HAWAII DEEP WATER CABLE PROGRAM

PHASE II-A

EXECUTIVE SUMMARY

artment of Planning and Economic Development

INTRODUCTION

This Executive Summary for the Hawaii Deep Water Cable (HDWC) Program summarizes the state-funded Phase II-A work that has been performed; indicates the interrelationships of the state- and federally-funded portions of the program; and identifies the major accomplishments of these efforts.

Background and Objectives

Crucial to Hawaii's efforts to reduce its dependence on imported fuel for electrical generation and increase utilization of its abundant renewable energy resources, is development of an electrical intertie between the islands of Hawaii and Oahu. The HDWC Program, a research, development and demonstration program, is determining the feasibility and practicality of establishing an interisland, submarine, high voltage direct current (HVDC) cable system. The principal goals of the program are:

(1) To determine the technical and economic feasibility of establishing an electrical transmission cable system in underwater depths up to 2,100 m (7,000 ft) and over a distance of more than 240 km (150 mi);

(2) To determine the ocean engineering problems and solutions of deploying, retrieving and repairing a deep water cable in the Hawaiian environment; and

(3) To develop a commercial cable criteria document that can be used by private industry or governmental agencies for the design, installation and maintenance of deep water electrical transmission cable systems.

Funding for the HDWC Program is being provided by the State of Hawaii (through the Department of Planning and Economic Development - DPED) and the U.S. Department of Energy. State support began in 1981 (State Fiscal Year 81-82) with the release of funding for work identified as Phases I and I-A. Work performed with these initial funds is described in six technical reports, an Executive Summary and a narrated 35 mm slide program. Spurred on by this show of state support and the successes of Phases I and I-A, a multi-year federally-funded contract was signed in 1982. Continued state funding was assured with the appropriation of funds for state fiscal years 82-83, 83-84 and 84-85. All federally-funded activities are included in the designation Phase II. State-funded activities have been designated as II-A, II-B and II-C to correspond with the 82-83, 83-84 and 84-85 fiscal years.

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, hardware manufacture, computer modeling, utility system design, cable design, environmental analyses and program management. For both the state- and federally-funded portions of the HDWC Program, Hawaiian Electric Co., 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 System Integration Manager with management and technical support responsibilities throughout the program. Other firms and key consultants involved in the program are identified in the organizational chart (Figure 1).

Prior Work (Phases I and I-A)

As an aid to understanding the purposes and direction of the Phase II work efforts, the following identifies the major accomplishments of Phase I:

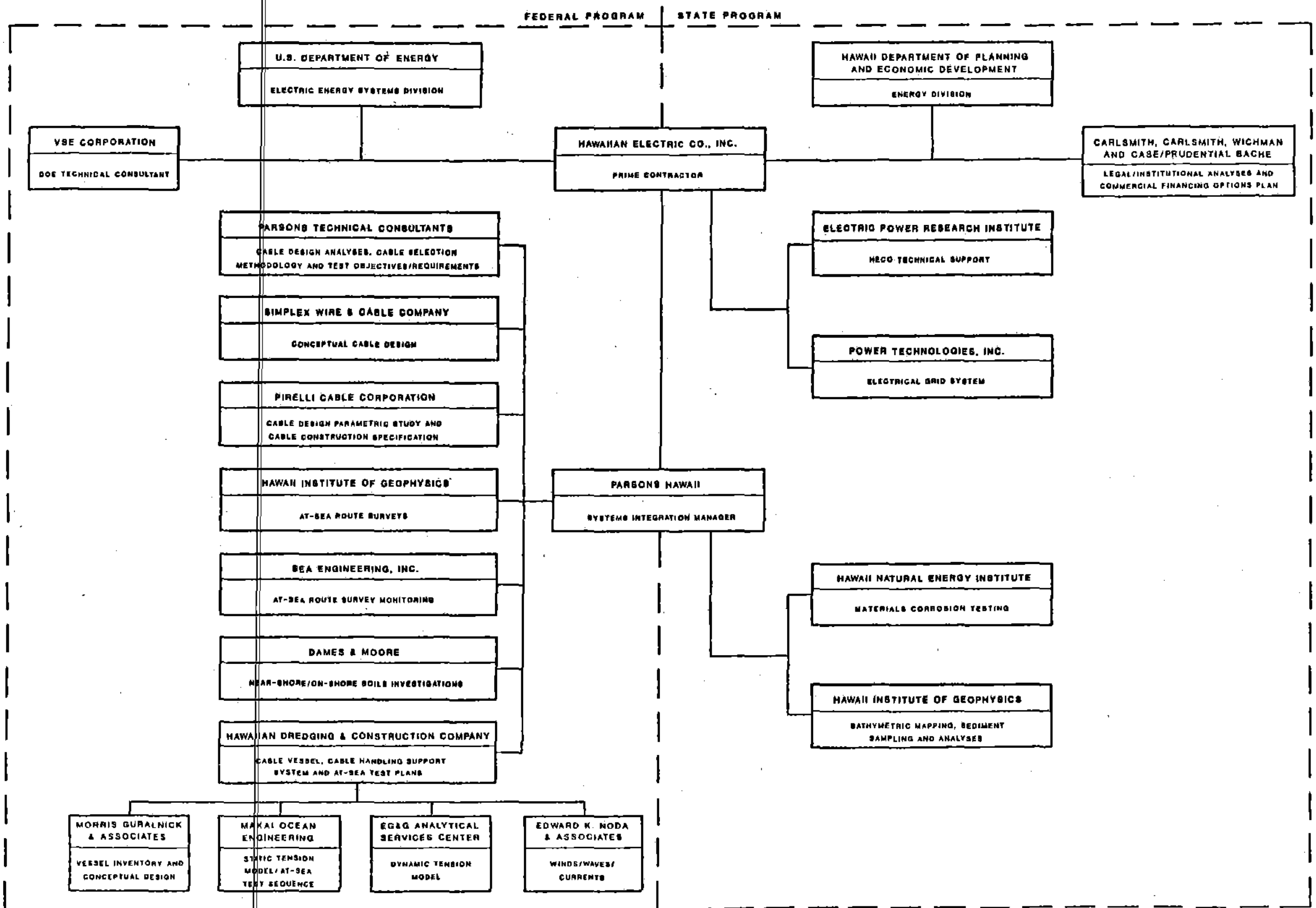
1. Preliminary Route Survey Analysis

Preliminary identification, mapping and environmental analyses of more than forty potential commercial cable system submarine and terrestrial routes or route segments were accomplished (Figure 2).

2. Preliminary Prototype Cable Design Criteria

Essential elements of the cable design were evaluated in this task. Considerations included materials characteristics (type, composition and weight) and dimensions (diame-

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



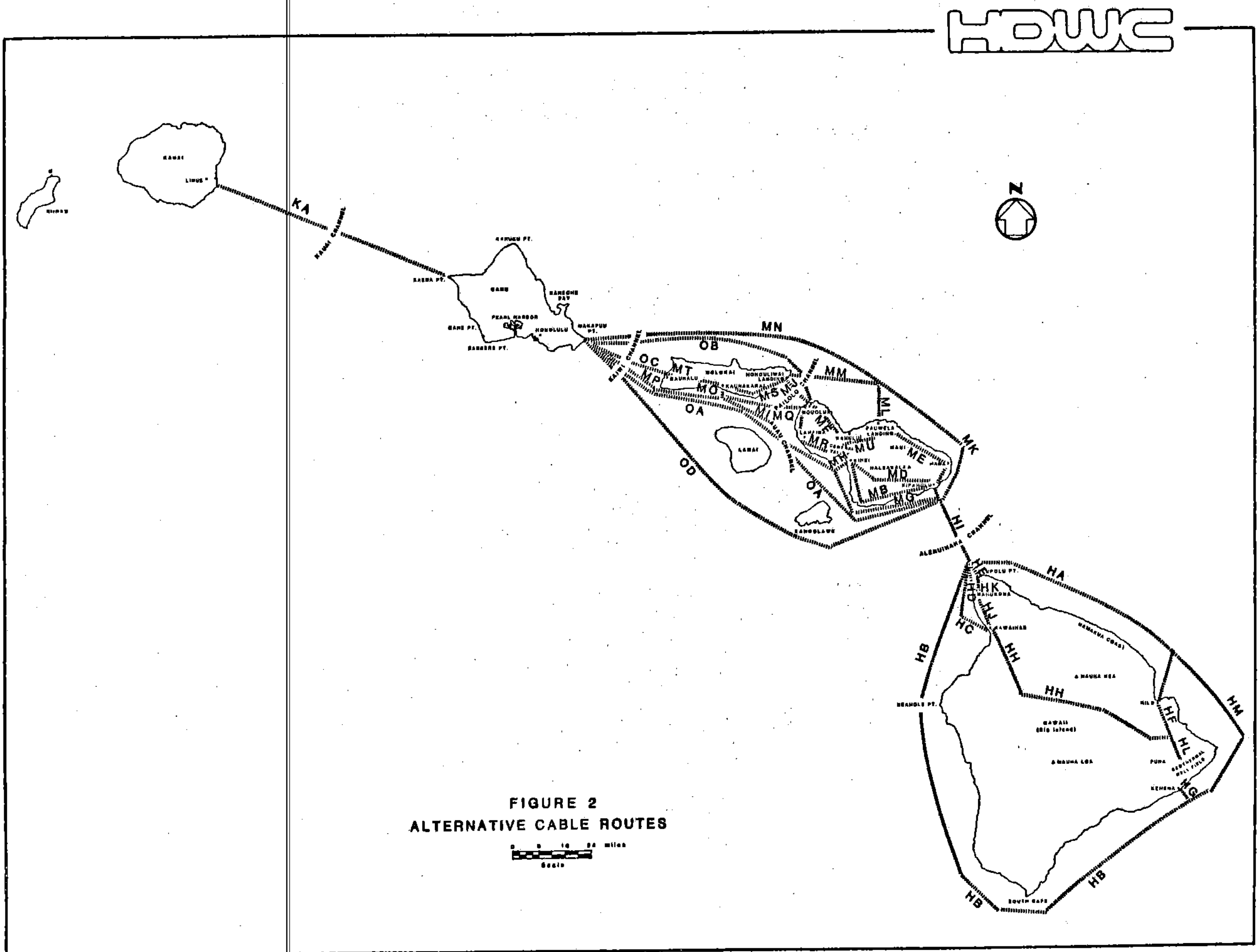


FIGURE 2
ALTERNATIVE CABLE ROUTES

-5-

ter, area and thickness) of cable conductors, insulations, sheaths and armors. Identified were five basic cable design configurations that could possibly successfully operate in the deep ocean around Hawaii. These five design configurations formed the basis for further detailed examination of cable designs in the federally-funded portion of Program.

3. Preliminary Cable Ship Inventory and Capabilities

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 testing program was subsequently developed.

4. Preliminary Electrical Grid System Integration Study

A conceptual plan was developed for integration of individual island grid systems into a unified HVDC system.

5. Public Informational Program

In addition to the Phase I Executive Summary which was widely distributed to public and private organizations to provide a basic introduction to the Program, a narrated, 35 mm slide program was prepared and presented to private and public sector groups and agencies. This slide program describes the goals/objectives of the HDWC Program and emphasizes the HDWC Program's interrelationship with alternate energy resource development programs.

6. General Management/Management Support

These efforts established the management framework for the remainder of the program. The principal product was a Program Management Plan (PMP) 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 (QAP) and a Program Mobilization Plan (Mob Plan).

CURRENT FEDERALLY-FUNDED WORK (PHASE II)

The following federally-funded Phase II tasks are now being accomplished concurrent with state-funded Phase II-A activities:

Task 1.1 - Program Management and Technical Support

Technical memoranda specifying cable laboratory and at-sea testing objectives and requirements, cable design selection methodology and technical report writing/formating requirements were prepared as was a cable selection report.

Near-shore and on-shore soils investigations were conducted at sites on the Big Island and Maui. Data from these investigations are providing cable designers with "actual condition" information on the physical, chemical, biological and thermal characteristics of the sediments in these areas.

Task 1.2 - Cable Design and Verification

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 meet or exceed all design constraints and, theoretically, are suitable for a commercial interisland cable system. The number of designs has subsequently been reduced to one design. This design, selected following a rigorous technical and economic analysis of all 251 candidate designs, is considered to be representative of an appropriate commercial cable.

A cable construction specification for the selected design is being prepared. This specification will form the basis of a request-for-proposals that will be issued to qualified cable manufacturing/testing firms for the laboratory test cable and, in later stages, for the at-sea test cable.

Task 1.3 - Cable Vessel and Cable Handling Support Systems

In Phase I, a cable vessel/equipment survey was conducted, and a cable vessel/equipment conceptual design prepared. Phase II work included reassessing cable vessel/equipment availability and applicability, and modeling of dynamic/static cable tensions using different vessel/equipment configurations. This work integrated the cable design information developed under Task 1.2 above, the sea conditions information developed under Task 5 of the Phase I work and the ocean bottom conditions information developed under Task 1.4 below. Results of this work indicate that, for the HDWC Program at-sea testing, a 400-foot long by 100-foot wide vessel will closely approximate the vessel necessary for a commercial cable deployment.

Task 1.4 - At-Sea Route Surveys

This work, by the University of Hawaii at Manoa - Hawaii Institute of Geophysics, included detailed bathymetric mapping of the Alenuihaha Channel as well as deep water sediment profiling/sampling/analyses and bottom photography. The data collected indicate 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 represent the first detailed mapping of the Alenuihaha Channel and will be supplemented with additional surveys under the next state-funded portion (Phase II-B) of the HDWC Program.

CURRENT STATE-FUNDED WORK (PHASE II-A)

The current state-funded portion (Phase II-A) of the program has accomplished the following:

Task 1. Environmental Analyses

A detailed environmental report, including an annotated bibliography of the electromagnetic field effects of HVDC systems, was prepared and identified as the Phase II-A Task 1 Report. For this report, 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. In the formal agency briefings, a number of concerns were expressed relative to a potential commercial cable system. These included concerns relative to route selection and land use plans, wildlife and other natural resources, pollution, public health and socioeconomic impacts.

Although the HDWC Program is technically complex and will result in establishment of new limits for submarine cable system criteria, its direct environmental impacts will be insignificant - limited to short-term ship operations and temporary disruption of small areas of marine benthic habitats.

Because of their small-scale, transient and research nature, the operational aspects (at-sea testing) of the HDWC Program will face few permitting requirements. To summarize: (1) It is anticipated that a temporary variance from a Conservation District Use Permit (CDUP) will be appropriate, although this has not been confirmed by the Board of Land and Natural Resources (BLNR); (2) Department of the Army (Corps of Engineers - "COE") requirements for a permit to work in navigable waters could be met through either its "Nationwide Permit" system or a "Letter of Permission"; (3) the U.S. Coast Guard (USCG) must be notified at least thirty days prior to initiation of at-sea testing to allow publishing of appropriate information in "Notices to Mariners"; and (4) no county permits will be required. A comparable project, the OTEC cold water pipe at-sea test, required neither a CDUP nor a COE permit.

Implementation of a commercial interisland HVDC intertie could have significant environmental impacts, and both state and federal Environmental Impact Statements (EIS's) will be required prior to implementation.

A commercial cable system development will require an extensive array of permits. The counties will require Special

Management Area (SMA) use permits (including an EIS), shoreline setback variances, building, grading and street usage permits and perhaps zoning waivers.

The principal state requirement will be a CDUP requiring a state EIS. Highway use permits will be required because overhead line segments will pass over state highways, and, depending on route selection, an airport zone use permit may also be required. A coastal zone consistency statement will be needed because federal permitting will be required.

A COE permit for work in navigable waters will be required. Restrictions on blasting activities associated with nearshore trenching may be added as conditions to the permit in order to minimize negative impacts on threatened and endangered marine mammals and sea turtles. A National Environmental Policy Act (NEPA) EIS will be a prerequisite of this permit.

The EIS's required will use essentially the same format, and preparation (but not submittal) may proceed concurrently. It is estimated that EIS preparation will require a minimum of six months and that the permitting activities will require a minimum of another eleven months.

Task 2. 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. The scope of this work was to develop:

(1) Advanced conceptual plans to directly link Hawaii and Oahu with an HVDC cable system

(2) Conceptual system designs and capital costs for HVDC cables and HVAC lines

(3) Operational scenarios and costs

(4) Economic feasibility projections

From the preliminary route survey, several alternative converter sites were analyzed for sending and receiving the bulk dc power (Figure 3). Alternative locations modeled as rectifier (ac to dc) sites on the Big Island included one near the geothermal wellfield (Kaumana) and one near an assumed submarine cable takeoff point at Mahukona. The Kaumana site was highly favored on technical, economic and environmental grounds.

Oahu inverter (dc to ac) sites modeled were Meadowlands, near Heeia, and Aniani, above Waimanalo. The latter was found to be technically adequate and environmentally preferable, although slightly more costly.

The developmental scenarios investigated included projecting system needs on Oahu and Hawaii with and without geothermal

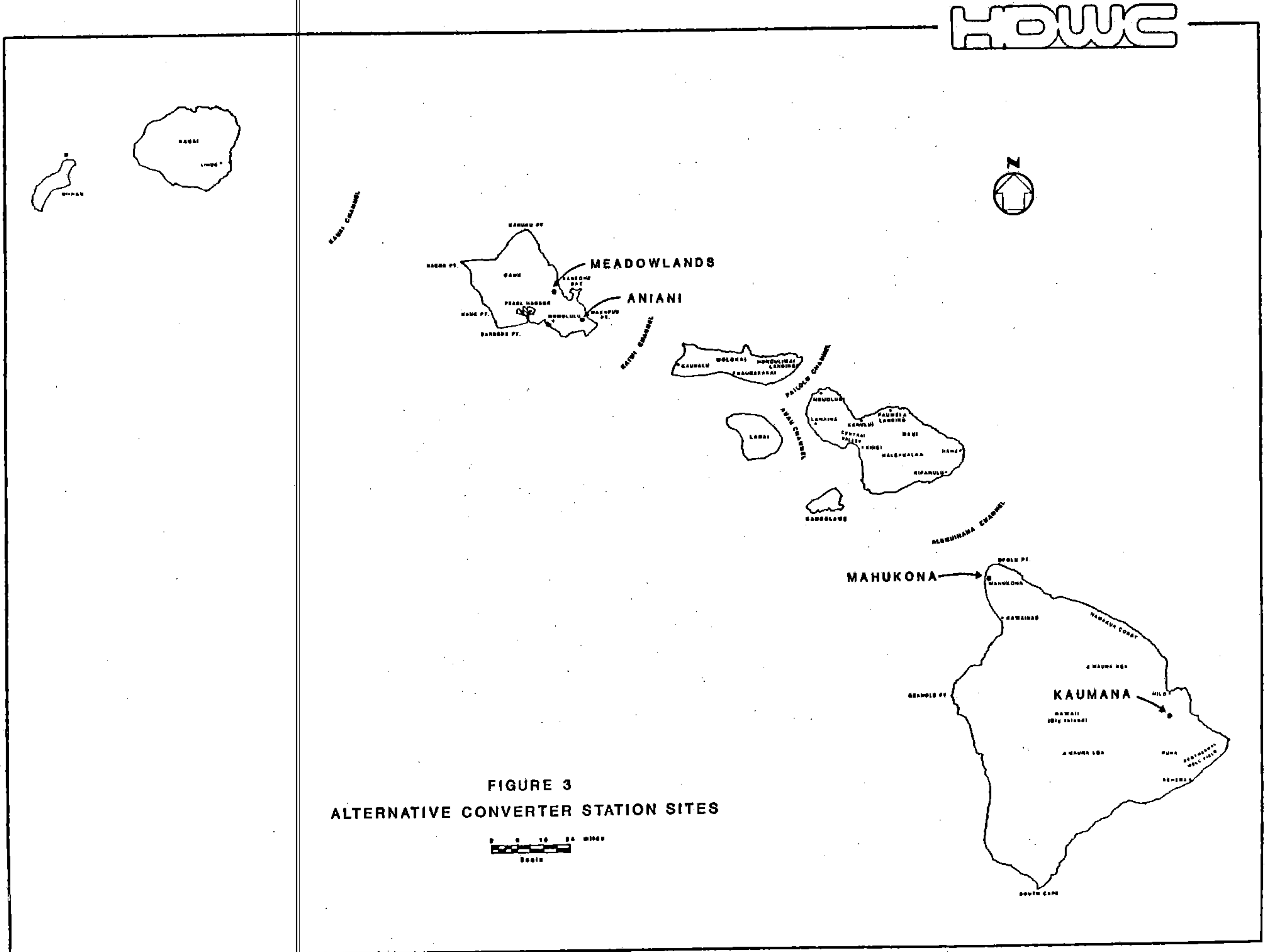


FIGURE 3
ALTERNATIVE CONVERTER STATION SITES

development and the cable system, at annual load growth rates of 0.3 and 2.0 percent. 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.

The projected electrical grid systems on Hawaii and Oahu were studied using several computer models. Load-flow studies described the characteristics of the grid systems at steady state. Dynamic simulations of the systems' responses during and after various types of faults were used to examine overvoltages, instabilities and frequency excursions. Overvoltage and instability were not found to be significant problems in the HECO grid system. The study revealed, however, that the possibility of losing an entire 500 MW block of power would require an extremely large and expensive spinning reserve. Thus, a major conclusion of this work is that the cable system should be modular, with units no larger than the largest existing HECO generator. A convenient size would be 125 MW "modules." Modules could be physically distinct cables (four) or potential overload capacity in less than four cables.

Task 3. Materials Corrosion Testing

This work is being performed by the Hawaii Natural Energy Institute (HNEI) at the University of Hawaii at Manoa and the Natural Energy Laboratory of Hawaii (NELH) at Keahole Point on the Big Island. Corrosion, abrasion and cathodic protection characteristics are being investigated for various types of metals which may be used as conductor, sheath or armor material. The information developed during Phase II-A and subsequent phases, will be provided to cable designers to assure that the characteristics of Hawaiian seawater will be considered in the cable design/fabrication/testing activities being pursued under the federally-funded portion of the program. These studies are all of a long-term nature and only preliminary results were developed during Phase II-A. Areas of ongoing investigation include:

(1) Long-term corrosion testing of steel, copper and aluminum alloys. These materials are typical of those that may be used for cable conductors, sheathing or armor materials.

(2) Crevice corrosion studies of stainless steel alloys. The stainless steel materials are also candidates for cable armoring. Corrosion studies are continuing using automatic monitoring of electrical potentials.

(3) Corrosion and fouling of cupronickel. Because this material may be used as an antifouling wrap on the cable, it is necessary to understand its corrosion and fouling characteristics.

(4) Abrasiveness of Hawaiian rocks to various potential cable armor steels. These studies will provide information required to properly armor cables to assure reliable operation in the Hawaiian ocean environment.

Task 4. Program Management and Technical Support

This task encompassed all administrative, financial and technical functions including scheduling, cost reporting and technical adequacy controls, as well as other functions including development of subcontractor scopes of work and contract documents necessary to continue the program.

Program management during Phase II-A evolved from and expanded upon the management plans (PMP, QA Plan, WBS, schedule and cost controls, etc.) developed in Phase I. The roster of tasks and subcontractors expanded, and scopes of work and contract documents were prepared and executed. The results of subcontractor and consultant efforts relative to vessels, equipment, cables, routes, environmental constraints and impacts, at-sea test scenarios, etc. were integrated and disseminated throughout the program team, as appropriate. A number of meetings of program participants and representatives of the funding agencies were held in Hawaii and on the mainland to exchange program information. These meetings also allowed effective planning and scheduling of future work and provided definition to all participants to assure that all program activities were moving forward in a unified and integrated manner. Additionally, program representatives regularly attended meetings of the Governor's Geothermal Advisory Committee to keep abreast of changes in the geothermal development schedule.

Based on the accomplishments of Phase II-A and refinement of future work requirements, a scope of work and budget for Phase II-B (FY 83-84 funding increment) were assembled, discussed and submitted to DPED. As a result of these activities, Phase II-B tasks have been initiated and will be reported on in early 1985.

FUTURE ACTIVITIES - PHASE II-B (FY 83-84)

Phase II-B work will, for the most part, be a continuation of Phase II-A work. As work on individual tasks proceeds, results will be integrated with those of preceding and concurrent tasks to provide increasingly well-defined and realistic plans for the HDWC Program and commercial cable system development. As in previous phases, information from federal- and state-supported tasks will be exchanged to further the overall HDWC Program goals. Tasks specific to state-funded Phase II-B are as follows:

Environmental Analyses

Work under this task will include preparation of the requisite environmental impact report and permit applications for the at-sea test portion of the HDWC Program. Potential route-specific environmental constraints will be further evaluated and integrated with the cable system route analysis work described below.

Electrical Grid System Integration Studies

Further analyses of the Hawaii-Oahu dc transmission link and the initial analysis of a Hawaii-Maui-Molokai-Oahu electrical interconnection are planned. Better quantification of system component reliability and availability will be sought. This information will be utilized to compile complete system costs and to further refine the economic analyses initiated during Phase II-A.

Cable Materials Corrosion Testing

Testing methods development and long-term experiments will continue through Phase II-B. These tests and experiments will include the long-term corrosion tests and crevice corrosion studies initiated under Phase II-A and more extensive abrasion tests. In addition, studies of corrosion protection potential and corrosion fatigue of lead sheathing in Hawaiian seawater will be conducted.

At-Sea Route Surveys

Submarine areas of potentially serious geologic hazard to a commercial cable system will be surveyed and mapped in detail. Sediment samples will be collected and analyzed and representative photographs collected.

Cable System Route Analysis

The focus of this task will be to reevaluate/refine the Phase I analyses performed on potential commercial cable routes by incorporating environmental analyses data, electrical grid system integration study data, at-sea hazards data and deployment/retrieval/repair/redeployment scenarios developed in Phases II-A and II-B. The purpose of this work will be to describe the specific environmental impacts associated with potential commercial cable routes and to refine commercial cable system costs.

Public Informational Program

Preparation of multi-media materials and the presentation/distribution of the prepared materials to the general public will be the primary focus of this task. The public informational program will be designed to describe, to government agencies and legislators, private organizations and the general public, the interrelationship of the HDWC Program with other renewable energy resource programs.

Program Management and Technical Support

This task will include coordinating/monitoring activities of all HDWC Program participants, preparing materials for reporting purposes and preparing/presenting materials to support all future funding requests.

Technical support efforts will include engineering guidance/review of program subcontractors' activities and updating of HDWC Program and commercial cable system schedules and costs.

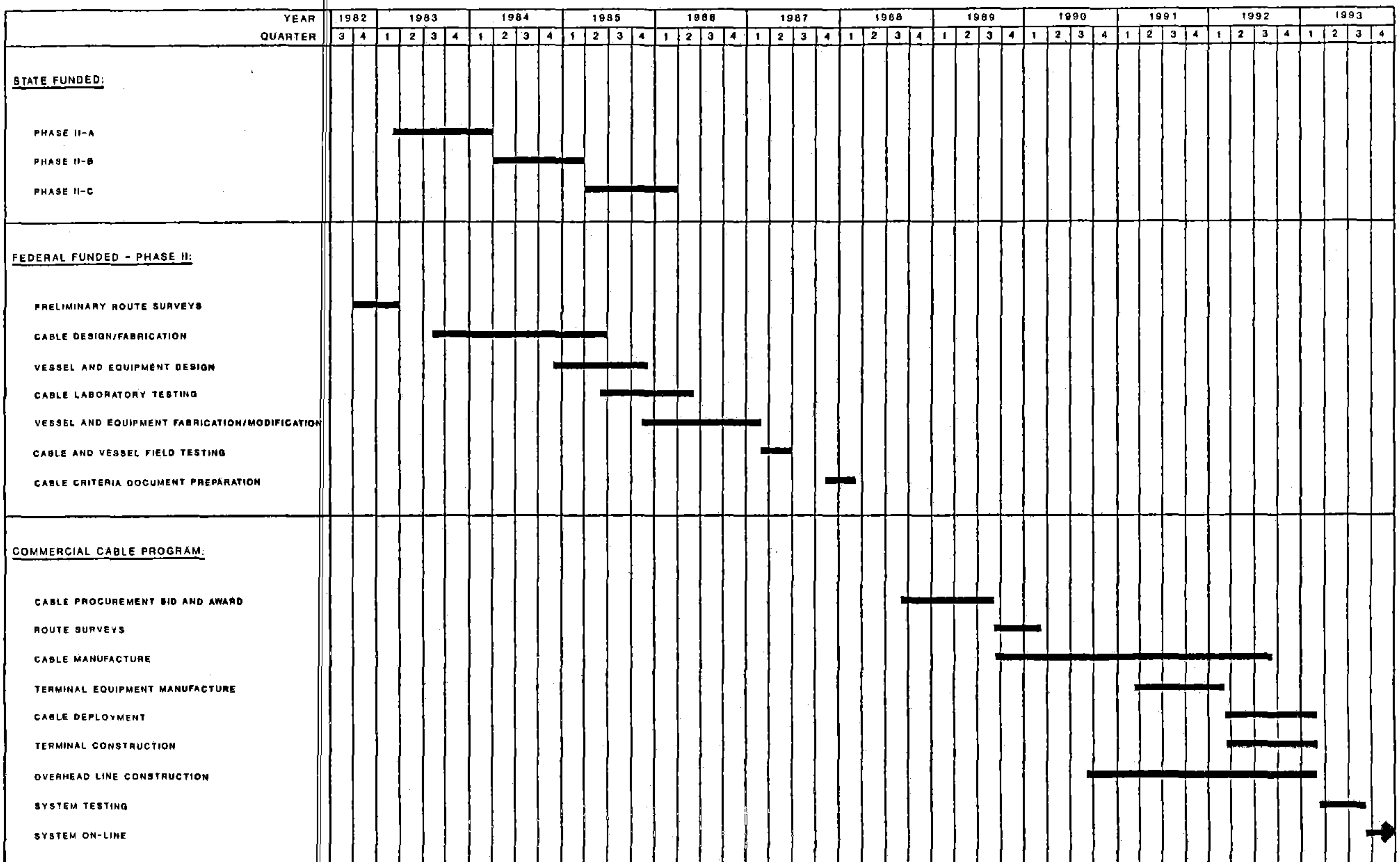
PROGRAM SCHEDULE

Timelines for the state- and federally-funded portions of the HDWC Program and a target schedule for commercial development of the system are shown in Figure 4. State-funded efforts are projected to proceed through the first quarter of 1986. Components of the federally-funded portion of the Program extend for an additional two years, and are presently scheduled to be completed in March 1988. The schedule assumes that, within six months of completion of the HDWC Program, an institutional framework to finance, install and operate the commercial program is available. If this is the case, it is anticipated that an operational transmission system could be "on line" in 1993.

HDWC

FIGURE 4

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



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 "most likely" 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 through 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.

As shown in Table 1, the total state-funded requirement is estimated to be $3,734,827, to which will be added approximately $375,000 in cost sharing provided by program participants. 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 (i.e., both state- and federally-funded portions) are now estimated to be $22,095,527.

TABLE 1

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	
Program Management	$ 82,633	$ -0-	$ 67,423	$ 302,450	$ 345,000	$ 647,450
Technical Support	82,038	18,000	67,424	150,977	180,000	330,977
Route Survey Analyses	50,435	-0-	-0-	66,165	100,000	166,165
Preliminary Prototype Cable Design Criteria	42,313	-0-	-0-	-0-	-0-	42,313
Cable Vessel Inventory	27,581	-0-	-0-	-0-	-0-	27,581
Materials Corrosion Testing	-0-	-0-	50,000	62,014	65,000	177,014
Electrical Grid System Investigations	-0-	19,497	213,915	325,733	350,000	909,145
At-Sea Route Surveys	-0-	-0-	-0-	218,582	260,000	478,582
Public Information Program	-0-	22,503	-0-	34,996	40,000	97,499
Environmental Analyses	-0-	-0-	151,238	178,910	160,000	490,148
TOTALS	$ 285,000	$ 60,000	$ 550,000	$1,339,827	$1,500,000	$3,734,827

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

Preliminary Commercial Cable System Costs

As stated in the introduction to this Executive Summary, one of the three principal goals of the HDWC Program is to determine the technical and economic feasibility of establishing an electrical transmission cable system in water depths up to 2,100 m (7,000 ft) and over a distance of more than 240 km (150 mi). The determination of the economic feasibility of such a system is no less difficult than determining the technical feasibility. The economics of a cable system are as complex and multi-faceted as the technical issues. Material, installation and shore-side 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 work efforts, several potential alternative routes were examined and cable system costs developed for those routes. With the completion of Phase II-A and a portion of the federally-funded Phase II work, further refinement of cable system costs has been accomplished and results are shown in Table 3.

During the cable design selection work performed under the federally-funded portion of the program, it was determined that, at least three "most likely" route options would be required as parameters 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

TABLE 3

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

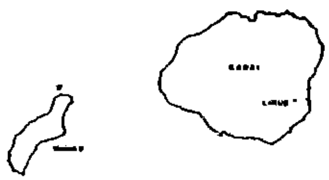
	COST ($ x 10^6 PRESENT WORTH 1983)		
CATEGORY	ROUTE 1	ROUTE 2	ROUTE 3
Capital Costs[1]	226.29- 408.51	226.08- 412.92	188.70- 336.14

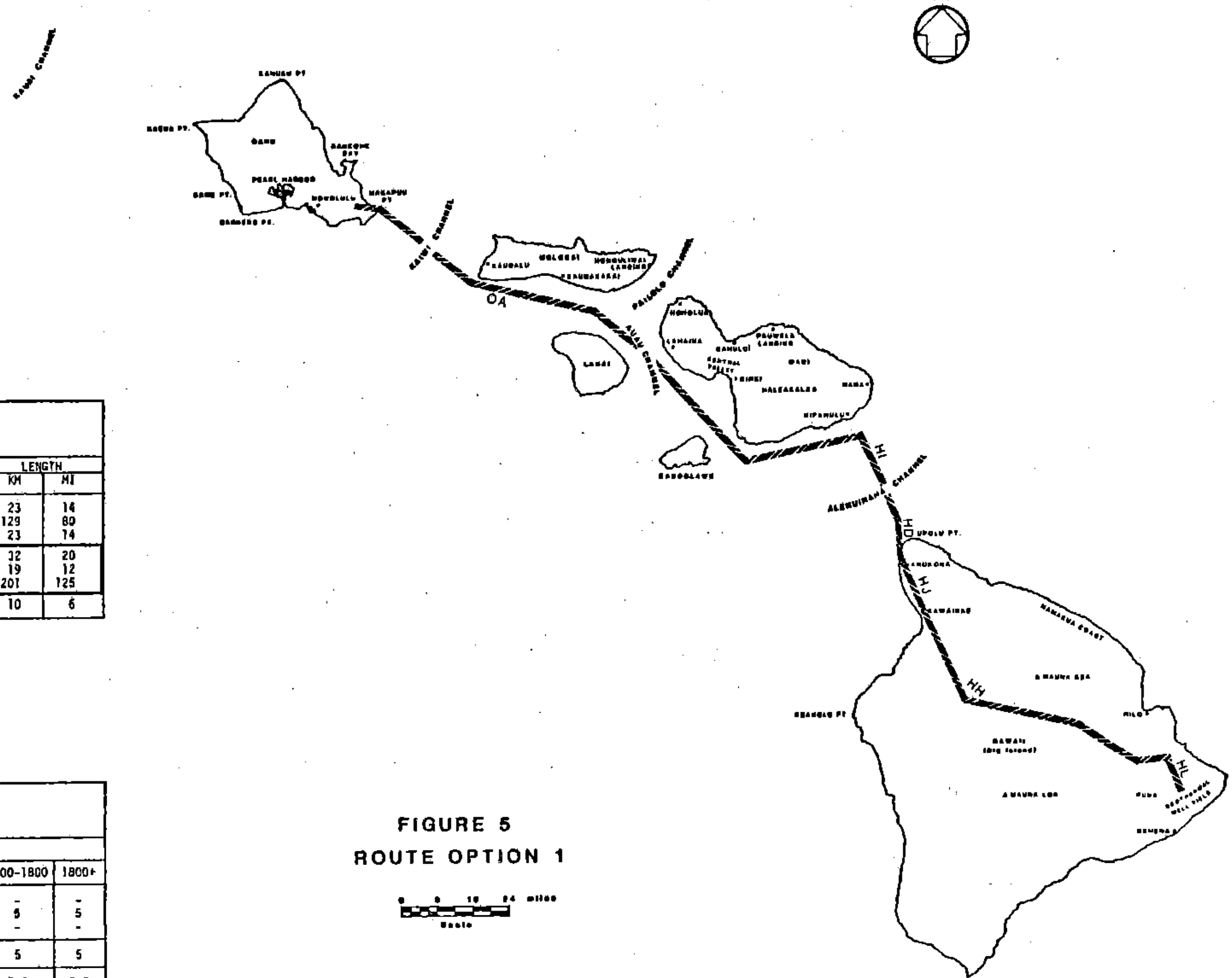
[1] "Capital Costs" for each route option is the total cost for the cable system including cable and losses, overhead lines and losses, HVDC equipment, laying and splicing, pumping plants for SCOF, landing costs and potheads.

economically feasible. The three route options selected are shown in Figures 5, 6 and 7. Cable system costs for these three different route scenarios, using the most appropriate cable design for each route, are shown in Table 3. It should be remembered that these costs are preliminary only and will be refined as the HDWC Program proceeds to completion.

Capital costs of the system include costs for cables, HVDC shore-side 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 and 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.

Overhead line costs vary considerably with tower design. The preferred single steel pole is the most expensive, with costs 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.





OPTION 1 HAWAII TO OAHU					
FROM	TO	PHASE I SEGMENT	OH/SUB	LENGTH KM	LENGTH MI
Puna	Keaau	HL	OH	23	14
Keaau	Kawaihae	HH	OH	129	80
Kawaihae	Mahukona	HJ	OH	23	14
Mahukona	Alenuihaha (H)	HD	SUB	32	20
Alenuihaha (H)	Alenuihaha (M)	HI	SUB	19	12
Alenuihaha (M)	Makapuu	OA	SUB	201	125
Makapuu	Aniani	--	OH	10	6

TOTAL OVERHEAD 185 km (114 mi)

TOTAL SUBMARINE 252 km (157 mi)

437 km (271 mi)

PERCENTAGE SUBMARINE = 57.7%

LONGEST SUBMARINE RUN = 252 km (157 mi)

APPROXIMATE DISTANCE WITHIN DEPTH RANGES FOR SUBMARINE PORTIONS (KM)							
	DEPTH (M)						
SEGMENT	0-300	300-600	600-900	900-1200	1200-1500	1500-1800	1800+
HD	22	5	5	-	-	-	-
HI	-	-	-	6	3	5	5
OA	159	26	16	-	-	-	-
TOTAL	181	31	21	6	3	5	5
%	71.8	12.3	8.3	2.4	1.2	2.0	2.0

FIGURE 5

ROUTE OPTION 1

OPTION 2 HAWAII TO MAUI TO OAHU					
FROM	TO	PHASE I SEGMENT	OH/SUB	LENGTH KM	LENGTH MI
Puna	Keaau	HL	OH	23	14
Keaau	Kawaihae	HH	OH	129	80
Kawaihae	Mahukona	HJ	OH	23	14
Mahukona	Alenuihaha (H)	HD	SUB	32	20
Alenuihaha (H)	Alenuihaha (M)	HI	SUB	19	12
Alenuihaha (M)	La Perouse Bay	OA (portion)	SUB	48	30
Offshore	Inshore (x2)	--	SUB	2	1
La Perouse Bay	Makapuu	OA (portion)	SUB	153	95
Makapuu	Aniani	--	OH	10	6

TOTAL OVERHEAD 185 km (114 mi)

TOTAL SUBMARINE 254 km (158 mi)

439 km (272 mi)

PERCENTAGE SUBMARINE = 57.9%

LONGEST SUBMARINE RUN = 153 km (95 mi)

APPROXIMATE DISTANCE WITHIN DEPTH RANGES FOR SUBMARINE PORTIONS (KM)							
	DEPTH (M)						
SEGMENT	0-300	300-600	600-900	900-1200	1200-1500	1500-1800	1800+
HD	22	5	5	-	-	-	-
HI	--	-	-	6	3	5	5
OA (por)	30	8	10	-	-	-	-
To Shore	2	-	-	-	-	-	-
OA (por)	129	18	6	-	-	-	-
TOTAL	183	31	21	6	3	5	5
%	72.0	12.2	8.3	2.4	1.2	2.0	2.0

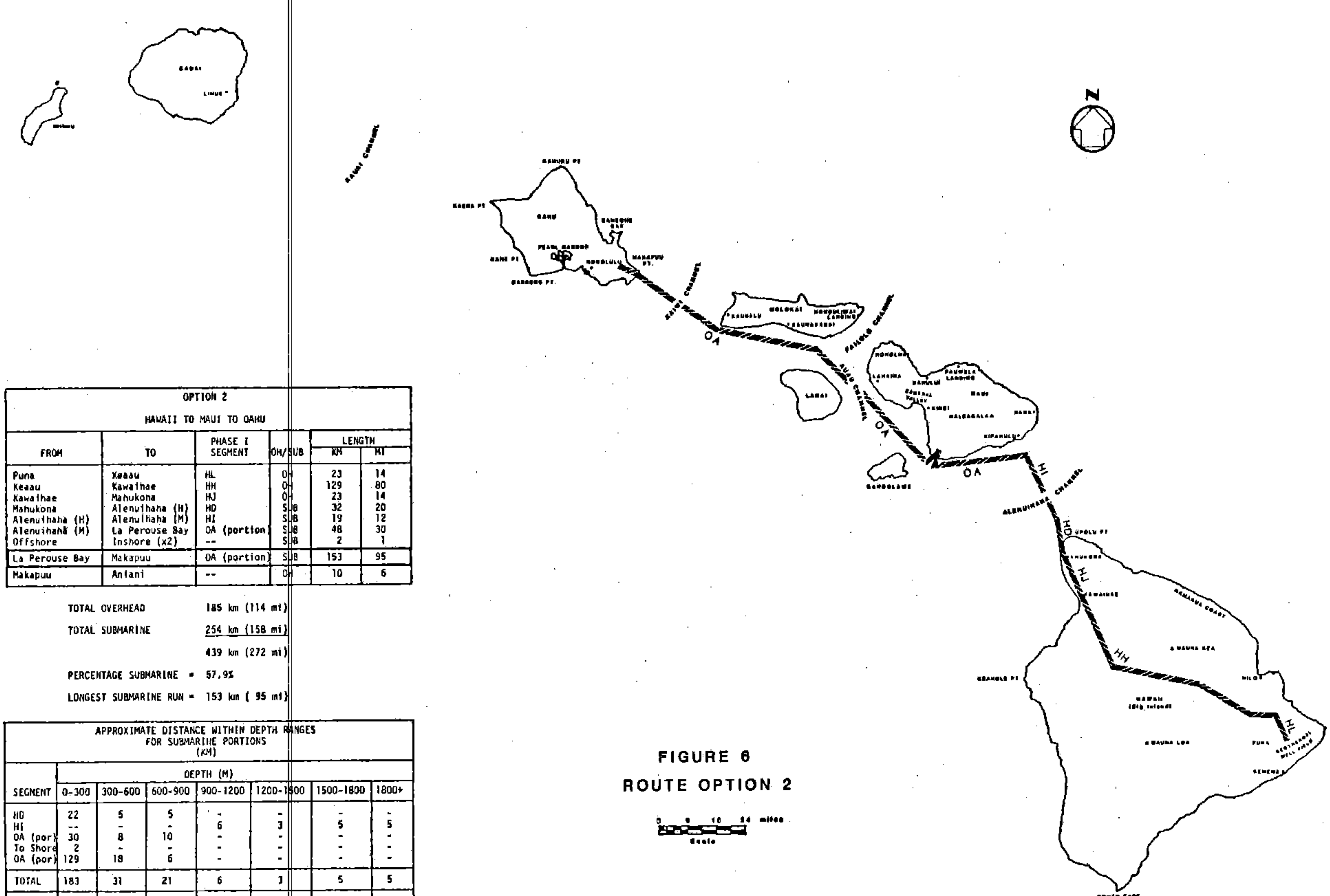
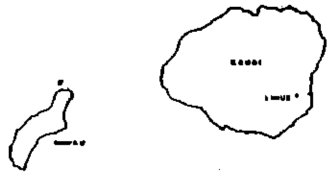
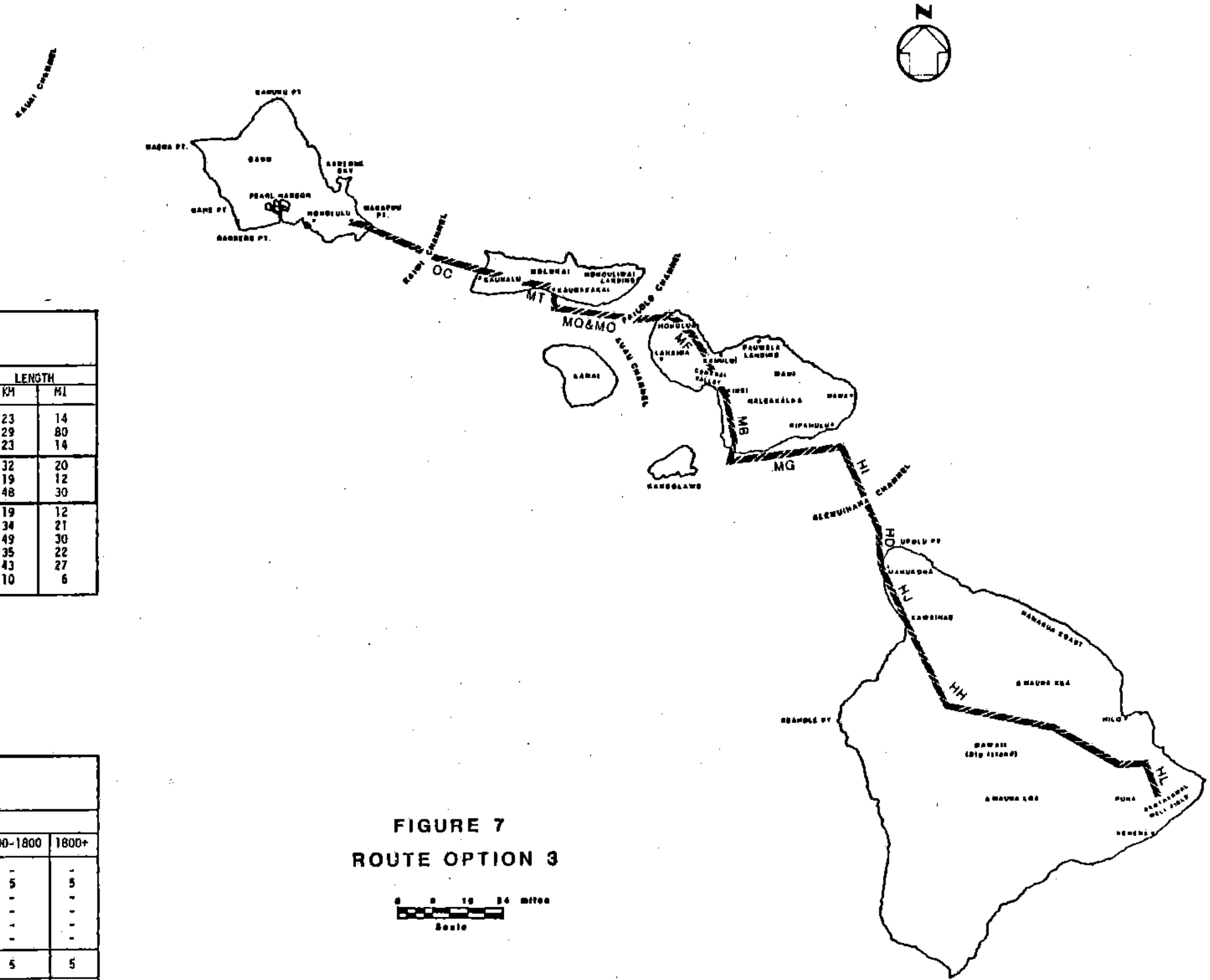


FIGURE 6
ROUTE OPTION 2





OPTION 3 HAWAII TO MAUI TO MOLOKAI TO OAHU					
FROM	TO	PHASE I SEGMENT	OH/SUB	LENGTH KM	LENGTH MI
Puna	Keaau	HL	OH	23	14
Keaau	Kawaihae	HH	OH	129	80
Kawaihae	Mahukona	HJ	OH	23	14
Mahukona	Alenuihaha (H)	HD	SUB	32	20
Alenuihaha (H)	Alenuihaha (M)	HI	SUB	19	12
Alenuihaha (M)	La Perouse Bay	MG (portion)	SUB	48	30
La Perouse Bay	Kihei	MB (portion)	OH	19	12
Kihei	Honolua	MF	OH	34	21
Honolua	Kaunakakai	MQ & MO	SUB	49	30
Kaunakakai	Kaunalu	MT	OH	35	22
Kaunalu	Makapuu	OC	SUB	43	27
Makapuu	Aniani	--	OH	10	6

TOTAL OVERHEAD 273 km (169 mi)

TOTAL SUBMARINE 191 km (119 mi)

464 km (288 mi)

PERCENTAGE SUBMARINE = 41.2%

LONGEST SUBMARINE RUN = 99 km (62 mi)

APPROXIMATE DISTANCE WITHIN DEPTH RANGES FOR SUBMARINE PORTIONS (KM)							
	DEPTH (M)						
SEGMENT	0-300	300-600	600-900	900-1200	1200-1500	1500-1800	1800+
HD	22	5	5	-	-	-	-
HI	--	-	-	6	3	5	5
MG (por)	30	8	10	-	-	-	-
MQ	44	-	-	-	-	-	-
MO	5	-	-	-	-	-	-
OC	21	14	8	-	-	-	-
TOTAL	122	27	23	6	3	5	5
%	64.0	14.1	12.0	3.1	1.6	2.6	2.6

FIGURE 7
ROUTE OPTION 3

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 emphasis of the HDWC Program through Phase II-A has been assessment of the technical feasibility of the Program concept. All results to date support a favorable conclusion.

Grid systems integration studies have revealed a number of significant practical guidelines for the cable system design. Optional sites for the physical interconnection with existing grid systems have been identified and system response modeling has shown very acceptable performance under normal and contingency operations. Optimal system component sizing has been done to minimize future spinning reserve requirements.

The potential environmental impacts of system development have been surveyed, with the results indicating minimal impacts in the marine environment and terrestrial impacts which are mitigable through judicious route and terminal site selection and installation methodology. Impacts of system operation appear insignificant at the intended voltage levels.

A cable which will perform mechanically during deployment and electrically during operation, despite the severe constraints imposed by the depth and rugged bottom conditions surrounding the Hawaiian islands, has been selected in federally-funded studies. Laboratory and at-sea tests are still required to confirm preliminary conclusions, but at this time no theoretical obstacles to its successful deployment and operation have been encountered.

Similar successes have characterized federally-funded studies of cable vessel configuration, cable handling support systems and deployment scenarios.

A variety of vessel sizes and shapes were computer modeled for performance during deployment, and a 400-foot by 100-foot barge was found to be acceptable. The cable tensions expected during deployment operations are larger than any previously experienced in cable laying, and exceed those of most pipe laying operations. The cable handling support systems thus require engineering research and development, but design and fabrication of an appropriate system is not expected to present any major technical or economic obstacles.

Interactions of the cable, cable handling equipment and the cable vessel during deployment have been extensively modeled, varying vessel size, overboarding point, cable weight, wind, waves and currents. Additional meteorological and oceanographic studies are planned to develop a better capacity to predict "weather windows" for this challenging operation, but all information developed thus far in the Program points to the feasibility of developing a successful deployment scenario.

At this point in the HDWC Program, all major system components and operations appear technically feasible. In coming phases, technical feasibility will be examined further, and, as components are better defined, increasingly refined projections of system economics will be made. Economic viability will depend not only on hardware and construction costs, but on institutional arrangements for financing the system and methods of establishing rates to consumers for the bulk-transmitted power.