integration concepts and the preliminary route survey data from Phase I, plans, designs and costs to reliably link Hawaii and Oahu were developed. Alternative converter sites on Hawaii and Oahu were analyzed for sending and receiving the bulk dc power.

The developmental scenarios investigated included projecting system needs on Oahu and Hawaii with and without geothermal development and the cable system, at several projected annual load growth rates. Staging of geothermal development was assumed to take place at the rate of five 25 MW geothermal power plants per year beginning in 1992, and staging of the transmission system development was assumed to proceed in conjunction with this generation development scenario.

Materials Corrosion and Abrasion Testing

In Phase II-A, experiments were begun to investigate the corrosion, abrasion and cathodic protection characteristics of various types of metals which could be used as conductor, sheath or armor material. Specific areas of investigation included:

(1) Long-term corrosion testing of steel, copper and aluminum alloys.

(2) Crevice corrosion studies of stainless steel alloys.

(3) Corrosion and fouling of cupronickel.

(4) Abrasiveness of Hawaiian rocks to various potential cable armor steels.

These studies are all of a long-term nature and only preliminary results were developed during Phase II-A.

FEDERALLY-FUNDED WORK CONCURRENT WITH PHASE II-B

The Federally-funded tasks (Phase II), which began in 1982 in parallel with State-funded Phase II-A, were continued throughout Phase II-B. Continued management reassessments of the Program, however, resulted in several significant modifications to Program direction during this period. As design and verification efforts on the subsystem components proceeded, new information was generated which, in several of cases, suggested further investigations not anticipated at the outset. Consequently, a major revamping of the scope of the Federally-funded portion of the Program was undertaken. Recognizing that budget reductions pursuant to Federal deficit reduction plans would impact the completion of the HDWC Program as originally envisioned, there ensued a comprehensive reevaluation of options for the costly at-sea test sequence. Three basic alternatives were examined: a full-scale test using the same cable design as that to be laboratory tested; a reduced-scale test using a surrogate cable and smaller vessel and handling equipment; and elimination of at-sea testing in favor of computer modeling only. It was concluded in January, 1986 that by executing a reduced-scale test, considerable money could be saved without sacrificing realistic verification of subsystems performance as would be the case if no at-sea test were conducted.

To increase management efficiency and program control capabilities, design and implementation of a computerized program cost and schedule tracking system was undertaken during this time. This system is patterned after the DOE Mini-Performance Measurement System (PMS).

Cable Design and Verification

Significant advances in the cable subsystem design and verification plans were made during this period. The final Cable Design Parametric Study was submitted, the draft Cable Construction Specification was finalized, and a study of cable catenaries was completed. The latter study evaluated the probability and consequences of the occurrence of unsupported cable spans based on available information regarding bottom roughness, water currents and anticipated residual tension on the deployed cable. This work illustrated the need for a much better understanding of bottom roughness along the most likely route, and considerable supplementary work in this area resulted. In addition, during this time, the laboratory test protocol for the cable was completed and development of a cable repair plan was initiated.

Cable Vessel and Cable Handling Equipment

Design of the cable vessel and cable handling equipment subsystems entered a period of hiatus while the evaluation of the options for at-sea testing progressed. After it was decided in January, 1986 that the reduced-scale at-sea test option, using a surrogate cable, was to be implemented, a revised report on cable handling equipment was produced. Also, as a part of the test cable deployment/retrieval operations plan development, initial inspection of candidate vessels began.

At-Sea Route Surveys

As a result of the analyses performed in the cable catenary study and other considerations, it was determined necessary to gather significantly more precise information about bottom roughness in the Alenuihaha Channel. To do this, a unique precision acoustic measuring system was designed, built, tested and installed on the University of Hawaii's research vessel Moana Wave, and a survey cruise was successfully completed. Following analyses of the data gathered, it was determined that, to rigorously satisfy the

Program's objective, sufficient information would be required to state conclusively that a technically feasible route across the Alenuihaha Channel exists, and that this will require an even more "fine-scaled" examination of the bottom. For this, it is planned to utilize personnel and equipment from Scripps Institution of Oceanography in the State-funded Phase II-C. In addition to the bathymetric work, during this period, interim reports summarizing ongoing measurements of wave heights, surface currents and wind vectors were completed.

PHASE II-B: STATE-FUNDED WORK

Phase II-B of the State-funded portion of the HDWC Program began in late 1984 and continued through calendar year 1985. The areas of investigation were similar to and built upon the work completed in Phase II-A. The following sections summarize the accomplishments of Phase II-B.

Environmental Analyses

Scoping for the commercial cable system EIS continued as an EIS outline was drafted and circulated to appropriate agencies and persons for review. Integration of information from the route surveys, grid system studies and at-sea investigations continued. The computerized data base searches for information relative to the effects of HVDC electromagnetic fields were continued and information was updated. Reference materials on the subject were acquired and reviewed for incorporation into the environmental assessment planned for Phase II-C and for use in the public information program.

For the at-sea test phase of the Program, permit applications were completed in draft form. The required environmental information for the at-sea test activities was condensed into a mini-environmental assessment entitled "Summary of HDWC Program". Meetings were held with the two agencies requiring permit action for the at-sea tests (the Army Corps of Engineers and the Department of Land and Natural Resources). In both cases, agency personnel requested that permit applications not be submitted until about six months prior to initiation of the action.

An "Environmental Review Plan" was prepared which describes the present commercial cable system concept and alternatives; identifies key issues; summarizes the results of literature reviews and original research focused on these issues; and identifies areas needing further analysis. In essence, it provides a bridge from the Phase II-A report entitled "Environmental Analysis" to the Environmental Assessment to be produced in Phase II-C.

Electrical Grid System Investigations

Hawaiian Electric Company and Power Technologies Inc. have developed the following information:

1. Conceptual schemes with or without a 50 MW Maui tap for both 10 and 15 year geothermal development horizons.

2. Cost estimates of the above, including the ac/dc interfaces.

3. Production cost estimates to integrate with the capital costs estimates above to identify the potential savings per kilowatt hour available to purchase geothermal energy.

Proprietary computer software was adapted to perform reliability analyses for the overhead line and cable systems and translate the results for use in the production cost studies. Optimization analyses for the configuration of the overhead lines were performed. Additional analyses on the metallic return requirements of the commercial cable system were performed as part of the ongoing efforts to define the optimum cable system configuration. Other system studies included load-flow analyses for the MECO network and dynamic studies to evaluate the stability and dynamic overvoltage characteristics of the MECO system with a 50 MW tap assumed in service.

Materials Corrosion and Abrasion Testing

Phase II-A work by the Hawaii Natural Energy Institute continued at the University of Hawaii at Manoa and on the Big Island at the Keahole Point, Natural Energy Laboratory of Hawaii. Long-term corrosion testing of potential cable materials, including twelve different metals and metal alloys, has utilized the unique capability of the NELH to supply seawater from both shallow (300 feet) and deep (2000 feet) depths to simulate actual conditions of environmental exposure. Samples have been exposed to flowing seawater in darkened troughs for various lengths of time. Weight loss and depth of pitting have been measured. It was found that corrosion of samples exposed to waters at NELH was slightly less than that reported at other tropical sites. Generally, samples exposed to deep waters showed less corrosion than those exposed to shallow waters, except aluminum, which corroded faster in deeper waters.

The abrasion potential of basalt and coral rock were studied using a range of standard test materials of various hardnesses. The test apparatus, designed and fabricated specifically for the HDWC Program, was then employed to test actual samples of cable armor wire. Additional experimentation utilized a "U-bend" tester constructed for the Program to examine the fatigue characteristics of the cable lead sheathing material.

At-Sea Route Surveys

Within this task, three distinct subtasks were accomplished. The Hawaii Institute of Geophysics, University of Hawaii, produced a computer-contoured bathymetric atlas of the entire HDWC Program area. Newly released digitized data were provided by the National Oceanic and Atmospheric Administration. The atlas divided the study area into 17 sections which were plotted at a scale of 1:100,000. Additional "areas of special interest," bottom segments known or suspected to be of particular hazard to a cable, were plotted at a scale of 1:20,000. Included also were three-dimensional perspective views and slope gradient maps of these areas as well as photomosaics of bathymetry measured with the SeaMARK II system and overlaid with contour lines.

To gain a better understanding of actual bottom conditions to which a cable would be exposed, the Hawaii Undersea Research Laboratory, University of Hawaii, conducted a series of dives using the submersible Makali'i. These dives took place offshore of Kawaihae and Mahukona on the Island of Hawaii and offshore of Kaupo, Maui. During these dives, continuous videotapes were made of the ocean floor from about 200 feet deep to the submersible's maximum diving depth (about 1,200 feet). A series of 35 mm slides were taken to supplement the videotapes. Other information collected included current and various environmental parameter data.

Route Survey Analysis

In Phase II-B, potential corridors for overhead transmission lines on Hawaii, Maui, and Oahu were identified. Data were gathered through field surveys and literature reviews, and corridors were identified using an overlay mapping technique. Four types of excluded areas and fourteen various geophysical, biological, socioeconomic and cost factors rated by degree of constraint were mapped and overlayed to show the composite effect of all constraints and exclusion areas. Viable corridors were identified on each island studied, and these form the basis for future investigations of detailed alignments for the HVDC transmission lines.

Public Information Program

Three significant products were produced under this Phase II-B task: a video tape, a slide show and a scale model of the Alenuihaha Channel. The videotape is designed to overview the HDWC Program, its objectives, accomplishments and conclusions, for the purpose of informing and educating legislators, agency personnel, community groups and the general public. It will be used to supplement informational presentations in Phase II-C and will be offered to Hawaii Public Television for wider exposure. The slide show and model will also be used in presentations to explain and illustrate the technical challenges inherent in the Program.

FUTURE ACTIVITIES, PHASE II-C

Phase II-C of the State-funded portion of the Program will include new areas of investigation as well as continue work on established tasks. Following is a summary of the statement of work for Phase II-C of the HDWC Program:

Environmental Analyses

In this State-funded increment, a formal environmental assessment (EA) of the most likely route for the commercial cable system will be prepared. Both submarine and overhead route segments as well as their nearshore interfaces will be examined in light of potential impacts resulting from system construction, operation, maintenance and repair.

Additional studies to be performed under this task include:

- Completion of the permitting for the at-sea test program
- A literature review of hydrogen sulfide concentrations in the seafloor along the anticipated cable route
- An assessment of the potential environmental impact of using a sea return rather than a metallic return
- A visual analysis of overhead transmission lines and support structures
- An investigation of nearshore cable embedment requirements

ELECTRICAL GRID SYSTEM INTEGRATION STUDY

Grid system studies in Phase II-C will focus on several major issues. To allow the electrical supply to vary with daily cyclical fluctuations in demand, cycling of generating units, geothermal or oil-fired, will be necessary. Possible modifications to existing oil-fired units and the cycling capabilities of geothermal plants will be investigated. This information will be complemented by system operations studies to define operating constraints and requirements on the HVDC link resulting from either existing generating facilities or planned geothermal plants. In further work under this task, cable transient and dynamic behavior will be researched to verify requirements and capabilities of the cable insulation and surge arrestors. An equipment specification document detailing the requirements for the land-based portions of the system will be drafted and issued to prospective bidders for comment.

Materials Testing

Investigations of the long-term survival potential of a cable produced to the proposed final specifications will be the focus of this task. In particular, survival of the armor wire material and the polyethylene jacket material under accelerated, simulated service conditions will be studied. This portion of the State-funded Program will be integrated with the laboratory test program to be funded under the federal portion. Tests to be completed under this task will be done according to the final cable laboratory test protocol.

Oceanographic Surveys

Information generated in Phases II-A and II-B, as well as in the Federally-funded portion of the Program, revealed the requirement for an oceanographic cruise to gather fine-scale data necessary to identify a technically-feasible route across the Alenuihaha Channel. The objective of this cruise will be to document the existence and characteristics (particularly width) of acceptable routes across the channel. Bottom roughness data will be acquired with a narrow-beam echo sounder and a side-looking sonar system towed near the bottom. Information from these systems will be complemented with photographic coverage.

Overland Route Analysis

In Phase II-B, potential alternative corridors for transmission line placement were identified. However, it was assumed that corridors from Kaumana to Keamuku and from Pohoiki to Puna on the Big Island identified in prior studies as being appropriate for 138 kV ac lines would, perhaps with some widening, be appropriate for 300 kV dc lines. This subtask will confirm the II-B assumption or recommend alternative corridors through the subject regions. Also included in this task will be an assessment of economic and environmental trade-offs associated with potential overland transmission on Maui and Molokai as compared with an all submarine route.

Public Information Program

Informational materials produced in previous phases will be employed in public meetings, agency briefings, and other events. Written materials will be produced for general distribution. On the more specific topic of potential health and safety issues related to high voltage direct current transmission lines, expert briefings will be held on Oahu, Maui and Hawaii to aid assessment and management of the degree of both actual and perceived risk associated with exposure to the HVDC electrical environment.

Federally-Funded Tasks Concurrent with Phase II-C

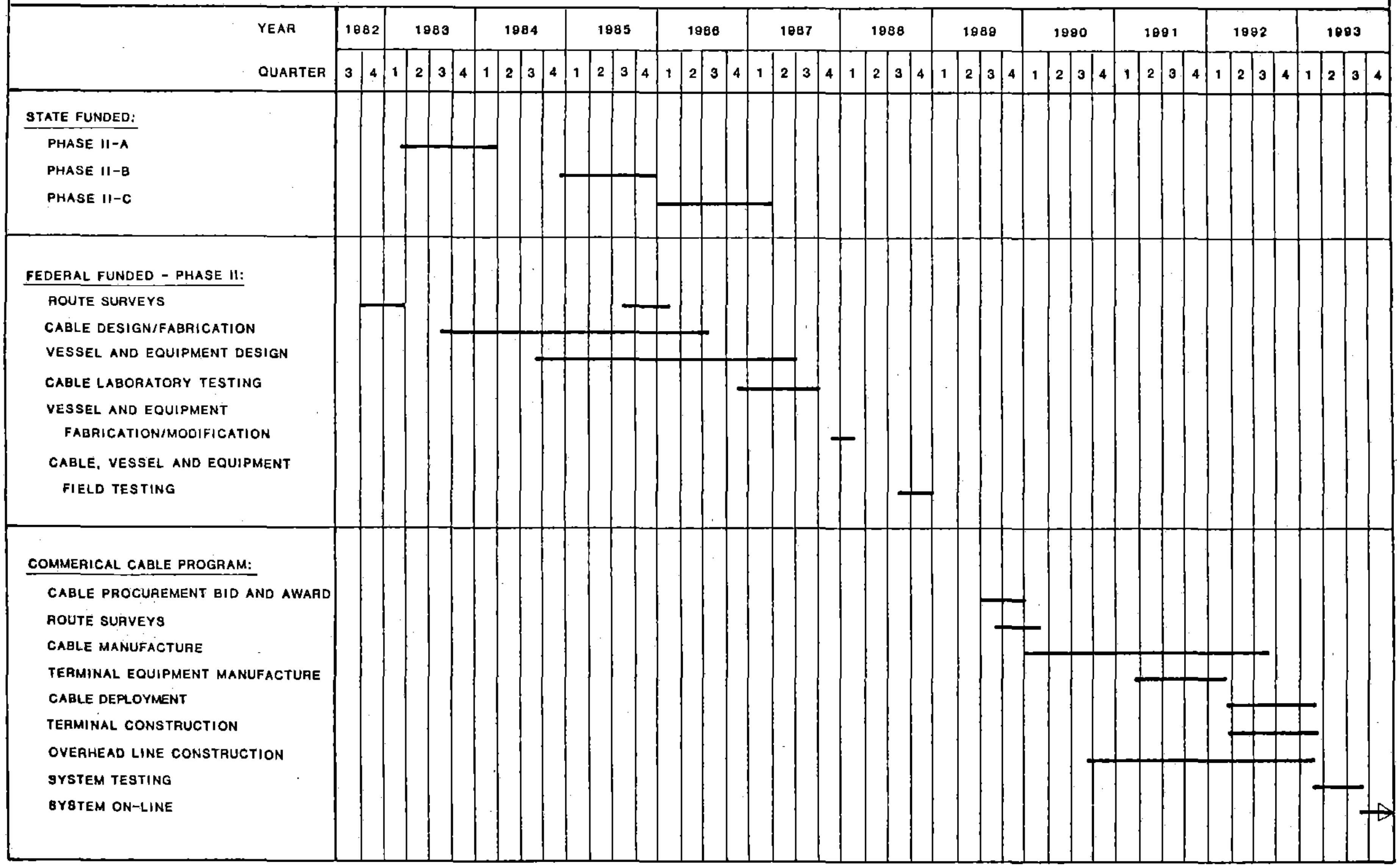
During the period of performance of State-funded Phase II-C, Federally-funded activities will focus on two major areas. The first is cable laboratory testing. A 6,000 foot length of cable will be fabricated to the specifications previously produced and subjected to an extensive series of electrical and mechanical tests. Simultaneously, design work will continue on components of the other two subsystems, the cable vessel and the cable handling equipment.

PROGRAM SCHEDULE

Timelines for the State-funded and Federally-funded portions of the HDWC Program and a target schedule for commercial development of the system are shown in Figure 2. State-funded efforts are projected to proceed through the first quarter of 1987 but an additional appropriation has been requested which would extend the State-funded portion of the Program to late 1987 or early 1988. At-sea testing under the Federal program is scheduled to be complete before the end of 1988.

Recent reevaluation of options for at-sea testing resulted in adoption of a "reduced-scale" concept using a "surrogate" cable rather than a length of the full-scale cable to be laboratory tested. This is possible because the full-scale cable will be fully tested electrically and mechanically in the laboratory. The at-sea tests are designed to test the effectiveness of the integration of the three subsystems- the cable, the vessel and the cable handling equipment- to deploy a cable along a pre-determined path with an appropriate residual tension. A much less costly surrogate cable has been identified which has mechanical characteristics very similar to those of the laboratory test cable, but is much lower in weight. Use of this surrogate in at-sea testing will allow use of available, conventional cable handling equipment rather than the very costly, custom-built equipment which would be required for a full-sized cable sample. Because of the excellent match of

FIGURE 2
HAWAII DEEP WATER CABLE PROGRAM AND
COMMERCIAL CABLE SYSTEM DEVELOPMENT PLANNING SCHEDULE



dynamic response characteristics of the surrogate system to the full-scale system, evaluation of the ability of the system to meet the defined technical feasibility criteria will not be compromised by using this surrogate cable. The use of a surrogate cable for at-sea testing has another significant advantage in that it decouples the two test programs (laboratory and at-sea) so that they may proceed in parallel rather than sequentially. If accelerated appropriations can be secured, this strategy would save more than a year on the HDWC Program.

HDWC PROGRAM AND COMMERCIAL CABLE SYSTEM COSTS

The following identifies the total estimated costs of the HDWC Program through completion and the estimated costs of three representative potential commercial cable routes.

HDWC Program Costs

Estimated costs for State-funded Phases I, I-A, II-A, II-B and II-C of the HDWC Program are shown in Table 1, and for Federally-funded Phase II, Increments 1 though 5, are shown in Table 2. Costs shown for completed phases or increments are those actually expended. Costs shown for future phases or increments are program budget estimates. Actual costs for many items will be determined through competitive bid procedures or based on updated cost proposals for given tasks once definitive scopes of work have been prepared.

TABLE I

HAWAII DEEP WATER CABLE PROGRAM
STATE FUNDED -- PHASES I AND II
ESTIMATED BUDGET REQUIREMENTS

TASK DESCRIPTION	FUNDING INCREMENT						TOTAL
	I	IA	II-A	II-B	II-C	II-D	
Program Management	$ 82,633	$ -0-	$ 67,423	$ 302,450	$ 185,000	(1)	$ 637,506
Technical Support	82,038	18,000	67,424	150,977	100,000	(1)	418,439
Route Survey Analyses	50,435	-0-	-0-	66,165	80,000	(1)	196,600
Preliminary Prototype Cable Design Criteria	42,313	-0-	-0-	-0-	-0-	(1)	42,313
Cable Vessel Inventory	27,581	-0-	-0-	-0-	-0-	(1)	27,581
Materials Corrosion Testing	-0-	-0-	50,000	62,014	70,000	(1)	182,014
Electrical Grid System Investigations	-0-	19,497	213,915	325,733	350,000	(1)	909,145
At-Sea Route Surveys	-0-	-0-	-0-	218,582	500,000	(1)	718,582
Public Information Program	-0-	22,503	-0-	34,996	20,000	(1)	77,499
Environmental Analyses	-0-	-0-	151,238	178,910	70,000	(1)	400,148
Legal, Institutional & Financial Study (2)	-0-	-0-	30,000	175,000	-0-	(1)	205,000
Economic Analysis (2)	-0-	-0-	20,000	-0-	-0-	(1)	20,000
Misc. Program Support (2)	-0-	-0-	-0-	-0-	75,173	(1)	75,173
TOTALS	$ 285,000	$ 60,000	$ 600,000	$1,514,827	$1,450,173	$1,000,000	$4,910,000

(1) Appropriation pending. Task budgets not finalized.
(2) Not funded through HECO.

TABLE 2

HAWAII DEEP WATER CABLE PROGRAM
FEDERALLY FUNDED - PHASES I AND II
ESTIMATED BUDGET REQUIREMENTS

TASK NO.	TASK DESCRIPTION	FUNDING INCREMENT 1	2	3	4	5	TOTAL
1.1	Program Management and Technical Support	$ 44,500	$ 600,000	$ 485,000	$ 432,000	$ 320,000	$ 1,881,500
1.2	Cable Design and Verification	48,000	250,000	450,000	900,000	3,325,000	4,973,000
1.3	Cable Vessel and Cable Handling Support Systems	107,200	377,900	420,000	5,925,000	3,450,000	10,280,100
1.4	At-Sea Route Surveys	226,100	-0-	-0-	-0-	-0-	226,100
	TOTALS	$ 425,800	$ 1,227,900	$ 1,355,000	$ 7,257,000	$ 7,095,000	$17,360,700

As shown in Table 1, the total State-funded requirement is estimated to be $3,910,000, to which will be added approximately $375,000 in cost sharing provided by Program participants. An additional one million dollar appropriation is pending. The total estimated Federal funding is $17,360,700 as shown in Table 2. The Program participants' cost share will be approximately $625,000. Total Program costs are now estimated to be $23,270,700.

Preliminary Commercial Cable System Costs

The economics of a cable system are as complex and multi-faceted as the technical issues. Material, installation and onshore facilities costs must be determined for potential routings. Also, finance costs, unquantifiable costs such as environmental and socioeconomic factors, and potential savings over present energy generation methods, must be calculated.

During Phase I, several potential alternative routes were examined and cable system costs developed for those routes. Since then further refinement of cable system costs has been accomplished and results are shown in Table 3.

During the cable design selection performed under the Federally-funded portion of the Program, it was decided that three route options would be examined as variables in the cable selection process. These options were required to assure that the cable design selected was not only technically feasible, but also one that was or appeared to be economically feasible. The three route options used in this costing exercise were: 1) an all-submarine route from Hawaii to Oahu; 2) an all-submarine route from Hawaii to Oahu with a stop on Maui for repressurization of the cable and possibly a power tap; 3) an island-hopping route with overhead transmission from southeast to northwest Maui and from central to western Molokai. Cable system costs for these three scenarios, using the most appropriate cable design for each route, are shown in Table 3. These costs are preliminary only and will be refined as the HDWC Program proceeds to completion.

Capital costs of the system include costs for sales, HVDC onshore terminal equipment, overhead ac lines and ac system modifications, and installation and cable splicing. These latter component costs were combined in various configurations (i.e., two to four cables) over various alignments (i.e., totally submarine or island-hopping) to develop total system capital costs. These total capital costs (including a small percentage of transmission losses) ranged from $189 million to $413 million. The most expensive component of the capital cost total is for submarine cables and is reflected in the difference between a totally submarine system and an island-hopping system based on the length of cable needed and the type of cable appropriate for that span.

TABLE 3

HAWAII DEEP WATER CABLE PROGRAM
COMMERCIAL CABLE SYSTEM
ESTIMATED COSTS BY ROUTE OPTION

	COST (\$ x 10^6 PRESENT WORTH 1983)		
CATEGORY	ROUTE 1	ROUTE 2	ROUTE 3
Capital Costs[1]	226.29- 408.51	226.08- 412.92	188.70- 336.14

[1] "Capital Costs" for each route option is the total cost for the cable system including cable and losses, overhead lines and losses, HVDC equipment, laying and splicing, pumping plants for SCOF, landing costs and potheads.

Overhead line costs vary considerably with tower design. The preferred single steel pole is the most expensive, with a cost of about $400,000 per mile. For the 94 miles from Puna to Kawaihae, the total costs would be $37.6 million, an order of magnitude less than cable costs.

HVDC equipment in the converter stations (rectifier and inverter terminals) is costed at $50 per kilowatt per terminal. For a two-terminal, 500 MW system this would total $50 million, again much less than cable costs.

AC system modifications are even less significant to overall economic feasibility. A range of $18.5 to $24 million was calculated for construction of transmission backup links and voltage support equipment.

CONCLUSIONS

The HDWC Program has produced a design and specifications for an electrical transmission cable for the most demanding oceanic installation ever attempted. A segment is now being built to these specifications for electrical and mechanical testing in the laboratory. These tests will run for about a year, beginning in late 1986. Materials testing to confirm a 30-year operating life potential will be completed in early 1987. Following all of these tests, it will only remain to confirm the validity of the subsystem integration plans in the at-sea tests scheduled for 1988.

The capabilities, availabilities and economics of all existing and planned cable laying vessels have been surveyed. Interactions among the cable, cable vessel and cable handling equipment subsystems and the environment have been computer modeled, and sensitivity analyses performed to identify key performance parameters. On this basis, generic vessels adequate for both the commercial system deployment and for the at-sea test sequence have been identified, and preliminary inspections of several candidate vessels have been completed.

Existing handling equipment for deployment of both cables and pipes has been comprehensively evaluated and design criteria established. Interactions of the handling equipment with the other subsystems during deployment have been modeled and conceptual layout plans developed. Efforts are underway to design an integrated control system to link the cable handling operations with vessel propulsion and navigation systems.

Land-based portions of the system have also been extensively evaluated. Adequate equipment exists to perform all necessary functions, and near-term technological developments are expected to reduce preliminary cost estimates for the commercial system. The challenges for the HDWC Program team in this area are to determine the most efficient and economical means to integrate an HVDC transmission system with other existing and planned facilities. Analyses to date have considered such things as likely locations for converter stations, overhead line configurations, component sizing, and spinning reserve requirements.

Potential environmental constraints have been analyzed in some detail. Bathymetric surveys have been summarized in a program atlas, and potentially hazardous areas identified and examined in greater detail. Submarine corridors have been identified through some areas; plans are in place to locate an acceptable corridor through the area of greatest bottom roughness. It is expected that with completion of the next bathymetric survey, a technically feasible submarine corridor will have been located and mapped. Other oceanographic work has included monitoring of winds, waves and currents in the Alenuihaha Channel to provide inputs to deployment operations modeling.

Terrestrial corridors along portions of potential routes have also been identified and mapped. Additional work is scheduled in this area, but preliminary indications are that environmentally and economically acceptable corridors can be located in all necessary areas. Preliminary landing sites have also been identified. Integration of the results of work completed in Phase II-B with all previous site-specific studies indicates that the "preferred route" shown in Figure 3 is at this time the most acceptable. Additional studies are being conducted, however, to examine other route options for technical, economic, environmental and social acceptability.

Preliminary research into the potential environmental impacts of installation and operation of a commercial cable system has been substantial. It appears that impacts to the marine environment will be minimal and that terrestrial impacts can be minimized through appropriate selection of routes and facilities sites as well as through adoption of appropriate installation and operation techniques.

Legal, institutional and financial aspects of a commercial system continue to be evaluated, but again, preliminary conclusions support system feasibility. Three scenarios for ownership and operation are being evaluated: private ownership and operation, public corporation ownership and operation, and public agency ownership with operations contracted out.

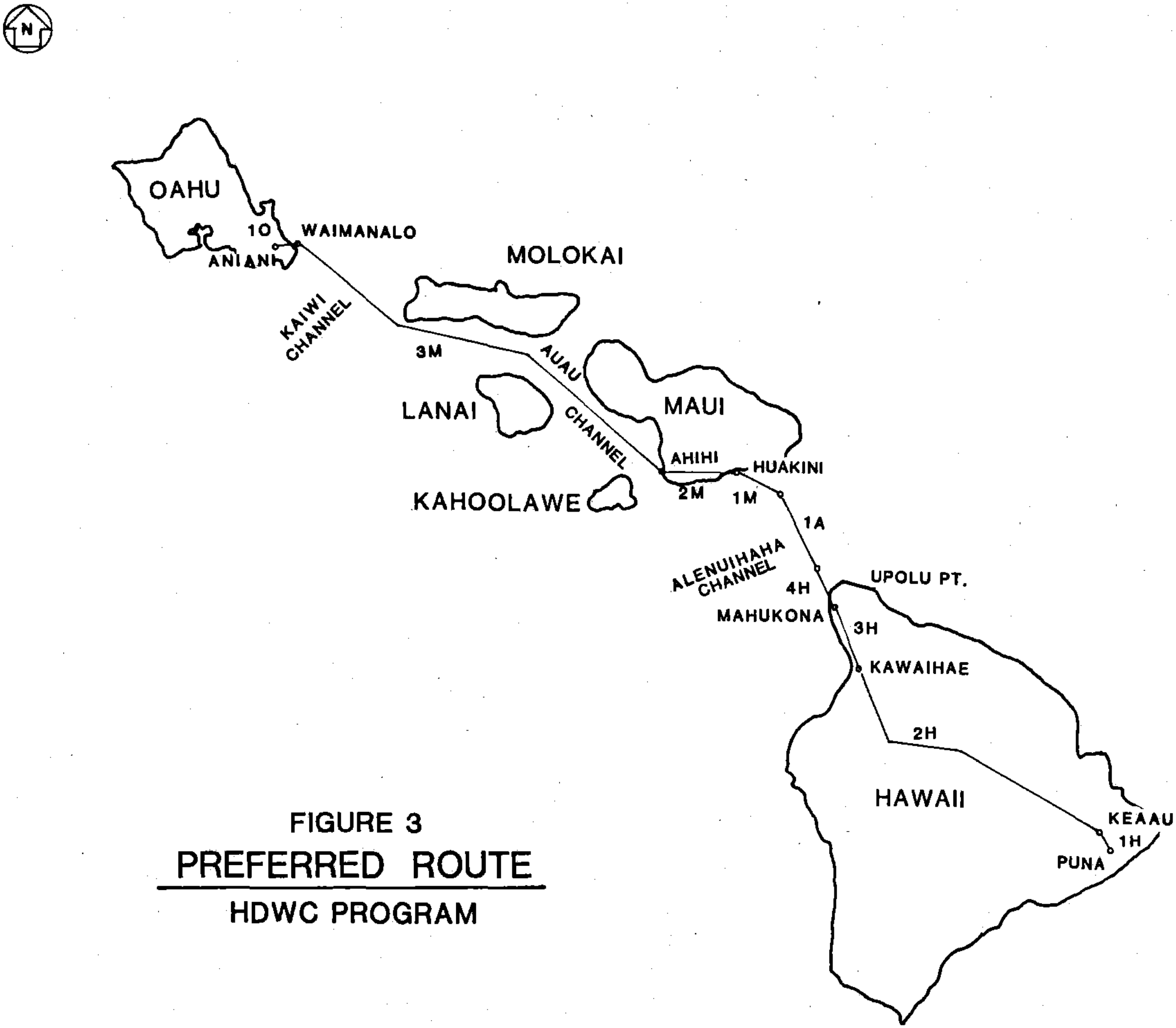


FIGURE 3

PREFERRED ROUTE

HDWC PROGRAM

The transition from technical theory to practicality involves economic analyses. Determination of economic feasibility of the system was dropped as a goal of the Federally-funded portion of the Program, but remains one of the most important areas of research in the State-funded portion of the Program. In the coming year, greater emphasis will be placed on development of system economic projections, as well as integration of the development scenario with that of geothermal development in Hawaii and with the larger issue of world petroleum markets.