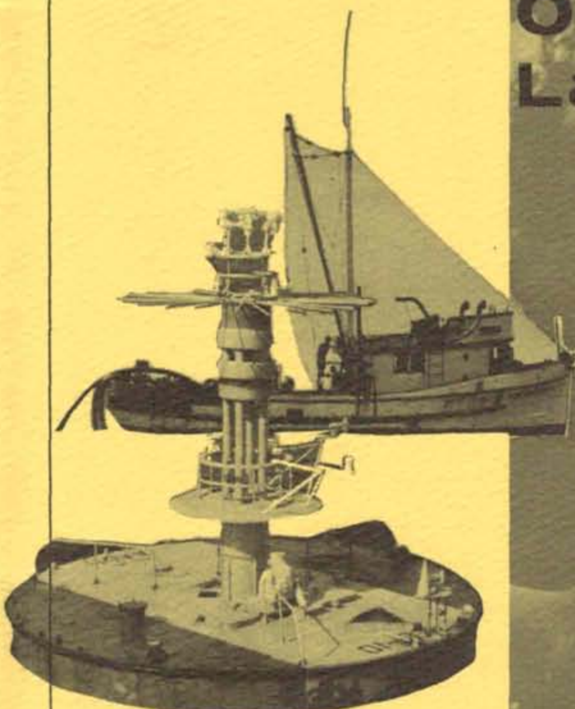
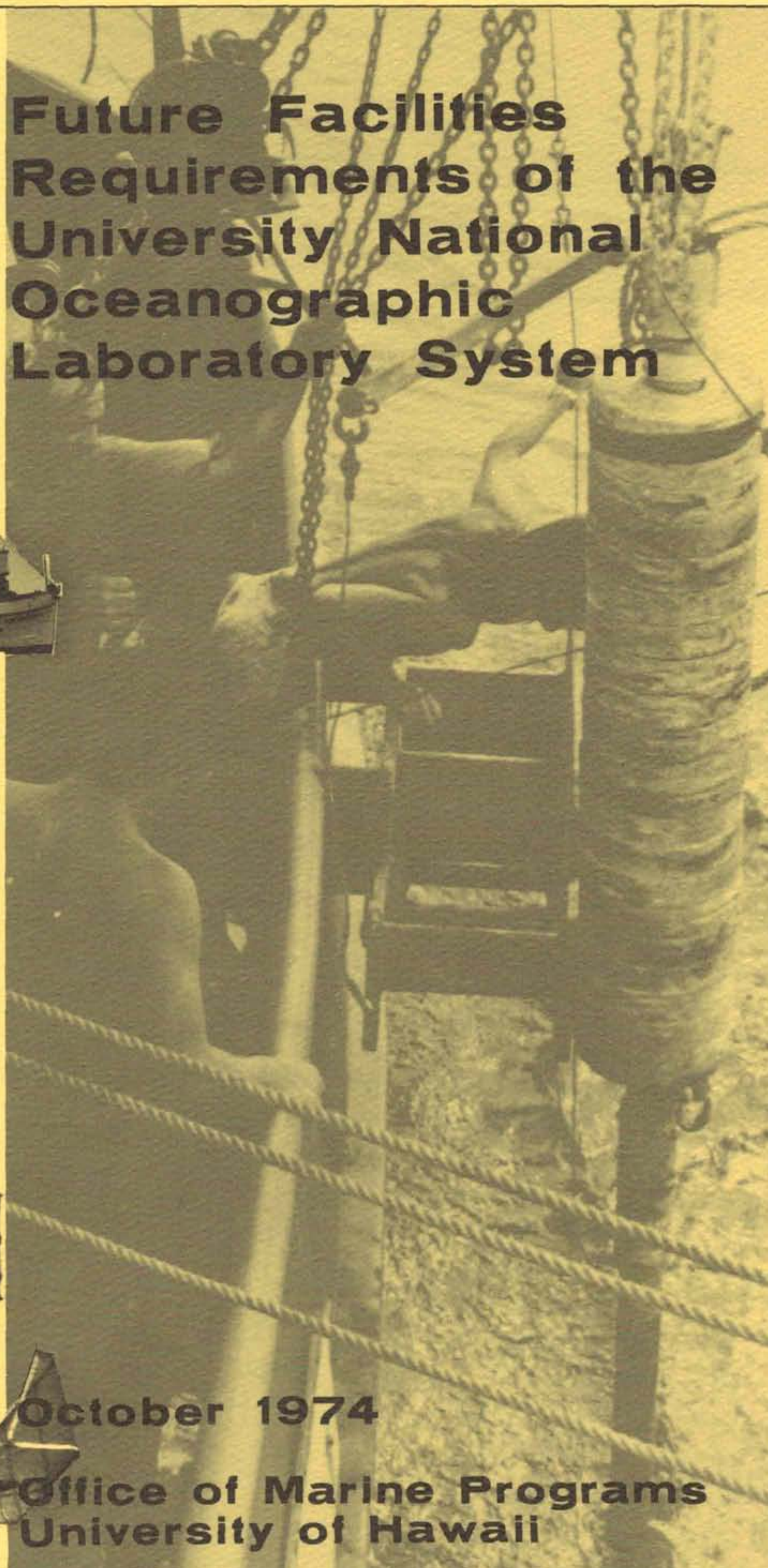
Future Facilities Requirements of the University National Oceanographic Laboratory System





October 1974

Office of Marine Programs
University of Hawaii

FUTURE FACILITIES REQUIREMENTS OF THE UNIVERSITY NATIONAL OCEANOGRAPHIC LABORATORY SYSTEM

by

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ABSTRACT

To provide information as a pedagogical tool and for the long-range planning of the University National Oceanographic Laboratory System Advisory Council, a study was undertaken to establish the decision parameters of the 1990 UNOLS profile. The size and composition of this profile are predicted using three independent bases. The first is expert opinion which estimates the size by anticipating the level of support over the next 16 years. The second is state-of-technology which predicts the state of marine technology during the same time period. The final basis is 1990 science; it anticipates a framework of the science of 1990 and determines the system mix. This information is analyzed using the Bayesian-Raiffa inference technique and predicts a 1990 system consisting of 33 conventional displacement ships greater than 65 ft; 6 SSP; 4 hydrofoils; 3 spar buoys; 2 acoustic arrays; 4 mobile units each with an unmanned-untethered device, unmanned-tethered device, and unmanned-towed device; 9 submersibles; and 3 habitats. The recommended implementation schedule calls for a real yearly growth rate of 10 percent in operating support and 6.7 percent in capital improvements.

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INTRODUCTION

As the United States moves toward the 21st century, the federal government is becoming increasingly concerned with identifying those critical choices which will preserve the economy and enhance the quality of life. One such area, the oceans, is gaining recognition as the environment from which the necessary raw materials and energy to maintain and improve this quality of life can be derived. To insure effective scientific understanding of the ocean, the federal and state governments and the nation's universities have combined their efforts to establish a comprehensive university oceanographic effort. The University National Oceanographic Laboratory System, chartered by Congress in September 1971, is currently reassessing and further defining its role with these national, state, and local institutions.

These institutions, primarily engaged in research in the areas of geophysics, marine biology, physical oceanography, geochemistry, and ocean engineering, are intimately involved with providing the necessary scientific information, data, and innovative ideas to realize the potential of the oceans. To facilitate acquisition of the modern facilities necessary for continuing the successful efforts of these institutions, a first order prediction of the 1990 scientific effort has been made. The nature of this scientific effort was used to determine the type of needed research vehicle. A more detailed study will be conducted by the UNOLS Advisory Council this fall when the senior scientists of the UNOLS institutions convene in Catalina, California to predict the direction of the ocean sciences over the next 16 years.

As a prelude to the meeting in the fall, a study was undertaken to provide information as a pedagogical tool and for input into the long-range planning for the UNOLS Advisory Council. This study was exploratory in nature. A summary of the results of the class project and an identification of the choices and critical decision parameters of a comprehensive university oceanographic system are presented. The report is organized such that the following two sections present the results of this study while the detailed logic to justify these conclusions is presented in Appendices I through VI. Support for this study came from the National Science Foundation (GD - 40476).

1990 UNIVERSITY OCEANOGRAPHIC LABORATORY SYSTEM PROFILE

At the outset, it must be pointed out that any system is designed to meet a human need that is subjective. Engineering efficiency is only one element of a system and if apparent engineering efficiency interferes with the attainment of systems goals, then it must be sacrificed. A systems design requires, therefore, a careful statement of the goal of the system. The subjective goal which has been defined for the 1990 University National Oceanographic Laboratory System is:

> a collection of oceanographic facilities and trained operators capable of collecting, processing, analyzing, and disseminating the ocean information which is required by the ocean science programs (UNOLS) of the collective universities of the United States in 1990.

To meet the subjective human purpose, the system was subdivided into eight major subsystems: (1) manned observatories at the air-sea interface--coastal, (2) manned observatories at the air-sea interface--blue water, (3) unmanned observatories at the surface, (4) command and control and information processing, (5) manned observatories underwater, (6) unmanned observatories underwater, (7) shore support facilities, and (8) manned/unmanned sensing from outside the environment. These subsystems were then assigned to the various class members who will henceforth be referred to as subsystem managers. (A detailed description of the class format is given in Appendix I.)

The size and composition of this resulting 1990 UNOLS profile are predicted using three independent bases. The first is experts opinion which involves generating information on the expected level of support that would be made available to a comprehensive university oceanographic system over the next 16 years. The second is state-of-technology which requires a prediction of the "state" of marine technology during the same time period. The final basis is 1990 science (see Appendix IV); it anticipates a framework of the science requirements. If past history may serve as a guide, it may be presumed that the volume of scientific investigations will be greater than can be accomplished with facilities available and, as a consequence, the magnitude of the science will not figure in the size projection. This information is then analyzed using a Bayesian-Raiffa inference technique to determine the system mix.

In the following sections of this paper, detailed logic is developed to justify the resulting 1990 UNOLS profile (see Appendix IV). A summary of the results is presented in Table 1. It indicates 33 conventional displacement ships greater than 65 ft; 6 SSP; 4 hydrofoils; 3 spar buoys; 11 stable platforms; 9 major shore facilities; 46 buoys; 2 acoustic arrays; 4 mobile units each with an unmanned-untethered device, an unmanned-tethered device, and an unmanned-towed device; 9 submersibles; 3 habitats; and 122 computerized command and control and information processing systems. The final subsystem--manned/unmanned remote sensing from outside the environment--was not completed; hence, no detailed information is given. It was estimated, however, to include at least 7 aircrafts.

TABLE 1. SUMMARY OF 1990 UNOLS PROFILE

Subsystem	Size	Distribution
Manned observatories at the air-sea interface		
Blue water	29 ships	21 Conventional 2 SSP 3 Spar buoys 3 Stable platforms
Coastal	28 ships greater than 65'	12 Conventional 4 SSP 4 Hydrofoils 8 Stable platforms (non-self-propelled)
	17 ships 50 ships	50' < ships < 65' 26' in length
Shore support facilities	9	1 in each of 9 zones
Unmanned observatories	6 units	2 Acoustic arrays 4 Mobile units, each with: 1 Unmanned-untethered device 1 Unmanned-tethered device 1 Unmanned towed device
Manned observatories underwater	12	9 Submersibles 3 Habitats
Computerized command and control and information processing	122 systems	
Unmanned observatories at the air-sea interface	46 buoys	

To realize this system by 1990, the resulting system was further defined in terms of facilities distribution, implementation schedule, and estimated cost. The recommended schedule (Table 2 and Figures 1 and 2) calls for a real yearly growth rate of 10 percent in operating support* and 6.7 percent in capital improvements over the next 16 years. (All estimates are given in terms of 1973 dollars and there has been no attempt to anticipate inflation.)

1990 UNOLS SIZE PROJECTION

The seven subsystems examined are presented in this section. The eighth was not completed because the subsystem manager withdrew from the course. The method for generating these predictions was based on (1) prior information, (2) likelihood information, and (3) posterior information. Under the first step each subsystem manager generated his best estimate. The subsystem managers then met with the available ocean technologists to generate their estimates. The incorporation of this information and the making of predictions based upon other available data constitutes the second step. These estimates were then systematically analyzed using a Bayesian-Raiffa inference technique with a resulting prediction on the size of each subsystem and is presented at the end of this section. The detailed logic for each estimate can be found in Appendix V.

Prior information

Subsystem	Average Size (m')	Standard Deviation (σ')
Blue water ships	32	5.0
Coastal ships	31	6.6
Shore support facilities	8	1.4
Unmanned observatories at the air-sea interface	48	10.0
Unmanned observatories underwater	16	9.0
Manned observatories underwater	10	3.0
Computerized command and control and information processing system	105	30.0

*Ms. Sandra D. Toye of the National Science Foundation reviewed the ship operating cost estimates and indicated that they were approximately 10 percent low.

Likelihood information

Source	Number	Assumed Confidence	Degree of Belief
	BLUE WATER SHIPS		
Expert 1	26 ships	5	0.294
Expert 2	42 ships	2	0.118
UNOLS Advisory Council's recommendation (analysis of the number of ships)	33 ships	2	0.118
UNOLS Advisory Council's recommendation (analysis of ship displacement)	35 ships	3	0.176
Budget analysis	26 ships	4	0.235
UNOLS fails	0 ships	1	0.059
	COASTAL SHIPS		
Budget	23 ships	4	0.174
UNOLS	29 ships	8	0.348
Woods Hole	32 ships	5	0.217
Expert 1	22 ships	6	0.261
	SHORE SUPPORT FACILITIES		
Expert 1	8 facilities		.500
Expert 2	7 facilities		.300
Expert 3	12 facilities		.180
Expert 4	19 facilities		.199
UNOLS fails	0 facilities		.001
	UNMANNED OBSERVATORIES AT THE AIR-SEA INTERFACE		
TRC	44 buoys		0.4
Expert 1	45 buoys		0.3
Expert 2	50 buoys		0.2
NORPAX	45 buoys		0.1
	UNMANNED OBSERVATORIES UNDERWATER		
Expert 1	9 devices	4	.4
Budget One	3 devices	2	.2
Budget Two	6 devices	4	.4

Likelihood information (continued)

Source	Number	Assumed Confidence	Degree of Belief
MANNED OBSERVATORIES UNDERWATER			
Budget	4 observatories	3	.104
Merging	10 observatories	6	.207
Other governmental agencies support	20 observatories	7	.241
Expert 1	11 observatories	9	.310
UNOLS report	25 observatories	4	.138
COMPUTERIZED COMMAND AND CONTROL AND INFORMATION PROCESSING			
Class	139		.2
UNOLS report	140		.3
Expert 1	113		.3
Budget	80		.2

Posterior information

Subsystem	Expected Size (m'')	Standard Deviation (σ'')
Blue water ships	29	2.98
Coastal ships	28	2.00
Shore support facilities	9	0.83
Manned observatories at the air-sea interface (buoys)	46	1.11
Unmanned observatories underwater	6	1.10
Manned observatories underwater	12	1.95
Computerized command and control and information processing system	122	10.70

TABLE 2. PROJECTED UNOLS IMPLEMENTATION SCHEDULE OF CAPITAL EQUIPMENT AND OPERATING BUDGET

Year	Item	Capital Cost $1973 × 10⁶	Operating Cost $1973 × 10⁶	Item	Capital Cost $1973 × 10⁶	Operating Cost $1973 × 10⁶	Item	Capital Cost $1973 × 10⁶	Operating Cost $1973 × 10⁶
	CONVENTIONAL SHIPS			**LOCAL CRAFT**			**TECHNICAL SUPPORT & SHIPBOARD EQUIPMENT**		
1976	250' - 300' R	11.00	19.05	(50' - 65')	.25	.08			2.25
1977	250' - 300' R	11.00	19.35		.25	.16	Technician		2.50
1978	200' - 250' R	7.00	19.65		.25	.24	Ship	.25	2.75
1979	150' - 200' R	4.00	19.95		.25	.32	Board	.25	3.00
1980	350' - 400' R	16.00	20.25	ONE	.25	.40	Equipment	.25	3.25
1981			21.30		.25	.48	and	.25	3.50
1982	150' - 200' R	4.00	21.30	EACH	.25	.56	Instrumentation	.25	3.75
1983	150' - 200'	4.00	21.60		.25	.64	Systems	.25	4.00
1984	200' - 250'	7.00	22.30	YEAR	.25	.72		.25	4.25
1985	200' - 250'	7.00	23.30		.25	.80		.25	4.50
1986	350' - 400'	16.00	24.30		.25	.88		.25	4.75
1987			26.05		.25	.96		.25	5.00
1988	200' - 250'	7.00	26.05		.25	1.04		.25	5.25
1989	200' - 250'	7.00	27.05		.25	1.12		.25	5.25
1990	250' - 300'	11.00	28.05		.25	1.20		.25	5.25
	MANNED UNDERWATER SYSTEMS			**STABLE PLATFORMS AND SPAR BUOY**			**AIR CRAFT**		
1976			1.00			.15			.08
1977			1.00			.15			.12
1978	Shallow Sub	.30	1.00			.15	Heavy Twin R	.75	.12
1979	Deep Sub	3.50	1.20			.15	Light Twin	.25	.24
1980			2.00			.15			.30
1981	Deep Sub	3.50	2.00	2 Platforms	3.00	.15	Heavy Twin	.75	.30
1982	Shallow Sub	.30	2.80	2 Platforms	3.00	.30	Light Twin	.25	.42
1983	Habitat	1.50	3.00	3 Spar buoys R	2.25	.60			.48
1984	Shallow Sub R	.30	3.50		2.25	.75			.48
1985	Habitat R	1.50	3.70	2 Platforms	3.00	1.05	Hi Performance	1.00	.48
1986	Shallow Sub	.30	4.20	2 Platforms	3.00	1.35			1.48
1987	Deep Sub R	3.50	4.40	Large	11.00	1.65	Light Twin	.25	1.48
1988	Shallow Sub	.30	5.20	Stable	6.00	1.65			1.54
1989	Habitat	1.50	5.40	Platform	5.00	2.65	Light Twin	.25	1.54
1990	Shallow Sub	.30	5.90	2 Platforms	3.00	3.85			1.64
	SSP AND HYDROFOIL			**SHORE FACILITIES**			**BUOY SYSTEMS**		
1976									
1977	Hydrofoil	4.00		As Need					
1978	SSP	4.50	.40		2.00	.50			
1979	SSP	4.50	1.10	To Provide	2.00	.75	2	.15	
1980			1.80			1.00	2	.15	.05
1981	SSP	4.00	1.80	9	3.50	1.20	3	.30	.10
1982	SSP	4.00	2.50		3.50	1.40	3	.30	.18
1983	Hydrofoil	4.00	3.20	Major	3.00	1.60	4	.38	.25
1984	Hydrofoil	4.00	3.60		2.00	1.80	4	.38	.35
1985	Hydrofoil	4.00	4.00	Facilities	2.00	2.00	6	.53	.40
1986			4.40			2.20	8	.75	.50
1987			4.40	by	4.00	2.40	8	.75	.63
1988	SSP	4.00	4.40		2.00	2.60	9	.83	.75
1989	SSP	4.00	5.10	1990	2.00	2.80	9	.83	.88
1990			5.80		2.00	3.00	12	1.05	1.00

R indicates replacement

TABLE 2. PROJECTED UNOLS IMPLEMENTATION SCHEDULE OF CAPITAL EQUIPMENT AND OPERATING BUDGET (con't)

Year	Item	Capital Cost $1973 × 10^6	Operating Cost $1973 × 10^6	Item	Capital Cost $1973 × 10^6	Operating Cost $1973 × 10^6	Item	Capital Cost $1973 × 10^6	Operating Cost $1973 × 10^6
	COMPUTER SYSTEM			TOTAL BUDGET					
1976					11.25	22.61			
1977					15.25	23.28			
1978					15.05	24.81			
1979					14.90	26.71			
1980					16.65	29.20			
1981					15.55	30.83			
1982					15.85	33.21			
1983					15.63	35.37			
1984					16.43	37.75			
1985					19.53	40.23			
1986					20.55	44.06			
1987					20.00	46.97			
1988					20.63	48.48			
1989	6th	1.00			22.08	51.79			
1990	generation	4.50			22.35	55.69			

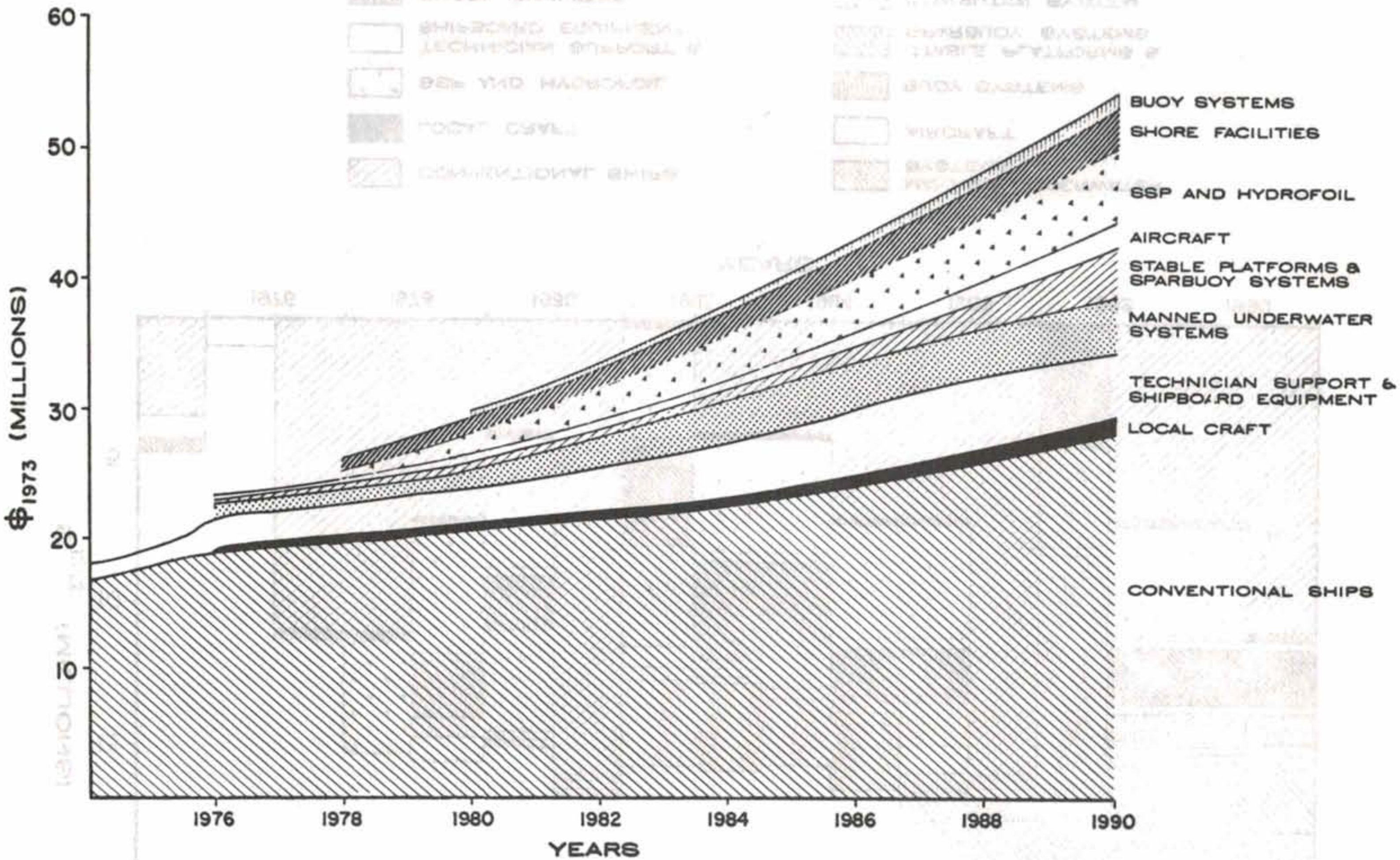

Figure 1. UNOLS operating budget projection.

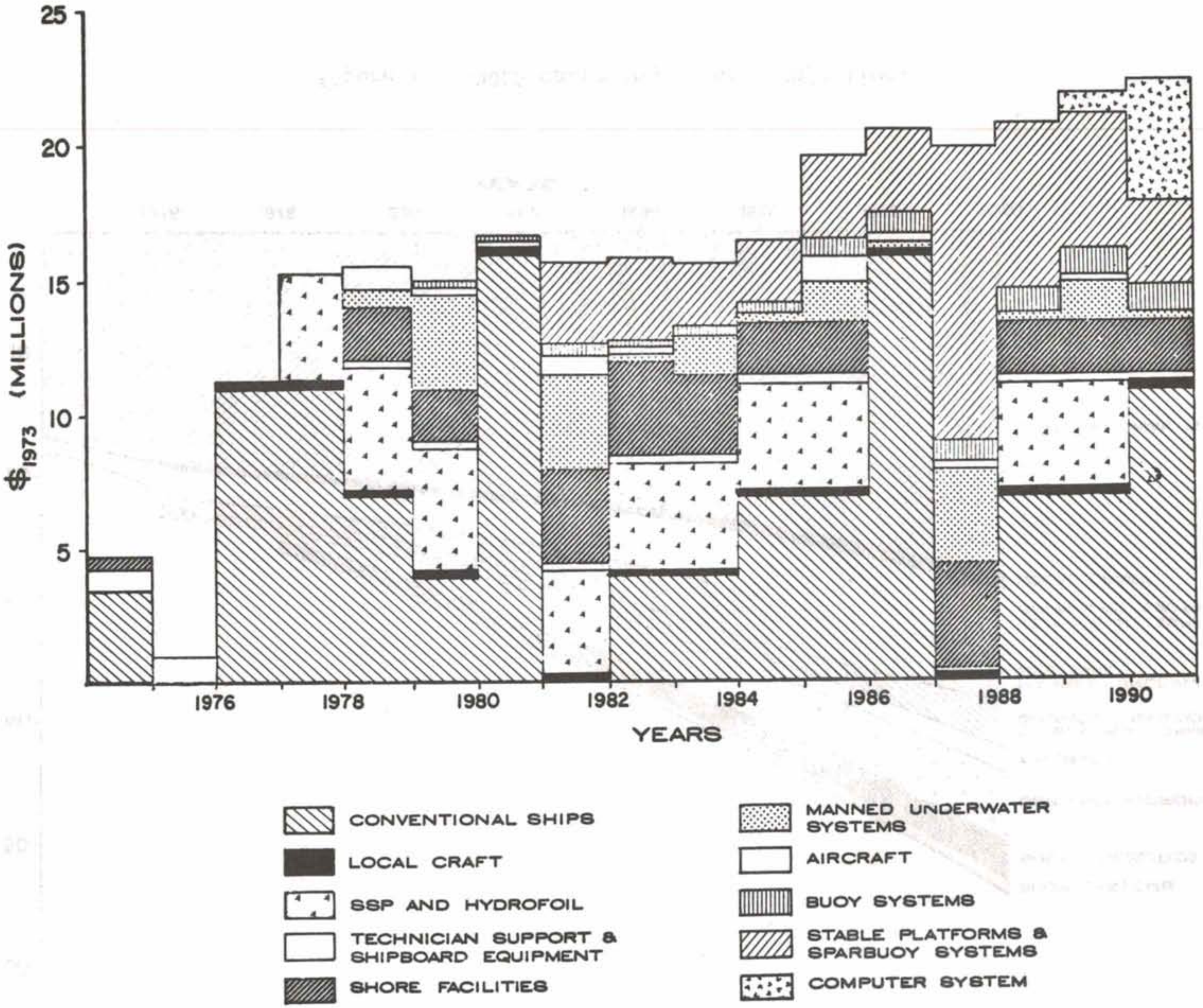

Figure 2. UNOLS capital projection.

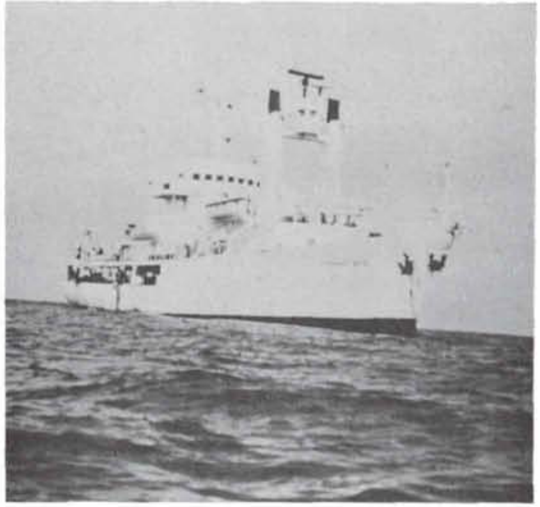

Figure 3. Blue water manned vehicle.

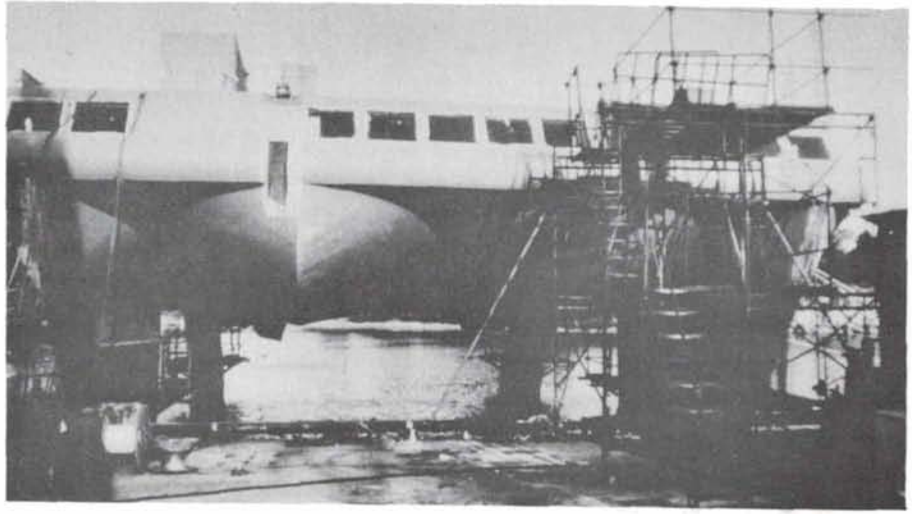

Figure 4. Semi-submerged platform.

Figure 5. Oceanographic buoy.

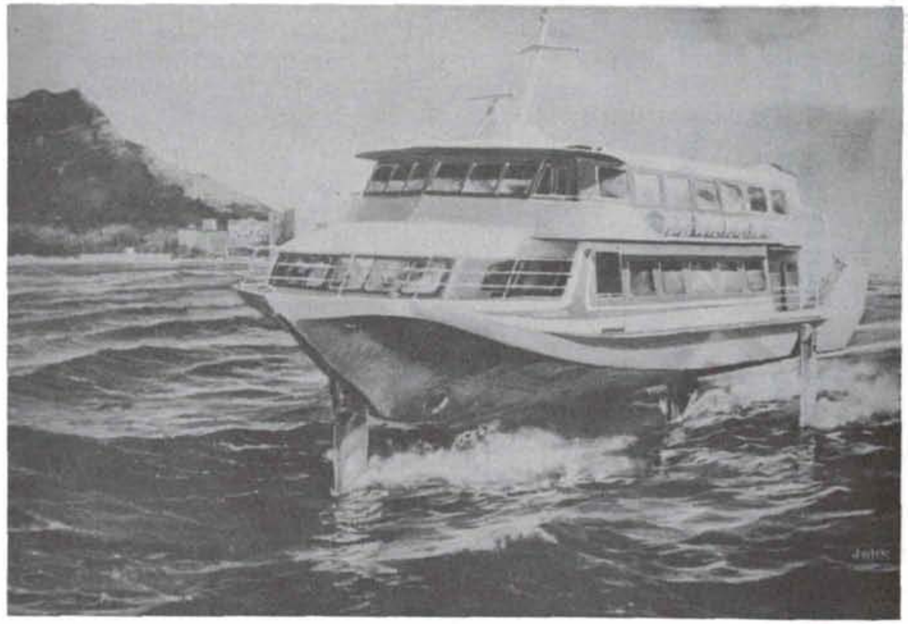

Figure 6. Hydrofoil.

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Raiffa, H., and R. Schlaifer. 1972. *Applied Statistical Decision Theory*. Cambridge: M.I.T. Press.

APPENDICES

APPENDIX I. CLASS ORGANIZATION

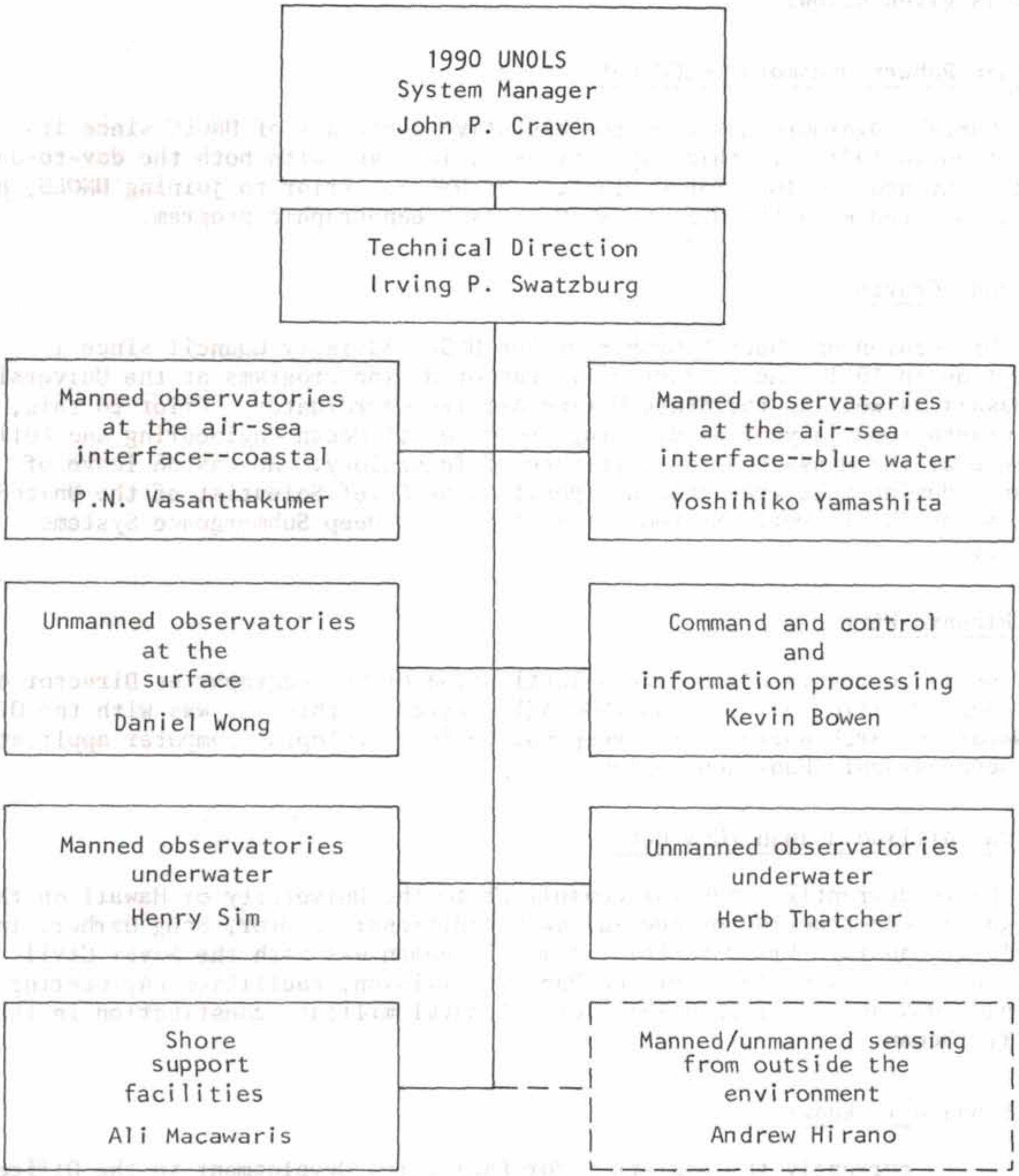
Ocean Engineering 681, a graduate course at the University of Hawaii, is open to all graduate students upon consent of the instructor, John Craven. For the 1973 fall term, eight engineering students signed up for the course. A breakdown of the class by education and country of origin is given in Table 3. Based upon educational background, indicated interest, and personal interviews, each student was assigned the task of developing and analyzing a subsystem of the 1990 University National Oceanographic Laboratory System (Table 4). The student assigned "Manned/Unmanned Remote Sensing From Outside the Environment" withdrew from the course; hence, no report is available on this particular subsystem.

The class met twice a week for 16 weeks with equal time spent between the class project and the theory of ocean engineering systems. The two textbooks for the course were: *Rational Descriptions, Decisions, and Designs* by M. Tribus (Pergamon Press, 1969) and *Ocean Engineering Systems* by J.P. Craven (M.I.T. Press, 1971). In addition to regular lectures, guest lecturers were invited to give special seminars on the existing and projected University National Oceanographic Laboratory System.

TABLE 3. STUDENT DISTRIBUTION

Student	Country	Degree Program	Background
Kevin Bowen	U.S.A.	MS Electrical Engineering	Field Engineer Ships Inertial Navigation System
Henry Sim	Hong Kong	MS Mechanical Engineering	
Ali Macawaris	Philippines	PhD Ocean Engineering	Assistant Dean College of Engineering Mindanao State University The Philippines
Herb Thatcher	U.S.A.	MS Ocean Engineering	BS Mining Engineering
P.N. Vasanthakumar	India	MS Ocean Engineering	Indian Government Coastal and Harbor Division
Yoshihiko Yamashita	Japan	PhD Ocean Engineering	MS Mechanical Engineering
Daniel Wong	Hong Kong	MS Ocean Engineering	

TABLE 4. 1990 UNIVERSITY NATIONAL OCEANOGRAPHIC LABORATORY SYSTEM



APPENDIX II. BACKGROUND OF EXPERTS

To predict the size and composition of the 1990 UNOLS profile, subjective estimates were generated by five ocean technologists. A brief biography of each is given below:

Captain Robert Dinsmore (USCG Ret.)

Captain Dinsmore has been the executive secretary of UNOLS since its inception in 1971. In this capacity he is involved with both the day-to-day management and the long-range planning of UNOLS. Prior to joining UNOLS, he was associated with the U.S. Coast Guard's oceanographic program.

Dr. John Craven

Dr. Craven has been a member of the UNOLS Advisory Council since its inception in 1971. He is currently Dean of Marine Programs at the University of Hawaii as well as the State Marine Affairs Coordinator. Prior to this, Dr. Craven spent a year as visiting professor of Ocean Engineering and Political Science at the Massachusetts Institute of Technology. He was on leave of absence during that year from his position as Chief Scientist of the United States Navy's Strategic Systems project and its Deep Submergence Systems project.

Dr. Richard Wirt

He is currently with Scripps Institution of Oceanography as Director of the North Pacific Buoy Program (NORPAX). Prior to this, he was with the Office of Naval Research where he was responsible for developing computer applications for oceanographic buoys and ships.

Admiral William Heaman (USN Ret.)

He is currently a Special Consultant to the University of Hawaii on the design and construction of the Marine Expeditionary Center, Snug Harbor, in Honolulu, Hawaii. Prior to this, Admiral Heaman was with the Naval Civil Engineer Corps as Director of the Pacific Division, Facilities Engineering Command, USN and was responsible for all naval military construction in the Pacific Ocean.

Mr. Leonard I. Knowles

He is currently the Assistant for Facilities Development in the Office of Marine Programs at the University of Hawaii. Prior to this, he was the Assistant Director of the Hawaii Institute of Geophysics at the University of Hawaii. In the latter capacity he was the alternative representative of the University of Hawaii to UNOLS.

APPENDIX III. BAYESIAN-RAIFFA INFERENCE TECHNIQUE

To meet scientific needs, projection in a real world cannot be made solely on the basis of cost effectiveness. Factors associated with the national economy, the available federal, state, and university budgets, caprice or subjective influence on the part of participating institutions, value judgments on the worth of science, historical growth, existence of facilities, etc., all lead to solutions which may be very far from the "cost effective" point. Therefore, it is the task of a system designer to produce the most effective system within real boundary conditions imposed by a subjective society.

The size projection for the UNOLS profile is therefore made by a Bayesian-Raiffa inference technique--subjective information from the human brain and from human experience is used as the basis for generating subjective probability estimates. The human expert accumulates a large amount of information which he is unable to convert to explicit data but which he is able to employ in making value judgments which, on the average, will be superior to those made by individuals with little or no experience. Validity of this is empirical and has been demonstrated particularly in the gambling field where estimates of point spreads on the average is correct (i.e., the average estimate is within the profit margin provided by the difference in point spreads for opposing bettors).

To estimate the size of the 1990 UNOLS profile, the probability of its existence in terms of the available parameters must first be defined:

$$P\,(U_{1990}/E) \quad = \quad K_n\, P\,(E/U_{1990})\; P\,(U_{1990}) \tag{1}$$

where:

U_{1990} = the 1990 UNOLS,

E = the set of expert estimations,

K_n = a normalizing constant,

$P\,(E/U_{1990})$ = the experts' probability estimate given the 1990 UNOLS profile,

$P\,(U_{1990})$ = the probability estimate of the 1990 UNOLS profile.

noting that:

$$P\,(E/U_{1990}) \quad = \quad P\,(x_1, \ldots\, x_n \;/\; U_{1990}) \tag{2}$$

and if we assume that each expert arrives at his prediction independently and that it can be described by a normal distribution, then:

$$P\,(x_1, \ldots x_n / U_{1990}) = \prod_{i=1}^{n} P\,(x_i / U_{1990})$$

$$= \prod_{i=1}^{n} \frac{1}{\sigma\sqrt{2\pi}}\, \varepsilon^{-\frac{(x_i - \mu)^2}{2\sigma^2}}$$

$$= \frac{1}{\sigma^n (2\pi)^{n/2}}\, \varepsilon^{-\frac{1}{2\sigma^2}\sum_{i=1}^{n}(x_i - \mu)^2} \qquad (3)$$

Letting:

$$m = \frac{1}{n}\Sigma x_i \qquad (4)$$

and noting:

$$\sum_{i=1}^{n}(x_i - \mu)^2 = \sum_{i=1}^{n}([x_i - m] + [m - n])^2$$

$$= \sum_{i=1}^{n}(x_i - m)^2 + n(m - \mu)^2 \qquad (5)$$

then:

$$P\,(E/U_{1990}) = \frac{1}{\sigma^n (2\pi)^{n/2}}\, \varepsilon^{-\frac{1}{2\sigma^2}\sum_{i=1}^{n}(x_i - m)^2}\, \varepsilon^{-\frac{1}{2\sigma^2} n(m - \mu)^2} \qquad (6)$$

which can be written as a normal distribution:

$$= K\, \varepsilon^{-\frac{1}{2\sigma^2} n(m - \mu)^2} \qquad (7)$$

where:

n = the number of experts

m = the average size estimate generated by the set of experts

K = a normalizing constant

By similar arguments, the probability of the 1990 UNOLS profile for a normally distributed, independent set of estimates can be expressed in compact form as:

$$P_n(U_{1990}/m'', (\sigma'')^2)$$

$$= P_n(E/m, \sigma^2) \cdot P_n(U_{1990}/m', (\sigma')^2) \quad (8)$$

where:

$P_n[U_{1990}/m', (\sigma')^2]$ is the prior information with average, m', and variance, $(\sigma')^2$, being the best available first estimate.

$P_n(E/m, \sigma^2)$ is the likelihood information and is is generated by the knowledge the designated UNOLS experts hold.

$P_n[U_{1990}/m'', (\sigma'')^2]$ is the posterior information with the mean, m'', and the variance, $(\sigma'')^2$, being the estimated profile of the 1990 UNOLS.

and:

$$\text{The mean } (\mu) = E(x) = \Sigma\, x_i \cdot p\,(x_i) \quad (9)$$

$$\text{The variance } (\sigma^2) = V\,(x) = E(x - E\,(x)\,)^2 = \Sigma\,(x_i - \mu)^2 P\,(x_i) \quad (10)$$

and:

$$n' \equiv \frac{\sigma^2}{(\sigma')^2} \quad (11)$$

The size of the 1990 UNOLS (m'') is:

$$m'' = \frac{n'm' + nm}{n' + n} \quad (12)$$

The variance of the 1990 UNOLS $(\sigma'')^2$ is:

$$(\sigma'')^2 = \frac{\sigma^2}{n' + n} \quad (13)$$

The individual subsystems are estimated with the parameters m'' (the mean size) and σ'' (the standard deviation) which are developed in this section.

APPENDIX IV. 1990 SCIENCE PROFILE

One of the more difficult tasks is to estimate the magnitude and nature of the scientific endeavors which will constitute the 1990 UNOLS scientific program. If past history may serve as a guide, it may be presumed that the volume of scientific investigations will be greater than can be accomplished with facilities available and, as a consequence, the magnitude of the science will not figure in the size projection. On the other hand, the type of research vehicle will be heavily dependent upon the nature of the scientific effort in 1990. Some attempt must therefore be made to estimate this effort. The projection will be in geophysics, marine biology, physical oceanography, geochemistry, and ocean engineering. A more detailed outline of the direction of the 1990 science profile is scheduled to be generated in the fall of 1974. Under the auspices of the UNOLS Advisory Council, the senior scientists of the UNOLS institutions and other invited guests will convene in Catalina, California to predict the direction of the ocean sciences over the next 16 years. As a prelude to this meeting, the following has been projected.

Geophysics and Geology

The major development of plate tectonic theory and the general notion of crustal spreading will markedly change the direction of geological and geophysical research. Although a great deal of work remains to be accomplished in the shallower plate measurements in order to understand the dynamics of plate movement, there will be a substantial shift to subplate mechanics. In particular, information is needed on heat generation, heat flow, and the geochemistry of phase changes under heat and temperature in order to determine stress patterns in the plates. This means a phase of deep, deep-sea drilling with a number of Mohole or Super Mohole projects will be initiated. Thus, there is a transition from global tectonics to localized tectonics on the surface and upper plate and the initiation of research on global deep mantle processes.

This suggests an increase in the number of stable platforms which are slowly mobile, capable of very deep drilling, and capable of spending extended periods of time on station.

Marine Biology

Marine biology will become increasingly bimodal, with blue water marine biologists developing in distinctly different directions from coastal marine biologists. Coastal marine biology will constitute the larger magnitude of the effort. By 1990, the engineering of offshore power plants, platforms, and industrial facilities will have resulted in the proliferation of the number of marine biological interactions between the natural and artificial environments. The early observation period which used to describe both natural and polluted environments will be replaced by the bio-engineering of the environment and research to obtain an understanding of the adaptive processes. This will result in a concentration of benthic and subsurface shallow water (i.e., 500 feet or less) marine biological studies.

In blue water marine biology the primary effort will be directed toward estimates of the nature and magnitude of the ocean biomass. Technology will have permitted more detailed understanding of scattering layers; and although the generalized areas of ocean upwelling will be understood, the blue water biologists will be interested in phenomena which create patchiness in biomass density and phenomena which change the form and substance of the biomass.

A number of auxiliary deep water programs will become important, such as the biological effects of disposal of nuclear wastes, the biological effects of manganese and other deep ocean resources, and the full life cycle of pelagic fish.

The implication of the UNOLS profile is that there will be increasing demand for blue water biological ship time accompanying the increasing demand for coastal biological ships.

Geochemistry

The development of the major outlines of earth movement will open up geochemistry as a major ocean research field. The geochemical transitions which result from the heat and pressure of the deep mantle, as well as the geochemical transitions which result from biological process, are such that the history of the ocean floor will soon be described in terms of its geochemistry. Extension of studies such as Geo Secs will be continued on a worldwide basis.

Physical Oceanography

The major physical oceanography problem still being actively pursued in 1990 will be the major interaction between atmosphere and ocean. The NORPAX study will have been completed and the extension of NORPAX to other parts of the world will have been undertaken. After an intensive period of activity to establish ground truth for satellites, there will occur the beginning of the more difficult period of establishing the sea surface/subsea surface interactions. This will require buoys and expendable bathythermographs from ships of opportunity and a wide variety of dispersing platforms. Since the subsurface constitutes the major area of heat storage, it is the long-range determinative boundary condition for atmospheric movement.

Ocean Engineering

At present ocean engineering research is a minuscule part of the UNOLS program. In the future the testing of materials and components in the ocean environment will be a significant part of ocean engineering. If the academic community follows the military in its experience, these tests will be conducted as close to shore as possible. Where deep water (15,000 ft or more) is required, then an open ocean environment will be desired. Ocean engineering development with respect to submersibles, transponders, deep ocean arrays, nuclear waste disposal, deep ocean dumping, etc., will become an increasing component of university research. Research on stable platforms and stable ships will require ship and facility time in the developmental stages.

APPENDIX V. RATIONALE OF 1990 UNOLS PROJECTION

To make a "good" prediction of the composition of the 1990 UNOLS profile, it was decided to couple subjective estimates with a probabilistic interpretation. More specifically, expert opinions were generated and interpreted, then the individual subsystem managers examined the background of the experts and assigned a degree of belief to each. The results were then systematically analyzed using a Bayesian-Raiffa interpretation to predict the characteristics of the 1990 UNOLS profile. It should be noted that these estimates were not based upon the 1990 oceanographic needs, but rather upon each expert's subjective judgment on what level of funding would be available through 1990 for a comprehensive university oceanographic system.

Manned Observatories at the Air-Sea Interface

BLUE WATER--more than 200 miles from land

Prior information

Number of ships (m') = 32

Standard deviation (σ') = 5

Prior rationale

Subjective number of blue water ships in 1990 is 32 (average) and the standard deviation is 5.

Blue water ships must satisfy the following characteristics:

Displacement (tonnage)	300
Length overall (fleet)	110

Likelihood information

x_i	Source	No. of Ships	Assumed Confidence	Degree of Belief
x_1	Dinsmore's Recommendation	26	5	0.294
x_2	Allyn Vine's Recommendation	42	2	0.118
x_3	UNOLS Advisory Council's Recommendation (Analysis of the No. of Ships)	33	2	0.118
x_4	UNOLS Advisory Council's Recommendation (Analysis of Ship Displacement)	35	3	0.176
x_5	Budget Analysis	26	4	0.235
x_6	UNOLS Fails	0	1	0.059
	TOTAL		17	1.000

$\mu = E(x_i) = \Sigma x_i \; p(x_i) = 28.8$

$\text{Variance} = \sigma^2 = \Sigma(x_i - \mu)^2 \cdot p(x_i) = 82.5$

$\sigma = 9.12$

Likelihood rationale

Captain Robert Dinsmore's recommendation

40 ships in 1990

3 blue water semi-submersibles in 1990

Analysis of the UNOLS first annual report indicated that 55.9 percent out of 34 UNOLS ships are blue water ships. This value is likely to be increased by 1990. Therefore, according to Captain Dinsmore's recommendation, there will be 23 ships in 1990 plus 3 more special ships for a total of 26.

Dr. Allyn Vine's recommendation (post 1975):

50 oceanographical ships

10 special ships

However, the predicted number of ships in 1990 is not given. To extend Allyn Vine's recommendation, the following assumptions have been imposed:

1. Number of ships under UNOLS will exceed the value proposed by Allyn Vine after 1975.

2. Rate of maximum increase of UNOLS ships after 1975 will follow the reference line.

3. Reference line starts at 1960 and intersects the middle of the line which is drawn from 1970 to 1972 and is projected with the same slope to 1990.

4. Rate of minimum increase of UNOLS ships from 1975 will follow the extension line of UNOLS' estimation from 1965 to 1975.

5. Average number of ships can be given by taking the intermediate value of maximum and minimum lines.

By following the previous assumptions, the average number of ships under UNOLS in 1990 is given as 66 (Figure 7). If it is assumed that 55.9 percent of the total ships are composed of blue water ships and with 5 special ships then there will be 42 blue water ships in 1990.

Analysis of UNOLS Advisory Council meeting

The UNOLS Advisory Council projected an analysis upon the number of academic ships which were operating between 1960 and 1970. The result indicated 27 ships by 1975. However, the UNOLS first annual report indicated that 36 ships were available under UNOLS in 1972. It seems that the projected number of ships estimated by the UNOLS Advisory Council in 1970 is offset by 9 ships (Figure 8). By following the UNOLS Advisory Council's first annual report and UNOLS Advisory Council meeting in 1973, the actual number of ships is plotted until 1972 and reference lines, which were described previously are then superimposed in Figure 8. Estimation of the number of ships in 1990 may be given by an approach similar to the previous recommendation and with the following assumptions:

1. Rate of maximum increase of the UNOLS ships after 1972 will follow the reference line.

2. Reference line starts from 1960 and intersects with the middle of the line which represents the actual number of ships from 1970 to 1972 and continues straight to 1990.

3. Rate of minimum increase of the UNOLS ships from 1972 will follow the extension line of UNOLS' estimation from 1965 to 1975.

4. Average number of ships will be given by taking the mean value of the maximum and minimum numbers.

By following the above assumptions, the average number of ships under UNOLS in 1990 is given as 53 (Figure 8). If it may be assumed that 55.9 percent of the total ships is composed of blue water ships and having 3 special ships, there will be 33 blue water ships in 1990.

Ship displacement analysis

The UNOLS Advisory Council reported the actual total ship displacement (tonnage) from actual academic research ships operating from 1960 to 1970. Projected total ships displacement was given for 1975. This was based on 27 research ships which will be available in 1975. However, detailed physical

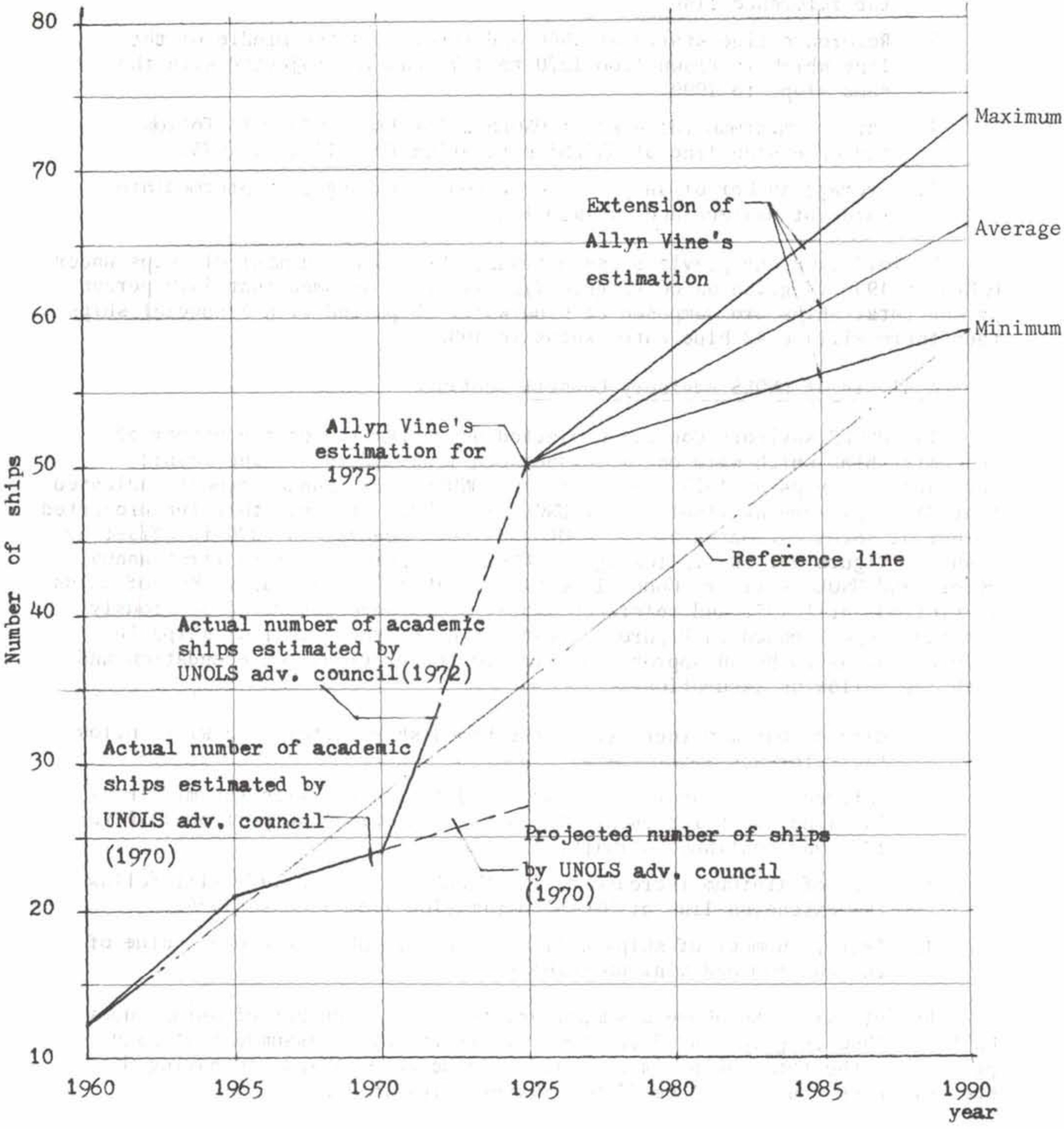


Figure 7. Estimated number of research ships projected for 1990 based on Allyn Vine's estimation.

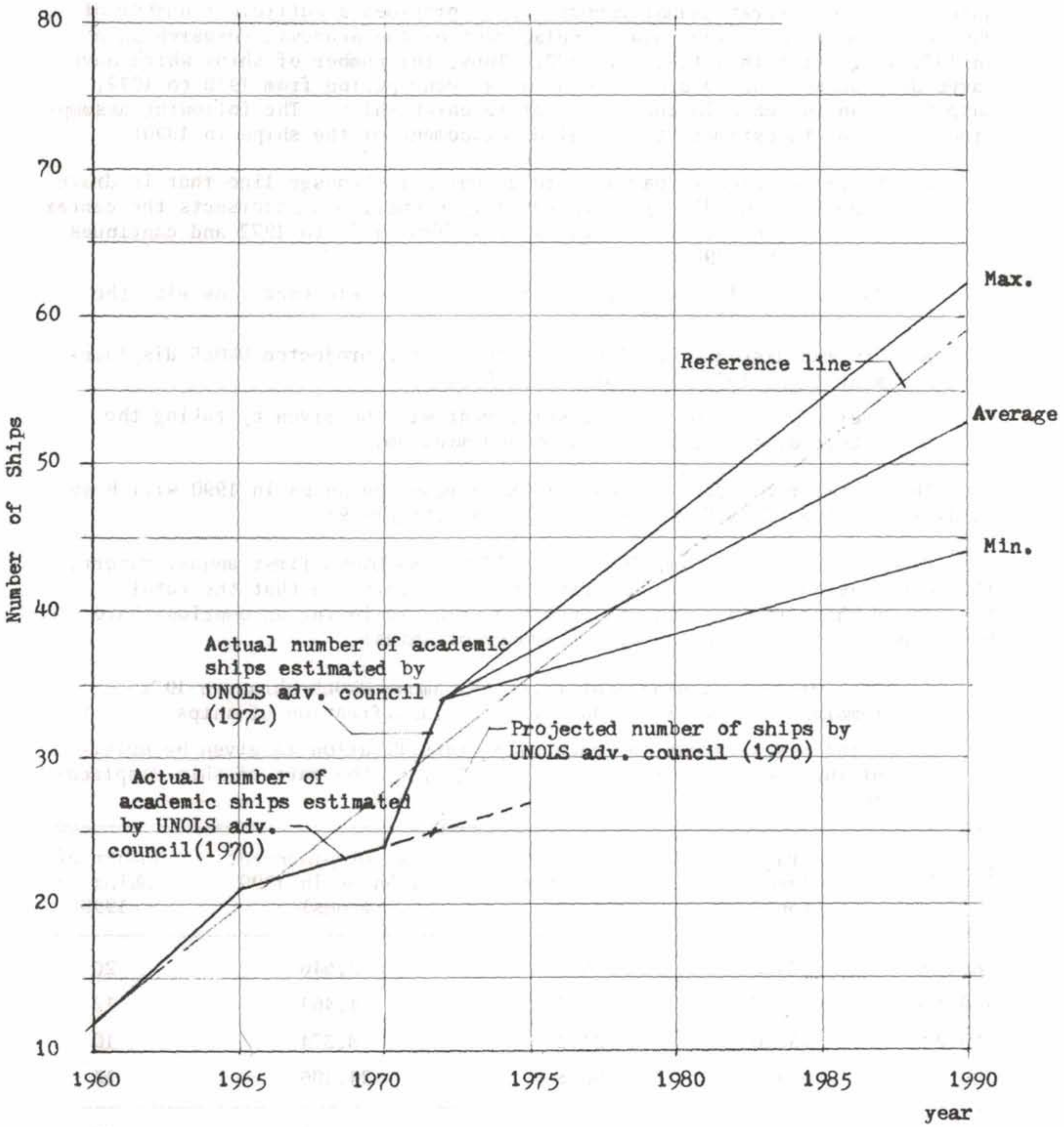


Figure 8. Estimated number of research ships projected for 1990 based on UNOLS Advisory Council's estimation.

dimensions such as length, displacement, and name of the ships, were not available. The UNOLS first annual report (1972) provides a sufficient number of physical dimensions. The total displacement of the academic research ships in 1970 is greater than that for 1972. Thus, the number of ships which have large displacement has decreased over a two year period from 1970 to 1972, inspite of an increase in the number of research ships. The following assumptions are made to estimate the total displacement of the ships in 1990:

1. Reference line is parallel to actual ship tonnage line that is drawn from 1965 to 1970 by UNOLS Advisory Council and intersects the center of ship tonnage line which is drawn from 1970 to 1972 and continues straight to 1990.
2. Maximum displacement line will follow the reference line with the same slope after 1972.
3. Minimum displacement line will follow the projected UNOLS displacement line (1970 to 1975) after 1972.
4. Average number of total displacement will be given by taking the intermediate value of maximum and minimum.

Therefore, total displacement of UNOLS research ships in 1990 will have an average value of 39,500 tons displacement (Figure 9).

From the survey information contained in the UNOLS first annual report, the ships may be classified according to their length so that the total tonnage of ships in 1990 can be estimated. The following assumptions have been made for the estimation of the number of ships:

1. Rate of ship displacement (percent) among UNOLS ships in 1972 remains the same for 1990 for each classification of ships.
2. Total displacement for each ship classification is given by multiplying the total displacement (39,500) by the rate of ship displacement.

Length (ft)	Average Displacement (tons)	Rate of Ship Displacement (percent)	Total Displacement of Ships in 1990 (tons)	Number of Ships in 1990
65-100	135.8	6.7	2,646	20
100-150	391.7	11.3	4,464	12
150-200	858.6	21.2	8,374	10
200-	1,639.7	60.8	24,106	15
TOTAL		100.0	39,500	57

3. Number of ships in 1990 is given by dividing the total displacement of each ship classification by average displacement.

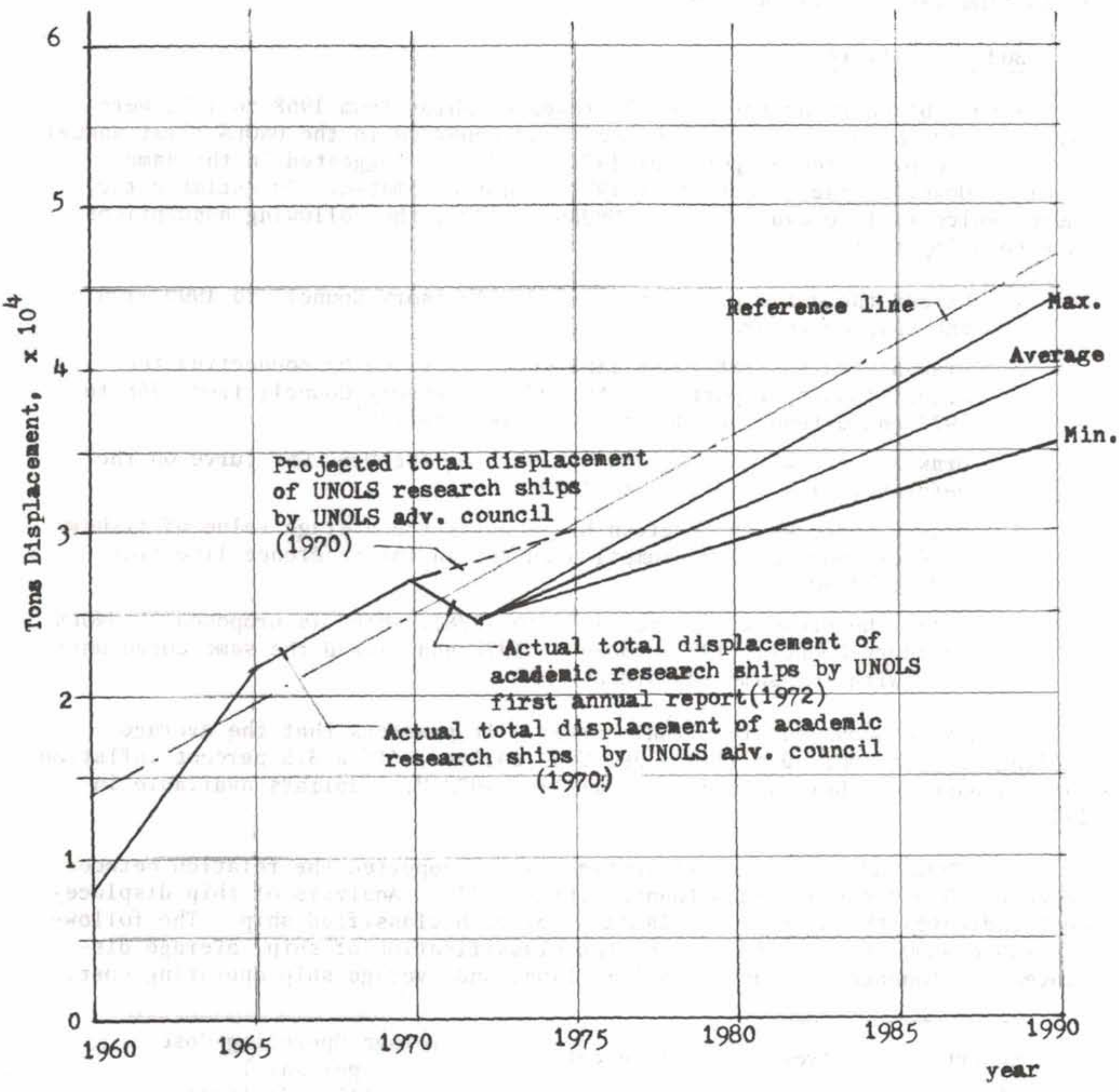


Figure 9. Estimated total displacement (tonnage) of UNOLS research ships projected for 1990 based on UNOLS Advisory Council and UNOLS first annual report estimations.

By following the above assumptions, the average number of ships in UNOLS in 1990 will be 57. If it is further assumed that 55.9 percent of the total ships are composed of blue water ships, and having 3 special ships, there will be 35 blue water ships in 1990.

Budget analysis

Actual block funds for academic research ships from 1968 to 1972 were estimated by the UNOLS Advisory Council and reported in the UNOLS first annual report. The projected budget from 1972 to 1978 is suggested in the same report. However, the budget after 1978 is not estimated. To estimate the budget which will be available for UNOLS in 1990, the following assumptions have been imposed:

1. Extend the curve projected by UNOLS Advisory Council to 1990 with the same curvature.
2. Draw a straight reference line which is given by connecting the actual funding reported by the UNOLS Advisory Council from 1968 to 1972 and extend the same line straight to 1990.
3. Draw a curve which is given by imposing the U.S. GNP curve on the reference line from 1973 to 1990.
4. Draw a curve which is given by imposing the average value of fishery products and metal consumption curves on the reference line from 1973 to 1990.
5. Shift the projected curve (1974 to 1978), which is proposed by UNOLS Advisory Council (1972), down to 1972 and extend the same curve until 1990 with the same curvature.

Figure 10 shows the resultant curves. It predicts that the average funding stays around 49 million 1990 U.S. dollars. If a 3.5 percent inflation rate is assumed, there will be 26.4 million 1972 U.S. dollars available in 1990.

The UNOLS Advisory Council meeting (1973) reported the relation between research ship costs and ship tonnage (Figure 11). Analysis of ship displacement indicates the average displacement of each classified ship. The following table shows the relation among the classification of ship, average displacement (tonnage) of each classification, and average ship operating cost.

Length (ft)	Average Displacement (tons)	Average Operating Cost (per ship) (million dollars)
65-100	135.8	0.195
100-150	391.7	0.430
150-200	858.6	0.645
200-	1,639.7	0.958

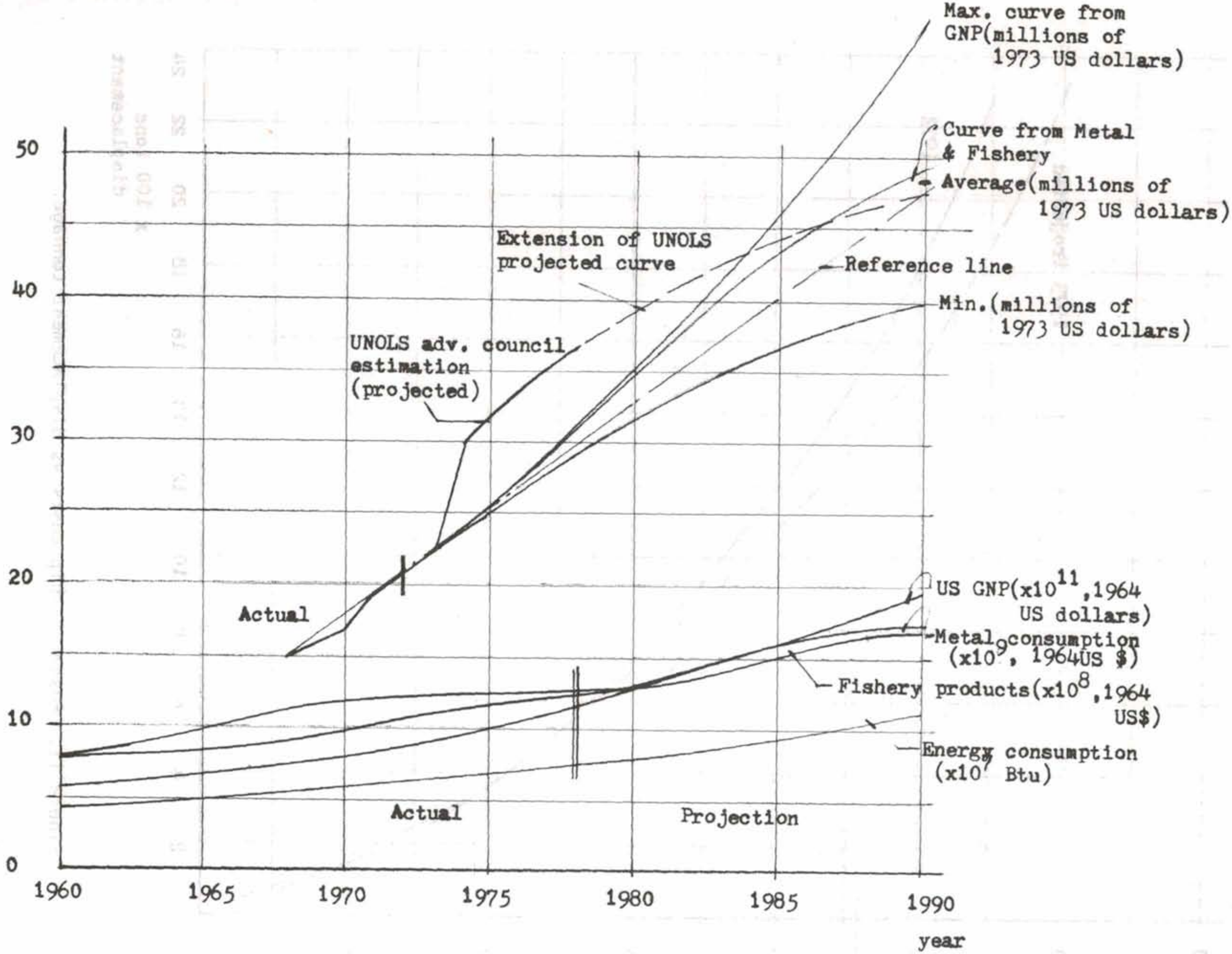


Figure 10. Summary of recommended funding.

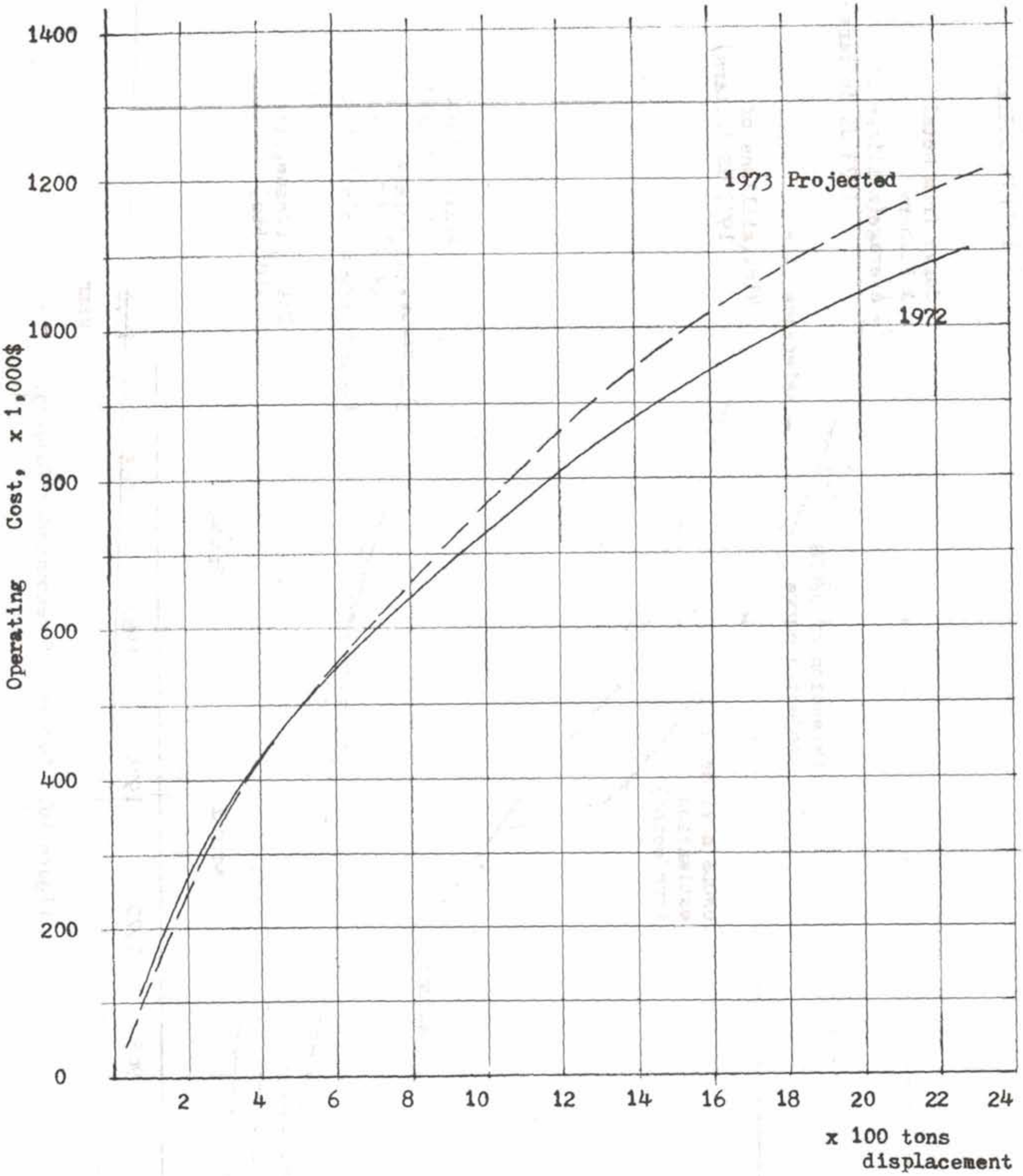


Figure 11. Research ship costs vs displacement tonnage.

According to the UNOLS first annual report, ship operating cost ranges from 63 to 75 percent of the total ship research fund. As new ships are built, the operational cost will decrease; it can be expected to drop to about 62 percent of the total ship research fund by 1990. Therefore, ship operation in 1990 based on 1970 U.S. dollars will be \$30.4 million.

If there are three special ships by 1990 and if it is assumed that each of them cost \$2 million of the operational monies, there should be \$3.4 million of available funds for ship operation in 1990.

Length (ft)	Average Displacement (tons)	Average Operating Cost (million dollars)	Allocation	
			No. of Ships	Cost (million dollars)
65-100	135.8	0.195	2	0.390
100-150	391.7	0.430	2	0.860
150-200	858.6	0.645	2	1.290
200-	1,639.7	0.958	1	0.958
		TOTAL	7	3.498

Thus, approximately 7 ships will be added to the number of 1972 UNOLS research ships bringing the number to 41 ships in 1990.

If it is assumed that 55.9 percent of the total is composed of blue water ships, and with 3 additional special ships, there will be 26 blue water ships in 1990.

Posterior information

$$m = \frac{1}{n} \Sigma x_i = 27$$

$$n' = \frac{\sigma^2}{\sigma'^2} = 3.30$$

The predicted size is:

$$m'' = \frac{n'm' + nm}{n' + n} = 28.8$$

with a variance of:

$$\sigma''^2 = \frac{\sigma^2}{n' + n} = 8.87$$

$$\sigma'' = 3.0$$

Therefore, there will be 29 blue water ships (average) with a respective standard deviation of 3 in 1990.

Remarks

Among the various types of manned vehicles, conventional craft, semi-submerged platforms, and spar buoys are best suited as blue water manned vehicles in 1990. It seems that the number of special ships such as SSP and spar types of vessels will increase by 1990 due to the complexity of research. Therefore, 8 special manned vehicles and 21 conventional ships will provide the reliability and performance of the needed blue water subsystem.

COASTAL

Prior information

Number of ships (m') = 31

Standard deviation (σ') = 6.57

Prior rationale

Maximum size. One larger coastal ship (100 to 150 ft) is required for each zone for geological and biological research studies. Assuming that an average of two 65 ft ships are required for each university, the total number of ships required will be 42.

Average size. One large coastal ship (100 to 150 ft) and three 65 ft ships are required for each zone for geological and biological work. This implies 32 ships.

Minimum size. Three large coastal ships, one each for the Atlantic, Gulf, and Pacific Coasts and eighteen 65 ft ships, one for each UNOLS member or two for each zone with the extra ships to Woods Hole and Scripps Institution are required. This implies 21 ships.

Likelihood information

x_i	Source	Number of Ships	Assumed Confidence	Degree of Belief
x_1	Budget	23	40	0.174
x_2	UNOLS	29	80	0.348
x_3	Woods Hole	32	50	0.217
x_4	Dinsmore	22	60	0.261
		TOTAL		1.000

$$\text{mean} = m = \frac{1}{n} \Sigma x_i = 26.5$$

$$\text{variance} = \sigma^2 = \Sigma(x_i - \mu)^2 \cdot p(x_i) = 15.9$$

Likelihood rationale

Budget estimate. The ship operating funds from 1960 to 1973 and projected funding from 1974 to 1977 are plotted in Figure 12. The projections to 1990 are made for maximum, average, and minimum values. The values in 1990 will be:

maximum	\$32.5 million
average	\$25.5 million
minimum	\$21.5 million

Estimating to 1973 dollars:

$$\text{funding} = \frac{s}{(1 + i)^n}$$

where:

s = funding in 1990

i = interest rate

n = number of years (17)

Thus, the 1973 funding is estimated at:

Level	Amount (million dollars)	1990 Funding (million dollars)	Interest Rate (percent)
maximum	16.7	32.5	4
average	8.2	25.5	7
minimum	4.3	21.5	10

The operating costs for vessels (obtained from the total operating costs for each class of vessel as given in the UNOLS report on university research ships) are as follows:

Ship Size (ft)	Federally Funded (dollars per year)	University Ships (dollars per year)
65-150	330,000	-
65	100,000	61,000
50- 65	80,000	60,000

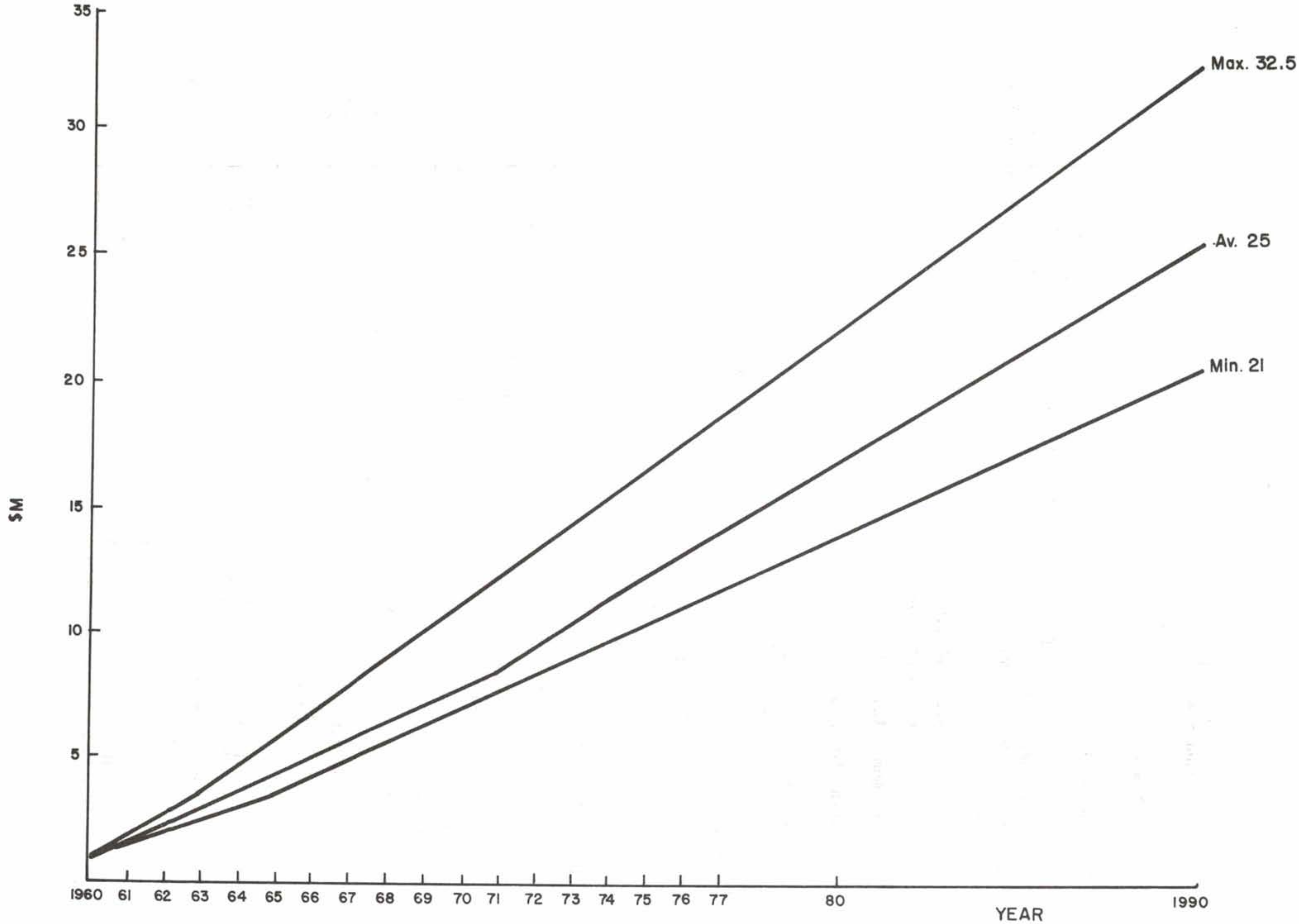


Figure 12. Projection of funding to UNOLS.

The federally funded ships are found to be highly utilized. Since the research ships in UNOLS are assumed to be used effectively on a cooperative basis, the operational cost of federal funding is taken for calculations. The useful life of a research vessel is now considered to be about 20 years. The funding for fleet replacement is 60 years. Every year $3.5 million is ailoted for the construction of new ships.

The maximum size fleet will be:

Ship Size (ft)	Number of Ships	Cost (million dollars)
65-150	12	3.96
65	30	3.00
50- 65	18	1.44
< 50	60	0.60
	operational costs	9.00
	replacement costs	7.70
	TOTAL	16.70

The average size fleet will be:

Ship Size (ft)	Number of Ships	Cost (million dollars)
65-150	5	2.30
65	18	1.80
50- 65	5	0.50
< 50	20	0.20
	operational costs	4.70
	replacement costs	3.40
	TOTAL	8.20

The minimum size fleet will be:

Ship Size (ft)	Number of Ships	Cost (million dollars)
65-150	2	0.66
65	12	1.20
50	10	0.80
< 50	14	0.14
	operational costs	2.80
	replacement costs	1.50
	TOTAL	4.30

According to budget estimate, the UNOLS fleet in 1990 will consist of:

Size	Number of Ships		
	maximum	average	minimum
ships greater than 65 ft	42	23	14
ships less than 65 ft	78	25	24

UNOLS estimate for ships greater than 65 ft. (Source: Long-range Plan for University Research Ships.)

Coastal	125 ft - 180 ft	17 ships
Institutional (local)	65 ft - 125 ft	12 ships
	TOTAL	29 ships

National Academy of Engineering (NAE) estimate for ships greater than 65 ft. (Source: Woods Hole Oceanographic Institution.)

	pre 1965	post 1975
Ships	94	50
Special ships	2	10
	TOTAL	60

This fleet is for coastal and blue water research. Assuming that most of the special ships are for blue water (it is recommended that almost all coastal ships must be multipurpose) the fleet size for coastal zone is 32. (This is based on the present fleet of 34 ships, out of which 16 are greater than 150 ft in length for blue water research.)

Captain Robert Dinsmore's estimate:

Total oceanographic fleet - 40 ships

Based on arguments similar to those in the previous case, the number of coastal zone research ships greater than 65 ft will be 22.

Posterior information

$$n = 4$$

$$n' = \frac{\sigma^2}{(\sigma')^2} = 0.37$$

The predicted size is:

$$m'' = \frac{n'm' + nm}{n' + n} \simeq 28$$

with a variance of:

$$\sigma''^2 = \frac{\sigma^2}{n' + n} = 4$$

Maximum size of fleet = 32 ships

Average size of fleet = 28 ships

Minimum size of fleet = 24 ships

Remarks

The Bayesian-Raiffa analysis is only valid for ships greater than or equal to 65 ft in length since data is not available on ships smaller than 65 ft. Ships less than 65 ft, particularly those 26 ft in length, will be used for nearshore research. This category, which is not presently federally funded, must be included in UNOLS to make the fleet complete.

Summary of coastal fleet

Ships greater than 65 ft. In the existing coastal fleet there are eight ships which are less than a year old and hence will still be operating in 1990. The remaining vessels will be constructed between now and 1990 with the following recommended distribution:

Conventional Ships	4
Hydrofoils	4
SSP	4
Non-self-propelled Stable Offshore Pl: forms	8

Ships less than 65 ft. Since the operating costs of 59 to 65 ft ships are about $80,000 per year, about 17 ships, one for each university, is recommended. Ships of 26-ft length need about $10,000 per year for operations. These are useful for nearshore works and also for auxilliary work such as installation or maintenence of buoys. Fifty ships of 26-ft length are recommended for the UNOLS coastal fleet.

Shore Support Facilities

Prior information

1. The minimum number and the associated variance are 5 and 1, respectively.
2. The expected number and the associated variance are 8 and 2, respectively.
3. The maximum number and the associated variance are 9 and 2, respectively.

Likelihood information

MINIMUM NUMBER OF FACILITIES

x_i	Source	Number of Facilities	Degree of Belief
x_1	Dinsmore	--	----
x_2	Craven	6	.800
x_3	Knowles	5	.180
x_4	Heaman	17	.019
x_5	No UNOLS	0	.001
		TOTAL	1.000

AVERAGE NUMBER OF FACILITIES

x_i	Source	Number of Facilities	Degree of Belief
x_1	Dinsmore	8	.500
x_2	Craven	7	.300
x_3	Knowles	12	.180
x_4	Heaman	19	.199
x_5	No UNOLS	0	.001

MAXIMUM NUMBER OF FACILITIES

x_i	Source	Number of Facilities	Degree of Belief
x_1	Dinsmore	--	----
x_2	Craven	11	.800
x_3	Knowles	14	.180
x_4	Heaman	21	.199
x_5	No UNOLS	0	.001

Facilities	Average (m)	Mean (μ)	Variance (σ^2)
minimum	7.0	6.04	2.60
average	9.2	8.64	5.15
maximum	11.5	11.70	3.18

Likelihood rationale

Captain Robert Dinsmore's estimate. Captain Dinsmore estimated that eight shore facilities will be needed by UNOLS in 1990. The subsystem manager assigned a degree of belief of 50 percent to the estimate.

Dr. John Craven's estimate:

1. minimum number = 6
2. expected or probable number = 7
3. maximum number = 11

The subsystem manager assigned the following degrees of belief to the estimates:

1. 80 percent for the minimum estimate
2. 30 percent for the expected estimate
3. 80 percent for the maximum estimate

Mr. Leonard I. Knowles' estimate:

1. minimum number = 5
2. expected or probable number = 12
3. maximum number = 14

The subsystem manager assigned the following degrees of belief to the estimates:

1. 18 percent for the minimum estimate
2. 18 percent for the expected estimate
3. 18 percent for the maximum estimate

Admiral William Heaman's estimate:

1. minimum number = 17
2. expected number = 19
3. maximum number = 21

The subsystem manager assigned the following degrees of belief to the estimates:

1. 1.99 percent for the minimum estimate
2. 1.99 percent for the expected or probable estimate
3. 1.99 percent for the maximum estimate

No UNOLS estimate. Based on the assumption that there will be no UNOLS in 1990, it is estimated that there will be no UNOLS shore support facility, i.e., the minimum, expected, and maximum numbers are equal to zero. This was assigned a degree of belief of .001 percent.

Posterior information

$$n = 5$$

$$n' = \frac{\sigma^2}{(\sigma')^2}$$

The predicted size is:

$$m'' = \frac{n'm' + nm}{n' + n}$$

Thus, the estimated number of shore support facilities is:

Number of Facilities	Mean (m")	Variance (σ")
minimum	6	0.39
average	9	0.68
maximum	11	0.59

Unmanned Observatories at the Air-Sea Interface

Prior information

The expected number of observatories (m') = 48
Standard deviation (σ') = 10

Likelihood information

x_i	Source	No. of Buoys	Degree of Belief
x_1	TRC	44	0.4
x_2	Dinsmore	45	0.3
x_3	Craven	50	0.2
x_4	NORPAX	45	0.1

$m = \frac{1}{n} \Sigma x_i = 46$

$\mu = \Sigma x_i \cdot p(x_i) = 45.6$

$\text{Variance} = \sigma^2 = \Sigma(x_i - \mu)^2 \cdot p(x_i) = 5.04$

Likelihood rationale

The Traveller Research Center (TRC) report

The Traveller Research Center is a professional scientific research center in Hartford, Connecticut and has published a report for the U.S. Coast Guard by E.J. Aubert and G.M. Northrup entitled, *A Study of Preferred Technical Development Plans for a National Data Buoy System* (Contract No. DOT-CG-82504-A, October 1967).

The report is complete and presented in six sections:

1. *"Applicability of National Data Buoy Systems to Refined National Requirements for Marine Meteorological and Oceanographic Data".* Vol. I. TRC Report 7493-332a. October 1968.
2. *"Applicability of National Data Buoy Systems to Refined National Requirements for Marine Meteorological and Oceanographic Data".* Vol. II. Appendices. TRC Report 7493-332b. October 1968.
3. *"Cost Effectiveness Sensitivity of National Data Buoy Systems".* TRC Report 7493-336. December 1968.
4. *"An Analysis of Cruise Strategies and Costs for Deployment of National Data Buoy Systems".* TRC Report 7493-337. November 1968.
5. *"National Requirements for Marine Meteorological and Oceanographic Data".* TRC Report 7485-253. April 1967.
6. *"Buoy and Buoy Components Data Compilation and Analysis".* TRC Report 7485-256. July 1967.

The data of the above reports were based on detailed interviews by TRC Inc. specialists. Seventy-eight separate Agency-Mission Operations (AMOs) were visited. They were considered the best qualified and able to provide the required information. (All UNOLS present members with buoy stations were included here.)

Cost information was given by both AMOs and the buoy manufacturers. (Based on 1967 prices and converted to 1973 prices assuming $i = 10$ percent in $S = P(1 + i)^n$.)

Buoy size estimations (personal logic):

1. Only 10 UNOLS members out of 17 had buoy research stations in 1967.
2. Twenty-two buoys were owned by the ten UNOLS members.

Estimation of the number of buoys in 1990 is based on the following assumptions:

1. In 1990, all UNOLS members will have buoy research in operation.
2. In 1990, each member will have the same ratio of buoys as the 10 members in 1967.

ESTIMATE OF MEMBERSHIP OF 1990 UNOLS

Low	Medium	High
17 members	20 members	24 members

Therefore,

low value x_1 = 38 (buoys)

medium value x_2 = 44 (buoys)

high value x_3 = 53 (buoys)

Note:

The number of members at present is 17. A subjective estimate that 3 to 7 new members may join from now up to 1990, assuming that no members drop out from now to 1990.

Captain Robert Dinsmore

These estimates are based on personal correspondence with Captain Dinsmore:

1. October 1, 1973 Private Discussion
2. October 2, 1973 Class Lecture
3. October 2, 1973 Private Discussion
4. October 2, 1973 UNOLS Special Seminar

His information is based on his experience as executive secretary of UNOLS.

Captain Dinsmore estimated that the number of UNOLS members in 1990 will be:

Low	Medium	High
17 members	20 members	24 members

Politically, international regime, constraints and funding possibilities were all considered by Captain Dinsmore.

Dr. John Craven

These estimations are based largely on the class lectures by Dr. Craven in an ocean engineering systems class, conducted in the fall of 1973 at the University of Hawaii.

Frequent private discussion with Dr. Craven are reflected in this estimate.

Dr. Craven is an acknowledged expert and experienced specialist in ocean-related fields.

Dr. Craven predicted that the number of UNOLS members in 1990 will be:

Low	Medium	High
17 members	20 members	24 members

Dr. Richard Wirt

These estimations are based on a one and a half hour lecture by Dr. Wirt on October 9, 1973 at the University of Hawaii.

The lecturer has been working with the North Pacific Buoy Program (NORPAX) for a period of three years. He has acquired an extensive background on NORPAX and this knowledge would be quite helpful in analyzing other buoy systems.

Posterior information

$$n' = \frac{\sigma^2}{(\sigma')^2} = 0.0504$$

The predicted size is:

$$m'' = \frac{n'm' + nm}{n' + n} \simeq 46.0$$

with a variance of:

$$\sigma''^2 = \frac{\sigma^2}{n' + n} = 1.22$$

Thus, the expected number of buoys in the 1990 UNOLS profile will be 46.

Unmanned Observatories Underwater

Prior information

The expected number of observatories $(m') = 16$

Standard deviation $(\sigma') = 9$

Prior rationale

This estimate consists only of major subsystems which could be unique and costly enough to warrant UNOLS block funding such as CURV's, SPURV's, and acoustic arrays. It is the subsystem manager's feeling that the relatively simple items such as coring devices, bathymetric profilers, and trawls are necessary to carry out the mission as set forth in the subjective human purpose but would not come under direct block funding from UNOLS.

The cost penalties incurred by manned observatories beneath the air-sea interface are such that there must be some growth from the present low levels of interest and effort in the field of unmanned underwater platforms.

Estimate for 1990:

Description	Number in 1990	Uncertainty
Self-propelled (non-tethered)	2	1
Tethered	4	3
Towed	6	2
Free-floating	1	1
Bottom-mounted	3	2
TOTAL	16	9

Likelihood information

x_i	Source	Number of Devices	Assumed Confidence	Degree of Belief
x_1	Dinsmore	9	4	.4
x_2	Budget One	3	2	.2
x_3	Budget Two	6	4	.4

$m = \frac{1}{n} \Sigma x_i = 6$

$\mu = \Sigma x_i \cdot p(x_i) = 6.84$

$\text{Variance} = \sigma^2 = \Sigma(x_i - \mu)^2 \, p(x_i) = 4.08$

Likelihood rationale

Captain Robert Dinsmore

During his visit, Captain Dinsmore provided the following data. None of his categories directly reflect an expected growth in the unmanned underwater observatories subsystem. The subsystem growth is therefore estimated on the basis of expected UNOLS growth.

Description	1973	1990	Percent Growth
Institutions	17	20	8
Ships	32	40	25
Submersibles	2	11	450
Buoys	4	6	50
Aircraft	1	8	700
Communications	0	4	---
Major Shore Support Facilities	2	8	300
	TOTAL		1542

Average Percent Growth = 257

Use 300 percent

Budget One

Lack of published data concerning the cost of unmanned underwater devices has caused another journey into the area of indirect prediction of growth. This is done by extrapolating the total academic research funding curve to the year 1990 and discounting the resulting dollar sum to 1973 dollars using a range of discounting rates. These figures are then used to generate a percent growth and the assumption is made that the subsystem will grow at a rate similar to the funding rate (Figure 13).

Discounting rates of 7 percent, 5 percent, and 3 percent:

Low $$P = S\left[\frac{1}{(1 + .07)^{17}}\right] = \$49.8 \text{ million}$$

Medium $$P = S\left[\frac{1}{(1 + .05)^{17}}\right] = \$68.5 \text{ million}$$

High $$P = S\left[\frac{1}{(1 + .03)^{17}}\right] = \$95.0 \text{ million}$$

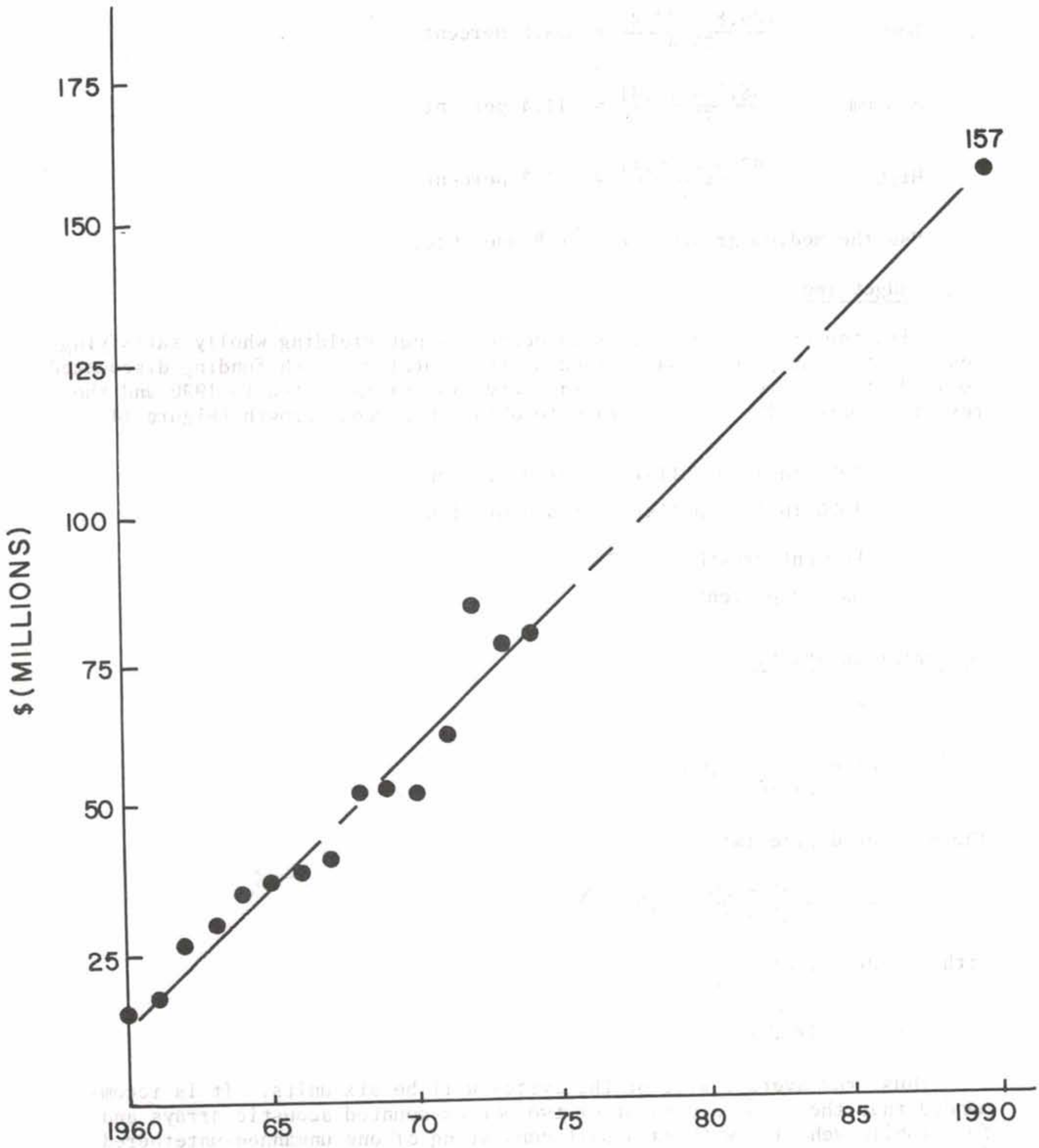


Figure 13. Academic research funding projected to 1990.

Percent growth:

Low $\frac{(49.8 - 77.4)}{77.4} = -35.5$ percent

Medium $\frac{(68.5 - 77.4)}{77.4} = -11.4$ percent

High $\frac{(95.0 - 77.4)}{77.4} = 22.7$ percent

Use the medium growth rate for Budget One.

Budget Two

With the previous exercises in economics not yielding wholly satisfying results, the subsystem manager then plotted total research funding discounted to 1960 at a rate of 5 percent. The curve was extrapolated to 1990 and the result compared with the 1973 rate to obtain a percent growth (Figure 14).

1973 in 1960 dollars = $41.0 million

1990 in 1960 dollars = $78.0 million

Percent growth = 90.2

Use 90 percent

Posterior information

$$n = 3$$

$$n' = \frac{\sigma^2}{(\sigma')^2} = .05$$

The predicted size is:

$$m'' = \frac{n'm' + nm}{n' + n} = 5.9$$

with a variance of:

$$(\sigma'')^2 = \frac{\sigma^2}{n' + n} = 1.3$$

Thus, the average size of the system will be six units. It is recommended that these units consist of two bottom-mounted acoustic arrays and four mobile vehicles with each unit consisting of one unmanned-untethered device, one unmanned-tethered device, and one unmanned-towed device.

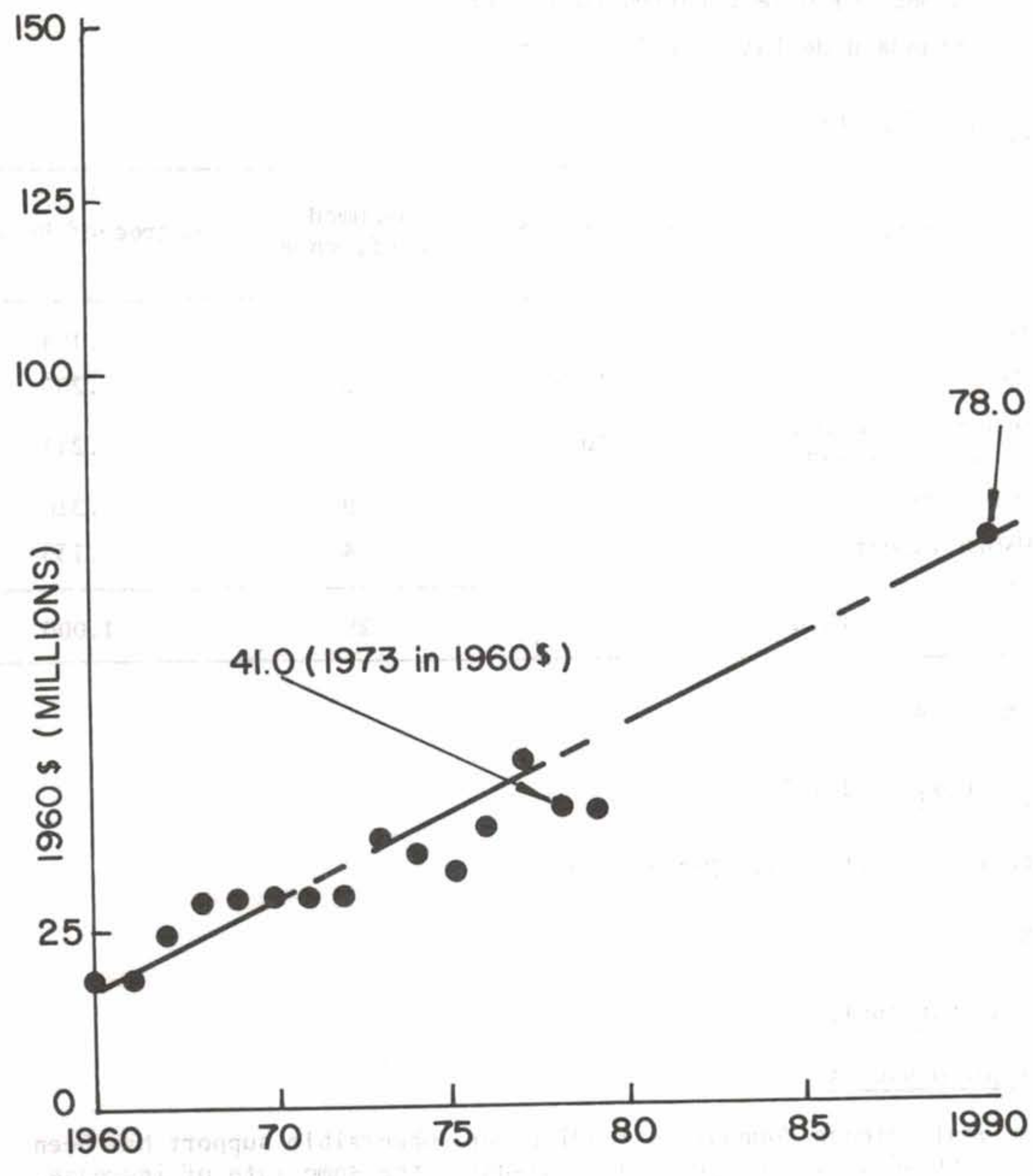


Figure 14. Projected academic research funding.

Manned Observatories Underwater

Prior information

Number of observatories (m') = 10

Standard deviation (σ') = 3

Likelihood information

x_i	Source	Observatories	Assumed Confidence	Degree of Belief
x_1	Budget	4	3	.104
x_2	Merging	10	6	.207
x_3	Other governmental agencies support	20	7	.241
x_4	Dinsmore	11	9	.310
x_5	UNOLS report	25	4	.138
	TOTAL		29	1.000

$$m = \frac{1}{n} \Sigma x_i = 14$$

$$\mu = \Sigma x_i \cdot p(x_i) = 14.17$$

$$\text{Variance } (\sigma^2) = \Sigma(x_i - \mu)^2 \, p(x_i) = 33.9$$

$$\sigma = 5.82$$

Likelihood rationale

Budget projection

National Science Foundation funding for submersible support has been increasing at $0.2 million per year. Assuming the same rate of increase, there will be approximately $4 million per year by 1990. Converting this number to 1973 dollars using:

$$P = S \frac{1}{(1 + i)^n}$$

where:

i = interest rate percent

n = number of years

and assuming an inflation rate of 5 percent, $4 million converts to only $1.7 million in 1973 (Figure 15).

The following are estimates for purchasing and operating costs for submersibles.

Description	Purchasing Cost (million dollars)	Operating Cost (dollars per day)
shallow submersible (3,000 ft)	3 to 5	2,000 to 3,000
deep submersible (20,000 ft)	10 to 30	2,000 to 3,000
habitat	1	1,000

Assuming an operating cost of $2,000 per day and operating for 250 days per year, operating cost per year would come to $0.5 million per year. Using this figure, UNOLS would only be able to operate a maximum of four submersibles in 1990.

Merging with the Office of Naval Research (ONR) and possibly the National Oceanic and Atmospheric Administration (NOAA)

The Office of Naval Research had a smaller budget than NSF but used a higher percent of this budget on submersibles support than NSF. The same is true of NOAA. Thus, the merging of these organizations should about double the capacity of the present NSF system, bringing the number of submersibles to about 10.

Support from other governmental agencies

In the future, there will probably be a boom in the development of ocean resources. An increase in support from the oil industry, fishery and aquaculture industries, and the government for underwater research activities can be expected. A rough estimate would be 20 observatories by 1990.

Captain Robert Dinsmore

Captain Dinsmore estimates there will be 9 observatories by 1990.

UNOLS Advisory Council

The first annual report of the UNOLS Advisory Council to federal funding agencies (July 1, 1972) predicts the number of submersibles after 1975 to be 15. Based on this rapid rate of growth, UNOLS should have 25 submersibles by 1990.

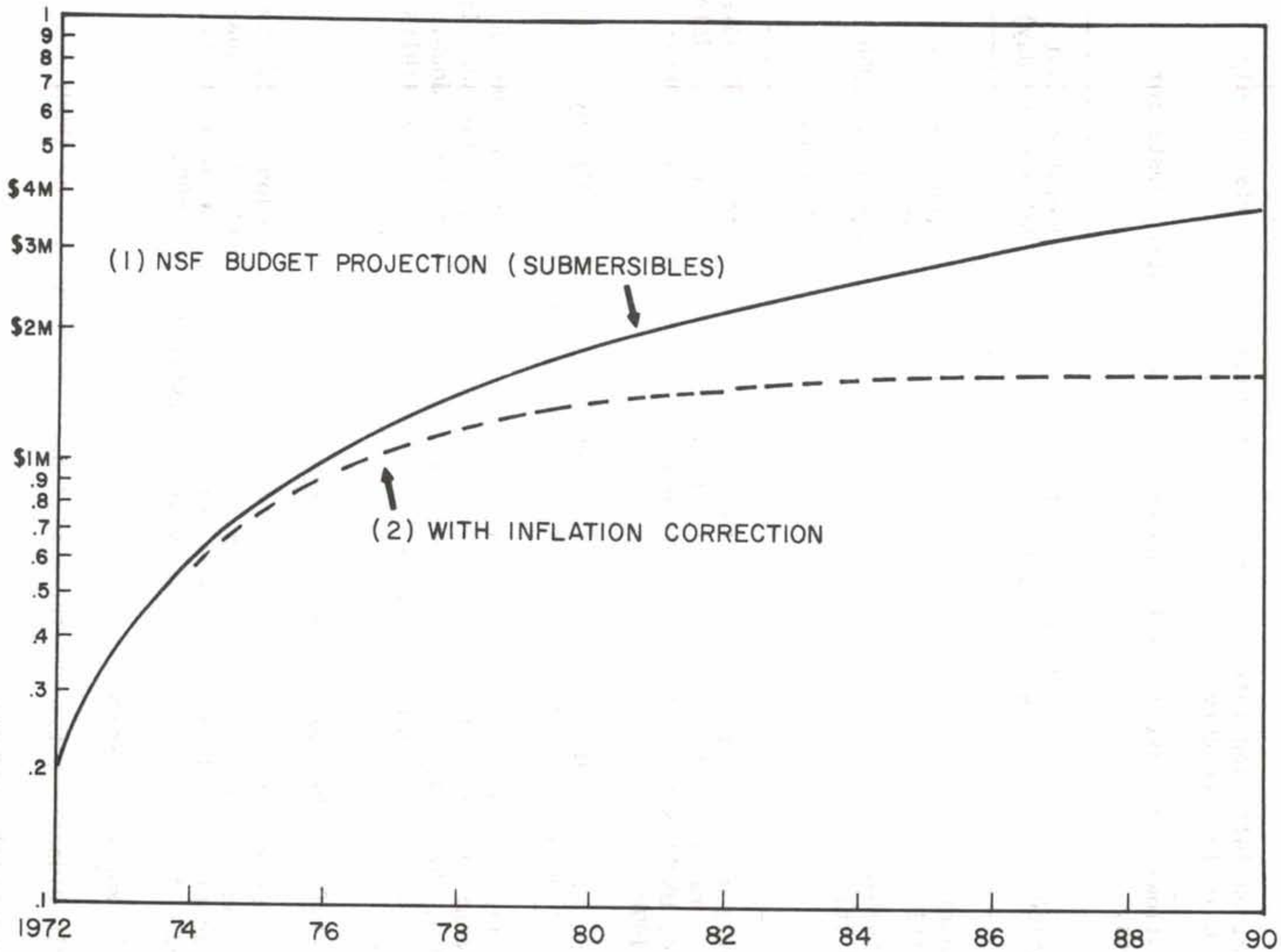


Figure 15. National Science Foundation submersible projection.

Posterior information

$$n = 5$$

$$n' = \frac{\sigma^2}{(\sigma')^2} = 3.76$$

The predicted size is:

$$m'' = \frac{n'm' + nm}{n' + n} = 12.3$$

with a variance of:

$$(\sigma'')^2 = \frac{\sigma^2}{n' + n} = 3.87$$

$$\sigma'' = 1.97$$

Therefore, the projected number of underwater observatories is 12 with a minimum of 8 and a maximum of 16. It is further recommended that 9 be submersibles and 3 be habitats.

Computerized Command and Control and Information Processing Systems (CCCIPS)

Prior information

The expected number of CCCIPS = 105

Standard deviation = 30

Prior rationale

7 coastal ships. There are 14 coastal ships over 65 ft long now; four of them were built before 1950. Very few ships can survive more than 40 years even with excellent maintenance; hence, at least four ships will be laid up by 1990. Currently they are being replaced on a 60-year cycle; therefore, one replacement can be expected in the next 15 years. This leaves 11 coastal ships over 65 ft of which some will be solely sample-gathering vehicles; seven of them can be expected to be equipped with CCCIPS. The vessels under 65 ft simply could not afford a system costing more than $20,000.

3 platforms. Platforms will certainly replace moored ships in shallow water as data-gathering stations. Though they lack the mobility of a ship, they have the important advantage of not being subject to the motions of a ship. This is important when trying to make accurate measurements of ocean parameters. As a conservative estimate, at least three can be expected to be supported by UNOLS.

16 blue water ships. There are 20 blue water ships in the UNOLS fleet now; six of them were built before 1950. By using the same rationale for coastal ships, four ships are to be laid up by 1990 and two to be replaced. Further, all 16 remaining blue water ships can be expected to have CCCIPS.

5 semi-submersibles. Semi-submersibles are superior to conventional ships because they are more stable and provide a better platform for oceanographic sensors. At least five should be in existence by 1990, all of them having CCCIPS.

8 submersibles. Approximately one per region can be expected, each having a CCCIPS.

3 habitats. Large habitats having CCCIPS are more likely to be found in warmer regions with better climates and more marine life. Three can be expected in warmer regions.

3 planes. There are three large oceanographic research planes in existence now; no significant increase in this area is expected.

No satellites. Due to their large cost, UNOLS will probably not be acquiring satellites as part of its basic system.

10 towed vehicles. There should be increased use of towed vehicles because they do not slow the ship down appreciably. They can accommodate a large number of oceanographic sensors and are decoupled from ship motions and surface conditions. Two-thirds of blue water ships can be expected to have towed instrument packages.

5 tethered, self-propelled vehicles. Tethered vehicles accommodate a large number of oceanographic sensors but would be used less frequently than towed vehicles because they immobilize the ship while in operation. Thus, possibly five ships would be equipped with tethered vehicles.

2 acoustic arrays. Only two can be expected because of their large expense and the few locations that are suitable for their use. These would probably be largely supported by the military.

35 buoys. There are 17 buoys in the UNOLS fleet presently. This number can be expected to double by 1990.

8 shore support facilities. One can be expected for each region, each containing a CCCIPS, especially for reception of information transmitted from buoy networks.

Likelihood information

x_i	Source	Number	Degree of Belief
x_1	Subsystem managers, class	139	.2
x_2	UNOLS report	140	.3
x_3	Captain Dinsmore	113	.3
x_4	Budget	80	.2

$n = 4$

$m = \frac{1}{n} \Sigma x_i = 118$

$\mu = \Sigma x_i \cdot p(x_i) = 118$

$\sigma^2 = \Sigma (x_i - \mu)^2 \cdot p(x_i) = 529$

$\sigma = 23$

Likelihood rationale

Estimates were assessed from each subsystem manager of this project. An estimate of 139 systems were generated.

UNOLS report

This information was taken from the UNOLS first annual report of the UNOLS Advisory Council to federal funding agencies, July 1, 1972. It was estimated that 140 systems would be needed.

Captain Robert Dinsmore

12 coastal ships. Captain Dinsmore foresees a higher replacement cycle and modular CCCIPS developed by the Massachusetts Institute of Technology for small boats.

3 platforms. Little mention was made of platforms; hence, a low estimate was given.

22 blue water ships. Approximately the same number of ships in 1990 as at present is anticipated.

5 semi-submersibles. Future additions to the UNOLS feet are seen.

4 submersibles. Little mention was given; hence, there is a low estimate.

3 planes. They continue to have the same number as at present.

No satellites. There will be no satellites because of their high cost.

8 towed vehicles. Little mention was given to them; hence, a low estimate was given.

4 tethered vehicles. Little mention was given; hence, there is a low estimate.

40 buoys. High optimism for the successful implementation of a UNOLS buoy network is seen.

8 shore support facilities. Not in sharp disagreement with the sub-system manager's estimate.

Budget

All budget estimates are on the low end of the spectrum as that seems to be the trend of UNOLS fleet funding. The following graph (Figure 16) is a projection of federal funding for the UNOLS fleet. The lower curve represents the current leveling off of federal funds. The upper curve is a straight line projection of the past history of federal funding. This gives a range of $15 to $50 million by 1990. To calculate the dollars needed in 1990 from 1973 dollar value:

$$P = \frac{S}{(1 + i)^n}$$

where:

P = present dollar value

S = future dollars

i = inflation about 5 percent

n = number of years (17)

Hence, about 1.94 times as much money in 1990 will be needed to equal the 1973 value. This would give a value of $7.4 to $25 million for the 1990 budget. The future UNOLS budget is not expected to go below $15 million nor above $25 million in value between now and 1990.

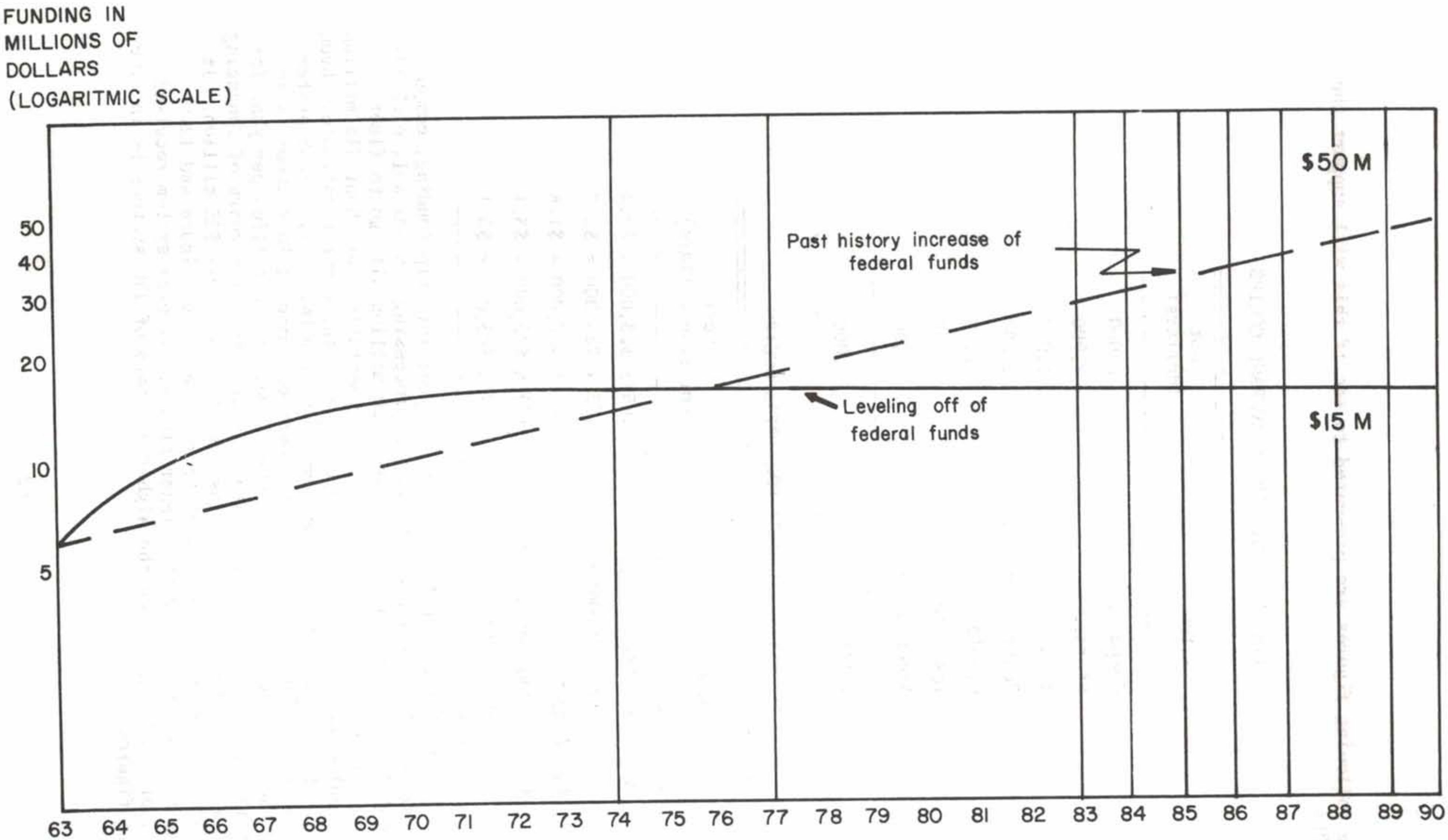


Figure 16. Trend of UNOLS funding.

The following figures are presented to see if this will support the 1990 UNOLS.

ESTIMATED COST FOR AN AVERAGE CCCIPS

Item	Cost (dollars)
Computer	8,000
Storage	8,000
Input/output	1,000
Control console	1,000
Display	1,000
Test equipment	2,000
Accessories	2,000
TOTAL	23,000

ESTIMATED COST FOR TOTAL CCCIPS

Source	Cost (million dollars)
A. Subsystem managers	105 x $23,000 = $2.4
B. Captain Dinsmore	113 x $23,000 = $2.7
C. Budget	80 x $23,000 = $1.8
D. Systems manager	139 x $23,000 = $3.1
E. UNOLS report	140 x $23,000 = $3.1

Given the 1973 level of $15 million per year for ship funding, computerized command and control and information processing systems will probably mature about 1980. In the next ten years $150 million will go to fleet funding; 10 percent of that will be for instrumentation, or about $15 million. It would require 12 percent of the budget to meet the highest estimate. Even at a rough estimate of eight systems comprising the UNOLS, with each system receiving one-eighth of the budget, the lower estimate of 80 systems is in line with these figures. Using the higher level of $25 million per year for ship funding, CCCIPS will probably mature about 1980. Ten years of financing the fleet with 10 percent going for instrumentation allows $25 million. It would require 7 percent of the budget to meet the lower figure and 12.6 percent of the budget to meet the higher figure. If each system received one-eighth of the budget, then the higher estimate of 140 systems is in line with these figures.

Posterior information

$$n' = \frac{\sigma^2}{(\sigma')^2} = .59$$

The predicted size is:

$$m'' = \frac{n'm' + nm}{n' + n} = 122$$

with a variance of:

$$\sigma''^2 = \frac{\sigma^2}{n' + n} = 115$$

$$\sigma'' = 11$$

Therefore, there should be 122 ± 11 systems in existence in 1990.

APPENDIX VI. 1990 MARINE TECHNOLOGY

In order to develop a subjective intuition on the time constants involved in the advancement of marine technology, a historical approach was used by the student subsystem managers. These time constants then provided the basis to predict the likelihood of advances in marine technology over the next 16 years. This prediction was then applied to the systems, subsystems, etc., tradeoffs to synthesize the best overall system to meet the subjective human purpose of the 1990 UNOLS.

These reports, although not edited, are available for inspection. The technical tradeoff parameters (Tables 5 through 11) and system block diagrams (Figures 17 through 25) are summarized in this section. The resulting system decisions were incorporated into the previous sections of this paper.

TABLE 5. MANNED OBSERVATORIES AT AIR-SEA INTERFACE

BLUE WATER	
Life Support	Ship Operations
Supply	Power and propulsion
Recreation	Hull and structure
Health	Stability and control
Environment	Navigation
	Crane, winch, and frame
Laboratory	Mission Analysis
COASTAL	
Available platforms	Food management
Selection criteria	Recreation
Hull and structure	Health
Power and propulsion	Waste management
Stability and control	Navigation
Material	Communications
Arrangement of space	Desk machinery
Laboratory design	Auxilliary services
Environmental control	Maintenance
Water management	Mission analysis

TABLE 6. SHORE SUPPORT FACILITIES

Personnel Requirements

	Number
Administration	26
Ship maintenance and repair	29
Storage and supply	7
Operations and maintenance	34
TOTAL	94

Space Requirements*

Subsystem	Net Floor Space (ft^2)	Gross Floor Space (ft^2)
Administration	5,140	7,000
Ship maintenance and repair	23,152	32,400
Storage and supply	27,485	38,500
Operations and maintenance	23,761	33,000
TOTAL	69,538	101,100

*To obtain the gross floor space requirements from the net floor space requirements, a ratio of gross floor space to net floor space of 1.4 is used.

TABLE 7. UNMANNED OBSERVATORIES AT THE AIR-SEA INTERFACE

Area covered
Distance from shore
Vertical distance
Delivery
Maintenance
Test and evaluation
Data coverage
Data transmission
Mission analysis

TABLE 8. UNMANNED OBSERVATORIES UNDERWATER

Mission analysis
Methods of data collection
Location
Types of data
Instrumentation

TABLE 9. MANNED OBSERVATORIES UNDERWATER

Operating depth
Collapse depth
Overall length
Beam
Height
Life support
Speed
Propulsion
Crew
Payload
Maneuverability
Viewpoints

TABLE 10. GENERAL SPECIFICATIONS OF PROPOSED VEHICLES

Shallow submersibles	
Operating depth	2,000 ft - 3,000 ft
Collapse depth	1.5 x operating depth
Overall length (maximum)	40 ft
Beam (maximum)	8 ft
Height (maximum)	12 ft
Air weight (maximum)	62,000 lb
Speed (cruise)	2 knots
Speed (maximum)	4 knots
Propulsion endurance	8 - 12 hr at 2 knots
Life support endurance (normal)	12 hr
Life support endurance (maximum)	48 hr
Crew	2 - 3
Payload	1,500 - 3,000 lb
Viewports	must have adequate front, side, and bottom oriented viewports
Maneuverability	must be towable on a launch-retrieve and transport (LRT) platform up to 8 knots up to and including state 4 seas
Must have interchangeable work-equipment packages to satisfy different mission requirement.	
Must have provisions for battery-charging at sea.	
Expected life	20 years
Deep submersibles	
Operating depth	20,000 ft
Overall length (maximum)	50 ft
Beam (maximum)	20 ft
Height (maximum)	15 ft
Dry weight (maximum)	75 tons
Speed (cruise)	3 knots
Speed (maximum)	4 knots
Propulsion endurance	20 hr at 3 knots

TABLE 10. GENERAL SPECIFICATIONS OF PROPOSED VEHICLES (con't)

Deep submersibles (con't)	
Life support endurance (normal)	24 hr
Life support endurance (maximum)	48 hr
Crew	3 - 4
Payload	2,000 - 4,000 lb
Viewports	must provide for front and bottom viewports
Towability	must be towable up to 8 knots and seaworthy up to and including state 4 seas
Maneuverability	must be towable up to 8 knots and seaworthy up to and including state 4 seas
Must have provisions for battery-charging at sea.	
Expected life	30 years
Long-range submarine	
Operating depth	3,000 ft
Collapse depth	5,000 ft
Size and weight	not restricted
Speed	4 knots maximum under its own power
Propulsion endurance	21 days
Life support endurance	6 men for 6 weeks
Crew	1 pilot, 5 passengers to operate submersible on a 24 hr rotating shift
Payload	5 tons
Viewports	must provide visibility in all directions
Should be able to recharge its own batteries while surfaced or snorkeling.	
Should utilize a totally integrated instrumentation suit to optimize operations.	
Expected life	35 years

TABLE 10. GENERAL SPECIFICATIONS OF PROPOSED VEHICLES (con't)

Habitats	
Depth	up to 3,000 ft
Crew	up to 8
Life support endurance unlimited with surface-support (exotic-gas mixtures).	
Must have laboratory provisions.	
Must have diver lock-outs.	
Must have stable anchorage.	
Habitat or diver support, lock-in, lock-out submersibles*	
Operating depth	up to 600 ft
Speed	variable up to 4 knots
Must have diver-locks to accommodate 2 to 4 divers. Locks and their internal equipment must be capable of withstanding internal elevated pressure of up to 20 atmospheres.	
Diver locks must:	
have controllable environment	
have variable gas make-up	
have a pressurization capability of 200 ft per min with self-pressurization and outside override	
be able to supply hook-up type breathing apparatus	
have good control over decompression rates between 15 min/ft to 100 ft/min	
hatches must be 34 in or over	
have a double-locked dry entry	

*Many of this type of submersibles are now in commercial operations and the recommendation is to rent or charter these vehicles as their need arises.

TABLE 11. COMPUTERIZED COMMAND AND CONTROL AND INFORMATION PROCESSING

Input/output	Communications
Integrated display	Transmission
Processor	Bit rate
Storage	

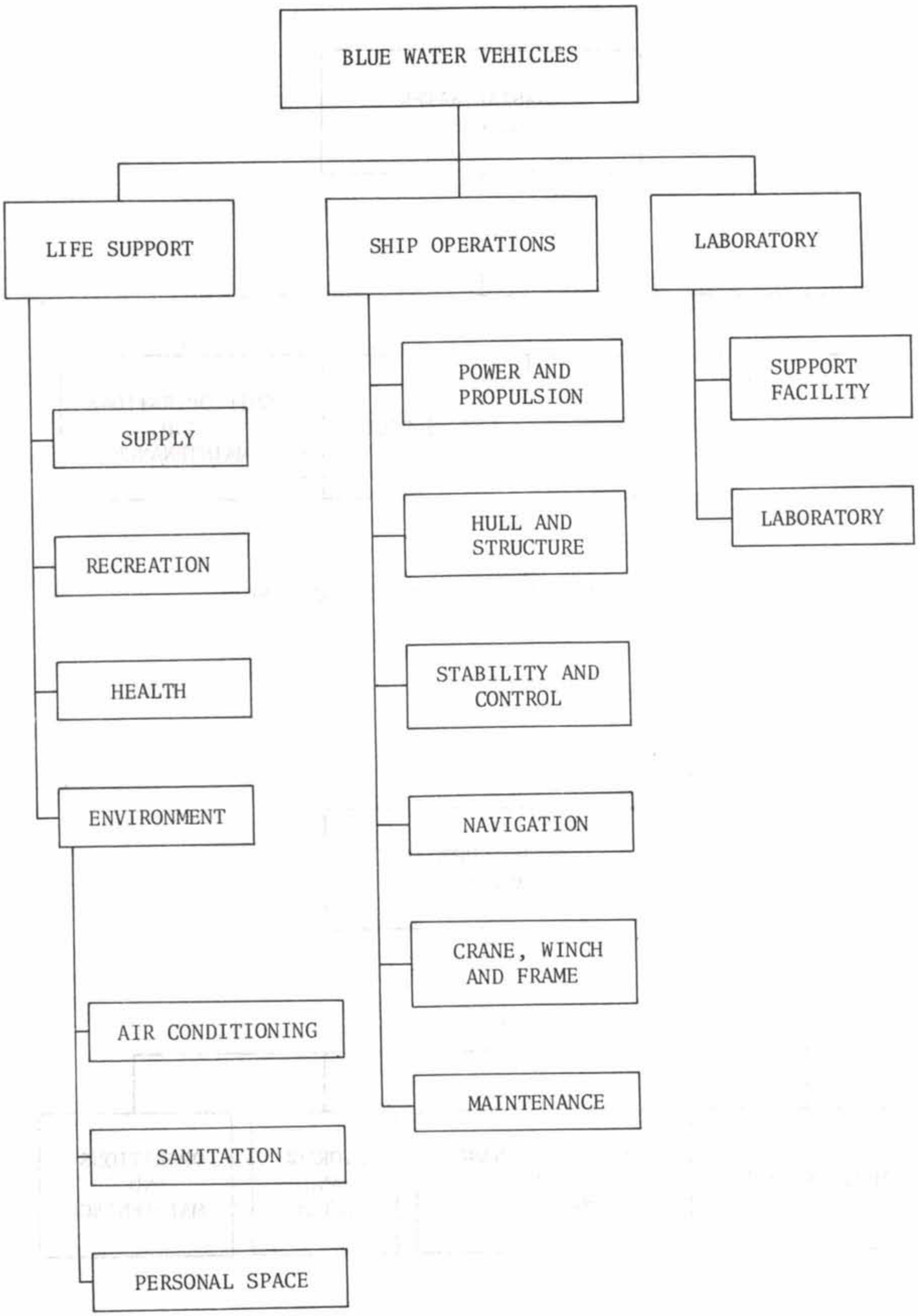


Figure 17. Blue water vehicles.

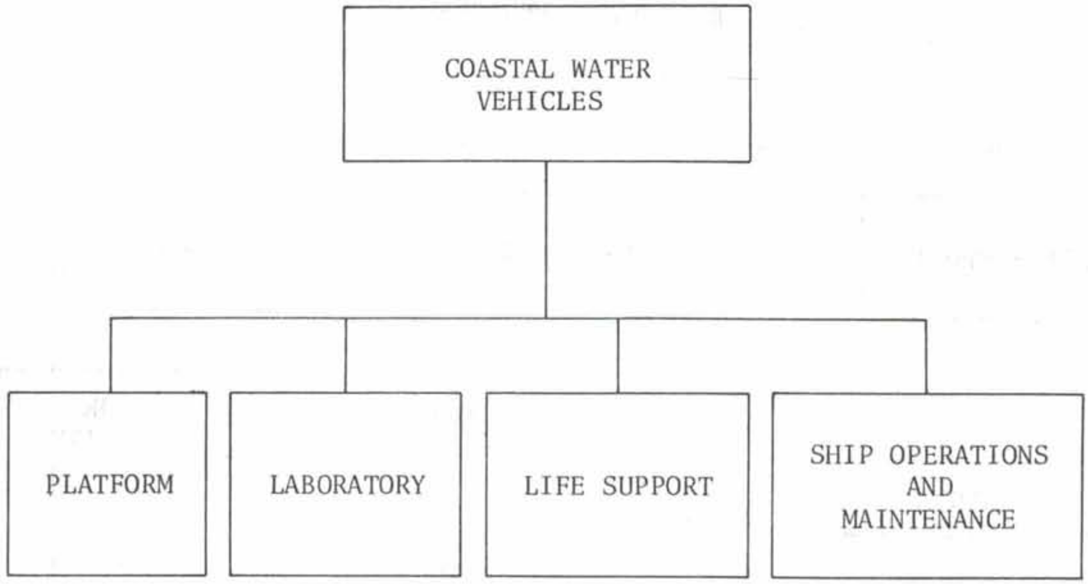


Figure 18. Coastal water vehicles.

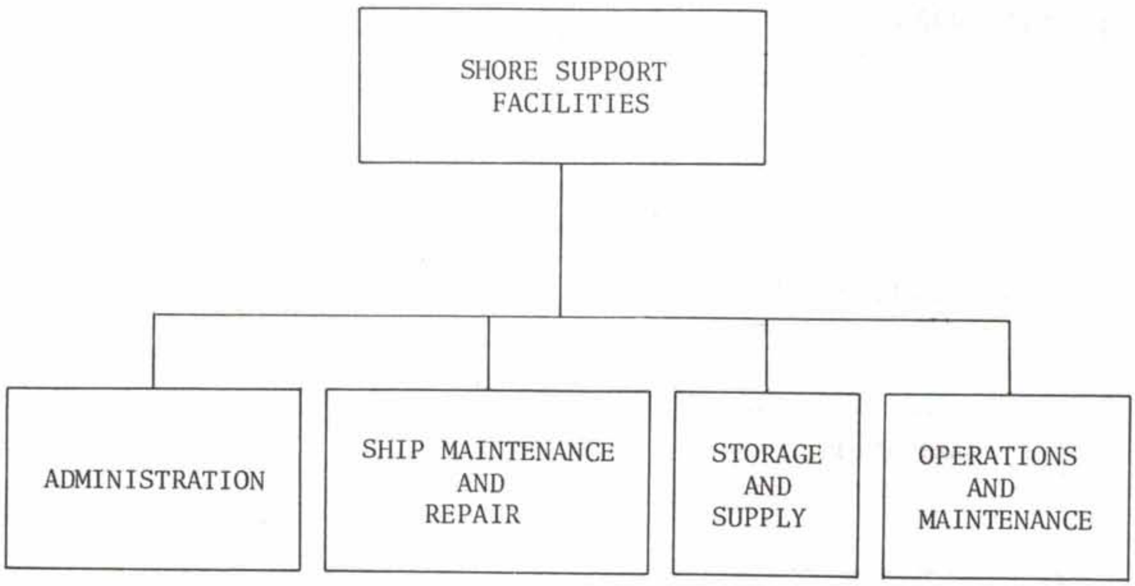


Figure 19. Shore support facilities.

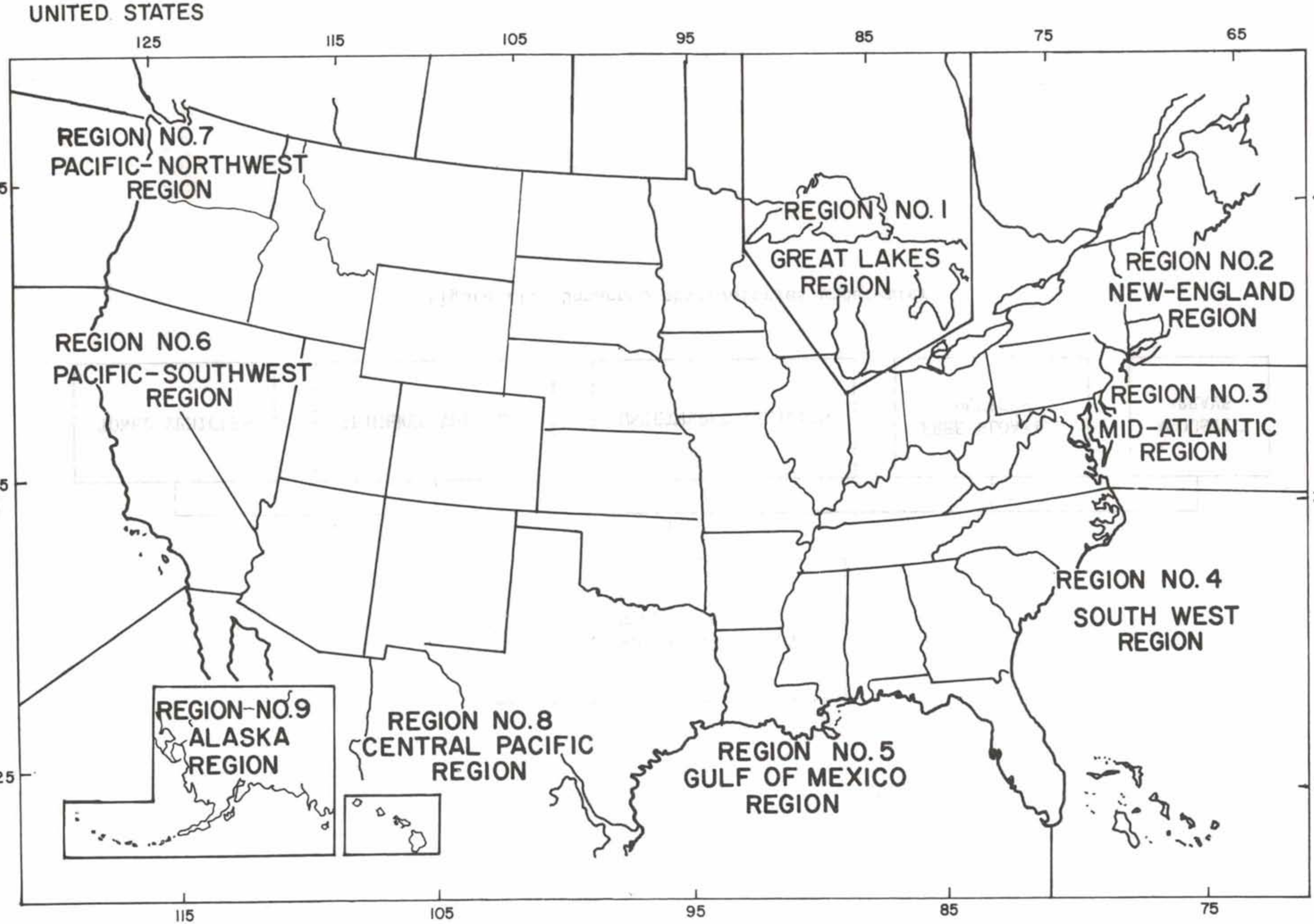


Figure 20. Location of nine shore support facilities.

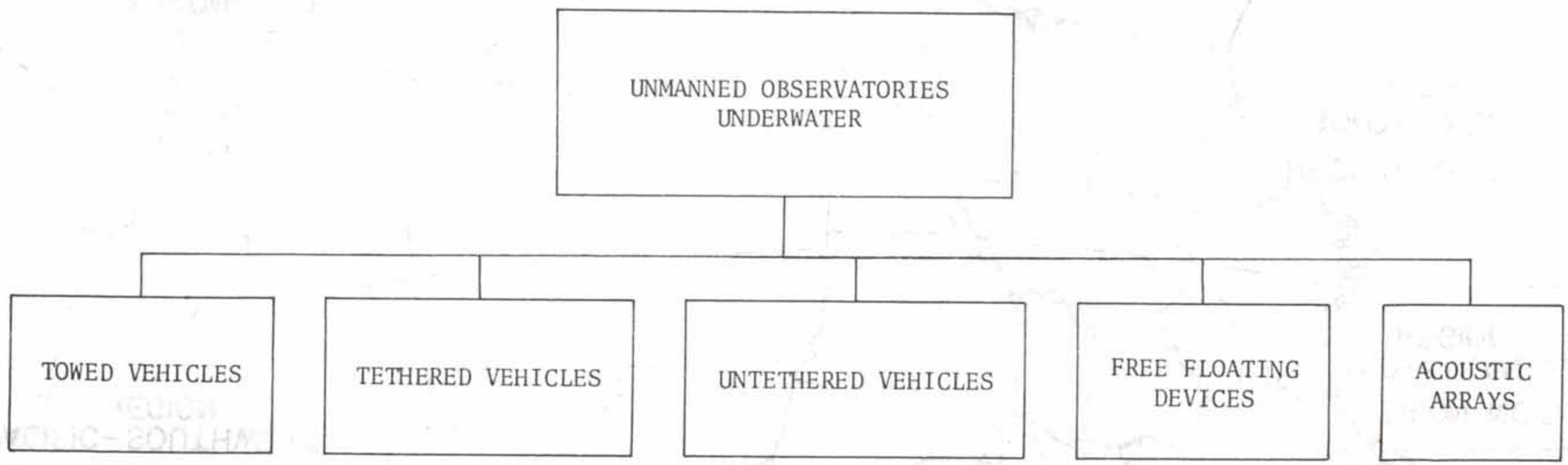


Figure 21. Unmanned observatories underwater

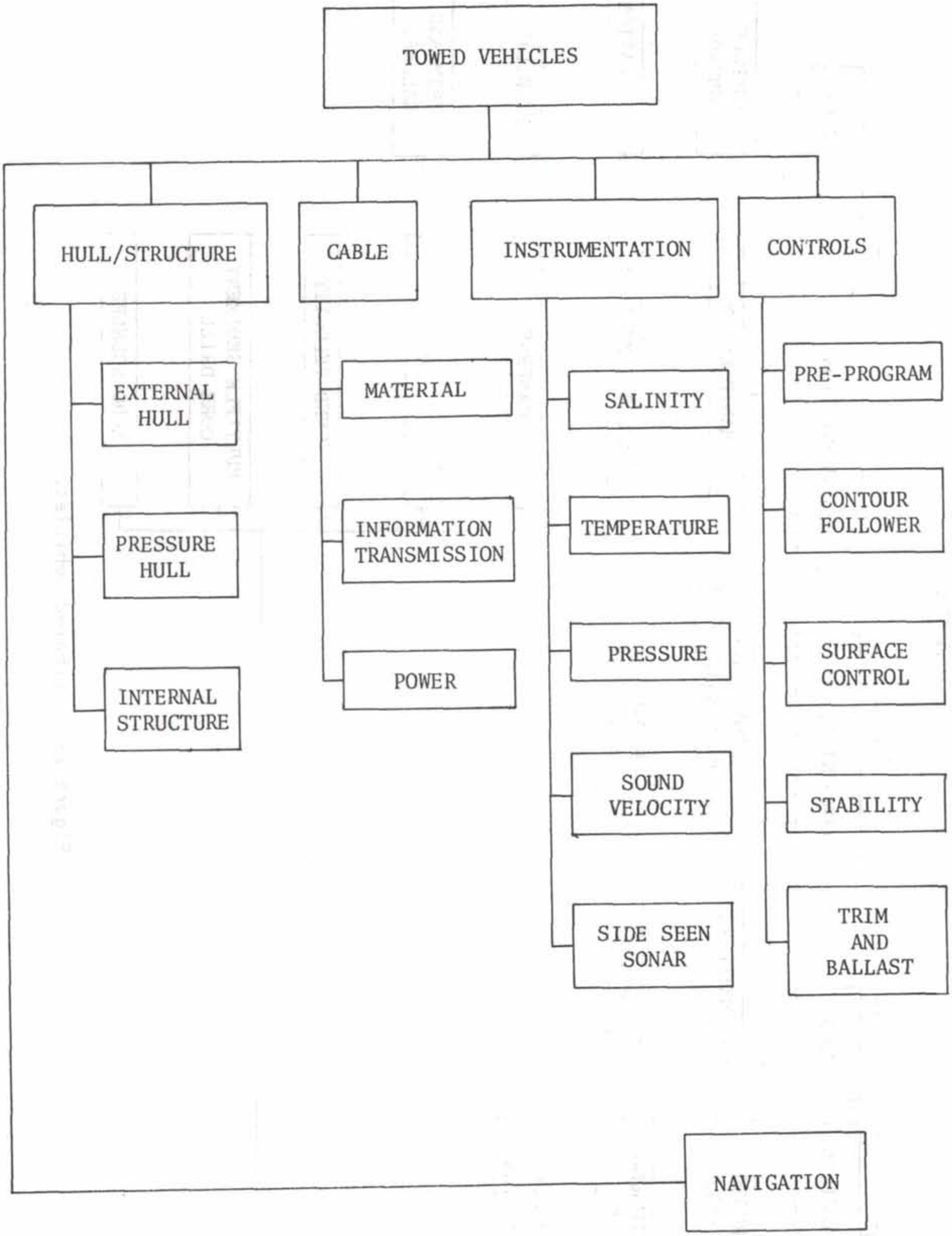


Figure 22. Towed vehicles.

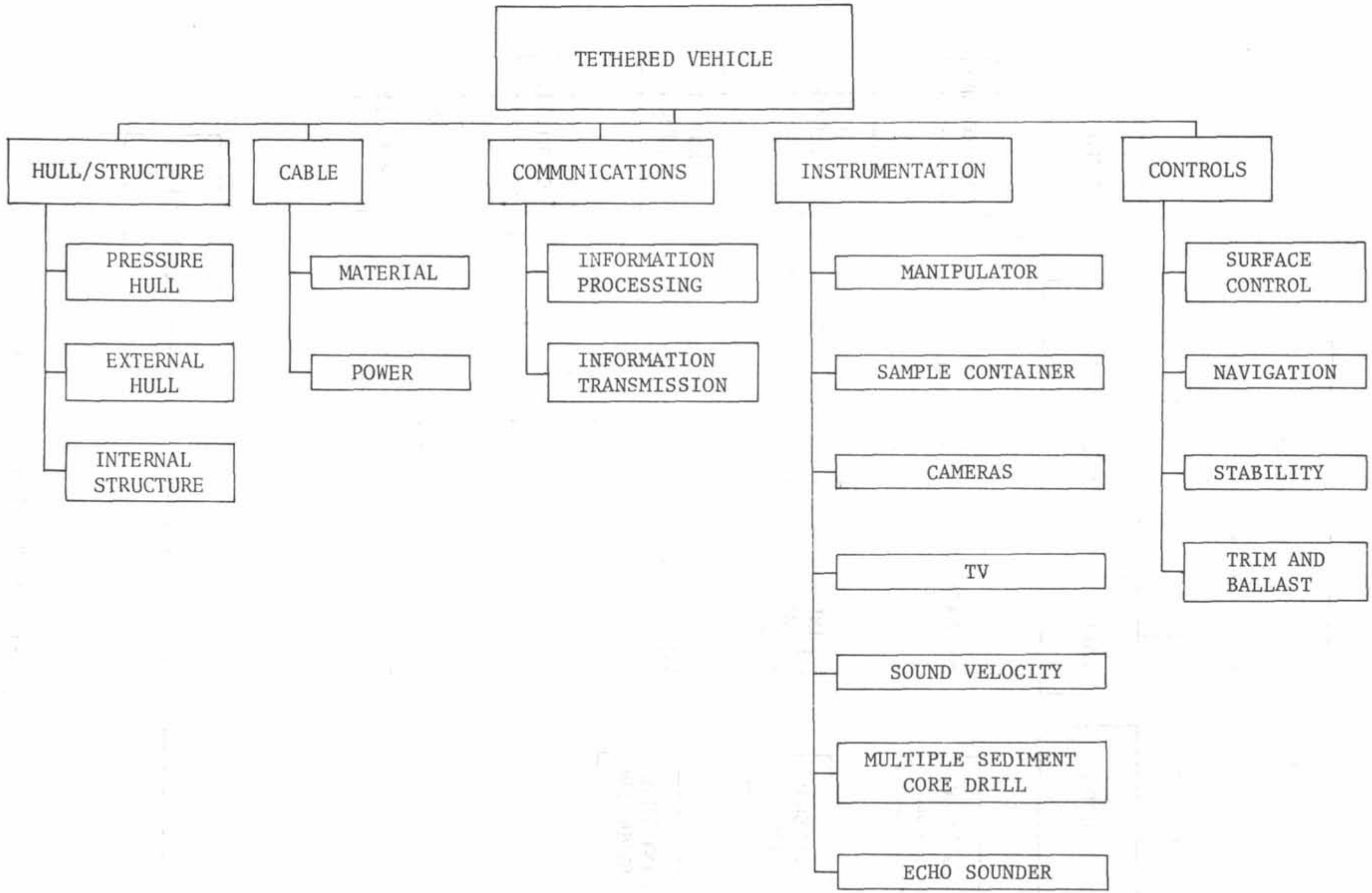


Figure 23. Tethered vehicles.

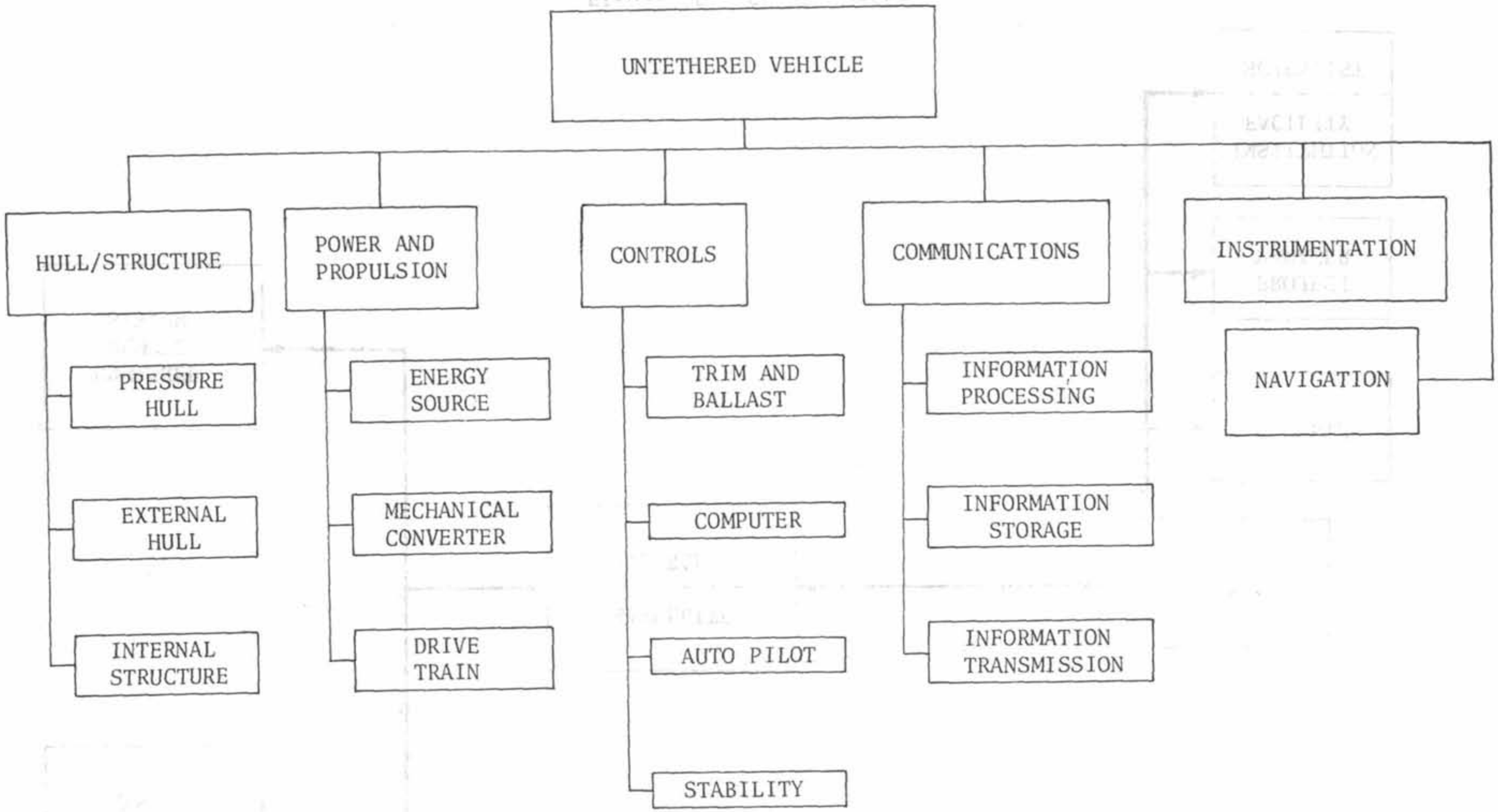


Figure 24. Untethered vehicles

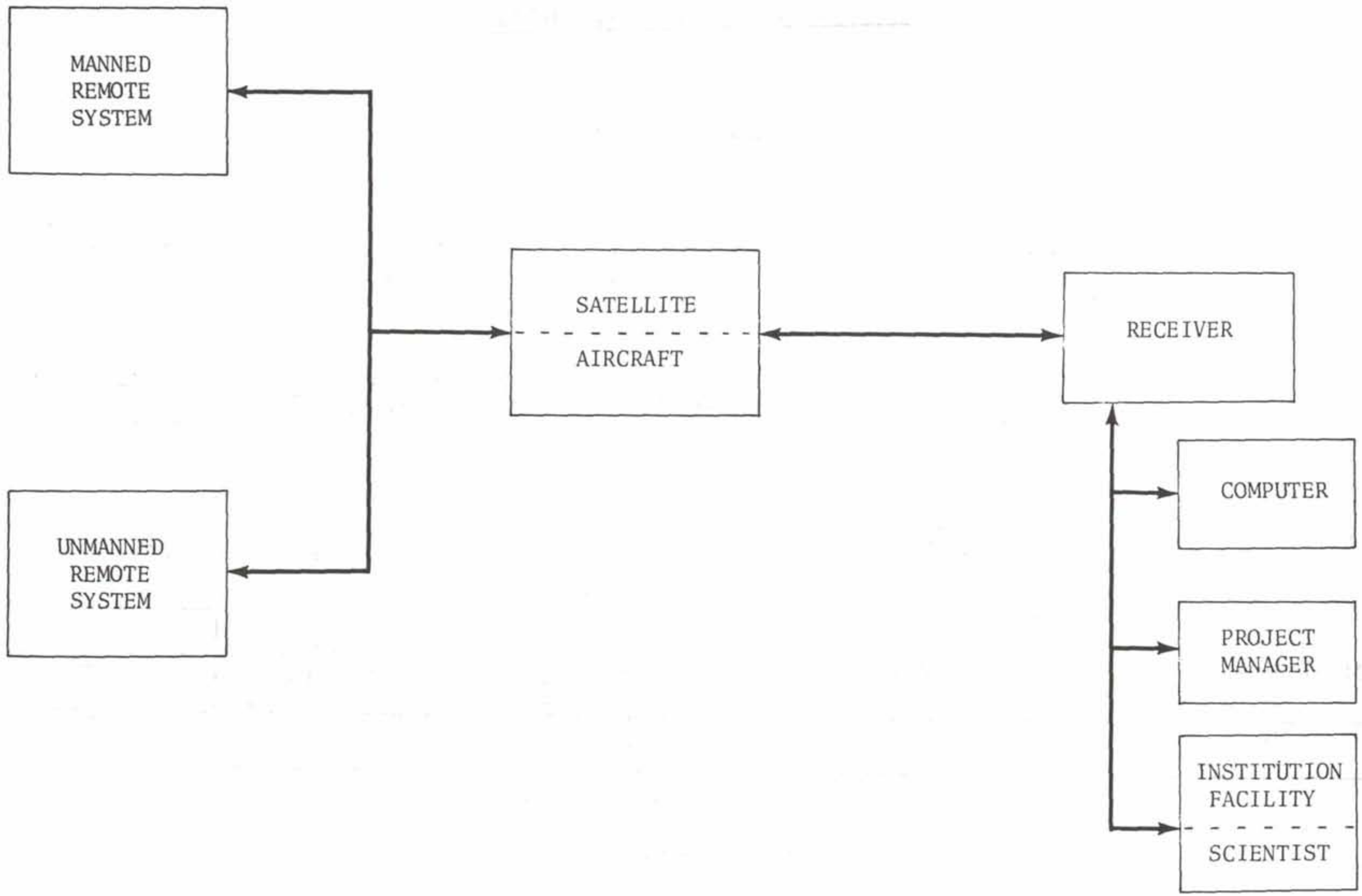


Figure 25. CCCIP system.