COST EFFECTIVENESS SENSITIVITY
OF
NATIONAL DATA BUOY SYSTEMS:
AN ESSAY

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December 1968

TRC Report 7493-336
Prepared for the U.S. Coast Guard
Under Contract No. DOT-CG-82504-A

E. J. Aubert
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Principal Investigators

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250 Constitution Plaza   Hartford, Connecticut 06103

This study was conducted in support of the U. S. Coast Guard National Data Buoy Systems Designated Project Office under Contract DOT-CG-82504-A.

Views or conclusions contained in this study report should not be interpreted as official opinion or policy of the Federal Government.

FOREWORD

Contract Number DOT-CG-82504-A between the U. S. Coast Guard and The Travelers Research Center, Inc. (TRC) consists of five parallel activities. The five final reports stemming from these activities are entitled:

(1) Applicability of National Data Buoy Systems to Refined National Requirements for Marine Meteorological and Oceanographic Data

(2) Characteristics of National Data Buoy Systems: Their Impact on Data Use and Measurement of Natural Phenomena

(3) Cost Effectiveness Sensitivity of National Data Buoy Systems: An Essay

(4) Computer Programs for National Data Buoy Systems Simulation and Cost Models

(5) An Analysis of Cruise Strategies and Costs for Deployment of National Data Buoy Systems

Each of these five reports is complete in itself, but it must be recognized that in all instances the other four activities both influenced and contributed to the results presented in each individual report.

The present USCG/TRC contract is an outgrowth of a study of the feasibility of National Data Buoy Systems performed by TRC and Alpine Geophysical Associates for the USCG during 1967. Need was evident for investigation, research, and analysis in greater depth in several areas to support the concept formulation and deployment planning efforts of the newly-formed U. S. Coast Guard National Data Buoy System Designated Project Office (NDBS DPO). This report and the other four cited above satisfy some of those needs.

All five TRC reports have benefited from the close cooperation and guidance afforded by the USCG NDBS DPO. Contributions have been made by Capt. J. Hodgman (Project Manager), Cmdrs. V. Rinehart, J. Wesler, E. Parker, and P. Morrill, and Lt. Cmdr. W. Merlin (Contract Monitor).

SUMMARY

A National Data Buoy System (NDBS) is being planned by the U.S. Coast Guard to be a part of a future national marine data acquisition system. NDBS planning and development must be cognizant of the fact that the national marine data acquisition system doubtless will include a mix of observation platforms to meet the many user data requirements. The characteristics of non-buoy systems included in a future marine data acquisition system will probably be to provide a planned overlap in data acquisition capabilities. NDBS design should maximize the non-redundant NDBS data acquisition capability with regard to the total capability required for the national marine data acquisition system. The cost effectiveness analysis described in this report was carried out to assess the potential role of the NDBS in the marine data acquisition system of the future and to determine the sensitivity of the NDBS design to complementary and competitive characteristics of other platform types in the national marine data acquisition system.

For this study a cost effectiveness model was designed to evaluate alternative mixes of buoy and non-buoy platforms against certain categories of stated data requirements provided by U.S. Government Agencies. The data requirements were categorized by type (research or operational), by geographical regions (Deep Ocean areas, Coastal North American regions, and Great Lakes and U.S. estuarine regions), and by vertical layers in the ocean and atmosphere. The analysis was performed using Deep Ocean operational and Coastal North America operational data requirements as the basis for evaluation of alternative system mixes of platform types. Parameters required by the users surveyed in the 1968 refinement of data requirements (carried out in parallel with this study under the TRC contract with the U.S. Coast Guard) were selected by the USCG NDBS Designated Project Officer (DPO) for inclusion in the cost-effectiveness evaluation.

Factors included in the effectiveness model include system capability, reliability, survivability, and areal coverage as a function of number of observation platform units employed. Capability is determined as the fraction of the user requirements that can be met at a given location using a given platform type. Reliability is defined as the probability of performance of an intended function for a specified time under specified environmental conditions. Survivability is defined as the probability that a platform

type will continue to exist in maintainable or repairable form for a specified time period under specified environmental conditions. In this study all platform types were assumed to have a survivability of 1.0. Areal coverage relates the number of platform units employed to the ability to acquire data over the entire geographical area of interest with the temporal intensity (cycling time) and spatial intensity (number of observation locations) required. Effectiveness is given by the product of these four terms.

Cost information was gathered for initial investment required and yearly operating costs including replacements and support activities for each of the platform types considered.

The eight platforms considered for the future national marine data acquisition system were:

- Aircraft of opportunity
- Buoys
- Horizontal sounding balloons
- Manned buoys
- Oceanographic vessels
- Reconnaissance aircraft
- Satellites
- Ships of opportunity

A limited number of data collection system configurations comprising alternative mixes of platforms were evaluated using the Deep Ocean and Coastal North America operational requirements. These regional requirements were stratified into six layers in the vertical to permit evaluation of the mixes in each of the layers, as well as an overall evaluation.

The evaluation showed that a system comprised solely of unmanned buoys was the most cost-effective system for meeting either set of requirements, as indicated in Figs. 3-1 and 3-11. However, the unmanned buoy system was relatively ineffective in meeting the data requirements for the atmosphere above the ocean surface interface layer because buoys were assumed to have no upper air sounding capability.* Systems of buoys mixed alternatively with satellites, horizontal sounding balloons, ships of opportunity and manned buoys were evaluated to examine the cost effectiveness of these pairings of systems; under these conditions, the performance in meeting both

*Development of an automated buoy-launched upper air sounding capability may be technologically feasible within five years. However, to take a conservative position with respect to buoys in this study, it was assumed that buoys would have no such capability.

atmospheric and oceanographic data requirements was found to be high. Several alternative assumptions that influence the effectiveness of the non-buoy systems (e.g., changing the areal coverage term) were considered in order to determine the boundaries of resultant cost and effectiveness system mixes. Some of the conclusions reached from the analysis were:

(1) A system comprised solely of unmanned buoys is potentially capable of providing a high percentage of the stated marine atmospheric and oceanographic data requirements of several major government agencies in both the Deep Ocean and Coastal North America regions.

(2) The cost of providing the marine data is relatively low for a system of unmanned buoys when compared with any system comprising other platform types. Buoys are the most cost-effective platform types when all parameters and all layers are jointly considered using the assumptions outlined in this report.

(3) An unmanned buoy system is ineffective in providing data for the atmosphere above the atmosphere-ocean interface layer, unless upper air sounding capabilities are provided. These were not considered in this report.

(4) Several other platform types can be used with unmanned buoys as complementary systems to provide observational data for the atmosphere with essentially no redundancy occurring between the buoy system and the non-buoy system employed.

(5) Any non-buoy platform that provides a capability for measuring atmospheric parameters above the ocean-atmosphere interface, when combined with buoys, will improve the overall system effectiveness, but those non-buoy platforms investigated appear to be relatively expensive and will, therefore, cause an increase in the combined system cost effectiveness ratio.

(6) The design of a buoy system as a part of a national marine data acquisition system is sensitive only to a relatively minor degree to the existence of other platform types.

The summary recommendation made as a result of this study is that planning for a National Data Buoy System should be carried forward considering the NDBS to be a major component of any future national marine data acquisition system.

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1.0 INTRODUCTION

1.1 Background

A National Data Buoy System (NDBS) is being planned and developed by the U.S. Coast Guard to be a part of a total national marine data acquisition system comprising several types of observing platforms. The role of the NDBS in the national marine data acquisition system needs to be defined so that the NDBS is designed to most effectively supplement the other observing systems to satisfy as many of the data requirements as possible for a minimum of cost.

The feasibility study carried out by TRC in 1967 included a cost effectiveness evaluation of buoy and non-buoy systems to meet marine data requirements. [1, 2, 3, 4, 5, 6]. The 1967 analysis was primarily aimed at a comparative evaluation of alternative buoy types. The marine data requirements considered were only those that could be met within the 5-year state-of-the-art for data buoy systems. The buoy versus non-buoy evaluation was a cursory comparison based upon the same data requirements. The 1967 evaluation study was carried out in the manner requested by the U.S. Coast Guard and was considered adequate for establishing the technical and economic feasibility of the NDBS. It is not adequate for the planning and design work leading to implementation of the NDBS.

The Ocean Engineering Panel of the National Council for Marine Resources and Engineering Development was briefed at the conclusion of the 1967 feasibility study and suggested that the Coast Guard should consider all types of marine data requirements and determine the sensitivity of the NDBS design to the existence of other types of observing systems that might comprise a national marine data acquisition system of the future. It was recognized that there will be several types of platforms used and that some of these will have capabilities that overlap those of unmanned buoys. It was recognized that the NDBS should not be designed to provide redundant observations where another type of system could provide these data more economically or in a more effective manner at equivalent cost. The suggestion by the Ocean Engineering Panel and Coast Guard recognition of the need for a firm cost effectiveness foundation for undertaking initial steps in NDBS design led to the inclusion in the present TRC study of a task aimed at the determination of the sensitivity of the NDBS to the presence of alternative platforms in the marine data acquisition system.

The potential impact of this sensitivity study on the NDBS development planning is obvious, because an unmanned buoy system cannot measure all of the parameters required by the many users of marine data. Other types of observing systems will have to be employed in any future conceivable marine data acquisition system. The parameters that are best measured by unmanned buoys, and the number of unmanned buoys in the total system, are greatly influenced by the mix of platform types in the total system and their capabilities to meet the user requirements.

1.2 Definition of the Problem

The discussion above points out that a total marine data acquisition system needs to be defined to meet user requirements. As a component of this system, the role of the NDBS within a mix of marine data acquisition systems must be determined. In order to determine the role of the NDBS an analysis method must be developed to evaluate the capability and cost effectiveness of buoy systems and systems employing alternative data acquisition platforms to provide a basis for decisions in developing the NDBS.

1.3 Objective of the Study

The objective of this study is to:

(1) Design a cost effectiveness model to evaluate buoy and non-buoy systems.

(2) To conduct cost effectiveness analysis of marine data acquisition systems, including representative mixes of platform types, and to analyze the results, in terms of system effectiveness, of alternative allocations of funds to buoy and non-buoy systems.

(3) The ultimate objective is to provide information useful in planning the development and implementation of unmanned buoy marine data acquisition systems.

1.4 Assumptions

The assumptions made in carrying out the sensitivity analysis are as follows:

(1) Cost effectiveness analysis is the best method for evaluating alternative marine data acquisition systems.

(2) The cost effectiveness analysis should be based upon a projection of the five-year state-of-the-art capability of all platforms, rather than present capabilities.

(3) The user requirements as stated by the government agencies interviewed and as assessed by TRC with government participation provide the metric for evaluation of alternative configurations of marine data acquisition systems.

(4) The factors included in the effectiveness model described in Section 3 are of primary importance for evaluation purposes.

1.5 Limitations of the Study

The sections that follow contain a description of the analysis method developed and some results obtained. It was recognized by the U. S. Coast Guard National Data Buoy Systems Designated Project Office (NDBC DPO) that the scope of effort allocated to this analysis would preclude an exhaustive evaluation of all options available in designing a total marine data acquisition system. Therefore, an analysis method was developed that is flexible and can be applied to determine the impact of changing and evolving rationales and assumptions concerning user requirements, platform capabilities, relative worth of data, system costs, and other considerations. Emphasis has been placed upon development of a framework for evaluation. The results presented are not intended to be interpreted as the total and final evaluation, but rather as a sample of the type of results that can be obtained using the methodology employed.* The results indicate the relative performance of a number of system configurations, but only a very limited number of options has been considered. Some conclusions have been drawn from this analysis. One conclusion is that the analysis method can be used to carry out additional tradeoff studies as more information is obtained concerning the relative worth of individual parameters observed at various geographical locations, at various levels in the vertical and with varying temporal and spatial intensities. Other conclusions are given in Section 5.0.

*The basic structure of almost any cost effectiveness analysis incorporates some arbitrary simplifying assumptions. It is hoped that these assumptions are clearly delineated in this report. As this study progressed, the NDBS DPO expanded the scope of the work and TRC prepared a more comprehensive cost-effectiveness structure which was completed near the end of the contract. It is anticipated that the new cost effectiveness structure would be used in future studies.

2.0 SENSITIVITY ANALYSIS

A number of platform types exist that can be employed to gather marine environmental data. It is reasonable to assume that the national marine data acquisition system of the near future will include many of these platform types as components of the system. This assumption appears valid because no one platform has the capability to satisfy all of the data needs of the many users of marine environmental information. The TRC 1967 National Data Buoy Systems Feasibility Study indicates that an unmanned buoy system is technically and economically feasible to serve as a part of the marine data acquisition system and to provide a portion of the environmental data required by many user groups. The design and implementation planning of National Data Buoy Systems must consider alternative configurations of a future national marine data acquistion system to determine the role that the NDBS should play in meeting the user requirements. The number of platform types that are logical candidates for inclusion in a national marine data acquisition system will have capabilities that overlap but will not be identical. This poses a question as to what part of the NDBS capability should be redundant with systems comprising other platform types; also, how should this redundancy affect the buoy system design? The analysis conducted to answer this question must include an evaluation of the potential of alternative platforms and mixes of platforms to satisfy the entire range of user requirements for marine environmental data. The approach used and the results obtained are discussed in the following sections.

2.1 Analysis Approach

The approach to the analysis involved seven key steps as described below.

(1) Determine user requirements by geographical regions and vertical layers.

(2) Define a list of potential platform types for inclusion in the marine data acquisition system.

(3) Develop a cost-effectiveness model for evaluating alternative data acquisition systems.

(4) Select alternative representative (logical) mixes of platforms to form systems to meet the user requirements.

(5) Perform cost effectiveness analysis on the alternative systems.

(6) Determine the buoy system sensitivity to reallocation of funds.

(7) Determine the impact on the cost effectiveness analysis results when certain evaluation criteria are varied.

The user requirements should be organized into coherent sets that can provide the yardstick for performance measurements of the alternative system configurations. The organization of the data requirements is most logically accomplished by determining geographical regions where the requirements are reasonably homogeneous and treating these separately. This study considers requirements in the northern hemisphere; in particular, those in the Deep Ocean (DO) and those in the Coastal North American (CNA) region, > 400 n mi out from the coast.

Division of the atmosphere and ocean into layers is desirable partly because of the variation of requirements in the vertical and in part because of the capabilities of the potential platforms to provide better observations in certain vertical layers than in others. The 1967 user requirements have been refined as part of the present USCG TRC contract, and the purpose of the analysis has been extended beyond the limited scope of the 1967 feasibility study. These factors have led to a reorganization of the data requirements for this study.

A list of potential platform types should be defined so that alternative marine data acquisition systems can be configured and evaluated. The list should include platform types presently employed in marine environmental data acquisition as well as those platforms expected to be available within the next five years. Selections of alternative mixes of platforms must be made to comprise alternative representative configurations of a marine data acquisition system. The total possible combinations of numbers and types of platforms is prohibitively large. With this in mind the selection has been restricted to a few mixes that are considered to be logical representations of future systems.

The need to develop a cost effectiveness model for evaluation of alternative data acquisition systems is apparent. A systematic evaluation using such a model should provide answers to such questions as how many of the stated requirements can be met by each of the several alternative systems at a given cost level or, conversely, how the effectiveness (or performance) changes as costs increase or decrease by varying the system composition. The cost effectiveness model used in the 1967 feasibility study is inadequate for this evaluation.

In this study the 1967 cost-effectiveness model was extended to provide a basis for comparing the NDBS with other potential marine data collection platforms -- platforms that are complementary to or in competition with the NDBS. In addition to comparison on a platform-by-platform basis, the cost effectiveness of hypothetical mixes of platforms has also been computed. In certain instances the capabilities and/or number of platforms of one type in the mix have been varied to determine the sensitivity of the NDBS to such changes. In other cases, available implementation and operating funds have been considered constant and cost effectiveness computed for different numbers of buoys and other platform types that could comprise the platform mix within the fixed cost constraint.

The cost effectiveness results, in themselves, do not tell the complete story. One must look at the basic capabilities of the platforms within each geographical region and each layer in the vertical to see where redundancy occurs. The redundancy among platform types is a factor that must be resolved in the final system design. Of course, a certain degree of redundancy may be desirable, particularly in the earlier stages of development of the national marine data acquisition system.

2.2 User Requirement Classification

The first step in the analysis study was to re-examine the requirements of the many users of marine environmental data and to establish coherent sets of requirements to use to measure the performance of future potential marine data acquisition system configurations. The final classification of the user requirements resulted through two parallel TRC study efforts and interaction with personnel of the NDBS DPO. Personnel involved in the TRC effort to refine and update the user requirements provided complete analyses of user requirements for operational data with sufficient lead time for application in this sensitivity analysis. Sufficient refined research requirements were not returned to TRC for assessment in time for inclusion in the sensitivity study. [7]

The user requirements for marine data for operational applications on a continuing basis fell into three basic categories. The first was for synoptic observations over the world's oceans with a comparatively large horizontal spacing between observation points, on the order of 500 n mi between points. These were classified as the Deep Ocean (DO) operational requirements, since they represented a coherent class of requirements generally useful to government agencies such as ESSA, U.S. Navy, USAF, USCG, and BCF.

The second category of requirements was for synoptic observations along the coast of North America extending from about 10 n mi to 400 n mi outward from the coasts and having an average horizontal spacing between observation points of about 100 n mi. These were classified as the Coastal North America (CNA) operational requirements and are a coherent set of requirements generally useful to the above government agencies plus FWPCA.

The third category of requirements was for synoptic observations in the Great Lakes and U.S. estuaries on a relatively fine horizontal spacing scale. The refinement of these requirements is still not completed and this requirement category was not used in the evaluation of alternative system configurations.

A seven layer vertical stratification of the user requirements was adopted at the recommendation of the NDBS DPO for evaluation of the alternative system configurations. The seven layers are listed in Table 2-1.

TABLE 2-1
VERTICAL LAYERS

Layer	Bottom	Top
1. Upper air	> 50,000 ft.	100,000 ft.
2. Upper air	> 45 ft.	30,000 ft.
3. Surface atmosphere	sea level	45 ft.
4. Surface ocean	10 meters	sea level
5. Subsurface ocean	500 meters	> 10 meters
6. Subsurface ocean	5000 meters	> 500 meters
7. Ocean bottom	At or near ocean bottom regardless of depth.	

There are Deep Ocean and Coastal North America user requirements that apply generally over the entire area of requirements and are required by several agencies. These requirements are listed in Tables 2-2 and 2-3 by individual layer.

TABLE 2-2
DEEP OCEAN OPERATIONAL PARAMETER REQUIREMENTS

Layer 1 (30,000 ft $<$ L $\leq$ 100,000 ft)

Air Temperature
Atmospheric Pressure
Wind Direction
Wind Speed
Dew Point
Cosmic Radiation
Ozone
Cloud Tops
Cloud Bases
Cloud Amount

Layer 2 (45 ft $<$ L $\leq$ 30,000 ft)

Atmospheric Electricity
Air Temperature
Atmospheric Pressure
Wind Speed
Wind Direction
Dew Point
Ice Crystal Size
Cloud Tops
Cloud Bases
Cloud Amount

Layer 3 (0 ft $\leq$ L $\leq$ 45 ft)

Insolation
Precipitation Rate
Visibility
Air Temperature
Atmospheric Pressure
Dew Point
Atmospheric Electricity
Wind Speed
Wind Direction
Ice Crystal Size

Layer 4 (0m $\leq$ L $\leq$ 10m)

Water Temperature
Wave Direction
Wave Height
Wave Period
Salinity
Current Speed
Current Direction
Water Pressure
Ambient Light
Transparency
Ambient Noise
Sound Speed
Tidal Fluctuation
Chemical Factors
Biological Factors

Layer 5 (10m $<$ L $\leq$ 500m)

Water Temperature
Salinity
Current Speed
Current Direction
Water Pressure
Ambient Light
Transparency
Ambient Noise
Sound Speed
Chemical Factors
Biological Factors

Layer 6 (500m $<$ L $\leq$ 5000m)

Water Temperature
Salinity
Current Speed
Current Direction
Water Pressure
Transparency
Ambient Noise
Sound Speed
Chemical Factors
Biological Factors

TABLE 2-3

COASTAL NORTH AMERICA OPERATIONAL PARAMETER REQUIREMENTS

Layer 1 (30,000 ft < L < 100,000 ft)

Air Temperature
Atmospheric Pressure
Wind Direction
Wind Speed
Dew Point
Cloud Amount

Layer 2 (45 ft < L ≤ 30,000 ft)

Air Temperature
Atmospheric Pressure
Wind Direction
Wind Speed
Dew Point
Cloud Amount

Layer 3 (0 ft ≤ L ≤ 45 ft)

Insolation
Precipitation Rate
Visibility
Air Temperature
Atmospheric Pressure
Dew Point
Atmospheric Electricity
Wind Speed
Wind Direction

Layer 4 (0m ≤ L ≤ 10m)

Water Temperature
Wave Direction
Wave Height
Wave Period
Salinity
Current Speed
Current Direction
Water Pressure
Ambient Light
Sound Speed
Tidal Fluctuation
Chemical Factors
Biological Factors

Layer 5 (10m < L ≤ 500m)

Water Temperature
Salinity
Current Speed
Current Direction
Water Pressure
Ambient Light
Transparency
Ambient Noise
Sound Speed
Chemical Factors
Biological Factors

Layer 6 (500m < L ≤ 5000m)

Water Temperature
Salinity
Current Speed
Current Direction
Water Pressure
Transparency
Ambient Noise
Sound Speed
Chemical Factors
Biological Factors

There are no Layer 7 requirements stated by any agency for Deep Ocean or Coastal North America areas for operational use, so this layer is not included in the tables.

The parameters required in the ocean layers (4, 5, 6) in the Deep Ocean and Coastal North America areas are seen to be identical, while the atmospheric layers (1, 2, 3) show a slight reduction in number of parameters included in the requirements for Coastal North American areas.

There are requirements stated by the users specifying how the parameters should be measured to be of value to the user in operational application of the data. These measurement requirements have been called "parameter characteristics". The eleven parameter characteristics contained in the requirements matrix used to evaluate the capability of alternate platform types are listed below with brief explanations of their meaning.

(1) Vertical layer — the vertical extent of the layer through which measurements are required.

(2) Range — the minimum and maximum values of the parameter that must be measured.

(3) Accuracy — the required accuracy of the measurement of the parameter.

(4) Duration — the averaging period over which the measurement must be made.

(5) Vertical sampling intensity — the number of levels in the vertical where measurements of the parameter are required.

(6) Temporal sampling intensity — the required cycling frequency of the parameter observation in time.

(7) Absolute (x, y) location accuracy — the accuracy required in the horizontal positioning of the parameter observation.

(8) Vertical (z) location accuracy — the accuracy required in the vertical positioning of the parameter observation.

(9) Synchronization in (z) — the maximum time difference permissible between the observations at all levels in the vertical layer.

(10) Synchronization in (x, y) - the maximum time difference permissible between observations at different locations in the horizontal grid network.

(11) Transmission lag - the maximum time allowable between the observation time and the time of receipt of the data at the users' data processing center.

Table 2-4 shows the requirements matrix of parameters and parameter characteristics for the Deep Ocean Operational (DOO) and Coastal North America Operational (CNAO) requirements. The only differences in the matrices are the Deep Ocean and Coastal North America parameters required (shown by the checks in the column to the extreme right to designate those parameters required over the Deep Ocean areas only) and the temporal sampling intensity characteristic values (shown in Column 6 where the more frequent cycling is required for the Coastal North America areas). The user requirements shown in Table 2-4 were used as the basis for measuring the performance of buoy and non-buoy systems in the cost effectiveness analysis.

2.3 Platform Types Considered in the Cost-Effectiveness Analysis

The types of platforms considered to have potential as a part of a total marine data acquisition system are listed below:

(1) Aircraft of opportunity - these are the commercial aircraft flown for purposes other than environmental data acquisition.

(2) Buoys - unmanned, moored.

(3) Horizontal sounding balloons - free floating, instrumented balloons interrogated by satellites, such as the GHOST system.

(4) Manned buoys - moored, manned platforms such as the FLIP or Seastation type.

(5) Oceanographic vessels.

(6) Reconnaissance aircraft - instrumented aircraft specifically flown for environmental data acquisition.

(7) Satellites

TABLE 2-4
DEEP OCEAN AND COASTAL NORTH AMERICA OPERATIONAL PARAMETER/CHARACTERISTIC REQUIREMENTS

Layer	Parameters	Vertical Layer: Bottom	Vertical Layer: Top	Range: Min	Range: Max	Accuracy	Duration (Minutes)	Vertical Sampling Intervals (# of Levels)	Temporal Sampling Intervals (Hours)	Absolute X-Y Location (Nautical Miles)	Accuracy of Location in Vertical	Synchronization in Vertical (Minutes)	Synchronization in X-Y (Minutes)	Transmission Lag (Hours)	Deep Ocean Requirement Only
	Air Temp	300K	100K	80°C	25°C	[illegible]		9	6	30	5%	10K	30	3	
	Air Press			4 mb	400 mb	[illegible]		9							
	Wind Direction			0°	360°	10°		9							
	Wind Speed			0 KTS	300 KTS	5%		9							
	Dew Point			60°C	25°C	2°C		9							
	Cosmic Radiation	400K									5%				X
	Ozone	400K						12			5%				X
	Cloud Tops	300K		30K	100K	20%					20%	NA	10		X
	Cloud Bases			30K	100K	20%					20%	NA			X
	Cloud Amount			0%	100%	25%					25%	NA			
	Atmos Elec	45	30K	0 KV	10 KV	.01 KV		8	6	30	[illegible]	NA	40		X
	Air Temp			80°C	40°C	[illegible]		12					30		
	Air Press			275 mb	1050 mb	5 mb							30		
	Wind Direction			0°	360°	15°		12							
	Wind Speed			0 KTS	300 KTS	5%		12							
	Dew Point			60°C	40°C	2°C									
	Ice Crystal Size										5%				X
	Cloud Tops			45	30K	10%		4			10%	NA	10		X
	Cloud Base			45	30K	20%		4			20%	NA			X
	Cloud Amount			0%	100%	25%					25%	NA			
	Insolation	85°C	45	0 LY/min	3.0 LY/min	1%			3	30	NA	NA	10		
	Precip Rate			0 in/hr	12 in/hr	.01 in/hr							60		
	Visibility			0 mi	20 mi	10%							15		
	Air Temp			20°C	40°C	.1°C									
	Air Press			850 mb	1050 mb	.1 mb									
	Dew Point			35°C	40°C	.2°C									
	Atmos Elec			0 KV	10 KV	.01 KV									
	Wind Speed			0 KTS	160 KTS	.5 KTS									
	Wind Direction			0°	360°	1°									
	Ice Crystal Size														X
	Water Temp	10 m	32°C	0°C	40°C	.01°C		2	3	10	5%				
	Wave Direction	40°C	40°C	0°	360°	5°					NA	NA			
	Wave Height			0 ft	100 ft	.1 ft					NA	NA			
	Wave Period			1 sec	45 sec	.1 sec					NA	NA			
	Salinity	10 m		10.0 ‰	40.0 ‰	.01 ‰									
	Current Speed			.01 KTS	15 KTS	.01 KTS									
	Current Direction			0°	360°	1°									
	Water Pressure			0 psi	16 psi	.1%									
	Ambient Light		10 m	0 LY/min	3 LY/min	1%					NA	NA			
	Transparency		10 m	1%/m	100%/m	1%					NA	NA			
	Ambient Noise		10 m	10 db	90 db	1 db									
	Sound Speed			4600 fps	5600 fps	.1 fps									
	Tidal Fluctuation	10 ft		0 ft	10 ft	.1 ft									
	Chemical Factors	10 m		N/A	N/A	N/A	30								
	Biological Factors			N/A	N/A	N/A	30								
	Water Temp	300 m	10 m	0°C	40°C	.01°C									
	Salinity			10.0 ‰	40.0 ‰	.01 ‰									
	Current Speed			.01 KTS	15 KTS	.01 KTS									
	Current Direction			0°	360°	1°									
	Water Pressure			14 psi	110 psi	.1%									
	Ambient Light			0 LY/min	3 LY/min	1%					NA	NA			
	Transparency			1%/m	100%/m	1%					NA	NA			
	Ambient Noise			60 db	90 db	1 db									
	Sound Speed			4600 fps	5600 fps	.1 fps									
	Chemical Factors			N/A	N/A	N/A									
	Biological Factors			N/A	N/A	N/A									
	Water Temp	1000 m	300 m	0°C	30°C	.01°C									
	Salinity			33 ‰	40 ‰	.01 ‰									
	Current Speed			.01 KTS	1 KTS	.01 KTS									
	Current Direction			0°	360°	1°									
	Water Pressure			100 psi	1750 psi	.1%									
	Transparency			1%/m	10%/m	1%					NA	NA			
	Ambient Noise			60 db	90 db	1 db									
	Sound Speed			4600 fps	5600 fps	.1 fps									
	Chemical Factors			N/A	N/A	N/A									
	Biological Factors			N/A	N/A	N/A									

NA Not Applicable

* Instantaneous or Short Period Average

N/A Specified Only as State of the art [illegible]

(8) Ships of opportunity - commercial or military ships capable of carrying instrument shelters and environmental data observer personnel.

(9) Submersibles

(10) Fixed Towers

In considering platforms for general purpose application over the world's oceans, platform types (9) and (10) were considered to be so limited in application as to be treated as special cases and not included in the cost effectiveness evaluation.

2.4 The Cost Effectiveness Model

The cost effectiveness model was developed as a flexible framework for analysis in consideration of the lack of high confidence data for many of the cost and performance factors. The model is intended to be a planning tool wherein many options can be specified as to input and results compared. For the purposes of this essay only a limited number of the input options were exercised to show representative results.

The performance factor used in the model is based upon an estimate of the five-year state-of-the-art of design for each of the platform types included in alternative system mixes. The system reliabilities used in the model are based upon expert judgement projecting the small amount of existing knowledge concerning the reliability of systems and components that may be potentially applicable for a future national marine data acquisition system.

2.4.1 Effectiveness

The generalized form of the effectiveness model is

$$E = \frac{\sum_{n=1}^{L} P_n E_n}{\sum_{n=1}^{L} P_n} \times A \qquad (2-1)$$

where

- E = system effectiveness
- b_n = weighting factor for Layer n
- L = number of layers in the vertical
- A = fraction of the geographical area of interest over which the system acquires data
- E_n = system effectiveness for Layer n

Layer n system effectiveness (E_n) is given by

$$E_n = \sum_{m=1}^{P} \frac{C_{nm}}{C_{n\,max}} R_m S_m \qquad (2\text{-}2)$$

where

- C_{nm} = capability score of platform type m for Layer n that is independent of the other platform types in the mix
- $C_{n\,max}$ = maximum layer capability score attainable
- R_m = platform average reliability
- S_m = platform average survivability
- P = number of platform types in the system mix.

2.4.1.1 Capability

The starting point in the computation of system effectiveness is the determination of the capability score for a given platform type. The composite user requirements matrix shown in Table 2-4 was used as the basis for determining the capability score. An estimate was made of the five-year state-of-the-art capability of each platform type to measure each parameter and parameter characteristic as specified in the matrix. A capability scoring matrix was established that corresponds to Table 2-4 and weights each parameter characteristic as unity in all applicable characteristics but vertical sampling. This matrix is shown in Table 2-5. In the vertical sampling intensity column a score of one is given for each level in the vertical layer where

TABLE 2-5

DEEP OCEAN AND COASTAL NORTH AMERICA CAPABILITY SCORING MATRIX

Layer	Parameters	Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Interval	Temporal Sampling Interval	Absolute X Y Location Accuracy	Accuracy of Location in Vertical	Synchronization in Vertical	Synchronization in Horizontal	Transmission Lag	Deep Ocean Parameters Only	Deep Ocean Total Score	Coastal North America Total Score
	Air Temp	1	1	1	1	9	1	1	1	1	1	1		19	19
	Air Press	1	1	1	1	9	1	1	1	1	1	1		19	19
	Wind Direction	1	1	1	1	[illegible]	1	1	1	1	1	1		19	19
	Wind Speed	1	1	1	1	9	1	1	1	1	1	1		19	19
1	Dew Point	1	1	1	1	9	1	1	1	1	1	1		19	[illegible]
	Cosmic Radiation	1	1	1	1	13	1	1	1	1	1	1	X	23	
	Ozone	1	1	1	1	13	1	1	1	1	1	1	X	23	
	Cloud Tops	1	1	1	1	1	1	1	1			1	\	[illegible]	
	Cloud Bases	1	1	1	1	1		1	1				\		
	Cloud Amount	1	1	1	1	1	1	1	1		1	1		[illegible]	[illegible]
	Atmos Elec	1	1	1	1			1	1		1	1	\	[illegible]	
	Air Temp	1	1	1	1		1	1	1	1				[illegible]	[illegible]
	Air Press	1	1	1	1	1	1		1			1		[illegible]	[illegible]
	Wind Direction	1	1	1		[illegible]	1	1		1				32	[illegible]
2	Wind Speed	1	1	1	1	[illegible]	1	1	1	1	1			[illegible]	32
	Dew Point	1	1		1	[illegible]	1	1	1						[illegible]
	Ice Crystal Size	1	1	1	1	[illegible]		1	1				\	[illegible]	
	Cloud Tops	1	1	1	1	4		1					\	13	
	Cloud Base	1	1	1	1	4	1	1					\	13	
	Cloud Amount	1	1	1	1	1	1	1	1			1			[illegible]
	Insolation	1	1	1	1	1	1	1			1	1		9	9
	Precip Rate	1	1	1	1	1	1	1			1			9	9
	Visibility	1	1	1	1	1	1	1						[illegible]	[illegible]
	Air Temp	1		1		1		1						9	[illegible]
	Air Press	1	1			1								9	9
3	Dew Point	1	1	1		1		1						9	[illegible]
	Atmos Elec	1	1	1	1	1								9	[illegible]
	Wind Speed													9	9
	Wind Direction													9	[illegible]
	Ice Crystal Size	1											X		
	Water Temp													[illegible]	[illegible]
	Wave Direction													[illegible]	[illegible]
	Wave Height													9	[illegible]
	Wave Period														[illegible]
	Salinity													[illegible]	[illegible]
	Current Speed													[illegible]	[illegible]
	Current Direction														[illegible]
4	Water Pressure													[illegible]	[illegible]
	Ambient Light													[illegible]	[illegible]
	Transparency													[illegible]	[illegible]
	Ambient Noise													[illegible]	[illegible]
	Sound Speed														[illegible]
	[illegible]														[illegible]
	Chemical Factors													[illegible]	[illegible]
	Biological Factors													[illegible]	[illegible]
	Water Temp														[illegible]
	Salinity													[illegible]	
	Current Speed													[illegible]	[illegible]
	Current Direction													[illegible]	
	Water Pressure														[illegible]
	Ambient Light													[illegible]	
	Transparency														[illegible]
	Ambient Noise													[illegible]	
	Sound Speed														
	Chemical Factors													[illegible]	
	Biological Factors													[illegible]	
	Water Temp														
	Salinity													[illegible]	
	Current Speed														
	Current Direction														
	Water Pressure													[illegible]	
	Transparency														
	Ambient Noise													[illegible]	
	Sound Speed														[illegible]
	Chemical Factors														[illegible]
	Biological Factors														[illegible]

an observation is required. The number of levels in the vertical will be explained parameter-by-parameter later in this section.

The capability score for any platform is obtained by applying the scores given in Table 2-5 to every parameter characteristic that the platform is capable of measuring. The total capability score is given as the fraction of the capability scoring matrix total that a platform can attain.

The capability scoring matrix totals are shown in Table 2-6.

TABLE 2-6
CAPABILITY SCORING MATRIX TOTALS

Layer	Deep Ocean	Coastal North America
1	171	105
2	191	134
3	90	81
4	162	162
5	198	198
6	171	171
Total	983	851

For the purposes of this study, with the exception of vertical sampling intensity, the parameters and parameter characteristics were equally weighted and scored on either one or zero, depending on whether the required parameter characteristic was completely met or not. It is a simple matter to compute a more sophisticated capability score using any given relative weighting of parameters and parameter characteristics. The columns and rows of the matrix can be multiplied by the selected weightings and the fractional score for any platform type determined.*

Column 5 in the capability scoring matrix in Table 2-5 contains the number of levels in the vertical at which observations are required. The basis for these requirements is listed below:

*It is recognized that more sophisticated scoring algorithms can be postulated. Provision for this has been incorporated in a more comprehensive cost effectiveness structure developed by TRC during the course of this study. Is it anticipated that this new cost effectiveness approach would be used in future studies.

- Air temperature, atmospheric pressure and dew point - required at 14 standard levels plus 5 significant levels and at the surface. This results in 9 levels in Layer 1, 10 levels in Layer 2 and 1 in Layer 3.

- Wind direction and wind speed - required every 1,000 feet to 10,000 feet, every 2,000 feet from 12,000 to 20,000 feet, at 23,000 feet, every 5,000 feet from 25,000 to 40,000 feet and every 10,000 feet from 50,000 to 100,000 feet. An additional 5 significant levels is required bringing the total to 32 levels for winds. These divide into 9 levels in Layer 1, 22 levels in Layer 2 and 1 level in Layer 3.

- Cosmic radiation and ozone - required every 5,000 feet from 40,000 to 100,000 feet for a total of 13 levels in Layer 1.

- Cloud bases and tops - required for up to 5 layers that are divided into 1 in Layer 1 and 4 in Layer 2.

- Cloud amount - required as one observation through the atmosphere, Layers 1 and 2.

- Atmospheric electricity and ice crystal size - required at 5,000 foot intervals from surface to 30,000 feet for a total of 6 levels in Layer 2 and 1 at the surface (Layer 3).

- Insolation, precipitation rate and visibility - required at the surface only (Layer 3).

- Water temperature, salinity, current speed, current direction, water pressure, ambient noise, chemical factors, biological factors - required at 20 IAPSO levels* from the surface to 5,000 meters. This results in 2 levels in Layer 4, 10 levels in Layer 5 and 8 levels in Layer 6.

- Wave direction, wave height, wave period, tidal fluctuations - required at the surface only (Layer 4).

- Ambient light - required at 2 levels: 1 in Layer 4 and 1 in Layer 5.

- Transparency - required at 3 levels: 1 each in Layers 4, 5 and 6.

*The IAPSO levels used are 0, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1500, 2000, 3000, 4000, and 5000 meters.

Appendix A contains the capability matrices developed for each platform type and an explanation on a parameter-by-parameter basis of the method of measurement estimated for each platform type.

2.4.1.2 Reliability

The reliability values used in Equation (2-2) are estimates of the average for each platform type for a one-year operating period. Reliability is defined here as in the feasibility study as the probability of performance of an intended function for a specified time period under specified environmental conditions. The reliability estimates used in the computations carried out in the evaluation analysis are shown in Table 2-7 for each platform type.

TABLE 2-7
PLATFORM RELIABILITIES

Platform	Reliability
1. Aircraft of opportunity	0.95
2. Buoy (with 12 month service interval)	0.80
3. Horizontal sounding balloon system	0.70
4. Manned buoy	0.95
5. Oceanographic vessel	0.95
6. Reconnaissance aircraft	0.95
7. Satellite	0.75
8. Ship of opportunity	0.95

The one-year average reliability values contained in Table 2-7 are the composite of values obtained from Alpine Geophysical Associates, Inc., TRC consultants, and several government agency and industry representatives interviewed during the 1967 TRC feasibility study. These values have been reviewed by the NDBS DPO staff and approved for the purposes of this study. The effectiveness model can be employed to determine the impact of variations in reliability but this has not been done in the current study.

2.4.1.3 Survivability

Survivability is defined as the probability that a platform type will continue to exist in maintainable or repairable form for a specified time period under specified environmental conditions. In the 1967 TRC feasibility study the survivability of a number of unmanned buoy systems was analyzed. The buoy specifications were matched with climatological data on the parameters to which the buoys were sensitive. Results of this study indicated that the large unmanned buoy (such as a 40-foot discus) had a one year probability of survival in excess of 0.99.* The survivability of platforms such as aircraft of opportunity, manned buoys, oceanographic vessels, reconnaissance aircraft and ships of opportunity would be expected to be 1.0 because of the conservative design and continuous maintenance on these platforms. Projecting the present capabilities of satellite systems and allowing for replacement on the basis of expected lifetime permits the use of a projected survivability of 1.0 for a satellite system. Finally, the horizontal sounding balloon system projected here is predicated upon the continual insertion of replacement balloons into the atmosphere as individual balloons fail. With these considerations in mind the value of survivability was assumed to be 1.0 for all platform types for the purposes of this study. The effectiveness model can be employed to determine the impact of survivability values of less than 1.0, if so desired.

2.4.1.4 Areal Coverage

The final term in Eq. (2-1) is the areal coverage term. In order to determine the effectiveness of a given platform type to meet user requirements one must not only be concerned with the basic observational capability of the platform, but must also consider the ability to acquire data over the entire geographical area of interest with the temporal intensity (cycling time) required.

To relate effectiveness to costs, the numerical value for A in Eq. (2-1) is related to the number of units of each platform type needed to satisfy system data collection requirements. The determination of A as a function of platform type can be one of the most difficult aspects of evaluating alternative configurations of a data acquisition system for certain platform types. The determination of A is simple for those platform types that can be fixed at a location. In that case, coverage is the number of platform units divided by the total number of locations for which observations are required.

*Assumes buoys are moored in regions between 60° north latitude and 60° south latitude.

Therefore, A is easily determined for unmanned buoys, manned buoys, and oceanographic vessels. The moving platforms, making up the remainder of the list, each require a separate rationale concerning the mode of operation. Satellites and reconnaissance aircraft and horizontal sounding balloon systems are specifically employed for environmental data acquisition and can be designed to maximize coverage for a given number of units. Aircraft of opportunity and ships of opportunity are operated for purposes other than data acquisition and the rationales for relating areal coverage to number of units is most difficult for these platforms. The value of A used in this study for each of the platform types is shown in Table 2-8 for the Deep Ocean operational requirements (Northern Hemisphere) and the Coastal North America requirements. An average grid spacing of approximately 500 n mi was used for the Deep Ocean requirements and approximately 100 n mi for the Coastal North America requirements. For the Northern Hemisphere, this results in 150 observation sites for the DO and 350 for the CNA requirements, providing the typical coverage shown in Fig. 2-1. The values listed were obtained using the following rationales:

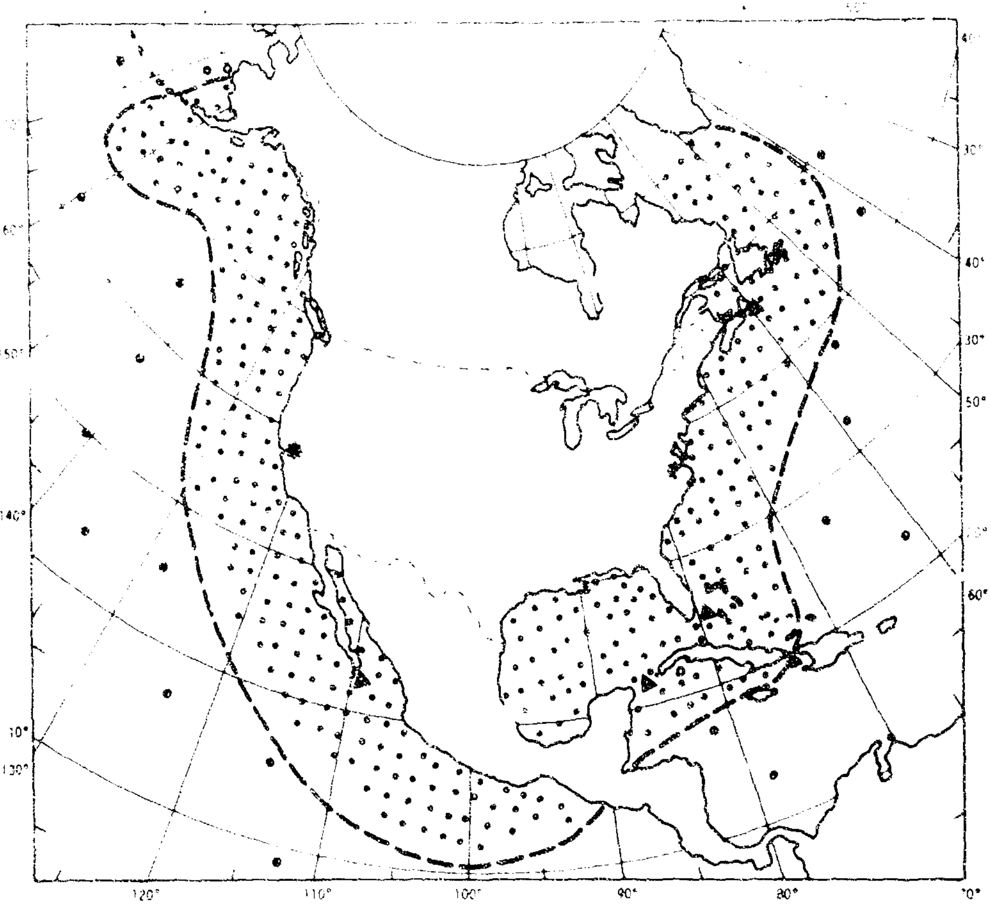
(1) Aircraft of opportunity - Deep Ocean areal coverage

- Assume 80% of all transoceanic commercial aircraft are airborne on any given day
- Assume 6 hours flight time across the Atlantic Ocean and 12 hours across the Pacific Ocean
- Assume that during each flight an aircraft will be at or near one Atlantic Ocean observation point or two Pacific Ocean observation points at an observation time
- Assume 75% of the observations from these aircraft are redundant in time and space due to flight schedules and concentration on air routes.

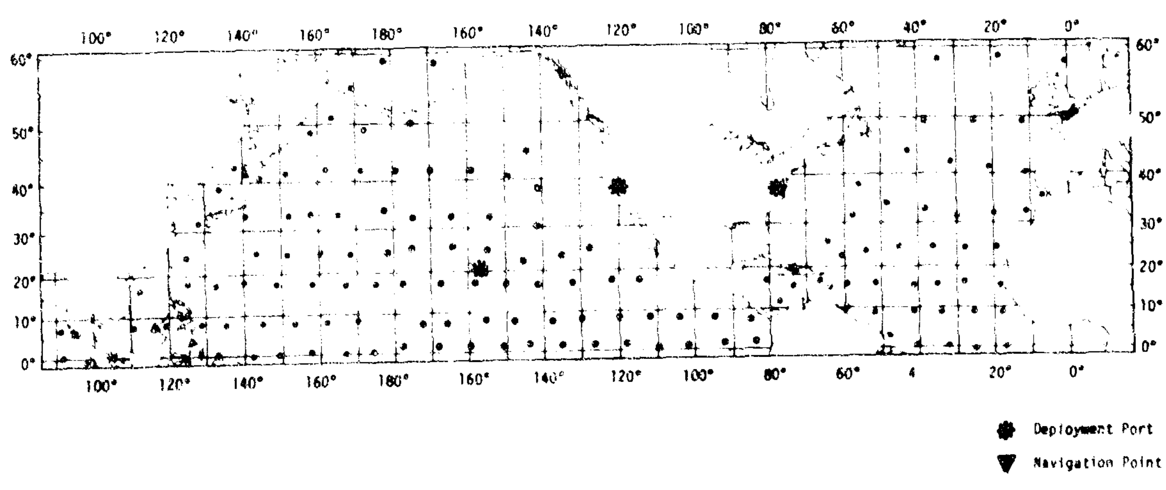
The assumptions for the CNA area coverage are:

- Assume that each flight will be at or near one of the 350 observation sites during an observation time.
- Assume 20% of the observations from these aircraft are redundant.

The lower redundancy for CNA, relative to DO, is based upon the higher density of observation sites resulting in more independent observations from aircraft being applicable.



a. Coastal North America Data Buoy Network (350)



b. Northern Hemisphere Deep Ocean Data Buoy Network (150)

Fig. 2-1. Data Buoy Networks

TABLE 2-8
AREAL COVERAGE RELATED TO PLATFORM UNITS

Platform Type	Percentage area covered per platform unit	
	Deep Ocean	Coastal North America
Aircraft of opportunity	0.05%	0.04%
Buoys	0.67%	0.29%
Horizontal sounding balloons	100%[1]	4.0%
Manned buoys	0.67%	0.29%
Oceanographic vessels	0.67%[2]	0.29%
Reconnaissance aircraft	0.20%	0.10%
Satellites	100%[3]	100%
Ships of opportunity	0.22%	0.03%

Notes:

[1]A unit is defined as 2500 balloons airborne in the Northern Hemisphere at 6 levels at any given time.

[2]A unit is defined as 3/2 of an oceanographic vessel, since 3 vessels are required to maintain two at observation sites at all times.

[3]A unit is defined as 4 Nimbus-type operational satellites airborne at any given time. These 4 satellites provide 100% coverage in both Deep Ocean and Coastal North America simultaneously.

(2) Buoys - each buoy occupies one of the 150 deep ocean observation sites for a DO areal coverage of 0.67% or one of the 350 CNA sites for a areal coverage of 0.29%.

(3) Horizontal sounding balloons - 2500 balloons evenly spaced over the Northern Hemisphere at six levels in the vertical will give 6.25/6 balloons per 500 n mi square block or 100% coverage for the Deep Ocean sites at the six levels only. This same balloon density, considering the 100 n mi square blocks of the CNA, will provide only a 4% coverage of the CNA sites.

(4) Manned buoys - same as buoys above.

(5) Oceanographic vessels - same as buoys and manned buoys except that three vessels are required to maintain two on site. A unit is defined as 3/2 of an oceanographic vessel.

(6) Reconnaissance aircraft - based upon the present weather reconnaissance tracks and operations, a fleet of 10 aircraft will provide 2% areal coverage of the Deep Ocean sites or 0.2% per unit aircraft. Similarly, for the CNA the unit aircraft coverage is 0.1%.

(7) Satellites - assuming a polar orbiting Nimbus-type operational satellite is required for the capability score assigned, it would require four satellites in orbit to provide 100% areal coverage of both the Deep Ocean and Coastal North America observation sites.

(8) Ships of opportunity - Deep Ocean areal coverage

- Assume an instrumented and manned fleet of 100 ships operating in the Northern Hemisphere
- Assume 2/3 of the ships at sea at any given time
- Assume 50% of the reports from these ships are redundant in space (two ships in the same 500 n mi square block at the same observation time due to the concentration within shipping lanes).

$$A = \frac{100}{150} \times \frac{2}{3} \times \frac{1}{2} = 0.22 \text{ or } 22\% \text{ per 100 ships}$$
$$0.22\% \text{ per ship}$$

For Coastal North America;

- Assume the same 100 instrumented ships
- Assume the ships are at sea two days out of three
- Assume a ship can produce 7 useful CNA observations in either the Atlantic or Pacific ocean on a crossing (7 observations at three hour intervals within 400 n mi of the coast)
- Assume a redundancy of 25% of the observations because of the concentration in shipping lanes
- Assume the ships are distributed such that of the 66 ships at sea, 44 are in the Pacific and 22 in the Atlantic
- Assume 6 days to cross the Atlantic and 9 days to cross the Pacific

A ship will provide 7 observations in 6 days in the Atlantic or 1.2 observations per day while a ship will provide 7 observations in 9 days in the Pacific or 0.8 observations per day. Thus for a given day the areal coverage is:

$$A = \frac{1.2 \times 22 + 0.84 \times 44}{8 \times 350} \times 0.75 = 2\% \text{ per 100 ships}$$
$$\text{or } 0.02\% \text{ per ship}$$

If one considers the average ship path to be at 45° to the coast the areal coverage increases to 0.03% per ship.

The areal term A in Equation (2-1) has been assigned values in this study based upon the above assumptions. The model allows for variation in A according to any alternative set of assumptions.

2.4.2 Costs

Initial investment and yearly operating costs were projected for each platform type. The operating costs include ground support facilities for each platform type with varying percentages of the ground support shared with other operational systems where applicable. The cost data used in this study were obtained from the U.S. Coast Guard, the TRC feasibility study and several references. [3, 4, 5, 6] Costs were developed on the unit basis for each platform type to facilitate the evaluation of alternative configurations of a total marine data acquisition system. These unit costs were projected on the basis of a ten-year operation. Replacement costs of equipment are incorporated into the operational costs. The affects of discounting or inflationary dollar value change were not included in this stage of the study and are not considered to be factors that would significantly change the results. The unit costs for each of the platform types are shown in Table 2-9. The details of the platform costs are contained in Appendix B.

2.4.3 Limitations of the Cost Effectiveness Analysis

The cost effectiveness model has been employed in this study to evaluate alternative configurations of a marine data acquisition system against particular user requirements. There are factors that are not taken into account in carrying

TABLE 2-9
UNIT COSTS OF PLATFORMS

Platform Type	Unit Cost ($ millions per 10 years)
Aircraft of opportunity	$ 0.008
Buoys	1.3
Horizontal sounding balloon	140.0[1]
Manned buoy	10.0
Oceanographic vessel	31.5[2]
Reconnaissance aircraft	42.0[3]
Satellite	166.0[4]
Ship of Opportunity	2.0

Notes:

[1] A unit is defined as 2500 balloons airborne at 6 levels over the northern hemisphere at any given time.

[2] Three vessels are required to maintain two observation sites so that the unit cost is 3/2 the cost of a vessel.

[3] Two reconnaissance aircraft are assumed required to maintain the daily operation on one track.

[4] A unit is defined as four satellites continuously in orbit. These 4 satellites provide 100% coverage in both Deep Ocean and Coastal North America simultaneously.

out this evaluation and these should be kept in mind when attempting to interpret the results. Some of these limitations of the analysis are listed below.

(1) Some of the platforms are capable of measuring parameters not included in the user requirements matrix for Deep Ocean and Coastal North America operational data and this capability is not reflected in the results.

(2) Some of the platforms are capable of providing data over land areas as well as ocean areas at no increase in costs. These are the satellite and horizontal sounding balloon systems.

(3) Satellites are also capable of providing southern hemisphere data in addition to northern hemispheres at essentially the same total cost.

(4) Several of the platforms are flexible in horizontal spacing and the temporal reporting of observations with little or no increase in cost involved; this added capability is not reflected in the results.

(5) The analysis has been conducted for requirements pertaining to gross areas of the Deep Ocean and Coastal North America regions. The results do not indicate cost effectiveness with respect to specific small geographical areas of the oceans.

The results presented in Section 3.0 are based upon the stated user requirements, equal parameter and parameter characteristic weighting, projected reliability, expected lifetime and survivability values and areal coverage based upon sets of assumptions on the operating mode of the platform types. These inputs to the cost effectiveness model can all be varied to determine the impact upon the cost effectiveness results. Only a few of these options have been exercised to determine sensitivity of selected cost effectiveness results, but the number of options that can be exercised is very large.

A detailed discussion of the method of computing effectiveness for a system comprising a mix of platform types is given in Appendix C. The method of accounting for redundancy among platforms and the consideration of joint reliabilities is also treated in Appendix C.

3.0 COST EFFECTIVENESS ANALYSIS RESULTS

3.1 Introduction

The cost effectiveness analysis was conducted with the eight basic observing platforms described in Section 2.3 for the Deep Ocean area and the Coastal North America area. Initially, the analysis comprised the computation of cost, effectiveness, and cost effectiveness ratio for each of several logical platform mixes according to the cost effectiveness model described in Section 2.4 and the basic rules defining the two data requirement areas. These computations provide a basis for assessing the relative merits of the various platforms under a fixed set of conditions. Next, some games were played with a few selected mixes of platforms in which some of the basic rules and conditions were varied through a large range of values. These games afford an understanding of the sensitivity of the results to some of the many factors inherent in the analysis model. They also provide a means of defining a bounded region in which the actual answer most probably will be found, depending, of course, upon the validity of the assumptions and other factors which were not varied.

3.2 Deep Ocean Area

The Deep Ocean area in the northern hemisphere includes the North Atlantic and North Pacific Oceans. The composite requirements for this area are for data every six hours on a grid mesh of approximately 500 n mi, from the ocean bottom up through most of the atmosphere. The specified grid requires data at 150 points for full horizontal coverage (see Fig. 2-1).

The individual platform capability scores for the Deep Ocean area (see Section 2.4.1.1 Capability) are given by parameter for each of the six layers in Table 3-1A and by layer in Table 3-1B. The layer effectiveness E_n of a platform is computed by summing the layer parameter capability scores, dividing by the total possible layer score, and multiplying by the platform reliability [see Eq. (2-2) in Section 2.4.1, considering only one platform type]. The weighted platform effectiveness averaged over the layers is given by

$$E = \frac{\sum_{n=1}^{6} b_n E_n}{\sum_{n=1}^{6} b_n} .$$

TABLE 3-1A
PLATFORM CAPABILITY SCORES BY PARAMETER FOR THE DEEP OCEAN AREA

Layer	Parameters	Buoys	Manned Buoys	Ocean Vessels	Satellites	Horizontal Sounding Balloons	Aircraft of Opportunity	Ships of Opportunity	Reconnaissance Aircraft	Maximum Possible Parameter Score
	Air Temperature	0	19	19	19	13	9	19	15	19
	Air Pressure	0	19	19	0	13	9	19	15	19
	Wind Direction	0	19	19	0	13	9	19	9	19
	Wind Speed	0	19	19	0	13	9	19	9	19
	Dew Point	0	19	19	19	13	9	19	15	19
1	Cosmic Radiation	0	0	0	0	0	0	0	10	23
	Ozone	0	23	23	23	13	0	23	10	23
	Cloud Tops	0	10	10	10	0	10	10	10	10
	Cloud Bases	0	10	10	0	0	10	10	10	10
	Cloud Amount	10	10	10	10	0	10	10	10	10
	Platform Layer Scores	10	148	148	81	78	75	148	113	171
	Atmos. Electricity	0	0	0	0	0	0	0	0	15
	Air Temperature	0	20	20	20	11	0	20	16	20
	Air Pressure	0	20	20	0	11	0	20	16	20
	Wind Direction	0	32	32	0	11	0	32	0	32
	Wind Speed	0	32	32	0	11	0	32	0	32
2	Dew Point	0	20	20	20	11	0	20	16	20
	Ice Cryctal Size	0	0	0	0	0	0	0	0	16
	Cloud Tops	0	13	13	13	0	13	13	13	13
	Cloud Base	0	13	13	0	0	13	13	13	13
	Cloud Amount	10	10	10	10	0	10	10	10	10
	Platform Layer Scores	10	160	160	63	55	36	160	84	191
	Insolation	9	9	9	0	0	0	9	0	9
	Precipitation Rate	9	9	9	0	0	0	9	0	9
	Visibility	0	9	9	0	0	0	9	0	9
	Air Temperature	9	9	9	9	0	0	9	0	9
	Air Pressure	9	9	9	0	0	0	9	0	9
3	Dew Point	9	9	9	9	0	0	9	0	9
	Atmos. Electricity	9	9	9	0	0	0	9	0	9
	Wind Speed	9	9	9	0	0	0	9	0	9
	Wind Direction	9	9	9	0	0	0	9	0	9
	Ice Crystal Size	0	0	0	0	0	0	0	0	9
	Platform Layer Scores	72	81	81	18	0	0	81	0	90
	Water Temperature	12	11	11	8	0	0	11	10	12
	Wave Direction	9	9	9	0	0	0	8	0	9
	Wave Height	9	9	9	0	0	0	8	0	9
	Wave Period	9	9	9	0	0	0	8	0	9
	Salinity	12	11	11	0	0	0	11	0	12
	Current Speed	12	11	10	0	0	0	0	0	12
	Current Direction	12	11	10	0	0	0	0	0	12
	Water Pressure	12	11	11	0	0	0	11	0	12
4	Ambient Light	9	9	9	0	0	0	9	0	9
	Transparency	9	9	9	0	0	0	8	0	9
	Ambient Noise	12	11	11	0	0	0	0	0	12
	Sound Speed	12	11	11	0	0	0	11	0	12
	Tidal Fluctuation	0	0	0	0	0	0	0	0	9
	Chemical Factors	0	11	11	0	0	0	11	0	12
	Biological Factors	0	11	11	0	0	0	11	0	12
	Platform Layer Scores	129	144	142	8	0	0	107	10	162
	Water Temperature	20	19	19	0	0	0	13	15	20
	Salinity	20	19	19	0	0	0	13	0	20
	Current Speed	20	18	18	0	0	0	0	0	20
	Current Direction	20	18	18	0	0	0	0	0	20
	Water Pressure	20	19	19	0	0	0	13	0	20
	Ambient Light	9	9	9	0	0	0	8	0	9
5	Transparency	9	9	9	0	0	0	7	0	9
	Ambient Noise	20	19	19	0	0	0	0	0	20
	Sound Speed	20	19	19	0	0	0	13	0	20
	Chemical Factors	0	19	19	0	0	0	13	0	20
	Biological Factors	0	19	19	0	0	0	13	0	20
	Platform Layer Scores	158	189	187	0	0	0	93	15	196
	Water Temperature	18	17	17	0	0	0	0	0	18
	Salinity	18	17	17	0	0	0	0	0	18
	Current Speed	18	17	16	0	0	0	0	0	18
	Current Direction	18	17	16	0	0	0	0	0	18
6	Water Pressure	18	17	17	0	0	0	0	0	18
	Transparency	9	9	9	0	0	0	0	0	9
	Ambient Noise	18	17	17	0	0	0	0	0	18
	Sound Speed	18	17	17	0	0	0	0	0	18
	Chemical Factors	0	17	17	0	0	0	0	0	18
	Biological Factors	0	17	17	0	0	0	0	0	18
	Platform Layer Scores	135	162	160	0	0	0	0	0	171

TABLE 3-1B
PLATFORM CAPABILITY SCORES BY LAYER FOR DEEP OCEAN OPERATIONAL REQUIREMENTS

Platform	Layer Capability					
	1	2	3	4	5	6
Acft of Oppor	0.44	0.19	0	0	0	0
Buoy	0.06	0.05	0.80	0.80	0.80	0.79
Hor Sound Bal	0.46	0.29	0	0	0	0
Manned Buoy	0.87	0.84	0.90	0.89	0.95	0.95
Ocean Vessel	0.87	0.84	0.90	0.88	0.94	0.94
Recon Acft	0.66	0.44	0	0.06	0.08	0
Satellites	0.47	0.33	0.20	0.05	0	0
Ship of Oppor	0.87	0.84	0.90	0.66	0.47	0

The layer weights b_n used in this section are $b_1 = b_6 = 0.6$, $b_2 = b_3 = b_4 = b_5 = 1$.* Parameters are all assumed to be of equal importance in all layers. Layer effectiveness and weighted average effectiveness, computed from Table 3-1A for each of the platforms, are given in Table 3-2. The scores in Table 3-2 represent the basic effectiveness of the one platform type.

The computation of the layer effectiveness of a mix of platforms within an area A involves the summation of independent capability scores, as indicated by Eq. (2-2). The independent capabilities are determined in the following manner. In Table 3-1A identify the platforms in the mix; within a layer select the platform with the highest reliability. Compute the layer effectiveness of this platform in the normal manner. Next, subtract these capability scores parameter by parameter from the capability scores of the platform with the next highest reliability. Compute the independent layer effectiveness of the second platform using the capability differences, ignoring any negative values. Add this effectiveness to the first platform effectiveness. If there is a third

*These layer weights were provided by the NDBS DPO for this study. Other layer weights are discussed in Section 4.

TABLE 3-2
DEEP OCEAN AREA LAYER EFFECTIVENESS AND WEIGHTED AVERAGE EFFECTIVENESS FOR EIGHT PLATFORMS

Platform	Deep Ocean Operational Basic Effectiveness						Weighted Avg. Effectiveness
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	
Buoy	0.05	0.04	0.64	0.6[illegible]	0.64	0.63	0.45
Manned Buoy	0.82	0.80	0.86	0.84	0.91	0.90	0.85
Ocean Vessel	0.82	0.80	0.86	0.83	0.90	0.89	0.85
Satellites	0.36	0.25	0.15	0.04	0	0	0.12
Hor Sound Bal	0.32	0.20	0	0	0	0	0.08
Acft of Oppor	0.42	0.18	0	0	0	0	0.08
Ship of Oppor	0.82	0.80	0.86	0.63	0.45	0	0.62
Recon Acft	0.63	0.42	0	0.06	0.07	0	0.18

platform in the mix, add the capabilities of the first platform and the difference capabilities of the second platform, parameter by parameter, and subtract the sum from the parameter capabilities of the third platform. The independent layer effectiveness of the third platform is computed from the resulting difference capabilities. This effectiveness is added to the sum of the first two platforms. The process is repeated for all platforms in the mix. The resulting layer effectiveness, F_n in Eq. (2-2), can never exceed the value of the highest reliability in the mix. Equation (2-1) is then used to get the system effectiveness over the area A, using the layer weights given above.*

In many combinations of platforms, the platforms do not all cover the same geographical area. They tend to overlap in some areas and not in others. This results in the formation of several sub-mixes, each with different combinations of platforms, and each with its own areal coverage. An effectiveness must be computed separately for each sub-mix in the manner described above. The sub-mix effectiveness values

*Computation of platform mix effectiveness is discussed in greater detail in Appendix C.

then are simply added to obtain the total areal-integrated effectiveness of the combination of platforms. The mix effectiveness values given in this section are the total areal-integrated values.

3.2.1 General Comparison of Typical Mixes

The results of an analysis of several typical mixes in the Deep Ocean area are shown in Table 3-3 in order of increasing cost. The cost effectiveness ratios of these mixes are given in Table 3-3 and graphically compared in Fig. 3-1.

From Fig. 3-1, the system with the lowest cost effectiveness ratio (low cost effectiveness ratio is desirable) is 150 buoys. The system with the greatest effectiveness is 150 manned buoys. Mix 4 -- 20 ocean vessels*, 100 ships of opportunity, and 10 reconnaissance aircraft (an observing system mix assumed to be somewhat better than the "present" one) -- has a low effectiveness and the worst cost effectiveness ratio. Adding 4 satellites to the "present" system (Mix 4) shows considerable improvement (Mix 5). But the addition of 137 buoys to Mix 5 doubles effectiveness and reduces the Mix 5 cost effectiveness ratio by 40% (Mix 6). Exchanging 10 buoys for 10 manned buoys (Mix 7) increases effectiveness, but also increases cost effectiveness ratio. The addition of buoys to all mixes results in an increase in effectiveness and an improvement in the cost effectiveness ratio. The improvement is especially significant when buoys are combined with horizontal sounding balloons, or satellites, or 100 ships of opportunity, i.e., Mixes 1, 2, and 3.

Table 3-3 gives further information about the mixes shown in Fig. 3-1. It includes areal coverage of the mix, cost, and effectiveness in an atmospheric layer (Layer 2) and an ocean layer (Layer 5). Of the systems listed, four are available for $200 million or less per ten years. They are the horizontal sounding balloons, satellites, buoys, and ships of opportunity. The buoys have little effectiveness in meeting atmospheric requirements; balloons and satellites are effective only in the atmosphere; while the ships of opportunity are capable of doing well in both the atmosphere and ocean (see Table 3-2), but are penalized by a low value for areal coverage.

Two-platform mixes of buoys with satellites, buoys with balloons, and buoys with ships of opportunity may be obtained for under $[illegible]00 million per ten years. The platforms in these mixes are complementary for the most part as indicated by the

*Thirteen ocean vessels are assumed to be on station.

TABLE 3-3
ANALYSIS OF VARIOUS PLATFORM MIXES IN THE DEEP OCEAN AREA

Platform Mix	Areal Coverage	Cost ($\$10^6$)	Effec-tive-ness	C/E ($\$10^9$)	Effect. in Layer 2 (Atmos)	Effect. in Layer 3 (Ocean)
2500 HSB	100%	140	0.0755	1.854	0.20	0.00
4 SAT	100%	166	0.124	1.334	0.25	0.00
150 B	100%	195	0.454	0.429	0.04	0.64
100 SOO	22%	200	0.1361	1.470	0.18	0.10
150 B, 2500 HSB	100%	335	0.530	0.632	0.24	0.64
150 B, 4 SAT	100%	361	0.5304	0.681	0.25	0.64
150 B, 100 SOO	100%	395	0.531	0.744	0.21	0.68
20 OV, 100 SOO, 10 RA	33%	820	0.216	3.797	0.26	0.18
20 OV, 100 SOO, 10 RA 4 SAT, 60 AOO	100%	986	0.302	3.270	0.43	0.18
137 B, 20 OV, 100 SOO 10 RA, 4 SAT, 60 AOO	100%	1164	0.622	1.872	0.78	0.79
127 B, 10 MB, 20 OV, 100 SOO, 10 RA, 4 SAT 60 AOO	100%	1251	0.645	1.941	0.78	0.79
150 MB	100%	1500	0.85	1.76	0.80	0.91

Definitions:

HSB = Horizontal Sounding Balloon

SAT Satellites

B = Buoy

SOO = Ship of Opportunity (2/3 are at sea)

OV = Oceanographic Vessel (2/3 of vessels are on station)

RA = Reconnaissance Aircraft (1/2 of aircraft are flying)

AOO = Aircraft of Opportunity (0.8 of aircraft are flying)

MB = Manned Buoy

DEFINITIONS	
Abbreviations	**Mixes**
HSB = Hor. Sound Bal	1 = 150 Buoys, 2500 HSB
AOO = Acft of Oppor	2 = 150 Buoys, 4 SAT
SAT = Satellites	3 = 150 Buoys, 100 SOO
RA = Recon Aircraft	4 = 20 OV, 100 SOO, 10 RA
B = Buoy	5 = 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO
SOO - Ship of Oppor	6 = 137 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO
OV = Ocean Vessel	7 = 127 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO, 10 MB
MB = Manned Buoy	

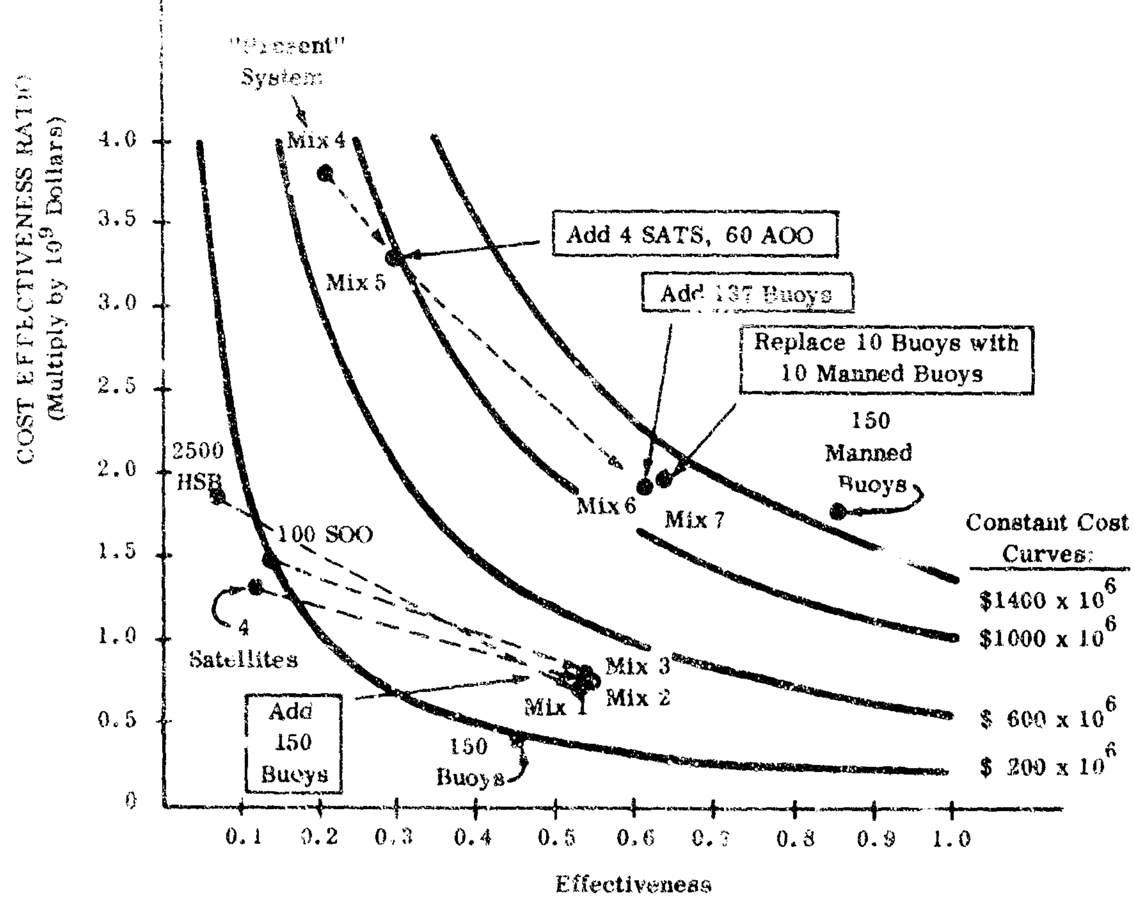


Fig. 3-1. Comparison of Cost Effectiveness Ratios for Platforms and Platform Mixes in the Deep Ocean Area

atmosphere and ocean effectiveness scores; however, the atmosphere effectiveness is still low compared with the ocean effectiveness.

To obtain a balanced, high effectiveness in both atmosphere and ocean it is necessary to spend over $1100 million per ten years. The highest balanced effectiveness is obtained with full coverage by manned buoys at a cost of $1500 million.

Thus it is seen that a respectable effectiveness in the ocean may be obtained rather inexpensively with buoys. Obtaining a similar effectiveness in the atmosphere, however, is quite expensive. It appears that, exclusive of an all-manned buoy system, any mix would, of necessity, contain a large unmanned buoy component. The remainder of the mix would depend upon how much money one is willing to spend for the atmospheric observations.

3.2.2 Comparison of Various Buoy-Manned Buoy Mixes

Assuming that buoys will be an essential part of a data gathering system, it remains to determine the best platform or platforms to be used with buoys to provide whatever degree of atmospheric effectiveness is desired. Toward this end, detailed analyses of buoy-manned buoy mixes and buoy-ships of opportunity mixes have been made. The former analyses are discussed in this section and the latter, in the next section.

The analysis of a large range of buoy-manned buoy mixes is given on a cost effectiveness ratio versus effectiveness diagram in Fig. 3-2. The basic assumption in these mixes is that buoys and manned buoys are never placed at the same location. Three curves are shown which indicate mixes that provide 1/3, 2/3 and 3/3 areal coverage, respectively. Each curve has a system of all buoys on one end and all manned buoys on the other end. Three other curves labelled I, II, III, indicate the buoy-manned buoy mixes available for $200 million, $600 million, and $1000 million, respectively.

The constant cost curves I, II, III show that the replacement of buoys with manned buoys results in a decrease of effectiveness and an increase in the cost effectiveness ratio. The constant areal coverage curves show that replacement of buoys with manned buoys results in an increase of both effectiveness and cost effectiveness ratio. The increase in effectiveness is of course accompanied by an increase in cost.

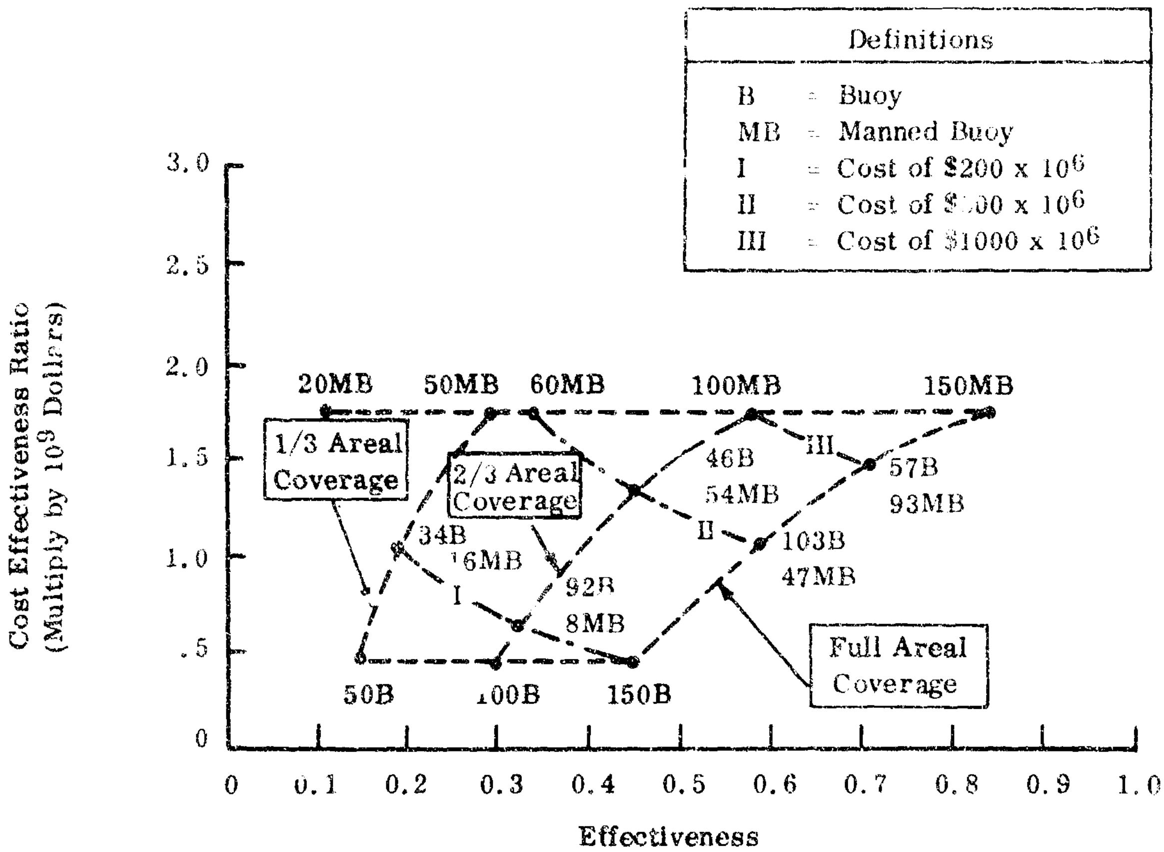


Fig. 3-2. Cost Effectiveness Ratio Comparisons of Various Buoy-Manned Buoy Mixes in the Deep Ocean Area

To show the effectiveness of the various buoy-manned buoy mixes in the atmosphere and ocean, the mixes of Fig. 3-2 have been presented on a Layer 5 versus Layer 2 effectiveness diagram in Fig. 3-3. This diagram shows that any mix with a large percentage of buoys results in poor atmospheric effectiveness. To obtain at least 0.5 effectiveness in both layers requires a mix on constant curve III representing a ten year cost of $\$1000 \times 10^6$. To obtain the proper mix of buoys and manned buoys one must specify the minimum acceptable atmospheric effectiveness desired. Basing the choice of a mix on cost effectiveness ratio alone would inevitably result in a very low atmospheric effectiveness.

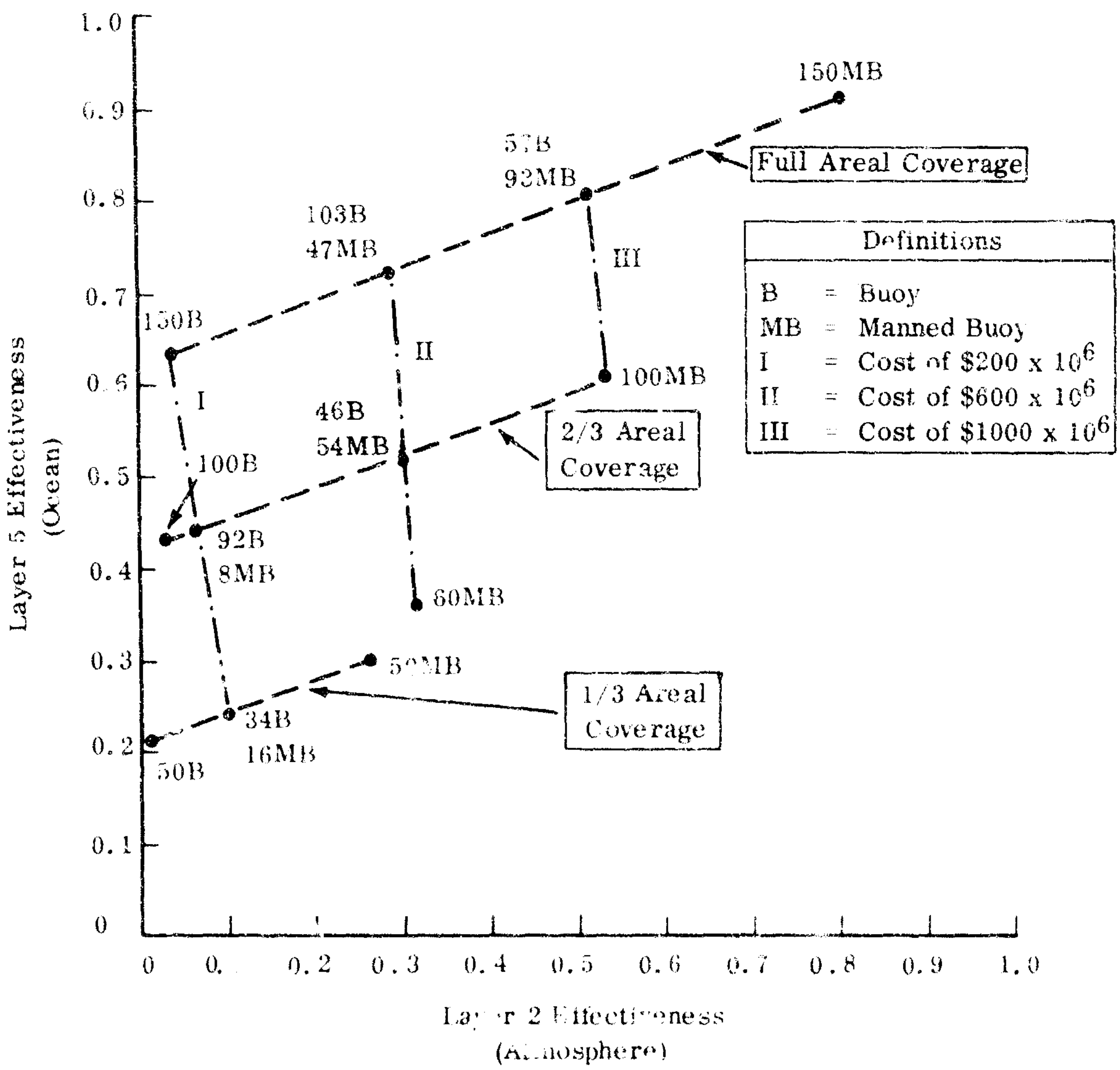


Fig. 3-3. Ocean Effectiveness (Layer 5) and Atmospheric Effectiveness (Layer 2) for Various Buoy-Manned Buoy Mixes in the Deep Ocean Area

3.2.3 Comparison of Various Buoy-Ship of Opportunity Mixes

Since buoys are fixed in location and ships of opportunity move around on their own schedules and in more or less fixed shipping lanes, we are obliged to allow some variability in the areal coverage capability of a given number of ships and the degree of overlap of areal coverage between buoys and ships. These factors are considered in the next few diagrams which show the analysis results of various buoy-ships of opportunity mixes.

Fig. 3-4 shows two curves relating number of ships to realizable areal coverage. The curve marked "normal" is our best estimate of what the relationship should be. The curve marked "high" is what we believe to be an optimistic estimate of the relationship. In the following diagrams, the curves marked I and III utilized the normal areal coverage curve while the curves marked II and IV utilized the high areal coverage curve.

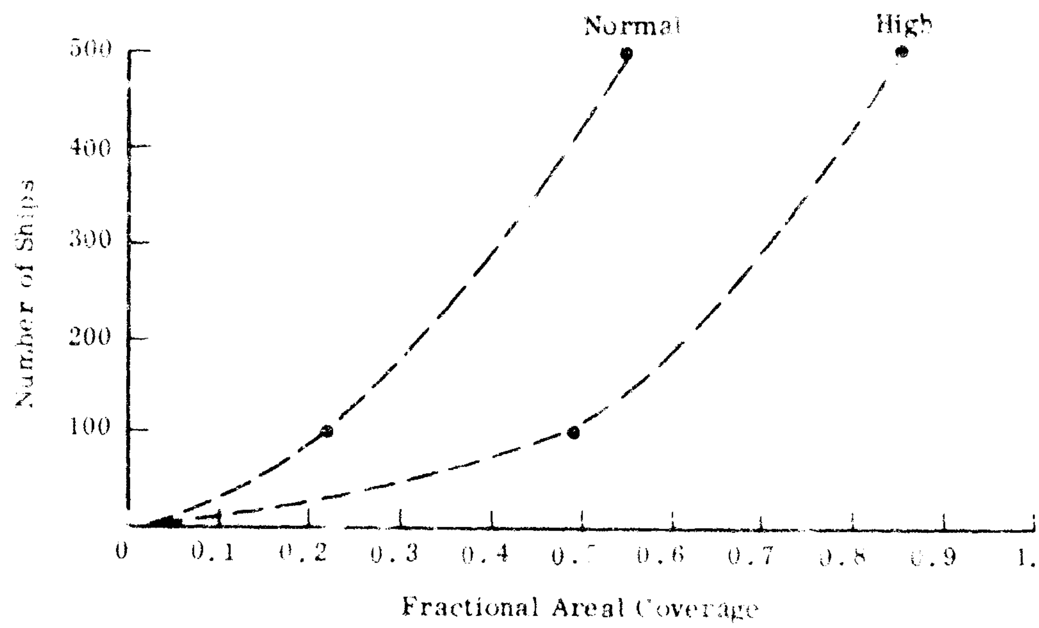


Fig. 3-4. Assumed Relationships Between Areal Coverage and Number of Ships of Opportunity in the Deep Ocean Area

Fig. 3-5, a cost effectiveness ratio versus effectiveness diagram, shows the analysis of a series of mixes, each with 150 buoys, giving 100% ocean areal coverage. To these 150 buoys are added 100, 200, and 500 ships of opportunity at Points 1, 2, and 3, respectively. Also given are the curves for ships of opportunity only and the point for 150 buoys only. The diagram shows buoys and ships of opportunity to be highly complementary. The addition of ships of opportunity is seen to increase the system effectiveness, however, at an increase in both cost and cost effectiveness ratio. The curves I and II may be considered to be reasonable bounds on the effectiveness attainable by these mixes.

To evaluate the effect of ships of opportunity in the ocean and atmosphere, the mixes shown in Fig. 3-5 are presented on a Layer 3 versus Layer 2 effectiveness diagram in Fig. 3-6. Here it is seen that most of the increased effectiveness due to ships of opportunity is in the atmosphere, as would be expected.

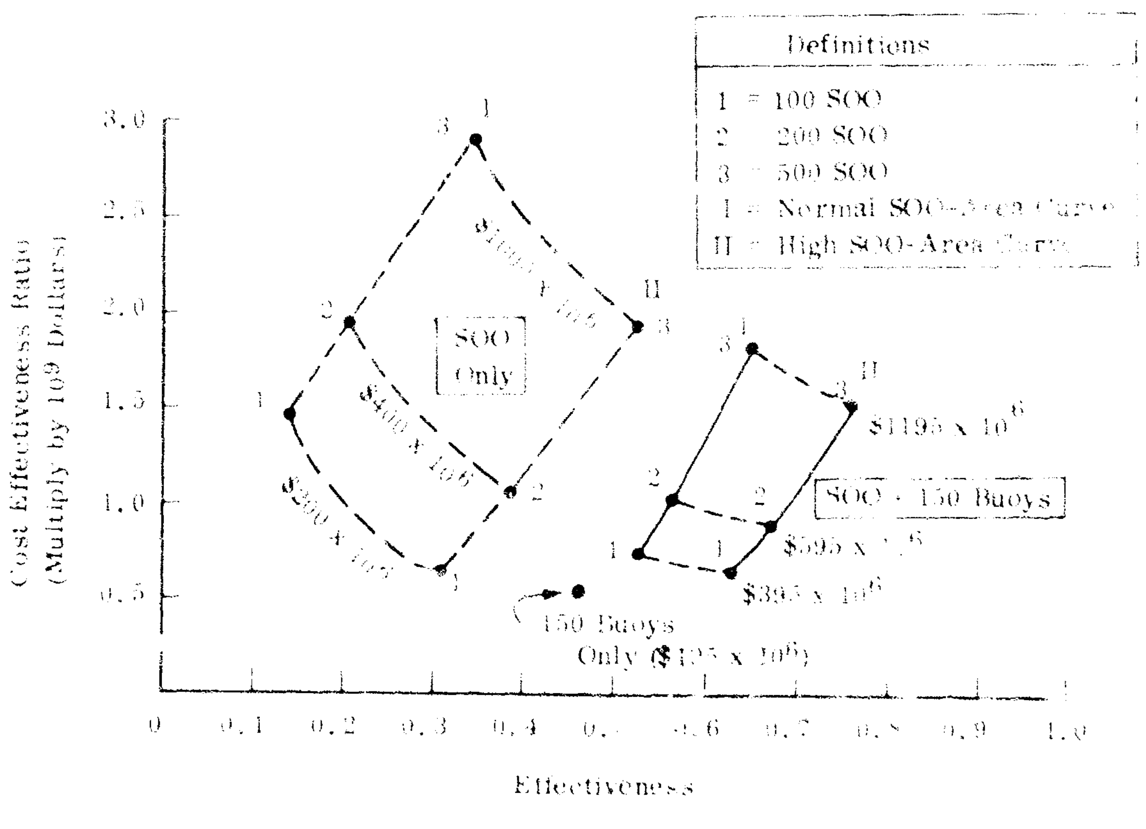


Fig. 3-5. Cost Effectiveness Ratio Comparisons for Various Mixes of SOO with 150 Buoys in the Deep Ocean Area

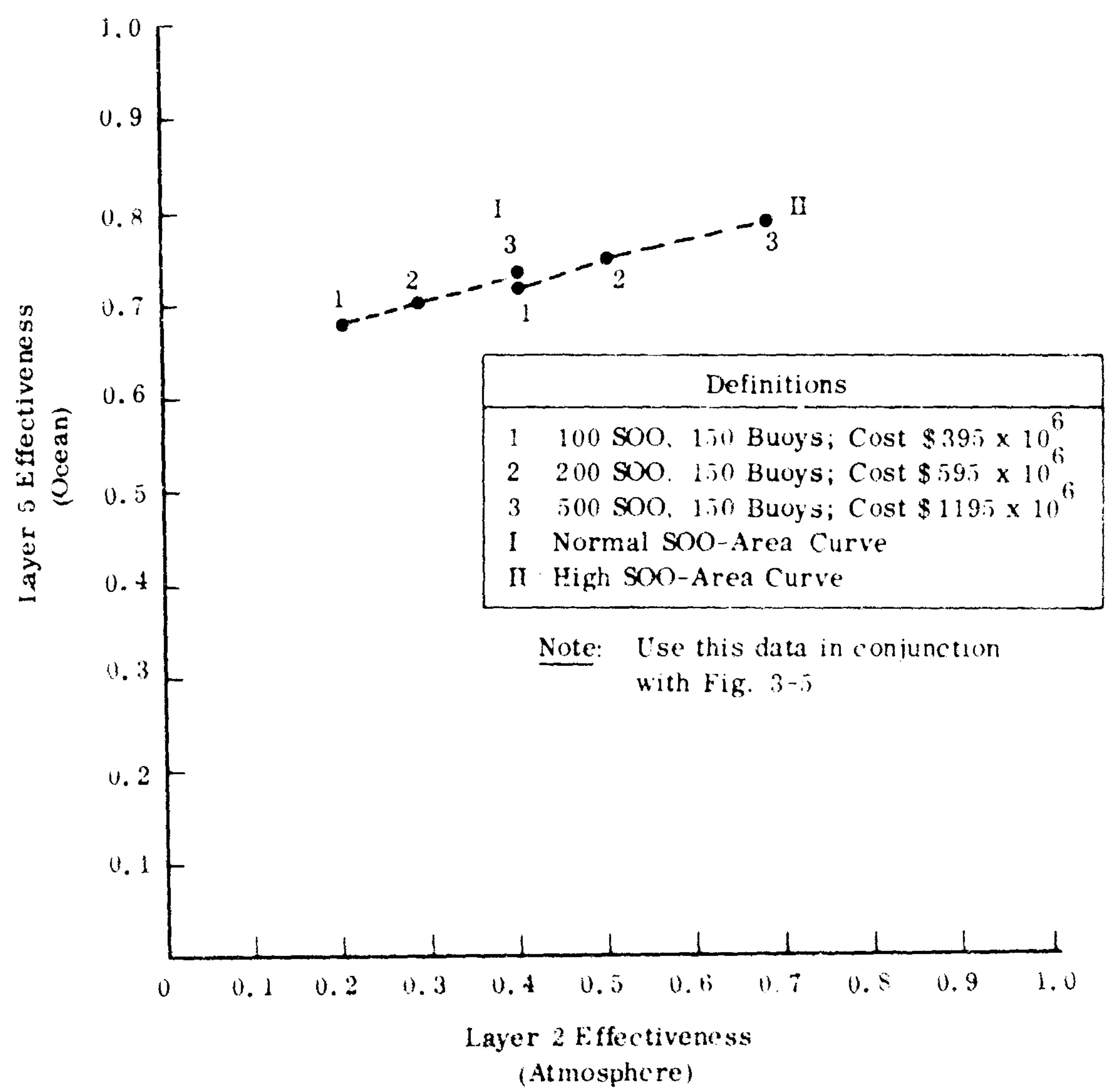


Fig. 3-6. Ocean Effectiveness (Layer 5) Versus Atmospheric Effectiveness (Layer 2) for the Buoy-Ship of Opportunity Mixes

The buoy-ships of opportunity mixes may be considered in a slightly different way. Suppose, to save money, we remove buoys in direct ratio to the areal coverage of the ships of opportunity. That is, if the areal coverage of ships of opportunity is 20% then remove buoys from 20% of the area. Furthermore, suppose that the ships always remain in the area vacated by the buoys, thus maintaining 100% areal coverage over the ocean. The mixes under these conditions for both the normal and high areal coverage curves for ships of opportunity are shown in Fig. 3-7. A comparison of the results with those of Fig. 3-5 shows the net result of saving money by removing buoys is a general reduction of effectiveness for all mixes.

The buoy-ships of opportunity mixes may be formed in a third way. Assume that the ships always overlap buoys and that the regions vacated by buoys are free of all platforms. This is the opposite extreme to the second method. The result of this method is an even greater loss of effectiveness.

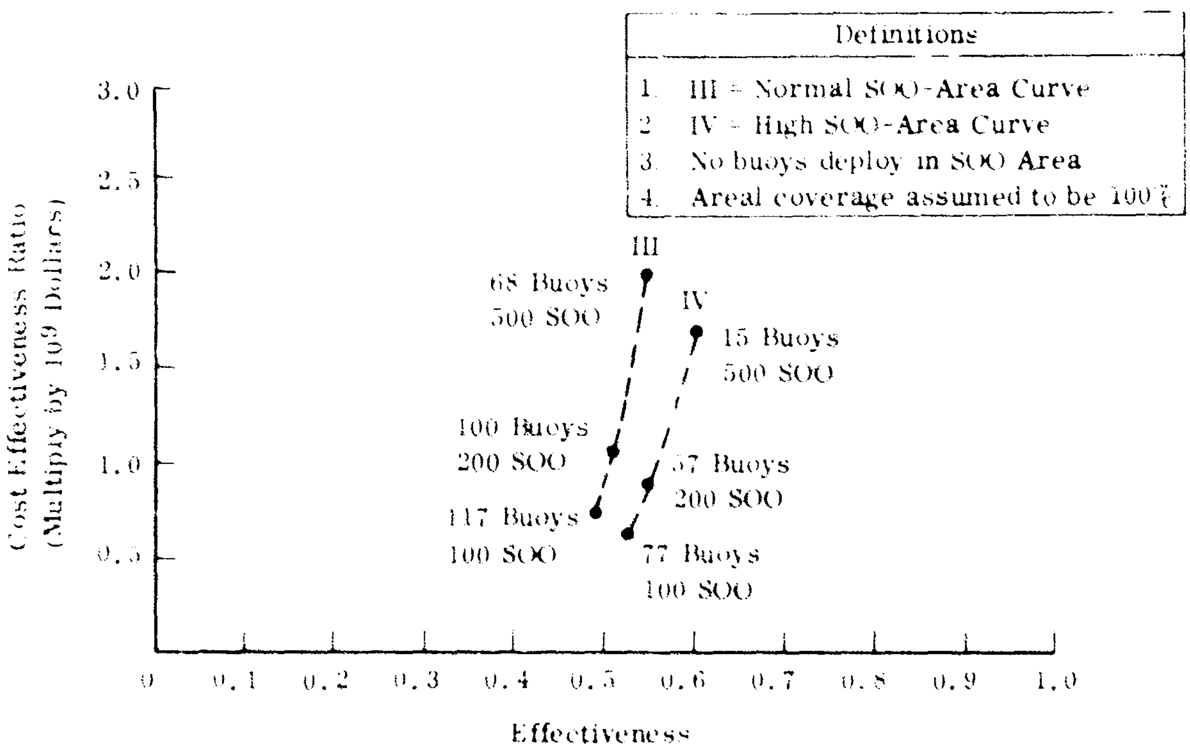


Fig. 3-7. Cost Effectiveness Ratio Comparisons for Various Buoy-SOO Mixes

Simple equations for the effectiveness of each of the three methods of combining buoys and ships of opportunity are easily derivable. In the first method we gave 100% areal coverage with buoys and S% coverage with ships. Let E_B be the platform effectiveness for buoys and E_{BS}, the effectiveness for a buoy-ship of opportunity mix. Thus the system effectiveness for the first method is

$$\bar{E}_1 = (1-S)\,E_B + SE_{BS} \text{ or}$$

$$\bar{E}_1 = E_B + S\,(E_{BS} - E_B)$$

For the second method, the system effectiveness is

$$\bar{E}_2 = (1-S)\,E_B + SE_S$$

where E_S is the platform effectiveness for ships of opportunity - This becomes

$$\bar{E}_2 = E_B + S\,(E_S - E_B)$$

For the third method,

$$\bar{E}_3 = (1-2S)\,E_B + SE_{BS} \text{ or}$$

$$\bar{E}_3 = E_B + S\,(E_{BS} - 2E_B).$$

If we substitute the values

$$E_B = 0.45, \quad E_S = 0.62, \quad \text{and } E_{BS} = 0.80$$

we get

$$\bar{E}_1 = 0.45 + 0.35\,S$$

$$\bar{E}_2 = 0.45 + 0.17\,S$$

$$\bar{E}_3 = 0.45 - 0.10\,S$$

The actual effectiveness of a mix in which buoys are removed as ships are added would lie somewhere between the extremes represented by $\bar{E}_2$ and $\bar{E}_3$.

Since the ships of opportunity provide observations in the Coastal North America area as well as in the Deep Ocean, we should consider the effect on the analysis of sharing the cost of operating the ships between the two requirement sets. Based on the amount of time the ships are in each area, we have recomputed the previous results charging the Deep Ocean requirements with 87% of the total ship operating costs. The results are shown in Fig. 3-8. This process does not change effectiveness but does lower the cost effectiveness ratio by a small amount.

3.2.4 Comparison of Manned Buoys with Ships of Opportunity When Mixed with Buoys to Give 100 Percent Ocean Areal Coverage

We may now ask whether manned buoys or ships of opportunity result in a more effective mix when combined with buoys to give 100% ocean coverage.

In Fig. 3-9 are shown the system effectiveness values of two sets of mixes. One set costs about $600 million per ten years and the other, about $1 billion per ten years. In each set there is a curve for ship of opportunity mixes available at the given cost (assuming different areal coverage capabilities as given by points I and L and manned buoy mixes also available at that cost. The data for this figure were extracted from Fig. 3-2 and Fig. 3-5. Fig. 3-9 shows that manned buoys and ships of opportunity are capable of producing about the same system effectiveness at both cost levels. If the ships of opportunity are restricted to the normal areal coverage (point I), the manned buoys have a slight advantage.

The atmosphere and ocean effectiveness values of the same two sets of mixes are shown in Fig. 3-10. The data for this figure were taken from Figs. 3-3 and 3-6. At $600 million, the ships of opportunity and manned buoys are equally effective when ships of opportunity are considered according to the normal areal coverage curve. At $1 billion the manned buoys are more effective under the same consideration.

Since the analysis shows manned buoys and ships of opportunity to be so closely matched, it appears that the decision to pick one or the other should depend on factors not yet considered; for example, the availability of crews for manned buoys, the effect of cost sharing with the Coastal North America area, and a more comprehensive evaluation of the areal coverage capability of a given number of ships of opportunity.

3.3 Coastal North America Area

The Coastal North America area comprises a band 400 miles wide adjacent to the coast of North America including Alaska. The composite requirements for this area are for data every three hours in the ocean, every 6 hours in the atmosphere,

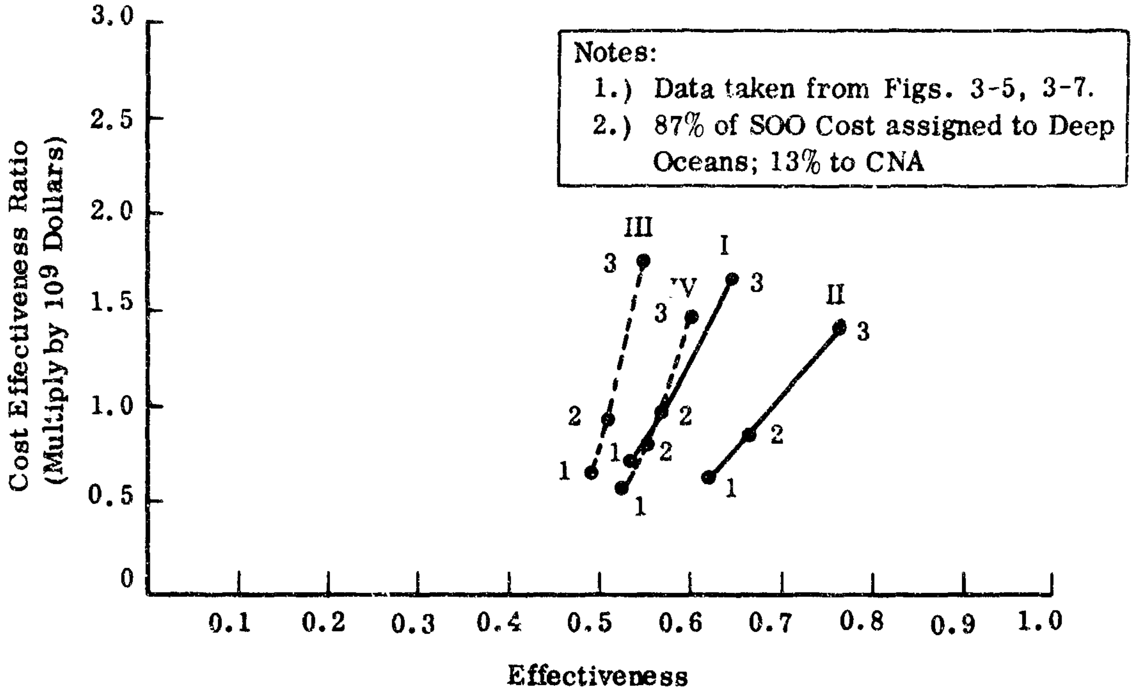


Fig. 3-8. Cost Effectiveness Ratio Comparisons for Deep Ocean Area Cost-Shared Platform Mixes

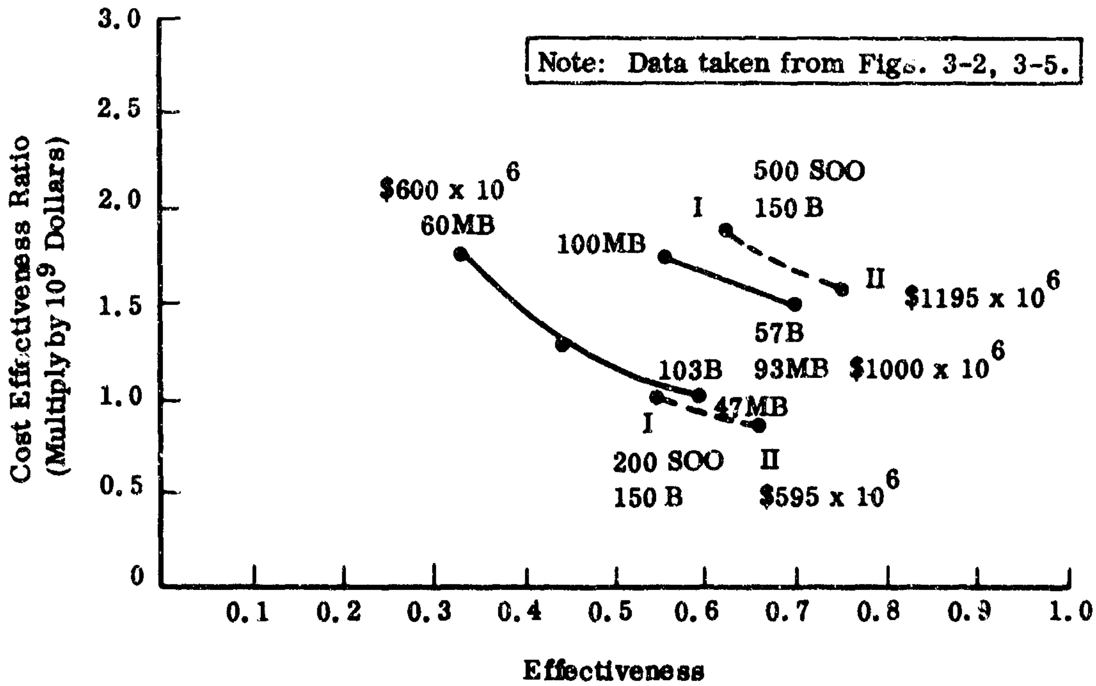


Fig. 3-9. Comparison Cost Effectiveness Ratios of Manned Buoys and Ships of Opportunity Mixed with Buoys to Give 100% Ocean Areal Coverage

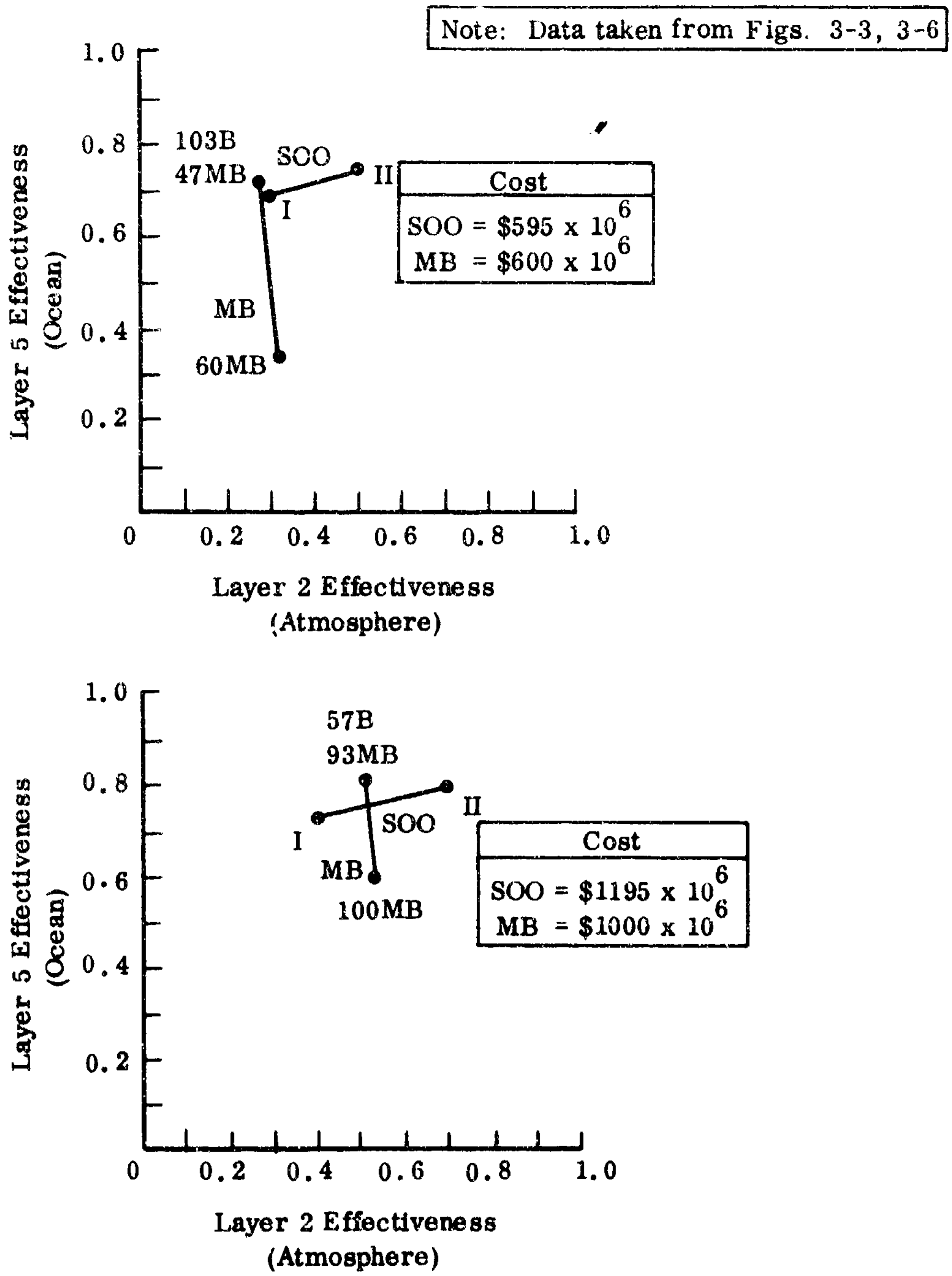


Fig. 3-10. **Comparison of Effectiveness of Manned Buoys and Ships of Opportunity Mixed with Buoys in the Deep Ocean Area**

from the ocean bottom up through most of the atmosphere, on a grid mesh averaging about 100 n mi between grid points. The specified grid requires data at 350 points for full horizontal coverage (see Fig. 2-1).

The individual platform capability scores for the Coastal North America area are given in Tables 3-4a and 3-4b (see Section 2.4.1.1 Capability) by parameter for each of the six layers and by layer respectively. The method for computing layer effectiveness and total areal-integrated effectiveness of a mix of platform is given in Section 3.2. These effectiveness values for single platforms are given in Table 3-5.

3.3.1 General Comparison of Typical Mixes

The results of an analysis of several typical mixes in the Coastal North America area are shown in Table 3-6 in order of increasing cost. The same mixes are plotted on a cost effectiveness ratio versus effectiveness diagram in Fig. 3-11.

From Fig. 3-11, the system with the lowest cost effectiveness ratio is one comprised of 350 buoys. A system of 350 manned buoys was not included in this group, since it is not a logical system for this requirement set. It would undoubtedly produce the highest effectiveness score. Certain platforms--horizontal sounding balloons, ships of opportunity, and satellites--all fare poorly when considered alone, but become more attractive when teamed with buoys. The mix of 60 aircraft of opportunity, 10 reconnaissance aircraft, and 4 satellites, a sample non-buoy mix, has a low effectiveness and high cost effectiveness ratio.

The effect of sharing cost of the various platforms in the mixes is indicated in Fig. 3-11. In most cases there is a marked improvement in cost effectiveness ratio although, of course, the effectiveness does not change. The cost sharing criteria are shown in Table 3-7 and are based essentially on the relative amount of time a platform spends taking observations in one or the other of the two areas.

Table 3-6 gives further information about the mixes shown in Fig. 3-11. It includes areal coverage of the mix, cost, and effectiveness in an atmospheric layer (Layer 2) and an ocean layer (Layer 5). Four systems are available for $350 million or less, all single platform systems. Of these only the buoys have an appreciable capability in the ocean and only the satellites, in the atmosphere. None of the mixes shown in Table 3-6 provides a balanced capability in both ocean and atmosphere.

TABLE 3-4A
PLATFORM CAPABILITY SCORES BY PARAMETER FOR THE COASTAL NORTH AMERICA AREA

Layer	Parameters	Buoys	Manned Buoys	Ocean Vessels	Satellites	Horizontal Sounding Balloons	Aircraft of Opportunity	Ships of Opportunity	Reconnaissance Aircraft	Maximum Possible Parameter Score
1	Air Temperature	0	19	19	19	13	9	19	15	19
	Air Pressure	0	19	19	0	13	9	19	15	19
	Wind Direction	0	19	19	0	13	9	19	9	19
	Wind Speed	0	19	19	0	13	9	19	9	19
	Dew Point	0	19	19	19	13	9	19	15	19
	Cloud Amount	10	10	10	10	0	10	10	10	10
	Platform Layer Scores	10	105	105	48	65	55	105	73	105
2	Air Temperature	0	20	20	20	11	0	20	16	20
	Air Pressure	0	20	20	0	11	0	20	16	20
	Wind Direction	0	32	32	0	11	0	32	0	32
	Wind Speed	0	32	32	0	11	0	32	0	32
	Dew Point	0	20	20	20	11	0	20	16	20
	Cloud Amount	10	10	10	[illegible]	0	10	10	10	10
	Platform Layer Scores	10	134	134	50	55	10	134	58	134
3	Insolation	9	9	9	0	0	0	9	0	9
	Precipitation Rate	9	9	9	0	0	0	9	0	9
	Visibility	0	9	9	0	0	0	9	0	9
	Air Temperature	9	9	9	9	0	0	9	0	9
	Air Pressure	9	9	9	0	0	0	9	0	9
	Dew Point	9	9	9	9	0	0	9	0	9
	Atmos. Electricity	9	9	9	0	0	0	9	0	9
	Wind Speed	9	9	9	0	0	0	9	0	9
	Wind Direction	9	9	9	0	0	0	9	0	9
	Platform Layer Scores	72	81	81	18	0	0	81	0	81
4	Water Temperature	12	11	11	8	0	0	11	10	12
	Wave Direction	9	9	9	0	0	0	6	0	9
	Wave Height	9	9	9	0	0	0	8	0	9
	Wave Period	9	9	9	0	0	0	8	0	9
	Salinity	12	11	11	0	0	0	11	0	12
	Current Speed	12	11	10	6	0	0	0	0	12
	Current Direction	12	11	10	0	0	0	0	0	12
	Water Pressure	12	11	11	0	0	0	11	0	12
	Ambient Light	9	9	9	0	0	0	9	0	9
	Transparency	9	9	9	0	0	0	8	0	9
	Ambient Noise	12	11	11	0	0	0	0	0	12
	Sound Speed	12	11	11	0	0	0	11	0	12
	Tidal Fluctuation	0	0	0	0	0	5	0	0	9
	Chemical Factors	0	11	11	0	0	0	11	0	12
	Biological Factors	0	11	11	0	0	0	11	0	12
	Platform Layer Scores	139	144	142	8	0	0	107	10	143
5	Water Temperature	20	19	19	0	0	0	13	18	20
	Salinity	20	19	19	0	0	0	15	0	20
	Current Speed	20	19	18	0	0	0	0	0	20
	Current Direction	20	19	18	0	0	0	0	0	20
	Water Pressure	20	19	19	0	0	0	13	0	20
	Ambient Light	9	9	9	0	0	0	8	0	9
	Transparency	9	9	9	0	0	0	7	0	9
	Ambient Noise	20	19	19	0	0	0	3	0	20
	Sound Speed	20	19	19	0	0	0	13	0	20
	Chemical Factors	0	19	19	0	0	0	13	0	20
	Biological Factors	0	19	19	0	0	0	3	0	20
	Platform Layer Scores	158	189	187	0	0	0	[illegible]	18	198
6	Water Temperature	18	17	17	0	0	0	0	0	18
	Salinity	18	17	17	0	0	0	0	0	18
	Current Speed	18	17	18	0	0	0	0	0	18
	Current Direction	18	17	16	0	0	0	0	0	18
	Water Pressure	18	17	17	0	0	0	0	0	9
	Transparency	9	9	9	0	0	0	0	0	18
	Ambient Noise	18	17	17	0	0	0	0	0	18
	Sound Speed	18	17	17	0	0	0	0	0	18
	Chemical Factors	0	17	17	0	0	0	0	0	18
	Biological Factors	0	17	17	0	0	0	0	0	18
	Platform Layer Scores	135	168	160	0	0	0	0	0	171

TABLE 3-4B
PLATFORM CAPABILITY SCORES BY LAYER FOR COASTAL
NORTH AMERICA OPERATIONAL REQUIREMENTS

Platform	Layer Capabilities					
	1	2	3	4	5	6
Acft of Oppor	0.52	0.07	0	0	0	0
Buoy	0.10	0.07	0.89	0.80	0.80	0.79
Hor Sound Bal	0.62	0.41	0	0	0	0
Manned Buoy	1.00	1.00	1.00	0.89	0.95	0.95
Ocean Vessel	1.00	1.00	1.00	0.89	0.94	0.94
Recon Acft	0.70	0.43	0	0.06	0.08	0
Satellite	0.46	0.37	0.22	0.05	0	0
Ship of Oppor	1.00	1.00	1.00	0.66	0.47	0

3.3.2 Comparison of Various Buoy-Manned Buoy Mixes

Again assuming that buoys will be an essential part of a national marine data gathering system because of their low cost effectiveness ratio and high ocean effectiveness, we next attempt to establish the best platform or platforms to augment the buoys, especially for increasing the atmospheric effectiveness. To complete the analysis started in the Deep Ocean area, it is again chosen to analyze buoy-manned buoy mixes and buoy-ship of opportunity mixes. The former analyses are discussed in this section and the latter, in the next.

In the analysis of buoy-manned buoy mixes, the effect of varying the atmospheric data density requirement was explored. Fig. 3-12 shows the result of this analysis. In all the computations a standard grid mesh of 100 n mi was used for the ocean layers data density requirement. There are 350 grid points that must be sampled on this grid. Three different grid meshes were used as the standard in the atmospheric Layers 1 and 2. They are a 200 n mi grid with a requirement of 88 grid points for 100%

TABLE 3-5
COASTAL NORTH AMERICA AREA LAYER EFFECTIVENESS AND WEIGHTED AVERAGE EFFECTIVENESS FOR EIGHT PLATFORMS

EFFECTIVENESS							
Platform	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Weighted Avg. Effectiveness
Buoy	0.08	0.06	0.71	0.64	0.64	0.63	0.48
Manned Buoy	0.95	0.95	0.95	0.85	0.90	0.90	0.92
Ocean Vessel	0.95	0.95	0.95	0.85	0.89	0.89	0.91
Satellite	0.35	0.28	0.17	0.04	0	0	0.13
Hor. Sound Bal	0.43	0.29	0	0	0	0	0.11
Acft of Oppor	0.49	0.07	0	0	0	0	0.07
Ship of Oppor	0.95	0.95	0.95	0.63	0.45	0	0.68
Recon Acft	0.67	0.41	0	0.06	0.07	0	0.18

areal coverage, a 280 n mi grid with 44 required points, and a 400 n mi grid with 22 required points. For the 200 n mi grid, three mixes were analyzed; one with 88 manned buoys and 262 buoys, giving 100% areal coverage in both the atmosphere and ocean; another with 44 manned buoys and 306 buoys, giving 50% areal coverage in the atmosphere and 100% areal coverage in the ocean; and the last with 22 manned buoys and 328 buoys, giving 25% coverage in the atmosphere and 100% in the ocean.

For the 280 n mi grid, two mixes were analyzed; one with 44 manned buoys and 306 buoys, giving 100% areal coverage in both the atmosphere and ocean; and the other with 22 manned buoys and 328 buoys, giving 50% atmospheric coverage and 100% ocean coverage.

For the 400 n mi grid, one mix was analyzed. It contains 22 manned buoys and 328 buoys to give 100% coverage in both the atmosphere and ocean.

In Fig. 3-12 the constant areal coverage lines are indicated as well as the constant manned buoy lines and constant grid mesh lines.

TABLE 3-6
ANALYSIS OF VARIOUS PLATFORM MIXES FOR
THE COASTAL NORTH AMERICA AREA

Platform Mix	Areal Coverage	Cost ($\$ \times 10^6$)	Effectiveness	C/E ($\$ \times 10^9$)	Effect. in Layer 2 (Atmos.)	Effect. in Layer 5 (Ocean)
2500 HSB	4%	140	0.0042	33.0	0.01	0.0
4 SAT	100%	166	0.1321	1.28	0.28	0.0
100 SOO	3%	200	0.0204	9.80	0.03	0.01
350 Buoys	100%	350	0.476	0.73	0.06	0.64
350 Buoys 2500 HSB	100%	490	0.480	1.021	0.07	0.64
350 Buoys 4 SAT	100%	516	0.549	0.939	0.28	0.64
350 Buoys 100 SOO	100%	550	0.492	1.119	0.10	0.65
30 AOO, 100 SOO 10 RA, 4 SAT	100%	576	0.151	3.815	0.30	0.01

Note:

HSB = Horizontal Sounding Balloon
SAT = Satellite
SOO = Ship of Opportunity
AOO = Aircraft of Opportunity
RA = Reconnaissance Aircraft

Fig. 3-12 permits an easy assessment of the impact of changes in funding (the constant buoy lines are also constant cost lines) and changes in the atmospheric data density requirements, two important factors which at present are not firmly established.

The effect of the mixes shown in Fig. 3-12 on the effectiveness in Layers 2 and 5 is given in Fig. 3-13. As would be expected there is little change in the Layer 5 (ocean) effectiveness over the range of mixes since both buoys and manned buoys do well in the ocean and the coverage there is 100%.

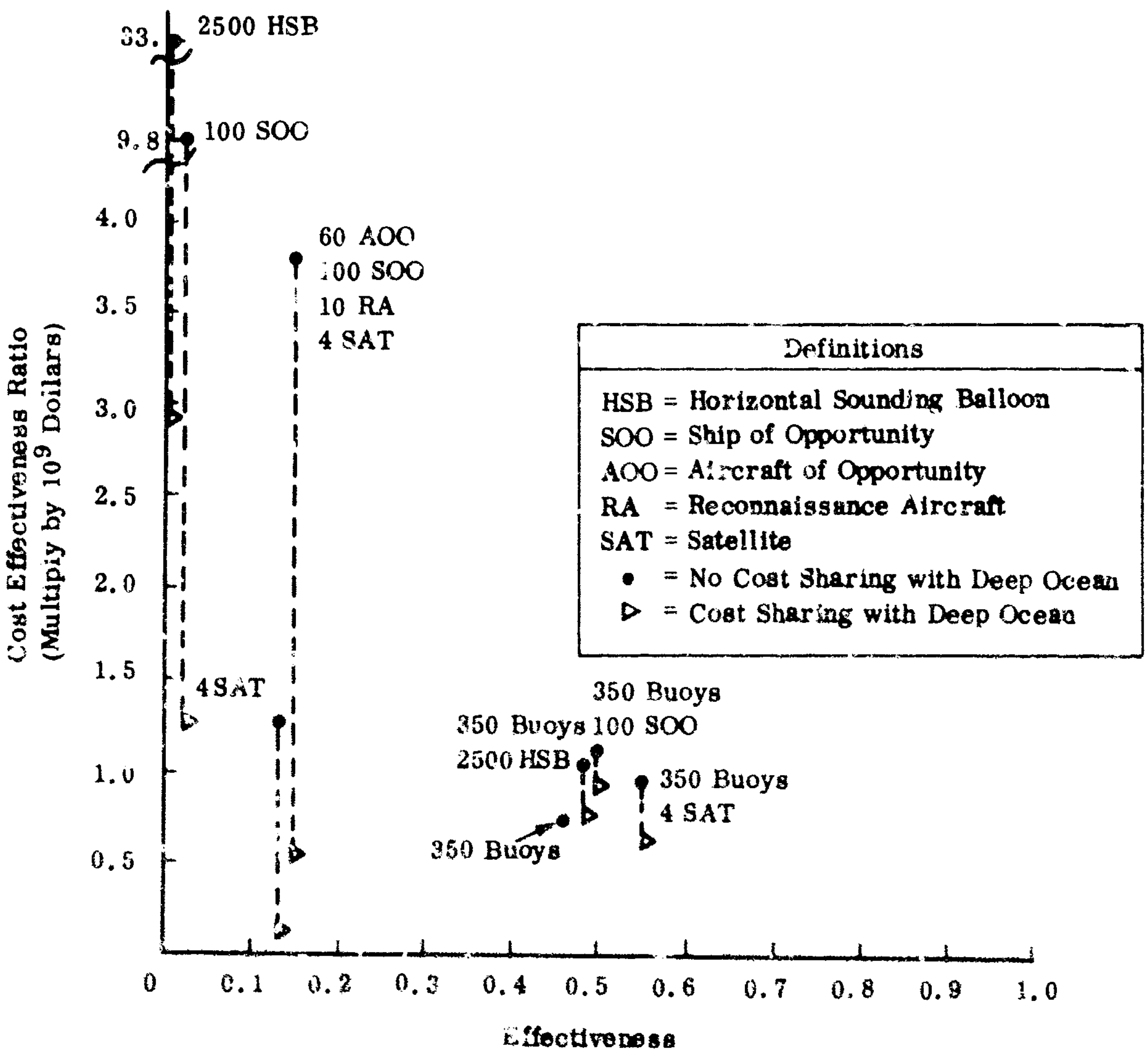


Fig. 3-11. Variations in Cost Effectiveness Ratios for Platform Mixes in the Coastal North America Area Due to Cost Sharing

TABLE 3-7
PERCENTAGE OF TOTAL PLATFORM COST CHARGED TO
DEEP OCEAN AND COASTAL NORTH AMERICA AREAS
FOR COST SHARING COMPUTATIONS

Platform	Coastal North America	Deep Ocean
Ship of Opportunity	13%	87%
Aircraft of Opportunity	13%	87%
Horiz. Sound. Balloons	8.5%	91.5%
Satellites	8.5%	91.5%
Reconnaissance Aircraft	19%	81%
Buoys	100%	100%
Manned Buoys	100%	100%
Ocean Vessels	100%	100%

The Layer 2 effectiveness (atmosphere), however, varies over a wide range, depending only upon the assumed areal coverage of a given mix in the atmosphere which, of course, is directly related to the assumed atmospheric grid mesh. For a fixed cost mix, the selection of atmospheric grid is thus seen to exert a profound influence on the Layer 2 effectiveness.

3.3.3 Comparison of Various Buoy-Ship of Opportunity Mixes

In the Coastal North America area, the analysis of buoy-ship of opportunity mixes evaluated the effect of different areal coverage capabilities for the ships, cost sharing of ships with the Deep Ocean area, and changes in the atmospheric data density requirements.

The normal and high areal coverage curves for ships of opportunity with respect to a 100 n mi grid requirement for atmospheric data are shown in Fig. 3-14. A procedure similar to the one used in Fig. 3-5 was employed to construct and analyze mixes utilizing these curves. The results of this analysis are shown in Fig. 3-15. The mixes comprise 350 buoys and 100 (point 1), 200 (point 2), and 500 (point 3) ships of opportunity, respectively. Curve I uses the normal areal coverage and Curve II, the high areal coverage. Because the areal coverage is generally low, Curves I and

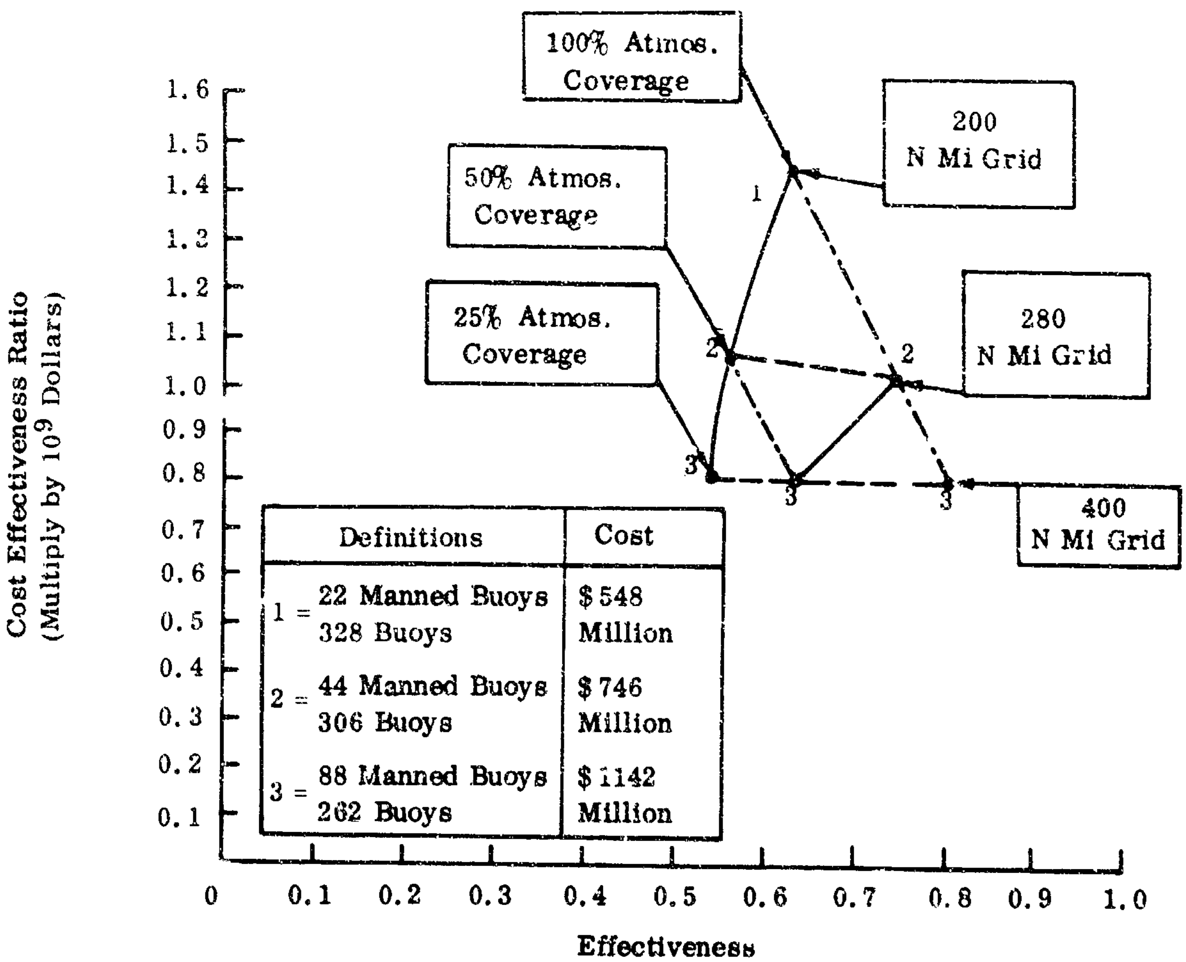


Fig. 3-12. Variations in Cost Effectiveness Ratios of Buoy-Manned Buoy Mixes in the Coastal North America Area with Respect to Variable Atmospheric Grid Requirements

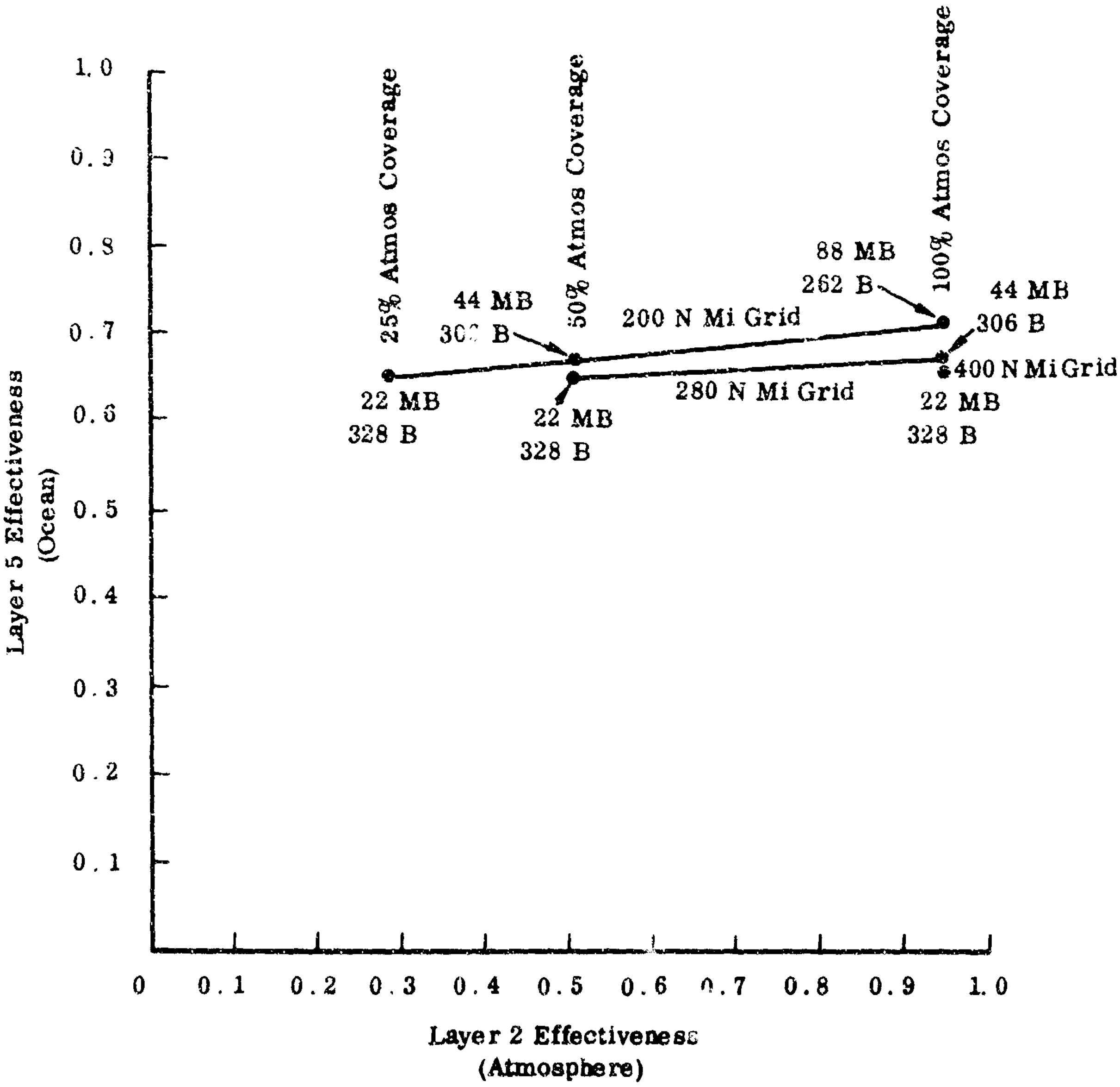


Fig. 3-13. Layer 5 Effectiveness Versus Layer 2 Effectiveness for the Buoy-Manned Buoy Mixes Shown in Fig. 3-12

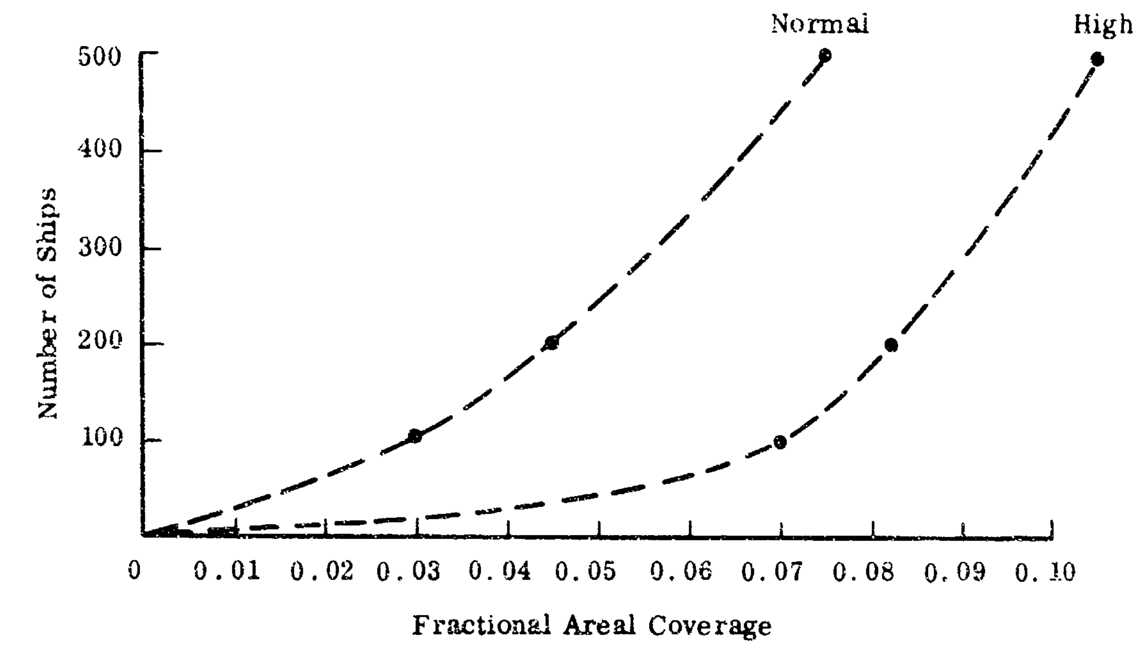


Fig. 3-14. Assumed Relationships Between Areal Coverage and Number of Ships of Opportunity in the Coastal North America Area (100 n mi Grid)

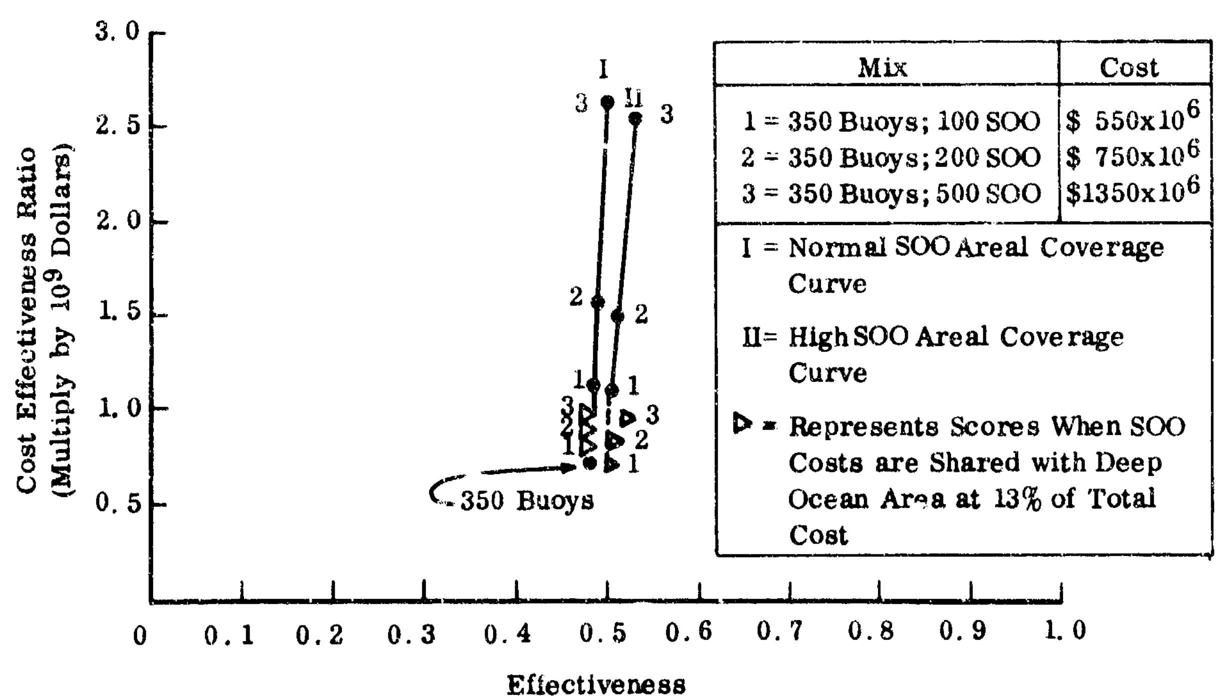


Fig. 3-15. Comparison of Cost Effectiveness Ratios of Various Buoy-SOO Mixes in the Coastal North America Area (100 n mi Grid)

II do not differ by much. The cost effectiveness ratio is seen to rise sharply with the addition of ships of opportunity, with only a marginal increase in effectiveness. When the cost of the ships is shared with the Deep Ocean at 13% of the total cost, however, the cost effectiveness approaches that of buoys alone.

To show the effect of the mixes shown in Fig. 3-15 in the ocean and atmosphere, they are presented in Fig. 3-16 on a Layer 5 effectiveness versus Layer 2 effectiveness diagram. The atmospheric effectiveness is seen to be quite low and the addition of ships of opportunity causes only small changes in both the ocean and atmosphere.

As in the Deep Ocean area (Fig. 3-7), mixes of buoys and ships of opportunity were analyzed, in which buoys were removed in proportion to the areal coverage of the ships, under the assumption that the ships always occupied the areas vacated by the buoys. The results of this analysis are shown in Fig. 3-17. This process results in a small net loss of effectiveness. The effect of cost sharing the ships (at 13% of total cost) with the Deep Ocean area is about the same as shown for the mixes in Fig. 3-15.

To test the effect of various data density requirements in atmospheric Layers 1 and 2, the ship-of-opportunity, areal-coverage curves for 100, 200, 280, and 400 n mi grids shown in Fig. 3-18 were constructed.

The analysis of several buoy-ship of opportunity mixes with variable atmospheric grid requirements is shown in Fig. 3-19. In all mixes, 100% ocean coverage is supplied by 350 buoys. With the buoys are mixed 100, 200, and 500 ships of opportunity respectively, to provide three points for each constant grid mesh curve. The 100 n mi grid mesh curve is identical to curve I in Fig. 3-15. It is seen that increasing the grid mesh in the atmosphere does improve the cost effectiveness ratio and the effectiveness, but only by small amounts. The effectiveness scale has been enlarged to show the values more clearly. The lack of more pronounced changes is due to the relatively low areal coverage attainable by ships of opportunity.

The analysis of the mixes in Fig. 3-19, when the ships are cost shared with the Deep Ocean area (at 13% of total ship cost), is given in Fig. 3-20. Here the cost-effectiveness ratio assumes an almost-constant, relatively low value. The mix effectiveness values, of course, do not change in cost sharing.

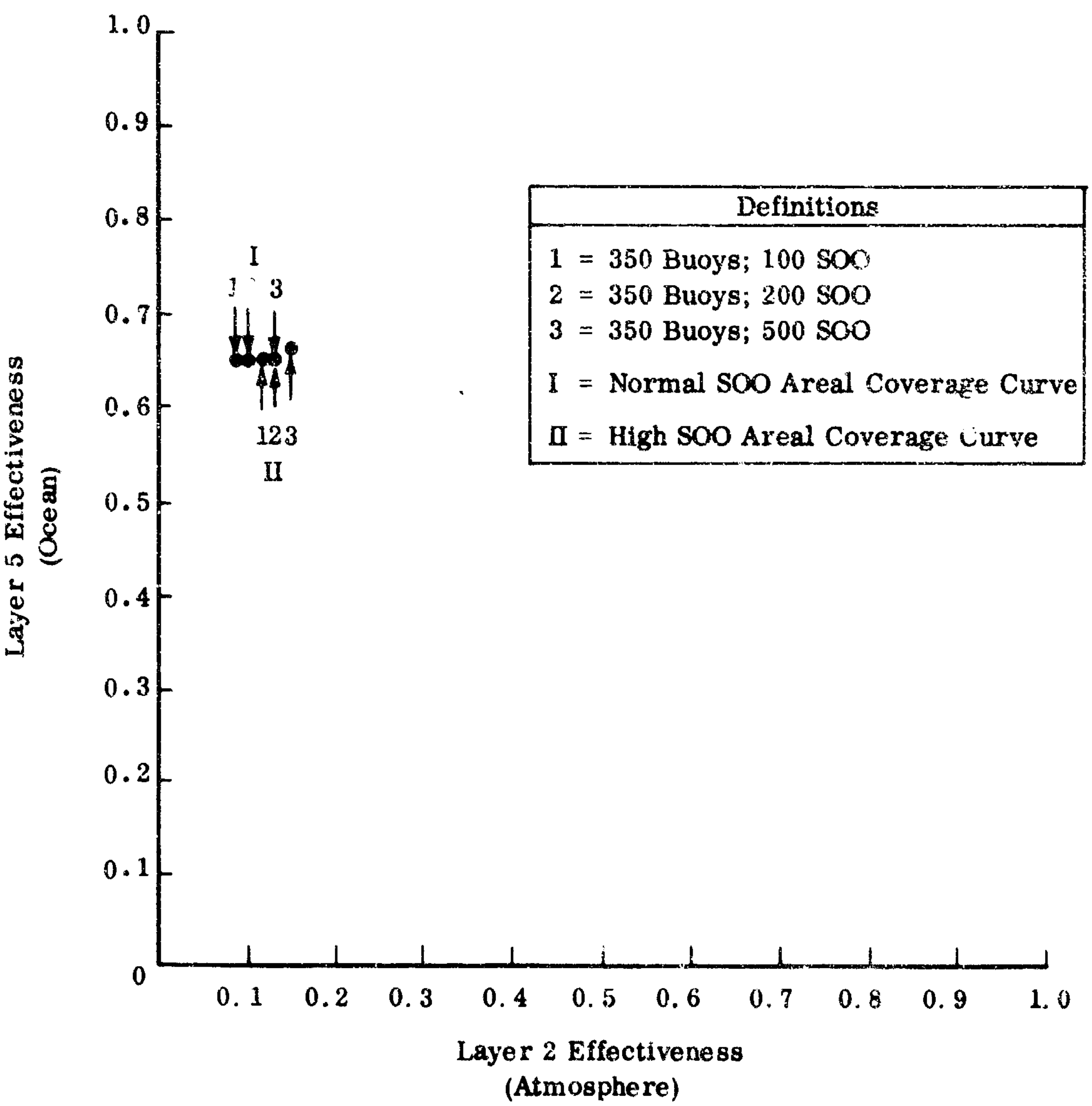


Fig. 3-16. Layer 5 Effectiveness Versus Layer 2 Effectiveness for the Buoy-SOO Mixes Shown in Fig. 3-15

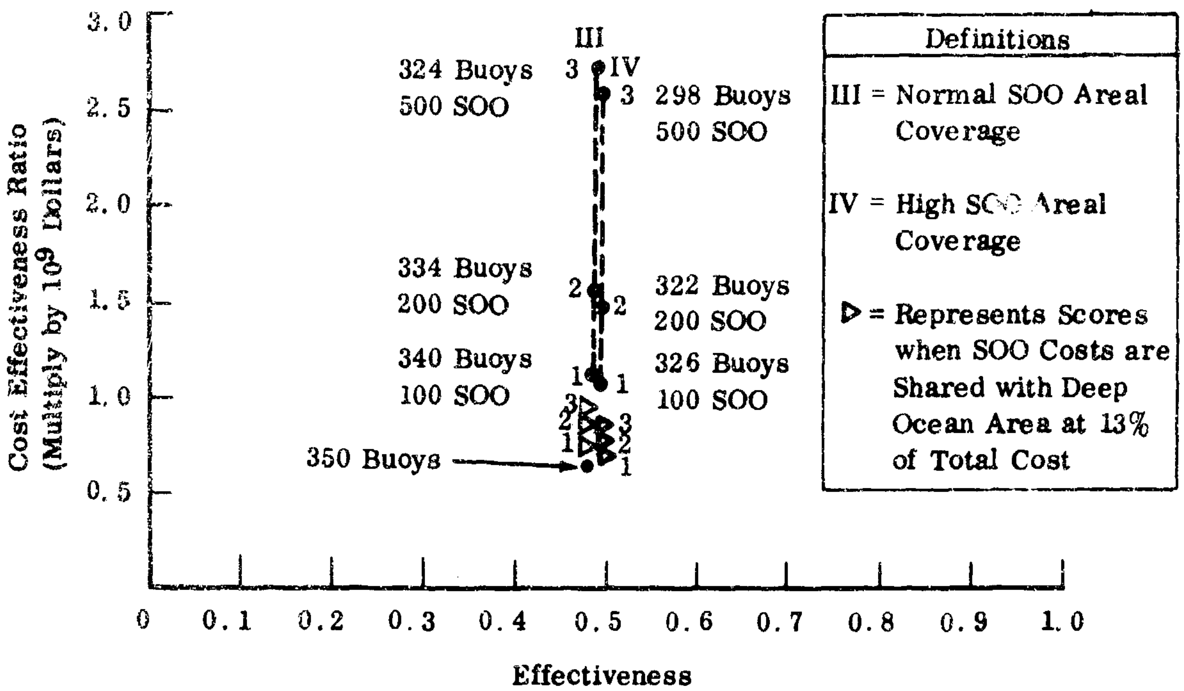


Fig. 3-17. Variations in Cost Effectiveness Ratios of Various Buoy-SOO Mixes in the Coastal North America Area Due to Cost Sharing (100 n mi Grid)

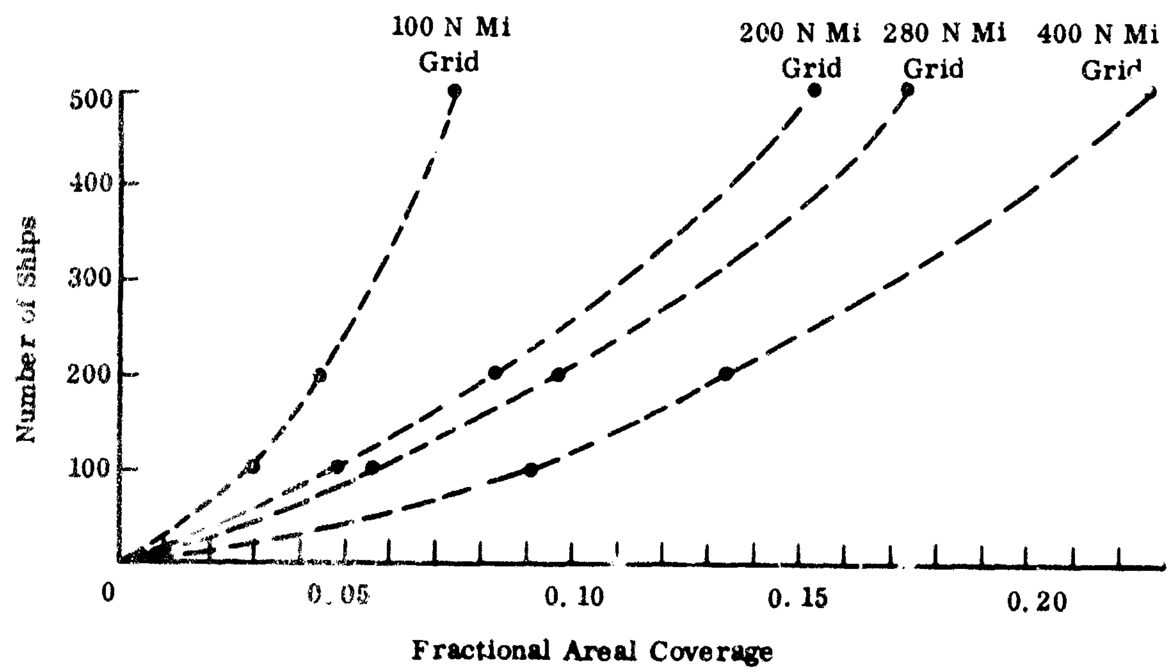


Fig. 3-18. Assumed Relationships Between Areal Coverage and Number of Ships of Opportunity in the Coastal North America Area for Various Grid Spacings

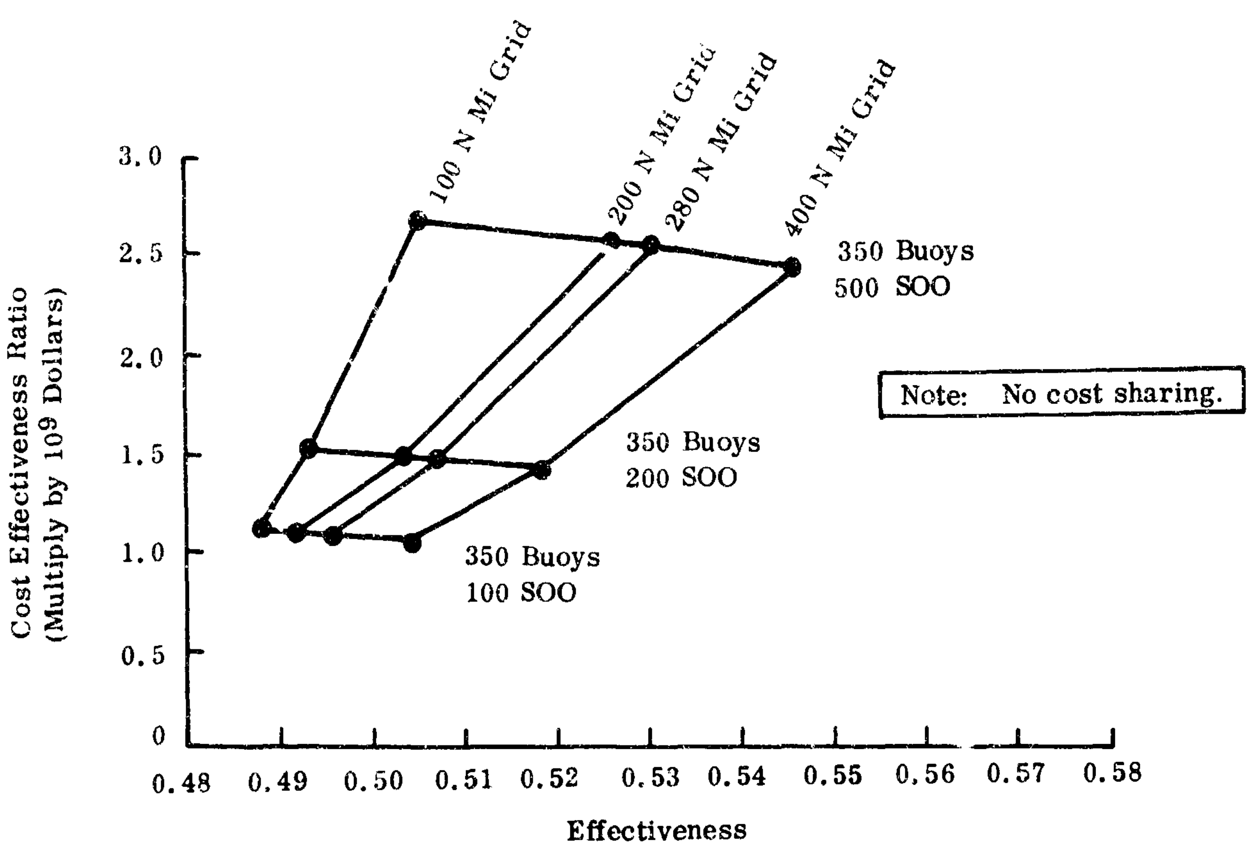


Fig. 3-19. Comparison of Cost Effectiveness Ratios of Various Buoy-SOO Mixes in the Coastal North America Area for Variable Atmospheric Grid Spacing Requirements

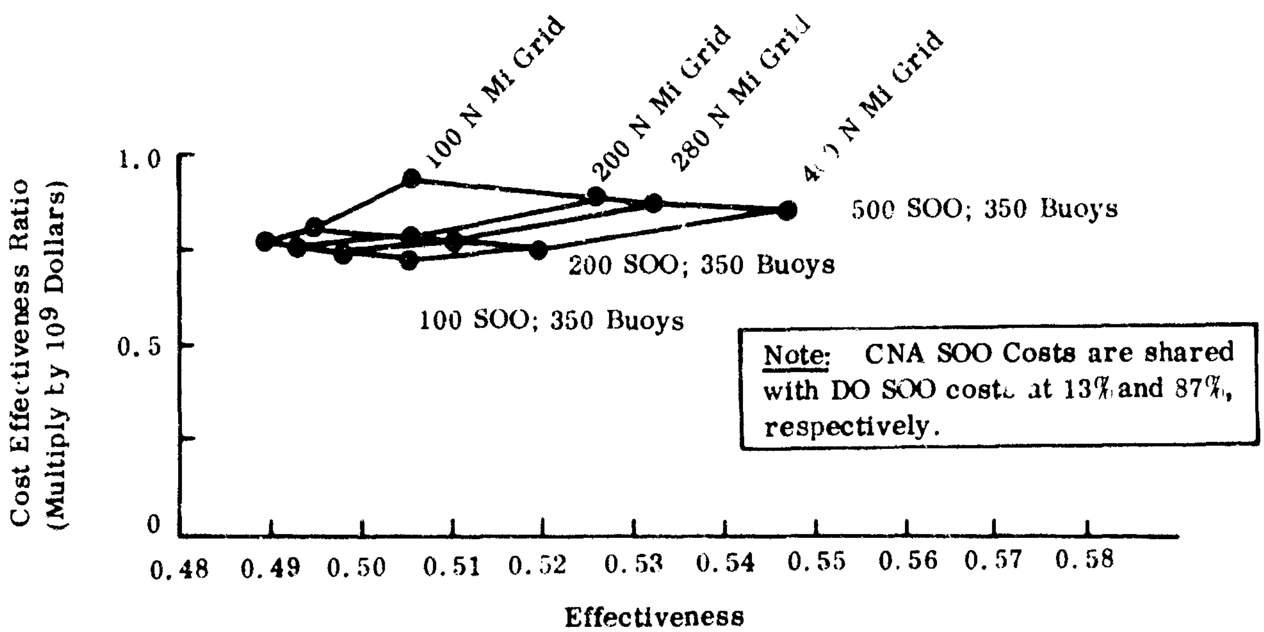


Fig. 3-20. Comparison of Cost Effectiveness Ratios of Various Buoy-SOO Mixes in the Coastal North America Area for Variable Atmospheric Grid Spacing Requirements and Cost Sharing

The resulting atmospheric and ocean effectiveness values for the mixes given in Fig. 3-19 are shown in Fig. 3-21. The atmospheric effectiveness, even for the most favorable mix and grid mesh, is seen to be relatively low, while the ocean effectiveness is not much greater than that attainable by buoys alone.

3.3.4 Comparison of Manned Buoys versus Ships of Opportunity when Mixed with Buoys to Give 100 Percent Ocean Coverage

The question of which platform should be teamed with buoys in the Coastal North America area – manned buoys or ships of opportunity – is considered in this section.

In Figs. 3-22 through 3-24 are comparisons of cost effectiveness ratios of the two types of mixes for grid meshes of 200, 280, and 400 n mi. These results have been taken from Fig. 3-12 and Fig. 3-19.

For the 200 n mi grid, the two types of mixes are competitive only for the lowest cost mixes in each type. As the cost of the mix is increased the buoy-manned buoy mixes are far superior. The buoy-ship of opportunity mixes attain a low cost effectiveness ratio when the cost of the ships is shared with the Deep Ocean area; however, their effectiveness is far below the best buoy-manned buoy mix.

As the grid mesh is increased the superiority of the buoy-manned buoy mixes increases (see Fig. 3-23 and g. 3-24).

Similar results are obtained on a Layer 5 versus Layer 2 effectiveness comparison, shown in Figs. 3-25 through 3-27.

For a given amount of money, the buoy-manned buoy mixes always produce a higher atmospheric effectiveness. The difference in effectiveness increases as the grid mesh increases.

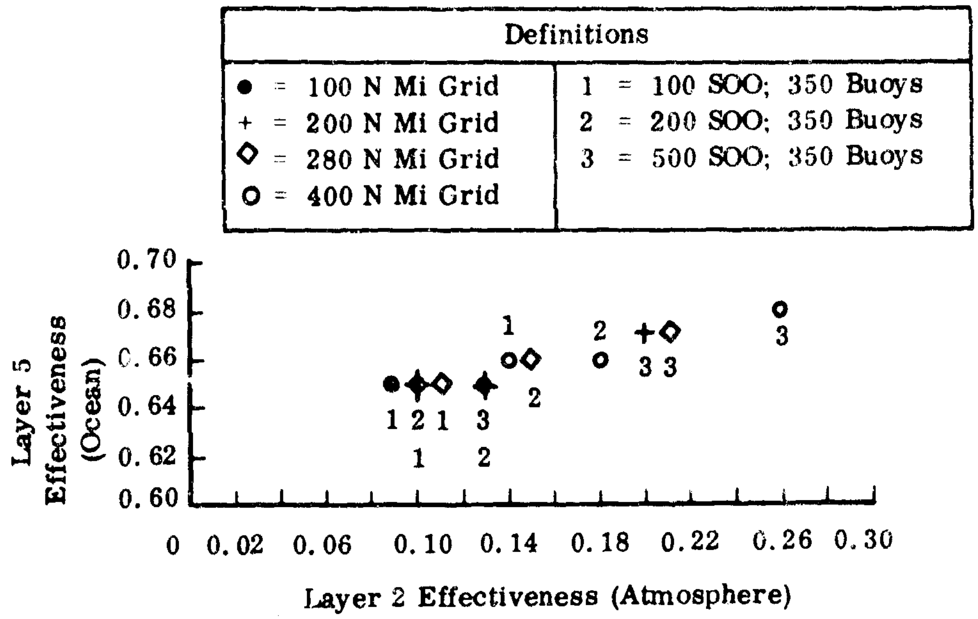


Fig. 3-21. Layer 5 Effectiveness Versus Layer 2 Effectiveness for the Buoy-SOO Mixes Shown in Fig. 3-19

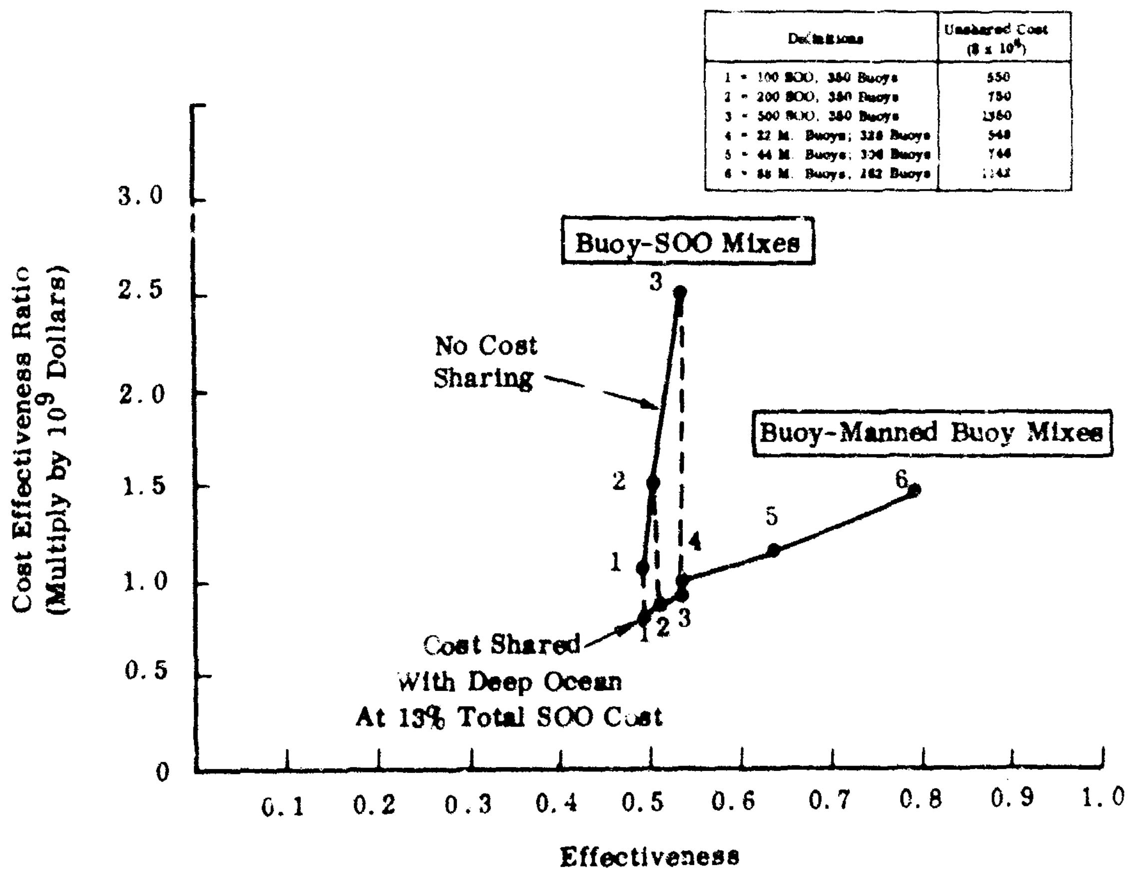
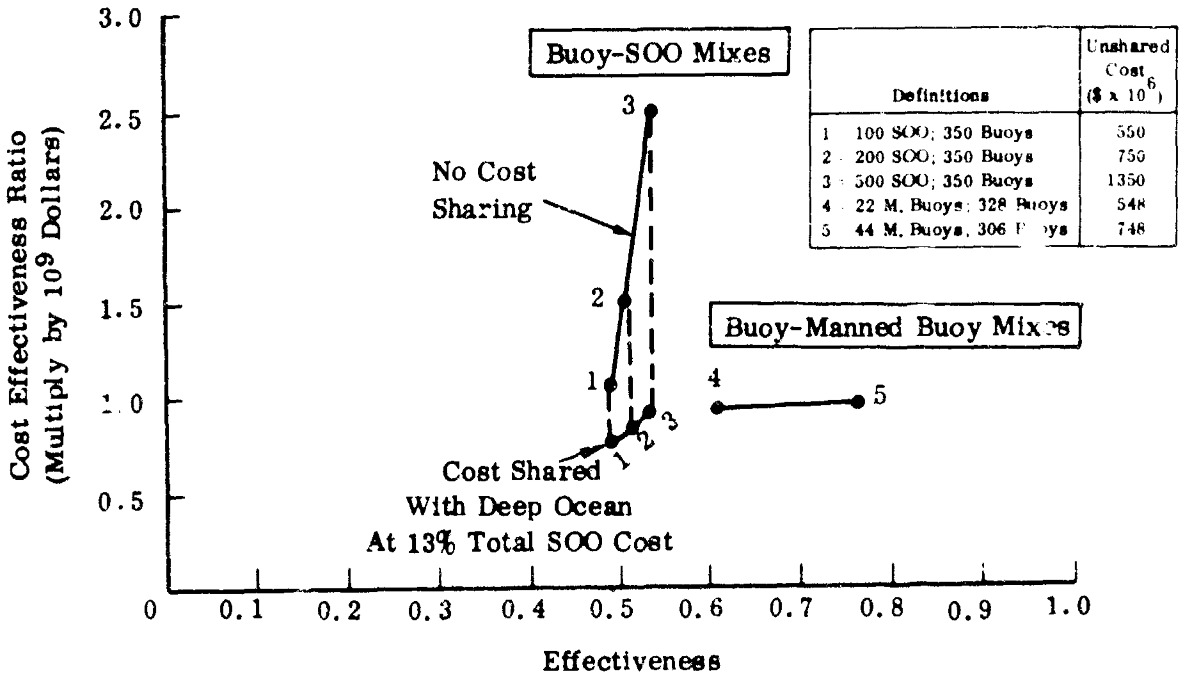
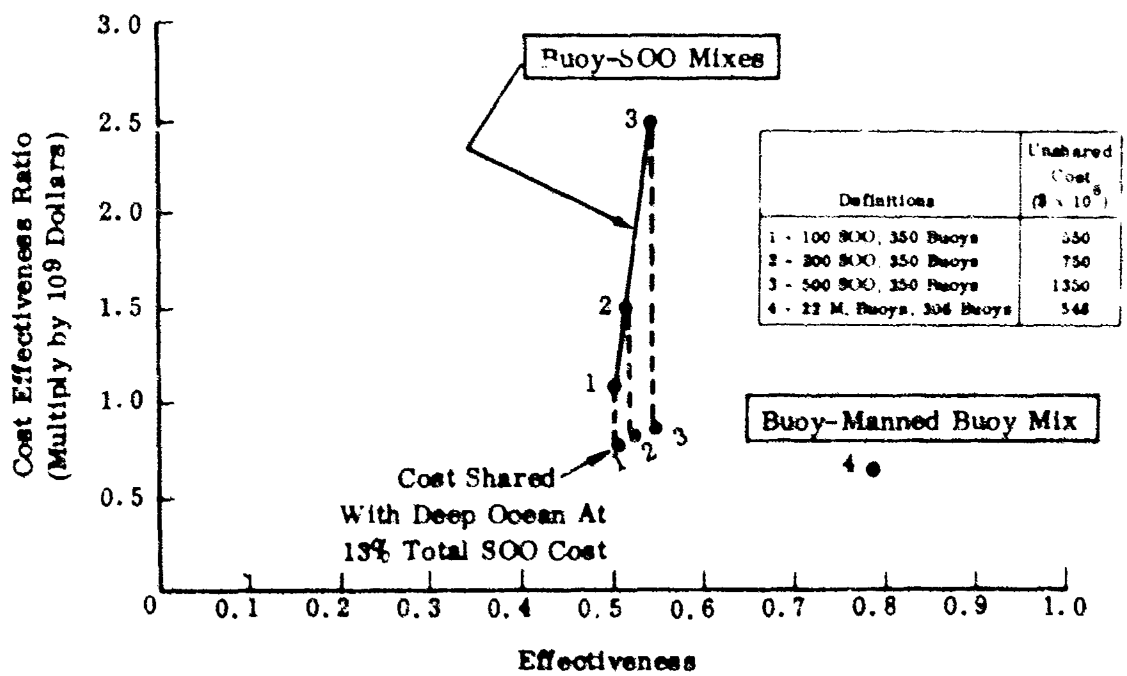


Fig. 3-22. Comparison of Cost Effectiveness Ratios of Buoy-Manned Buoy Mixes and Buoy-Ship of Opportunity Mixes. (200 n mi Grid for Atmosphere)



Definitions	Unshared Cost ($\$ \times 10^6$)
1 100 SOO; 350 Buoys	550
2 200 SOO; 350 Buoys	750
3 500 SOO; 350 Buoys	1350
4 22 M. Buoys; 328 Buoys	548
5 44 M. Buoys, 306 Buoys	748

Fig. 3-23. Cost Effectiveness Ratio Comparison of Buoy-Manned Buoy Mixes and Buoy-Ship of Opportunity Mixes (280 n mi Grid for Atmosphere)



Definitions	Unshared Cost ($\$ \times 10^6$)
1 - 100 SOO, 350 Buoys	550
2 - 200 SOO, 350 Buoys	750
3 - 500 SOO, 350 Buoys	1350
4 - 22 M. Buoys, 306 Buoys	548

Fig. 3-24. Cost Effectiveness Ratio Comparison of Buoy-Manned Buoy Mixes and Buoy-Ship of Opportunity Mixes (400 n mi Grid for Atmosphere)

Definitions	Unshared Cost ($ x 10^6)
1 = 100 SOO; 350 Buoys	550
2 = 200 SOO; 350 Buoys	.50
3 = 300 SOO; 350 Buoys	1350
4 = 22 M. Buoys; 328 Buoys	548
5 = 44 M. Buoys; 306 Buoys	746
6 = 88 M. Buoys; 262 Buoys	1142

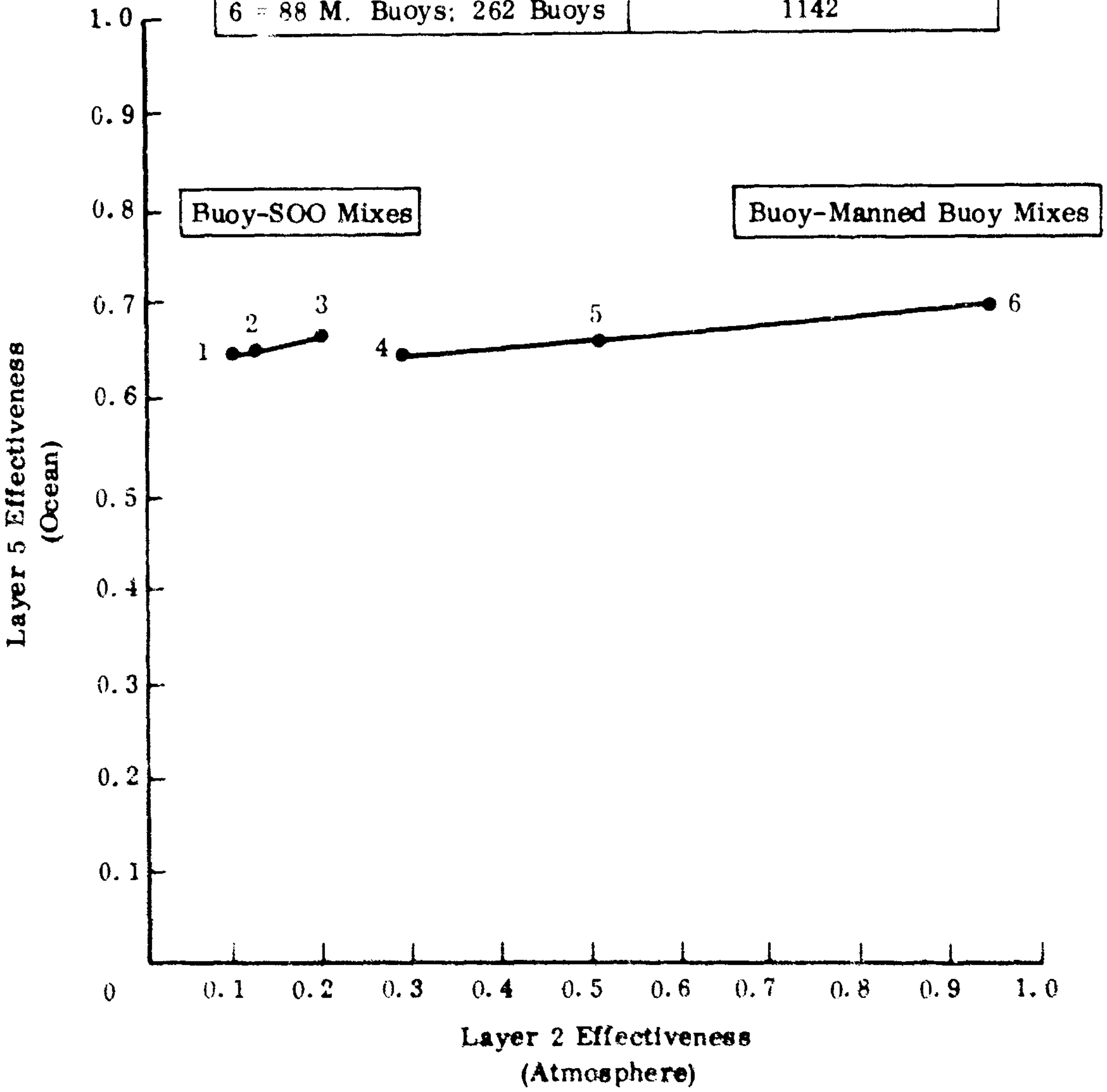
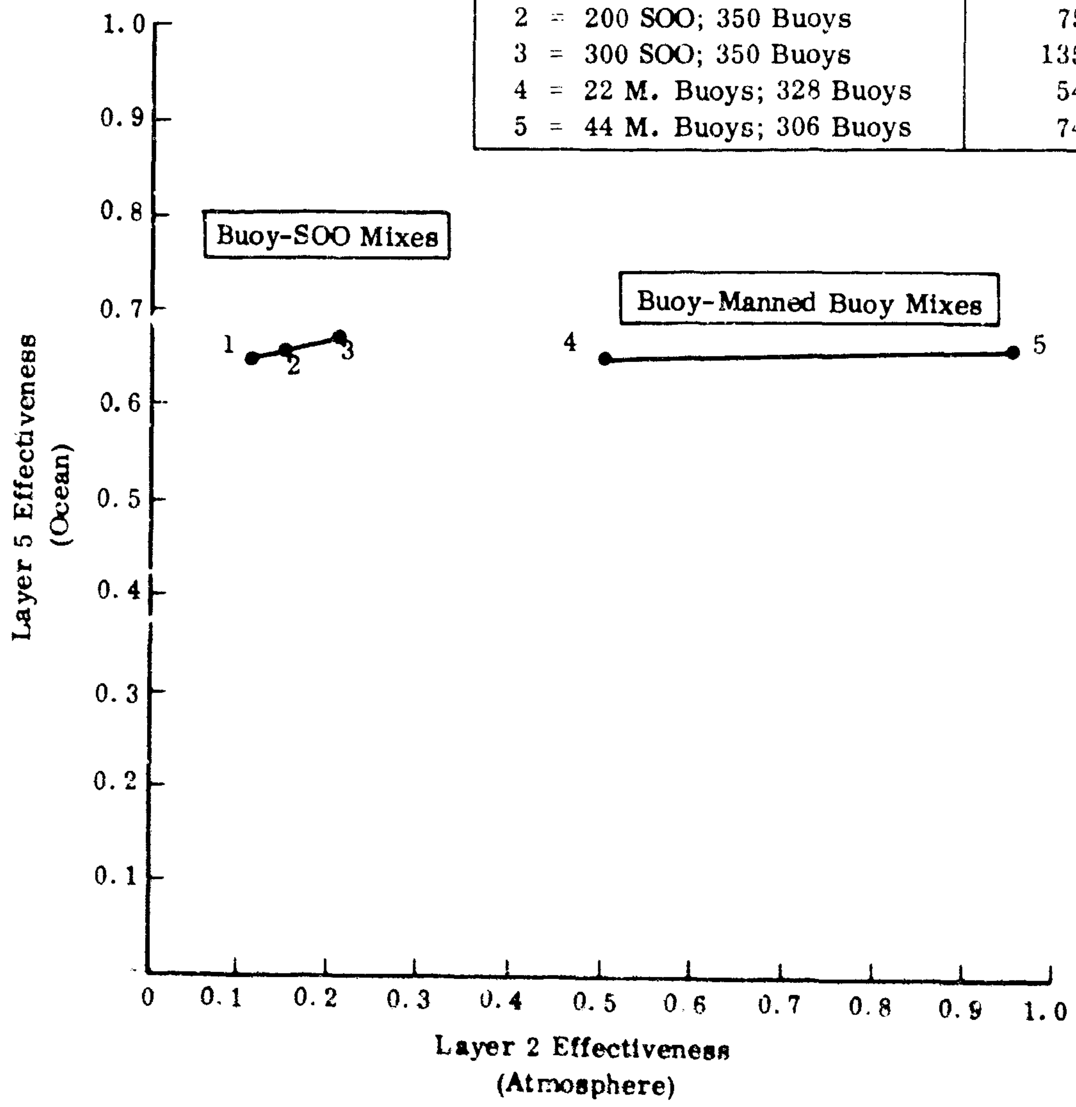


Fig. 3-25. A Layer 5 Effectiveness Versus Layer 2 Effectiveness Comparison of Buoy-Manned Buoy Mixes with Buoy-Ship of Opportunity Mixes (200 n mi Grid for Atmosphere)



Definitions	Unshared Cost ($\$x10^6$)
1 = 100 SOO; 350 Buoys	550
2 = 200 SOO; 350 Buoys	750
3 = 300 SOO; 350 Buoys	1350
4 = 22 M. Buoys; 328 Buoys	548
5 = 44 M. Buoys; 306 Buoys	746

Fig. 3-26. A Layer 5 Effectiveness Versus Layer 2 Effectiveness Comparison of Buoy-Manned Buoy Mixes with Buoy-Ship of Opportunity Mixes (280 n mi Grid for Atmosphere)

Definitions	Unshared Cost ($ x 10^6)
1 = 100 SOO; 350 Buoys	550
2 = 200 SOO; 350 Buoys	750
3 = 300 SOO; 350 Buoys	1350
4 = 22 M. Buoys, 328 Buoys	548

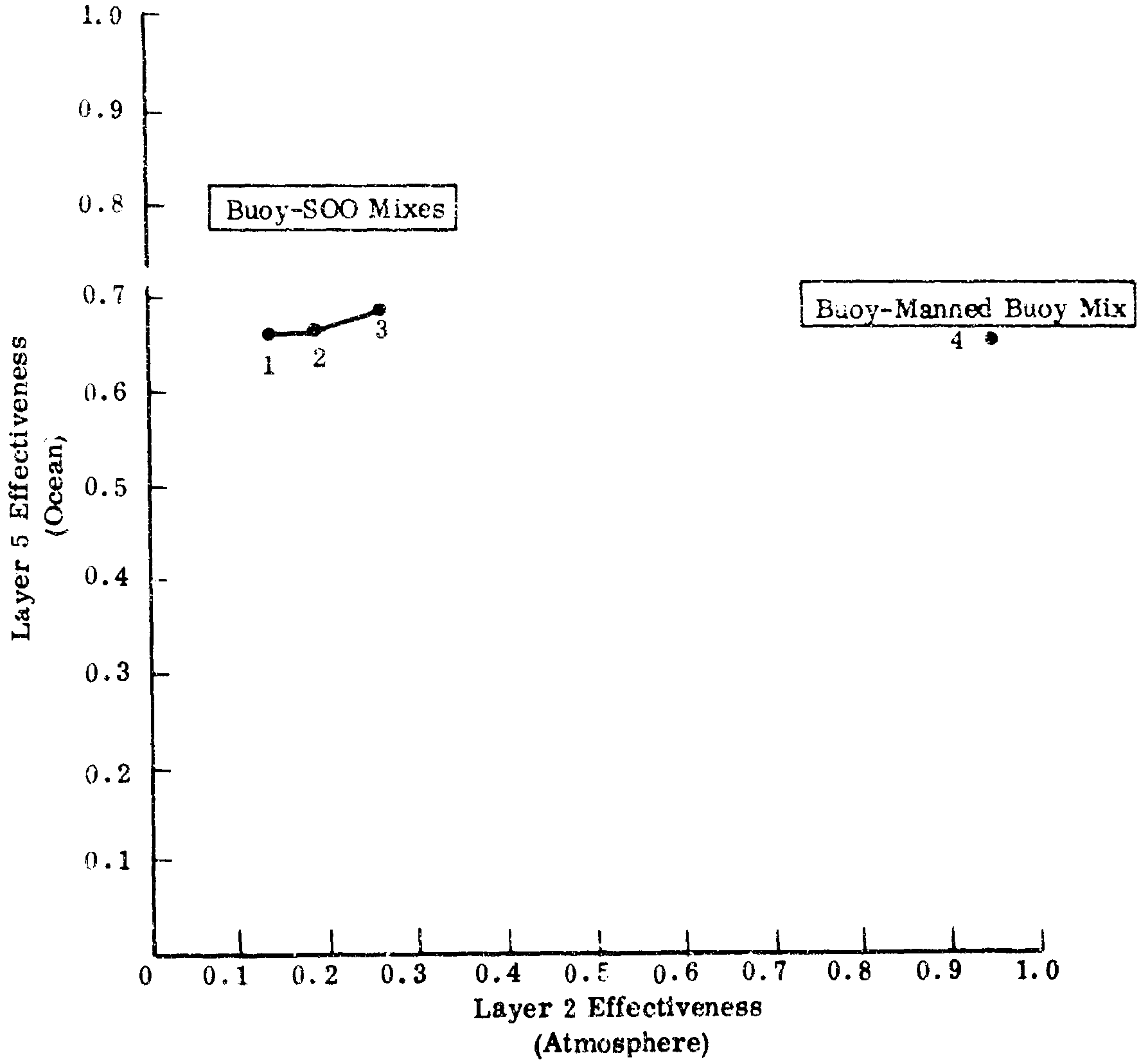


Fig. 3-27. A Layer 5 Effectiveness Versus Layer 2 Effectiveness Comparison of Buoy-Manned Buoy Mixes with Buoy-Ship of Opportunity Mixes (400 n mi Grid for Atmosphere)

4.0 ANALYSIS OF EFFECTS OF PARAMETER AND LAYER WEIGHTS

4.1 Background

In the previous sections of this report, all required parameters have been assumed to be of equal importance. The relative importance of the six layers thus far was defined by the NDBS DPO to be the following: Layers 1 and 6 = 0.6; Layers 2, 3, 4, 5 = 1.0. Throughout the course of this work, however, it was recognized by both the NDBS DPO and TRC that it would be desirable to incorporate in the cost effectiveness model the ability to accommodate relative importance weights for all the layers and the parameters required within each layer. Furthermore, it was deemed desirable to solicit relative importance weightings from U.S. Government Agencies with stated requirements for marine atmospheric and oceanographic data.

The NDBS DPO, assisted by TRC, solicited the relative importance of stated requirements for parameters and observing levels from four agencies with extensive operational requirements: Bureau of Commercial Fisheries (BCF), Environmental Science Services Administration (ESSA), U.S. Navy (USN), and U.S. Coast Guard (USCG). The solicited information was collected as a parallel part of the 1968 TRC effort to determine the applicability of NDBS to refined national requirements for marine meteorological and oceanographic data [7]. The information became available too late to be incorporated in the previous sections of this report.

Recognizing the importance of this collected data, the NDBS DPO requested that TRC conduct a selected set of calculations with the new data, to form a comparison with the work done in Section 3 for Figs. 3-1 and 3-11. In brief, the NDBS DPO sought an answer for the question: "What is the sensitivity of cost effectiveness results to the incorporation of agency-supplied relative importance weightings of parameter and layers?" The answer to the question is "The cost effectiveness results are relatively insensitive to parameter and layer relative importance weighting provided by agencies." The remainder of this section is devoted to substantiating that answer.

4.2 Solicitation of Parameter and Layer Relative Importance Weights

Each of the four agencies -- BCF, ESSA, USN, USCG, -- was requested to rate, in relation to the performance of its operational missions, 50 required parameters distributed throughout the seven vertical 'ayers (Table 2-1).* Some parameters appeared in more than one layer. The 50 operational parameters** selected for this purpose had been previously required by at least one of the four primary agencies and were judged to have the potential of general applicability for agency operational missions. The rating criteria for estimating relative importance are presented in Table 4-1.

TABLE 4-1
CRITERIA FOR ESTIMATING RELATIVE VALUES
OF PARAMETERS AND LAYERS

Criteria	Value
Must have to satisfy missions	5, 4***
Important to satisfy missions	3, 2***
Useful to satisfy missions	1
Of no value to satisfy missions	0

Two ratings were requested, one for those missions principally oriented toward atmospheric parameters and the other for those missions oriented toward oceanic parameters; however, the responding agencies preferred to make only one combined rating for all missions. Furthermore, each agency stated that the ratings were tentative and subject to change.

Table 4-2 contains tabulations of the four agencies' estimates of relative values of parameters and layers. The table shows the sum of all parameter relative values

*Although Layer 7 (bottom) relative importance values appear in Table 4-3, they were not used in the Section 3 or Section 4 computations, because they do not apply to operational requirements.

**Certain "parameters" used in this cost effectiveness analysis, such as biological factors and chemical factors, were more specifically delineated in the list of parameters sent to the agencies. The collected results were averaged to provide relative importance weights for the lists of parameters given in Tables 2-2 and 2-3. This was done to afford consistency with previous results. Future cost-effectiveness studies should be made with an expanded number of chemical and biological parameters, now that more specific information is available.

***The two numbers allow for a minor gradation of value.

TABLE 4-2
PARAMETER AND OBSERVING LAYER RELATIVE VALUES

Parameter	Agency Relative Values for Parameters and Layers: BCF Par	BCF Lyr	ESSA Par	ESSA Lyr	NAVY Par	NAVY Lyr	USCG Par	USCG Lyr	Parameter Sum	Agency Parameter x Layer Products: BCF	ESSA	NAVY	USCG	Sum of Parameter x Layer Products	Parameter and Layer a "Must" for: BCF	ESSA	NAVY	USCG
Layer 1: 100,000 ≥ Layer > 30,000 ft																		
1. Ozone Content	5	0	5	5	1	3	0	1	6	0	25	3	0	28		X		
2. Cosmic Radiation			3		1		0		4		15	3	0	18				
3. Cloud Tops			5		3		1		9		25	9	1	35		X		
4. Cloud Bases			5		3		1		9		25	9	1	35		X		
5. Cloud Amount			5		3		3		11		25	9	3	37		X		
6. Wind Speed			5		2		2		9		25	6	2	33		X		
7. Wind Direction			5		2		2		9		25	6	2	33		X		
8. Air Temperature			5		3		2		10		25	9	2	36		X		
9. Height			5		4		3		12		25	12	3	40		X		
10. Atmos. Pressure			5		5		3		13		25	15	3	43		X		
11. Dew Point/Humidity			5		3		2		10		25	9	2	36		X		
Layer 2: 30,000 ≥ Layer > 45 ft																		
1. Ozone Content	0	0	1	5	1	5	0	3	2	0	5	5	0	10				
2. Cosmic Radiation			1		1		0		2		5	5	0	10				
3. Cloud Tops			5		3		1		9		25	15	3	43		X		
4. Cloud Bases			5		5		1		11		25	25	3	53		X	X	
5. Cloud Amount			5		5		5		15		25	25	15	65		X	X	
6. Wind Speed			5		2		3		10		25	10	9	44		X		
7. Wind Direction			5		2		3		10		25	10	9	44		X		
8. Air Temperature			5		3		3		11		25	15	9	49		X		
9. Height			5		4		3		12		25	20	9	54		X	X	
10. Atmos. Pressure			5		5		3		13		25	25	9	59		X	X	
11. Dew Point/Humidity			5		3		2		10		25	15	6	46		X		
12. Atmos. Electricity			1		0		0		1		5	0	0	5				
Layer 3: 45 ≥ Layer > 0 ft																		
1. Wind Speed	5	5	5	5	5	5	5	5	20	25	25	25	25	100	X	X	X	X
2. Wind Direction	5		5		5		5		20	25	25	25	25	100	X	X	X	X
3. Air Temperature	5		5		5		5		20	25	25	25	25	100	X	X	X	X
4. Height	0		5		4		5		14	0	25	20	25	70		X	X	X
5. Atmos. Pressure	5		5		5		5		20	25	25	25	25	100	X	X	X	X
6. Dew Point/Humidity	5		5		5		4		19	25	25	25	20	95	X	X	X	X
7. Atmos. Electricity	0		1		1		0		2	0	5	5	0	10				
8. Insolation	5		3		3		5		16	25	15	15	25	80	X			X
9. Precipitation	4		5		3		3		15	20	25	15	15	75	X	X		
10. Visibility	0		5		3		2		10	0	25	15	10	50		X		
11. Mag. Field Declin.	0		5		2		1		8	0	25	10	5	40		X		
12. Mag. Field Inclin.	0		5		2		1		8	0	25	10	5	40		X		
13. Mag. Field Inten.	0		5		2		1		8	0	25	10	5	40		X		
14. Gravity	0		5		3		1		9	0	25	15	5	45		X		
Layer 4: 0 ≤ Layer < 10m																		
1. Wave Period	0	5	5	5	5	5	5	5	15	0	25	25	25	75		X	X	X
2. Wave Direction	0		5		5		5		15	0	25	25	25	75		X	X	X
3. Wave Height	0		5		5		5		15	0	25	25	25	75		X	X	X
4. Tidal Fluctuation	0		5		3		2		10	0	25	15	10	50		X		
5. Ambient Light	3		0		3		1		7	15	0	15	5	35				
6. Ambient Noise	2		0		3		1		6	10	0	15	5	30				
7. Current Direction	5		5		5		5		20	25	25	25	25	100	X	X	X	X
8. Current Speed	5		5		5		5		20	25	25	25	25	100	X	X	X	X
9. Salinity	5		5		5		5		20	25	25	25	25	100	X		X	X
10. Sound Speed	0		5		4		1		10	0	25	20	5	50		X	X	
11. Transparency	5		1		1		3		10	25	5	5	15	50	X			
12. Water Temperature	5		5		5		5		20	25	25	25	25	100	X	X	X	X
13. Propagation Loss	1		0		2		5		8	5	0	10	25	40				X
14. Depth	5		5		4		5		19	25	25	20	25	95	X	X	X	X
15. Water Pressure	0		5		5		2		12	0	25	25	10	60		X	X	
16. Oxygen	5		1		1		3		10	25	5	5	15	50	X			
17. Carbon Dioxide	2		1		1		1		5	10	5	5	5	25				
18. Phosphates	3		0		1		3		7	15	0	5	15	35				
19. Nitrates	3		0		1		3		7	15	0	5	15	35				
20. pH	3		0		1		2		6	15	0	5	10	30				
21. Nutrients	3		0		1		3		7	15	0	5	15	35				
22. Plankton	5		0		1		3		9	25	0	5	15	45	X			
23. Chlorophyl	3		0		1		1		5	15	0	5	5	25				
24. Biological Growth	2		0		2		2		7	10	0	15	10	30				
25. Photos of Fish	3		0		0		0		3	15	0	0	0	15				
26. Active Sonar	4		0		0		0		4	20	0	0	0	20	X			

TABLE 4-2
PARAMETER AND OBSERVING LAYER RELATIVE VALUES (Continued)

Parameter	Agency Relative Values for Parameters and Layers								Parameter Sum	Agency Parameter x Layer Products				Sum of Parameter x Layer Products	Parameter and Layer a "Must" for			
	BCF		ESSA		NAVY		USCG											
	Par	Lyr	Par	Lyr	Par	Lyr	Par	Lyr		BCF	ESSA	NAVY	USCG		BCF	ESSA	NAVY	USCG
Layer 5 10 ≤ Layer < 500 m																		
1. Ambient Light	[illegible]	5	0	5	3	5	1	5	7	15	0	15	5	35				
2. Ambient Noise	2		0		3		1		6	10	0	15	5	30				
3. Current Direction	4		5		3		5		17	20	25	15	25	95	X	X		X
4. Current Speed	4		5		3		5		17	20	25	15	25	85	X	X		X
5. Salinity	4		5		5		5		19	20	25	25	25	95	X	X	X	X
6. Sound Speed	0		5		2		1		8	0	25	10	5	40		X		
7. Transparency	4		1		3		3		9	20	5	15	15	55	X			
8. Water Temperature	5		5		5		5		20	25	25	25	25	100	X	X	X	X
9. Propagation Loss	1		0		2		1		4	5	0	10	5	20				
10. Depth	5		5		4		5		13	25	25	20	25	95	X	X	X	X
11. Water Pressure	0		5		5		2		12	0	25	25	10	60		X	X	
12. Oxygen	3		5		1		3		12	15	25	5	15	60		X		
13. Carbon Dioxide	2		1		1		1		5	10	5	5	5	25				
14. Phosphatee	3		0		1		[illegible]		7	15	0	5	15	55				
15. Nitratee	3		0		1		3		7	15	0	5	15	35				
16. pH	3		0		1		2		6	15	0	5	10	30				
17. Nutrients	3		0		1		3		7	15	0	5	15	35				
18. Plankton	5		0		1		3		9	25	0	5	15	45	X			
19. Chlorophyl	3		0		1		1		5	15	0	5	5	25				
20. Biological Growth	2		0		1		2		5	10	0	5	10	25				
21. Photos of Fish	2		0		0		0		2	10	0	0	0	10				
22. Vertical Currents	1		3		3		1		8	5	15	15	5	40				
23. Active Sonar	4		0		0		0		4	20	0	0	0	20	X			
Layer 6 500 ≤ Layer < 500 m																		
1. Ambient Noise	1	3	0	5	1	1	0	3	2	3	0	1	0	4				
2. Current Direction	3		5		1		2		11	9	25	1	6	41		X		
3. Current Speed	3		5		1		2		11	9	25	1	6	41		X		
4. Salinity	3		5		1		5		14	9	25	1	15	50		X		
5. Sound Speed	0		5		1		1		7	0	25	1	3	29		X		
6. Water Temperature	3		5		5		5		18	9	25	5	15	54		X		
7. Propagation Loss	1		0		1		1		3	3	0	1	3	7				
8. Depth	5		5		4		5		19	15	25	4	15	59		X		
9. Water Pressure	0		5		5		1		11	0	25	5	3	33		X		
10. Oxygen	2		1		1		3		7	6	5	1	9	21				
11. Carbon Dioxide	1		1		0		1		3	3	5	0	3	11				
12. Phosphates	2		0		1		3		7	6	0	1	9	16				
13. Nitrates	2		0		1		2		5	6	0	1	6	13				
14. pH	2		0		0		1		3	6	0	0	3	9				
15. Nutrients	2		0		1		3		6	6	0	1	9	16				
16. Photos of Fish	2		0		0		0		2	6	0	0	0	6				
17. Vertical Current	1		3		1		1		6	3	15	1	3	22				
18. Active Sonar	3		0		0		0		3	9	0	0	0	9				
Layer 7 At or near the bottom, regardless of depth																		
1. Tidal Fluctuation	0	5	5	5	0	1	0	1	5	0	25		0	25		X		
2. Ambient Noise	2		0		1		1		4	10	0	1	1	12				
3. Current Direction	4		5		1		1		11	20	25	1	1	47	X	X		
4. Current Speed	4		5		1		1		11	20	25	1	1	47	X	X		
5. Salinity	4		5		1		3		13	20	25	1	3	49	X	X		
6. Sound Speed	0		5		1		1		7	0	25	1	1	27		X		
7. Water Temperature	5		5		1		3		14	25	25	1	3	54	X	X		
8. Propagation Loss	1		0		1		1		3	5	0	1	1	7				
9. Depth	5		5		4		5		19	25	25	4	5	59	X	X		
10. Water Pressure	0		5		5		1		11		25	5	1	31		X		
11. Oxygen	3		1		1		3		8	15	5	1	3	24				
12. Carbon Dioxide	2		1		0		1		4	10	5	0	1	16				
13. Phosphates	3		0		1		3		7	15	0	1	3	19				
14. Nitrates	3		0		1		2		6	15	0	1	2	18				
15. pH	3		0		0		1		4	15	0	0	1	16				
16. Nutrients	3		0		1		3		7	15	0	1	3	19				
17. Biological Growth	2		0		1		2		5	10	0	1	2	13				
18. Photos of Fish	2		0		0		0		2	10	0	0	0	10				
19. Bottom Composition	1		5		4		1		11	5	25	4	1	35		X		
20. Photos of Bottom	1		1		1		1		4	5	5	1	1	12				
21. Bathymetry	1		5		2		3		11	5	25	2	3	35		X		
22. Sediment Deposits	1		3		2		1		7	5	15	2	1	23				
23. Active Sonar	4		0		0		0		4	20	0	0	0	20	X			

TABLE 4-2
PARAMETER AND OBSERVING LAYER RELATIVE VALUES

Parameter	Agency Relative Values for Parameters and Layers								Parameter Sum	Agency Parameter x Layer Products				Sum of Parameter x Layer Products	Parameter and Layer a "Must" for			
	BCF		ESSA		NAVY		USCG											
	Par	Lyr	Par	Lyr	Par	Lyr	Par	Lyr		BCF	ESSA	NAVY	USCG		BCF	ESSA	NAVY	USCG
Layer 1 100,000 ≥ Layer > 30,000 ft																		
1. Ozone Content	0	0	5	5	1	3	0	1	6	0	25	3	0	28		X		
2. Cosmic Radiation			3		1		0		4		15	3	0	18				
3. Cloud Tops			5		3		1		9		25	9	1	35				
4. Cloud Bases			5		3		1		9		25	9	1	35		X		
5. Cloud Amount			5		3		3		11		25	9	3	37		X		
6. Wind Speed			5		2		2		9		25	6	2	33		X		
7. Wind Direction			5		2		2		9		25	6	2	33		X		
8. Air Temperature			5		3		2		10		25	9	2	36		X		
9. Height			5		4		3		12		25	12	3	40		X		
10. Atmos. Pressure			5		5		3		13		25	15	3	43		X		
11. Dew Point/Humidity			5		3		2		10		25	9	2	36		X		
Layer 2 30,000 ≥ Layer > 45 ft																		
1. Ozone Content	0	0	1	5	1	5	0	3	2	0	5	5	0	10				
2. Cosmic Radiation			1		1		0		2		5	5	0	10				
3. Cloud Tops			5		3		1		9		25	15	3	43		X		
4. Cloud Bases			5		5		1		11		25	25	3	53		X	X	
5. Cloud Amount			5		5		5		15		25	25	15	65		X	X	
6. Wind Speed			5		2		3		10		25	10	9	44		X		
7. Wind Direction			5		2		3		10		25	10	9	44		X		
8. Air Temperature			5		3		3		11		25	15	9	49		X		
9. Height			5		4		3		12		25	20	9	54		X	X	
10. Atmos. Pressure			5		5		3		13		25	25	9	59		X	X	
11. Dew Point/Humidity			5		3		2		10		25	15	6	46		X		
12. Atmos. Electricity			1		0		0		1		5	0	0	5				
Layer 3 45 ≥ Layer > 0 ft																		
1. Wind Speed	5	5	5	5	5	5	5	5	20	25	25	25	25	100	X	X	X	X
2. Wind Direction	5		5		5		5		20	25	25	25	25	100	X	X		X
3. Air Temperature	5		5		5		5		20	25	25	25	25	100	X	X	X	
4. Height	0		5		4		5		14	0	25	20	25	70		X	X	X
5. Atmos. Pressure	5		5		5		5		20	25	25	25	25	100	X	X	X	X
6. Dew Point/Humidity	5		5		5		4		19	25	25	25	20	95	X	X	X	X
7. Atmos. Electricity	0		1		1		0		2	0	5	5	0	10				
8. Insolation	5		3		3		5		16	25	15	15	25	80	X			X
9. Precipitation	4		5		3		3		15	20	25	15	15	75	X	X		
10. Visibility	0		5		3		2		10	0	25	15	10	50		X		
11. Mag. Field Declin.	0		5		2		1		8	0	25	10	5	40		X		
12. Mag. Field Inclin.	0		5		2		1		8	0	25	10	5	40		X		
13. Mag. Field Inten.	3		5		2		1		8	0	25	10	5	40		X		
14. Gravity	0		5		3		1		9	0	25	15	5	45		X		
Layer 4 0 ≥ Layer ≥ 10m																		
1. Wave Period	0	5	5	5	5	5	5	5	15	0	25	25	25	75		X	X	X
2. Wave Direction	0		5		5		5		15	0	25	25	25	75		X	X	X
3. Wave Height	0		5		5		5		15	0	25	25	25	75		X	X	X
4. Tidal Fluctuation	0		5		3		2		10	0	25	15	10	50		X		
5. Ambient Light	3		0		3		1		7	15	0	15	5	35				
6. Ambient Noise	2		0		3		1		6	10	0	15	5	30				
7. Current Direction	5		5		5		5		20	25	25	25	25	100	X	X	X	X
8. Current Speed	5		5		5		5		20	25	25	25	25	100	X	X	X	X
9. Salinity	5		5		5		5		20	25	25	25	25	100	X	X	X	X
10. Sound Speed	0		5		4		1		10	0	25	20	5	50		X	X	
11. Transparency	5		1		1		3		10	25	5	5	15	50	X			
12. Water Temperature	5		5		5		5		20	25	25	25	25	100	X	X	X	X
13. Propagation Loss	1		0		2		5		8	5	0	10	25	40				X
14. Depth	5		5		4		5		19	25	25	20	25	95	X	X	X	X
15. Water Pressure	4		5		5		2		18	0	25	25	10	60		X	X	
16. Oxygen	5		1		1		3		10	25	5	5	15	50	X			
17. Carbon Dioxide	2		1		1		1		5	10	5	5	5	25				
18. Phosphates	3		0		1		3		7	15	0	5	15	35				
19. Nitrates	3		0		1		3		7	15	0	5	15	35				
20. pH	3		0		1		2		6	15	0	5	10	30				
21. Nutrients	3		0		1		3		7	15	0	5	15	35				
22. Plankton	5		0		1		3		9	25	0	5	15	45	X			
23. Chlorophyl	3		0		1		1		5	15	0	5	5	25				
24. Biological Growth	2		0		3		2		7	10	0	15	10	35				
25. Photos of Fish	3		0		0		0		3	15	0	0	0	15				
26. Active Sonar	4		0		0		0		4	20	0	0	0	20	X			

TABLE 4-2
PARAMETER AND OBSERVING LAYER RELATIVE VALUES (Continued)

Parameter	Agency Relative Values for Parameters and Layers: BCF Par	BCF Lyr	ESSA Par	ESSA Lyr	NAVY Par	NAVY Lyr	USCG Par	USCG Lyr	Parameter Sum	Agency Parameter x Layer Products: BCF	ESSA	NAVY	USCG	Sum of Parameter x Layer Products	Parameter and Layer a "Must" for: BCF	ESSA	NAVY	USCG
Layer 5 10 < Layer < 500 m																		
Ambient Light	3	5	0	5	3	5	1	5	7	15	0	15	5	35				
2. Ambient Noise	2		0		3		1		6	10	0	15	5	30				
3. Current Direction	4		5		3		5		17	20	25	15	25	85	X	X		X
4. Current Speed	4		5		3		5		17	20	25	15	25	85	X	X		X
5. Salinity	4		5		5		5		19	20	25	25	25	95	X	X	X	X
6. Sound Speed			5		2		1		8	0	25	10	5	40		X		
7. Transparency	[illegible]		1		3		3		9	20	5	15	15	55	X			
8. Water Temperature	5		5		5		5		20	25	25	25	25	100	X	X	X	X
9. Propagation Loss	1		0		2		1		4	5	0	10	5	20				
10. Depth	5		5		4		5		19	25	25	20	25	95	X	X	X	X
11. Water Pressure	0		5		5		2		12	0	25	25	10	60		X	X	
12. Oxygen	3		5		1		3		12	15	25	5	15	60		X		
13. Carbon Dioxide	2		1		1		1		5	10	5	5	5	25				
14. Phosphates	3		0		1		3		7	15	0	5	15	35				
15. Nitrates	3		0		1		3		7	15	0	5	15	35				
16. pH	3		0		1		2		6	15	0	5	10	30				
17. Nutrients	3		0		1		3		7	15	0	5	15	35				
18. Plankton	5		0		1		3		9	25	0	5	15	45	X			
19. Chlorophyl	3		0		1		1		5	15	0	5	5	25				
20. Biological Growth	2		0		1		2		5	10	0	5	10	25				
21. Photos of Fish	2		0		0		0		2	10	0	0	0	10				
22. Vertical Current	1		3		3		1		8	5	15	15	5	40				
23. Active Sonar	4		0		0		0		4	20	0	0	0	20	X			
Layer 6 500 < Layer < 500 m																		
1. Ambient Noise	1	1	0	5	1	1	0	3	2	3	0	1	0	4				
2. Current Direction	3		5		1		2		11	9	25	1	6	41		X		
3. Current Speed	3		5		1		2		11	9	25	1	6	41		X		
4. Salinity	3		5		1		5		14	9	25	1	15	50		X		
5. Sound Speed	0		5		1		1		7	0	25	1	3	29		X		
6. Water Temperature	3		5		5		5		18	9	25	5	15	54		X		
7. Propagation Loss	1		0		1		1		3	3	0	1	3	7				
8. Depth	5		5		4		5		19	15	25	4	15	59		X		
9. Water Pressure	0		5		5		1		11	0	25	5	3	33		X		
10. Oxygen	2		1		1		3		7	6	5	1	9	21				
11. Carbon Dioxide	1		1		0		1		3	3	5	0	3	11				
12. Phosphates	2		0		1		3		7	6	0	1	9	16				
13. Nitrates	2		0		1		2		5	6	0	1	6	13				
14. pH	2		0		0		1		3	6	0	0	3	9				
15. Nutrients	2		0		1		3		6	6	0	1	9	16				
16. Photos of Fish	2		0		0		0		2	6	0	0	0	6				
17. Vertical Current	1		3		1		1		6	3	15	1	3	22				
18. Active Sonar	3		0		0		0		3	9	0	0	0	9				
Layer 7 At or near the bottom, regardless of depth																		
1. Tidal Fluctuation	0	5	5	5	0	1	0	1	5	0	25	0	0	25		X		
2. Ambient Noise	2		0		1		1		4	10	0	1	1	12				
3. Current Direction	4		5		1		1		11	20	25	1	1	47	X	X		
4. Current Speed	4		5		1		1		11	20	25	1	1	47	X	X		
5. Salinity	4		5		1		3		13	20	25	1	3	49	X	X		
6. Sound Speed	0		5		1		1		7	0	25	1	1	27		X		
7. Water Temperature	5		5		1		3		14	25	25		3	54	X	X		
8. Propagation Loss	1		0		1		1		3	5	0	1	1	7				
9. Depth	5		5		4		5		19	25	25	4	5	59	X	X		
10. Water Pressure	0		5		5		1		11	0	25	5	1	31		X		
11. Oxygen	3		1		1		3		8	15	5	1	3	24				
12. Carbon Dioxide	2		1		0		1		4	10	5	0	1	16				
13. Phosphates	3		0		1		3		7	15	0	1	3	19				
14. Nitrates	3		0		1		2		6	15	0	1	2	18				
15. pH	3		0		0		1		4	15	0	0	1	16				
16. Nutrients	3		0		1		3		7	15	0	1	3	19				
17. Biological Growth	2		0		1		2		5	10	0	1	2	13				
18. Photos of Fish	2		0		0		0		2	10	0	0	0	10				
19. Bottom Composition	1		5		4		1		11	5	25	4	1	35		X		
20. Photos of Bottom	1		1		1		1		4	5	5	1	1	12				
21. Bathymetry	1		5		2		3		11	5	25	2	3	35		X		
22. Sediment Deposits	1		3		2		1		7	5	15	2	1	23				
23. Active Sonar	4		0		0		0		4	20	0	0	0	20	X			

(maximum possible score of 20) and also the products of parameter and layer relative values for each agency and the sum of products for all four agencies (possible maximum score of 100). In addition, Table 4-2 shows by agencies which parameters were estimated as "Must Have to Satisfy Missions" in each layer. Clearly, certain parameters and certain layers have been judged more important by the agencies. The distribution of agency "Musts" is illustrated by Table 4-3 which shows for each layer the total number of parameters that are a "Must" for at least one, two, three, and four agencies. There is little question that the four agencies consider Layers 3, 4, and 5 to be the ones most important for the collection of marine data. Layers 2 and 7 are next in line, with Layers 1 and 6 last in this crude ranking.*

TABLE 4-3
DISTRIBUTION OF "MUST HAVE" PARAMETERS

Layer	Total No. of Parameters in Layers	Total No. of Parameters that are a "Must" for at least			
		1 Agency	2 Agencies	3 Agencies	4 Agencies
1	11	10			
2	12	9	4		
3	14	13	8	6	5
4	26	16	10	8	5
5	23	11	6	5	3
6	18	7			
7	23	11	5		

*Using Table 4-3 as evidence of the "popularity" of layers could lead to unfortunate consequences. For example, certain data products prepared by ESSA are based on upper air measurements to at least 100,000 feet, and ESSA has indicated that upper air measurements are a "must" in Layer 1. Thus, to provide data for important ESSA data products, data collection from Layer 1 would be required, even though Table 4-3 might be construed to suggest that the relative importance of Layer 1 is small. This difficulty of interpretation could be alleviated by including an additional weighting factor for relative worth to the nation of the missions involved. Of course, it may be difficult to find an acceptable source for such information.

Considering both layer and parameter weights, the agencies could categorize a parameter within a layer in one of 10 categories, as shown in Table 4-4. The table also shows the distribution of the layer-parameter-agency elements of the matrix of agency scores in Table 4-2. The data from Table 4-4 are plotted in Fig. 4-1 to show more clearly the distribution. It is obvious from Fig. 4-1 that all four agencies considered Layers 3, 4, and 5 of prime importance. It is also evident that, in total, more parameters (142) were scored "Must" in layers also considered "Must," than any other possible categorization. However, the next highest number of parameters in layers scored (114) was in the "Of No Value" category. This is followed in order by the categories of "Important" (81) and "Useful" (59) in Layers scored "Must". Of the 508 possible scores, 44% are "Must" or "Important" parameters in "Must" layers, and 7.3% are "Must" or "Important" parameters in "Important" layers. Of the total possible scores, 22.4% are parameters "Of No Value" to some agency.

Table 4-5 lists 35 parameters defined to be "Must" in a "Must" layer. The table also shows 20 of these parameters were judged measurable by unmanned data buoys for this cost effectiveness study.*

4.3 Cost Effectiveness Results

The agency-provided layer and parameter relative importance weightings were normalized (i.e., the weighting range was converted to 0, 1) and applied to the same eight platform capability scores that provided the basis for the cost effectiveness results in Section 3 (see Appendix A). Also, reliability, values, costs, platform mixes, and areal coverages identical to those of Section 3 were used both for DO and CNA requirements. In addition to the layer and parameter weights provided by the four agencies, an average** of the weights from the four agencies was computed. Thus,

*As NDBS development plans become firm, it is possible that other parameters (and other layers) will be included within the buoy's capability. A conservative position has been taken in this cost effectiveness study, and only those parameters for which a high probability of measurement capability exists have been given non-zero scores in the buoy capability matrix (Table A-2).

**Throughout this section, "average" refers to the results obtained using layer and parameter weightings that are the averages of the agency provided values. In no case has the arithmetical average of the 4 agencies' effectiveness values been computed or used.

TABLE 4-4
CATEGORIZATION OF PARAMETER AND LAYER WEIGHTS BY FOUR AGENCIES

Layer	Number of Parameters Scored by Category										
	Layer Category									Of No Value	Total
	Must			Important			Useful				
	Parameter Category			Parameter Category			Parameter Category				
	Must	Import.	Useful	Must	Import.	Useful	Must	Import.	Useful		
1	10	1	5	2	7	2		7	2	13	44
2	13	5	5	1	6	2				16	48
3	32	10	6							8	56
4	39	25	18							22	104
5	25	29	20							18	92
6	7	1	2	4	17	10	3		11	17	72
7	16	10	8				4	10	24	20	92
Total	142	81	59	7	30	14	7	17	37	114	508

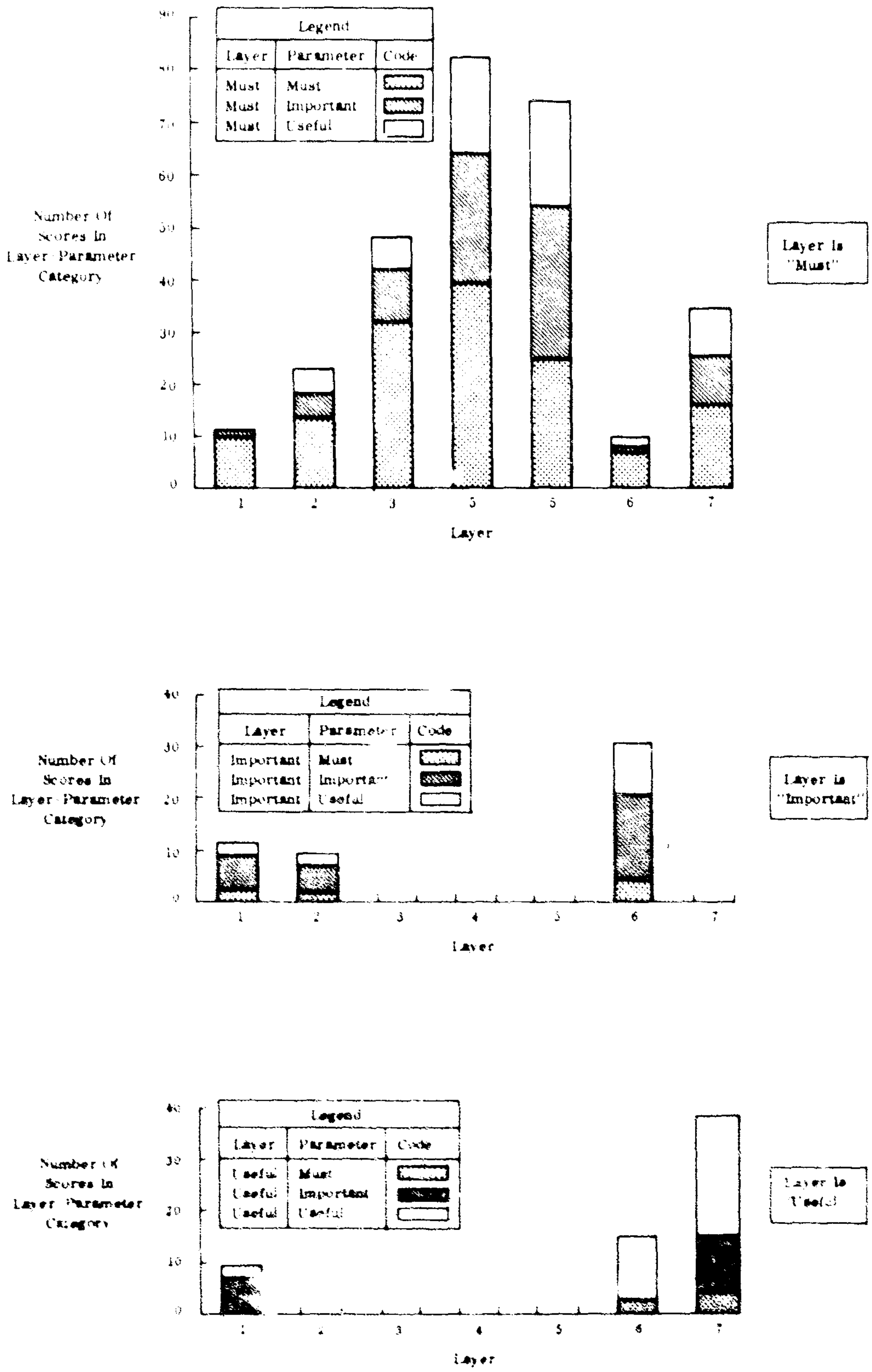


Fig. 4-1. Categorization by Agencies of Parameters and Layers

TABLE 4-5
PARAMETERS RATED "MUST" BY FOUR AGENCIES

Parameters	No. of Agencies for which the Parameter is a "Must"							Judged Measurable by Data Buoys
	Layer							
	1	2	3	4	5	6	7	
Meteorological								
1. Air Temperature	1	1	4					X
2. Atmos. Pressure	1	[illegible]	4					X
3. Cloud Amount	1	2						X
4. Cloud Bases	1	2						
5. Cloud Tops	1	1						
6. Dew Point/Humidity	1	1	4					X
7. Gravity			1					
8. Height	1	2	3					X*
9. Insolation			2					X
10. Mag. Field Declin.			1					
11. Mag. Field Inclin.			1					
12. Mag. Field Intensity			1					
13. Ozone Content	1							
14. Precipitation			2					X
15. Visibility			1					
16. Wind Direction	1	1	4					X
17. Wind Speed	1	1	4					X
Oceanographic								
18. Active Sonar				1	1		1	
19. Bathymetry							1	
20. Bottom Composition							1	
21. Current Direction				4	3	1	2	X
22. Current Speed				4	3	1	2	X
23. Depth				4	4	1	2	X**
24. Oxygen				1	1			
25. Plankton				1	1			
26. Propagation Loss				1				
27. Salinity				4	4	1	2	X
28. Sound Speed				2	1	1	[illegible]	X
29. Tidal Fluctuation				1			1	
30. Transparency				1	1			X
31. Water Pressure				2	2	1	1	X
32. Water Temperature				4	4	1	2	X
33. Wave Direction				3				X
34. Wave Height				3				X
35. Wave Period				3				X

*Obtained from atmospheric pressure measurement

**Obtained from water pressure measurement comparative results were prepared for six sets of parameter and layer weights: those weights used in Section 3; those from four agencies; and the average of the four agencies. *

The net result of the comparative effectiveness calculations for the eight platforms is given in Table 4-6 and is graphically summarized in Fig. 4-2 for Deep Ocean requirements, and in Fig. 4-3 for Coastal North America requirements. In preparing the table and these two figures, areal coverage has been assumed to be 100% for all platforms. Table 4-6 also includes effectiveness values for the mixes of platforms constituting part of the analysis in Section 3. The following conclusions can be drawn from Fig. 4-2 and 4-3.

- Use of the average of agency weights of parameters and layers produces calculated effectiveness values that are increased or essentially unchanged with respect to Section 3 values for buoys, manned buoys, and oceanographic vessels. The increase in calculated effectiveness, comparing average weight data with Section 3 values, is

Platform	Increase in Effectiveness	
	DO	CNA
Buoys	24%	20%
Manned Buoys	6.3%	0
Oceanographic Vessels	5.7%	0

The spread of agency results around the average is less than 1.4% for both manned buoys and oceanographic vessels. The spread about the average is as much as 21% (for BCF weights) for buoys.

*The computer program developed to handle the large number of calculations involved will easily accept any other combinations of parameters, layers, capabilities and relative importance weights.

TABLE 4-6
SYSTEM EFFECTIVENESS

A. Effectiveness for Deep Ocean Requirements

Platform	Effectiveness[1]					
	BCF	ESSA	USN	USCG	Avg. Weight	Sec. 3 Values
Acft of Oppor	0.0	0.108	0.124	0.048	0.077	0.083
Hor Sound Bal	0.0	0.096	0.091	0.052	0.066	0.076
Satellites	0.082	0.152	0.164	0.112	0.131	0.125
Recon Acft	0.067	0.222	0.258	0.141	0.180	0.178
Buoy	0.685	0.517	0.511	0.589	0.565	0.455
Ship of Oppor	0.537	0.629	0.729	0.619	0.635	0.619
Ocean Vessel	0.899	0.887	0.907	0.905	0.899	0.848
Manned Buoy	0.912	0.895	0.913	0.914	0.907	0.853
Platform Mixes						
Buoys, HSB	0.685	0.613	0.602	0.641	0.631	0.530
Buoys, Sats	0.685	0.613	0.538	0.628	0.626	0.531
Buoys, SOO	0.837	0.873	0.894	0.857	0.867	0.531
Sats, SOO	0.537	0.629	0.729	0.619	0.635	0.619
Sats, OSV	0.899	0.887	0.907	0.905	0.899	0.848
Sats, AOO	0.082	0.213	0.235	0.135	0.174	0.170
Sats, Recon Acft	0.129	0.276	0.318	0.193	0.237	0.223
M. Buoys, Sats	0.912	0.895	0.913	0.914	0.907	0.853
Buoys, Sats, SOO	0.837	0.873	0.894	0.857	0.867	0.804
Buoys, Sats, RA	0.696	0.717	0.727	0.680	0.705	0.615
Buoys, Sats, AOO	0.685	0.673	0.668	0.649	0.668	0.576

B. Effectiveness for Coastal North America Requirements

Platform						
Acft of Oppor	0.0	0.095	0.087	0.039	0.061	0.071
Hor Sound Bal	0.0	0.120	0.115	0.056	0.080	0.105
Satellites	0.082	0.145	0.164	0.111	0.129	0.133
Recon Acft	0.067	0.212	0.240	0.136	0.171	0.180
Buoy	0.685	0.524	0.518	0.590	0.569	0.475
Ship of Oppor	0.537	0.646	0.736	0.619	0.642	0.681
Ocean Vessel	0.899	0.904	0.914	0.905	0.906	0.910
Manned Buoy	0.912	0.912	0.919	0.914	0.914	0.916
Platform Mixes						
Buoys, HSB	0.685	0.644	0.633	0.646	0.646	0.580
Buoys, Sats	0.685	0.606	0.539	0.627	0.624	0.550
Buoys, SOO	0.837	0.890	0.901	0.857	0.874	0.867
Sats, SOO	0.537	0.646	0.736	0.619	0.642	0.681
Sats, RA	0.129	0.261	0.301	0.188	0.226	0.228
Sats, AOO	0.082	0.197	0.207	0.129	0.160	0.170

1. 100% areal coverage used to illustrate maximum possible effectiveness. The scores shown here are valid only if platforms can be deployed in sufficient numbers to achieve 100% areal coverage.

Notes:

1) Solid bars are for average of agency weights
2) x = Effectiveness from Section 3
3) △ = BCF
4) ▽ = ESSA
5) ▫ = USN
6) ∘ = USCG
7) 100% areal coverage used to illustrate maximum possible effectiveness

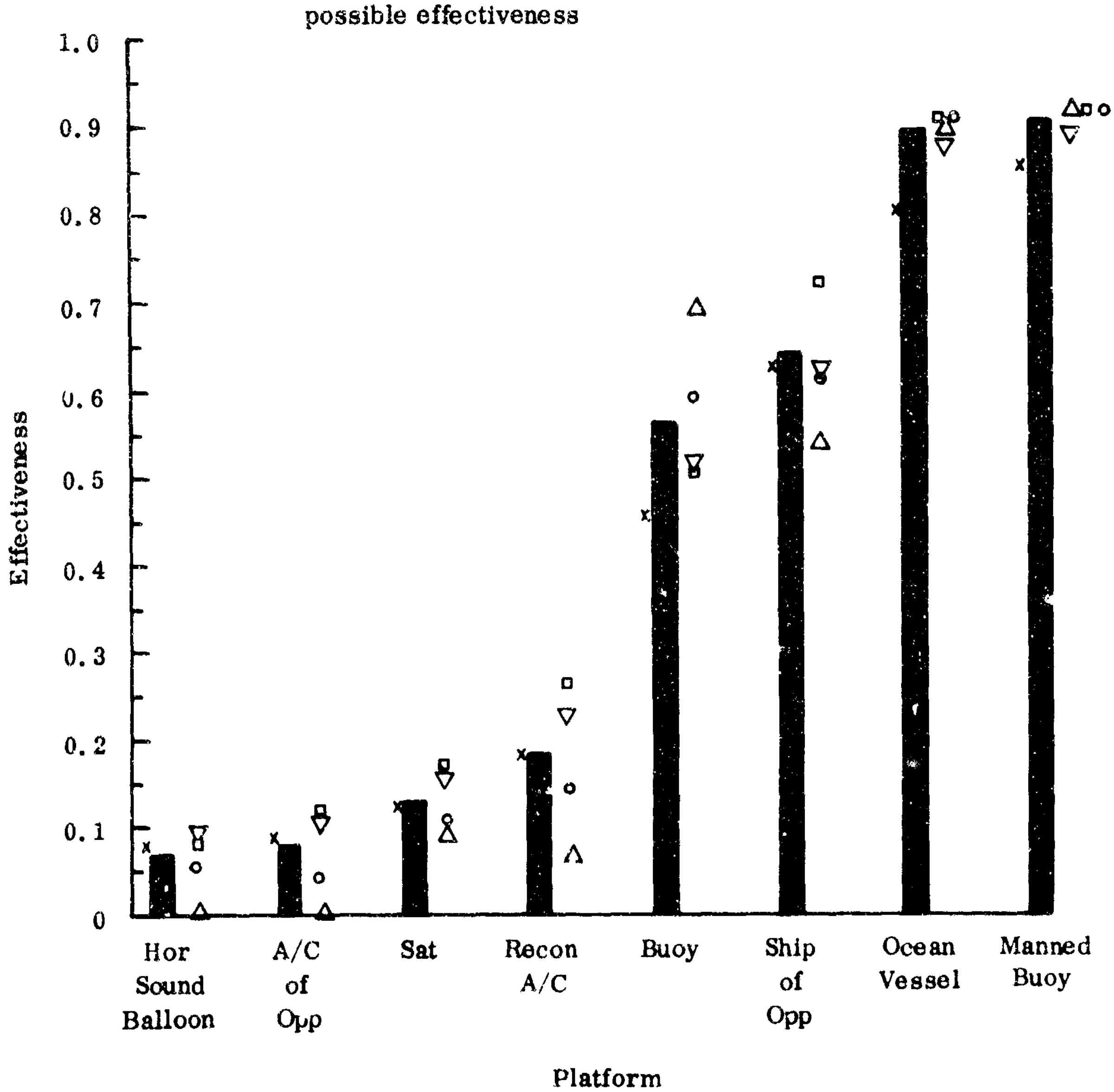


Fig. 4-2. Platform Effectiveness for Deep Ocean Requirements

Notes:

1) Solid bars are for average of agency weights
2) X = Effectiveness from Section 3
3) Δ = BCF
4) ∇ = ESSA
5) □ = USN
6) o = USCG
7) 100% areal coverage used to illustrate maximum possible effectiveness

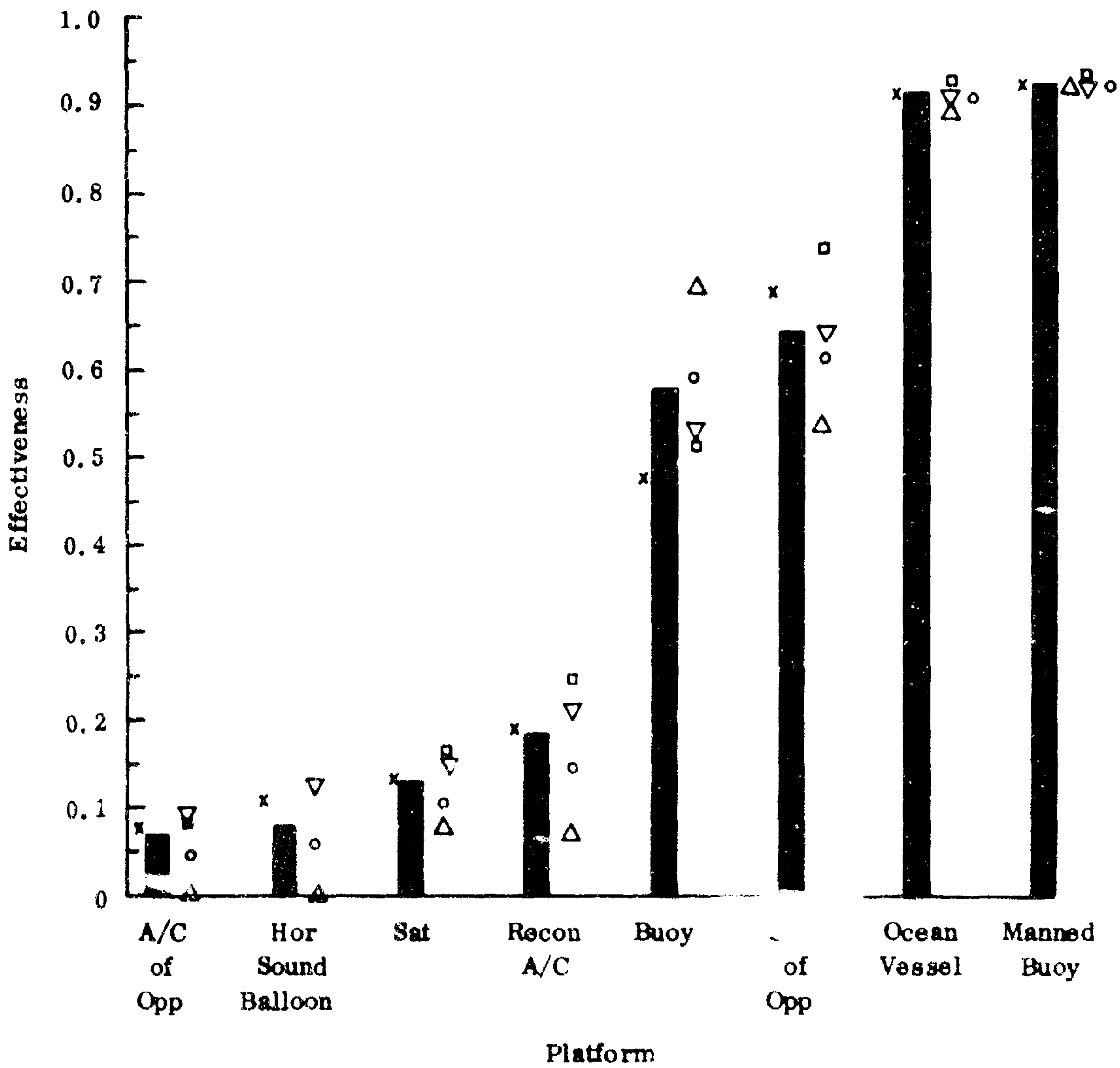


Fig. 4-3. Platform Effectiveness for Coastal North America Requirements

• For the remaining five platforms, comparison of average weight effectiveness and Section 3 values gives:

Platform	Change in Effectiveness	
	DO	CNA
Acft of Oppor	-7.2%	-14%
Hor Sound Bal	-13.0%	-24%
Satellites	4.8%	- 3%
Recon Acft	0	- 5%
Ships of Oppor	2.6%	-5.7%

In the majority of instances, it is apparent that use of agency-weighted parameters and layers results in a slight reduction in effectiveness of the above five platforms.

Using the costs noted in Section 3, and following the same computational procedures that gave rise to Figs. 3-1 and 3-11, cost effectiveness ratios have been computed for both systems of single platforms and systems of platform mixes, configures to satisfy Deep Ocean or Coastal North America operation data requirements. A graphical presentation of DO results is shown in Fig. 4-4; similar CNA results are given in Fig. 4-5.

In Figs. 4-4 and 4-5, the Section 3 results from Figs. 3-1 and 3-11 are denoted by "X's". Both DO and CNA results indicate clearly that layer and parameter weighting by agencies has produced better cost-effectiveness ratios for unmanned data buoys. In the case of systems of horizontal sounding balloons, satellites, or 100 ships of opportunity, the cost effectiveness ratio results are mixed -- better for some agency weights, poorer for others. However, when any one of these three platforms is paired with unmanned data buoys the resulting cost effectiveness ratio of the mix is a marked improvement over that of balloons, satellites, or ships of opportunity, and a reasonable improvement in mix effectiveness (about 20% in some cases, as evident from Table 4-6), compared to buoys. Of course, the total cost of the mixed systems is of the order of 75-100% greater than that of buoys alone, so the cost effectiveness ratios for the three mixes are always greater than that of unmanned buoys alone.

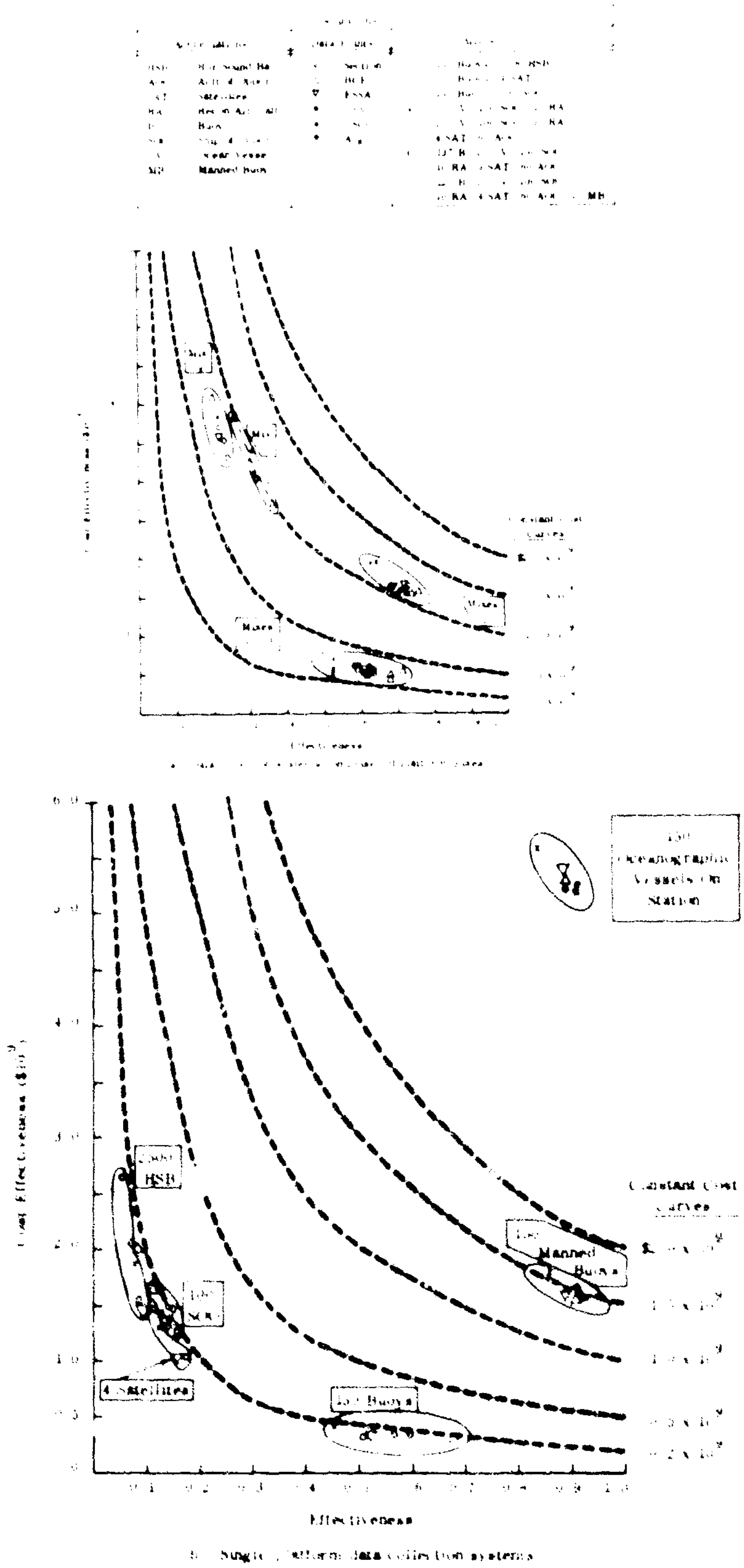


Fig. 4-4. Cost Effectiveness Ratios for Data Collection Systems Meeting Deep Ocean Operational Requirements

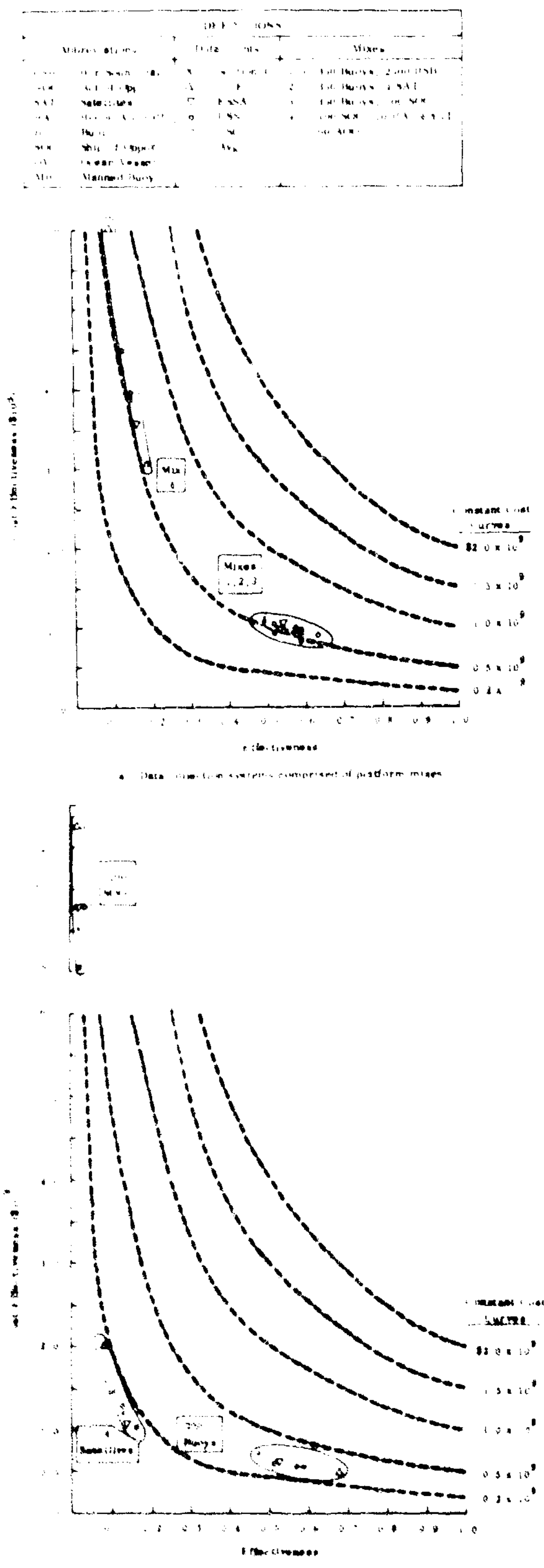


Fig. 4-5. Cost Effectiveness Ratios for Data Collection Systems Meeting Coastal North America Operational Requirements

For Deep Ocean requirement "today's" mix of platforms (Mix 4) has a cost-effectiveness ratio of the order of $\$3.5-4.0 \times 10^9$. Adding satellites and aircraft of opportunity shifts the cost effectiveness into the range $\$2.6-3.8 \times 10^9$ (Mix 5). Adding 137 or 127 unmanned buoys and 0 or 10 manned buoys, respectively, brings the cost effectiveness ratio down to about $\$1.6 \times 10^9$, in the vicinity of a system-mix effectiveness of 0.68 to 0.77 and an implementation-plus-10-year-cost of approximately $\$1.1 \times 10^9$ (Mix 6 and 7). In general, when compared to comparable Section 3 values, use of agency-provided parameter and layer weights in Mixes 6 and 7 has resulted in a reduction of approximately 18% in cost effectiveness ratio and an improvement in calculated mix effectiveness of 8 to 22%. The pattern of change is much the same for mixes of platforms used to meet Coastal North America requirements, as evident from Fig. 4-5. Plots of cost-effectiveness ratios for each set of agency-provided parameter and layer weights, the average weights across the four agencies, and the Section 3 data are presented for convenience on separate graphs in Appendix D.

4.4 Summary

The use of agency-provided parameter and layer weights afforded no new major conclusions. While changes in effectiveness could be noted, there were no drastic shifts or juxtapositioning of cost effectiveness of systems. The fact that many single-platform systems and systems comprised of mixes of platforms showed greater calculated effectiveness, and hence lower cost effectiveness ratios, indicates that in many cases the investigated systems were more closely satisfying an agency's requirements than had been evident, based on the results in Section 3. It is clear that even greater effort should be made to collect and refine agency estimates of parameter and layer weights.

5.0 CONCLUSIONS

The conclusions that can be drawn from the analyses performed for this essay must be tempered by the fact that only a limited number of options were investigated in analyzing certain mixes of observing platforms. The results obtained are based upon a cross-section of alternative mixes that are considered to be representative projections. Of course, other potential platform mixes could be specified and the results might lead to additional conclusions. The results are valid only to the degree that the assumptions and rationales are valid. In some instances where the assumptions were considered to be of critical importance, the analysis included alternatives to test the sensitivity of results to variation of the assumptions.

With the above considerations in mind, there are a number of conclusions that have been produced by this study. These are listed below:

(1) A system comprised solely of unmanned buoys is potentially capable of providing a high percentage of the observations required by several major agencies in both the Deep Ocean areas and the Coastal North America ocean area. This is particularly true for ocean-atmosphere interface and ocean layers (Layers 3, 4, 5 and 6).

(2) The cost of providing the above data is relatively low for a system of unmanned buoys, when compared with any system comprising other platform types. Buoys are the most cost effective platform type when all parameters and all layers are jointly considered.

(3) An unmanned buoy system (as viewed in this essay) is ineffective in providing data for the atmosphere above the ocean-atmosphere interface layer (Layers 1 and 2).

(4) Satellites, aircraft of opportunity, and horizontal sounding balloons can be used as complementary platform types to provide observational data for the atmosphere with essentially no redundancy between the buoy system and the non-buoy system employed.

(5) Ships of opportunity can be used to complement buoys by providing observational data for the atmosphere and they also provide an ocean observation capability that complements, to some degree, that of the buoys.

(6) Any non-buoy platform that provides a capability for measuring atmospheric parameters above the ocean-atmosphere interface when combined with buoys will improve the overall system effectiveness, but those non-buoy platforms investigated will be relatively expensive and will, therefore, cause an increase in the combined system cost effectiveness ratio.

(7) The design of a buoy system as a part of a total national marine data acquisition system is sensitive only to a very small degree to the existence of other platform types. Combining a buoy system with such complementary platforms as satellites or reconnaissance aircraft or horizontal sounding balloons or ships of opportunity produces a system with little redundancy of capabilities. Combining a buoy system with platforms such as oceanographic vessels or manned buoys would result in both highly complementary and highly redundant capabilities, if the buoys and non-buoys were collocated. However, these platforms can be controlled as to placement and would not be collocated with buoys in an effective mixed system. Because manned buoys and oceanographic vessels are each quite expensive to implement and operate, they are significantly less cost effective than buoys and would probably be used sparingly where their outstanding capabilities are of exceptional value to the composite of operational requirements

(8) Using the cost effectiveness model of this study, the reallocation of funds from unmanned buoys to any other platform type will result in a lower overall system performance. However, it is clear that the introduction of relative values of parameters, vertical layers, and geographic regions could modify this conclusion.

(9) The use of agency-provided parameter and layer weights results in increases in calculated effectiveness of unmanned data buoys (an 18-40% increase, depending on the agency). Manned buoys and oceanographic vessels showed smaller increases in effectiveness. The remaining five platforms had both increases and decreases in calculated effectiveness, depending on the agency providing the parameter and layer weights.

6.0 RECOMMENDATIONS

The following recommendations are made:

(1) Planning for a National Data Buoy System should be carried forward, considering the NDBS to be a major component of any future national marine data acquisition system.

(2) Studies should be undertaken under the appropriate government organization to determine the best composite national marine data acquisition system. Numbers and types of platforms that will be components of the overall system, and will complement the buoy system capability, should be specified after further cost effectiveness studies are completed.

(3) The cost effectiveness analysis should be extended to consider variable density networks, relative value weightings of parameters, parameter characteristics, vertical layers and specific geographical areas.

(4) The role of the NDBS in meeting the user requirements for research in all ocean areas and for operational purposes in the U. S. estuaries and Great Lakes should be specified on the basis of the refined data requirements for these uses. The DO and CNA operational data buoy systems can serve to meet some of the research requirements, but further planning is required to extend this service.

(5) The redesigned and automated cost effectiveness model should be used to facilitate studies wherein relative value weightings of parameters, parameter characteristics, vertical layers, and specific geographical areas can be considered along with variable density networks in a non-linear framework. This is suggested because the value of environmental data is generally not a linear or step function of grid mesh, vertical spacing or other characteristics of the observations. Since the relationship of value of the data to these factors is not known, it is desirable to consider the cost effectiveness of systems for a whole family of relative value curves.

(6) A study should be performed using the automated cost effectiveness model and only those parameters required to achieve selected benefits, rather than a composite set of parameter requirements for which data end-product uses are not thoroughly understood. This modification in the measure of effectiveness would make the cost effectiveness results more amenable for use in determining the benefit-to-cost ratio for selected deployment of buoys and mixes of buoys and other platforms.

7.0 REFERENCES

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APPENDIX A
PLATFORM CAPABILITY MATRICES AND SCORING RATIONALES FOR SENSITIVITY ANALYSIS

The rationales used in arriving at five-year state-of-the-art capability scores are explained here on a parameter-by-parameter basis. Although the sensitivity analysis was carried out considering the DO and CNA operational user requirements separated into six layers in the vertical, the parameters are listed here in alphabetical order with no subdivision into layers. Following the explanation of the assumed methods of measurement, Tables A-1 through A-8 contain the scores as determined for each of the six layers for each platform type.

TABLE A-1
AIRCRAFT OF OPPORTUNITY CAPABILITY MATRIX

		CHARACTERISTICS													
Layer	Parameters	Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Intensity	Temporal Sampling Intensity	Absolute X, Y Location Accuracy	Accuracy of Location in Vertical	Synchronization in Vertical	Synchronization in Horizontal	Transmission Lag	Deep Ocean Parameters Only	Deep Ocean Total Score	Coastal North America Total Score
1	Air Temp	0	1	1	1	1	1	1	1	0	1	1		9	9
	Air Press	0	1	1	1	1	1	1	1	0	1	1		9	9
	Wind Direction	0	1	1	1	1	1	1	1	0	1	1		9	9
	Wind Speed	0	1	1	1	1	1	1	1	0	1	1		9	9
	Dew Point	0	1	1	1	1	1	1	1	0	1	-		9	9
	Cosmic Radiation	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Ozone	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Cloud Tops	1	1	1	1	1	1	1	1	-	1	1	X	10	-
	Cloud Bases	1	1	1	1	1	1	1	1	-	1	1	X	10	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
2	Atmos Elec	0	0	0	0	0	0	0	0	0	0	0		0	0
	Air Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Air Press	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Dew Point	0	0	0	0	0	0	0	0	0	0	0		0	0
	Ice Crystal Size	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Cloud Tops	1	1	1	1	4	1	1	1	-	1	1	X	13	-
	Cloud B[illegible]	1	1	1	1	4	1	1	1	-	1	1	X	13	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
3	Insolation	0	0	0	0	0	0	0		-	0	0		0	0
	Precip Rate	0	0	0	0	0	0	0		-	0	0		0	0
	Visibility	0	0	0	0	0	0	0	-	-	0	0		0	0
	Air Temp	0	0	0	0	0	0	0		-	0	0		0	0
	Air Press	0	0	0	0	0	0	0		-	0	0		0	0
	Dew Point	0	0	0	0	0	0	0	-	-	0	0		0	0
	Atmos Elec	0	0	0	0	0	0	0		-	0	0		0	0
	Wind Speed	0	0	0	0	0	0	0			0	0		0	0
	Wind Direction	0	0	0	0	0	0	0		-	0	0		0	0
	Ice Crystal Size	0	0	0	0	0	0	0	0	0	0	0	X	0	-
4	Water Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wave Direction	0	0	0	0	0	0	0		-	0	0		0	0
	Wave Height	0	0	0	0	0	0	0	-		0	0		0	0
	Wave Period	0	0	0	0	0	0	0	0	0	0	0		0	0
	Salinity	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Water Pressure	0	0	0	0	0	0	0	0	0	0	0		0	0
	Ambient Light	0	0	0	0	0	0	0	-	-	0	0		0	0
	Transparency	0	0	0	0	0	0	0	-	-	0	0		0	0
	Ambient Noise	0	0	0	0	0	0	0	0	0	0	0		0	0
	Sound Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Tidal Fluctuation	0	0	0	0	0	0	0	-	-	0	0		0	0
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
5	Water Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Salinity	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Water Pressure	0	0	0	0	0	0	0	0	0	0	0		0	0
	Ambient Light	0	0	0	0	0	0	0		-	0	0		0	0
	Transparency	0	0	0	0	0	0	0	-	-	0	0		0	0
	Ambient Noise	0	0	0	0	0	0	0	0	0	0	0		0	0
	Sound Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
6	Water Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Salinity	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Water Pressure	0	0	0	0	0	0	0	0	0	0	0		0	0
	Transparency	0	0	0	0	0	0	0	-	-	0	0		0	0
	Ambient Noise	0	0	0	0	0	0	0	0	0	0	0		0	0
	Sound Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0

TABLE A-2
BUOY CAPABILITY MATRIX

Layer	Parameters	CHARACTERISTICS: Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Intensity	Temporal Sampling Intensity	Absolute X, Y Location Accuracy	Accuracy of Location in Vertical	Synchronization in Vertical	Synchronization in Horizontal	Transmission Lag	Deep Ocean Parameters Only	Deep Ocean Total Score	Coastal North America Total Score
1	Air Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Air Press	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Dew Point	0	0	0	0	0	0	0	0	0	0	0		0	0
	Cosmic Radiation	0	0	0	0	0	0	0	0	0	0	0	X	0	
	Ozone	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Cloud Tops	0	0	0	0	0	0	0	0		0	0	X	0	-
	Cloud Bases	0	0	0	0	0	0	0	0	-	0	0	X	0	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
2	Atmos Elec	0	0	0		0	0	0	0	0	0	0		0	0
	Air Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Air Press	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Dew Point	0	0	0	0	0	0	0	0	0	0	0		0	0
	Ice Crystal Size	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Cloud Tops	0	0	0	0	0	0	0	0	-	0	0	X	0	-
	Cloud Base	0	0	0	0	0	0	0	0	-	0	0	X	0	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
3	Insolation	1	1	1	1	1	1	1	-		1	1		9	9
	Precip Rate	1	1	1	1	1	1	1		-	1	1		9	9
	Visibility	0	0	0	0	0	0	0	-		0	0		0	0
	Air Temp	1	1	1	1	1	1	1	-	-	1	1		9	9
	Air Press	1	1	1	1	1	1	1			1	1		9	9
	Dew Point	1	1	1	1	1	1	1	-	-	1	1		9	9
	Atmos Elec	1	1	1	1	1	1	1			1	1		9	9
	Wind Speed	1	1	1	1	1	1	1		-	1	1		9	9
	Wind Direction	1	1	1	1	1	1	1	-		1	1		9	9
	Ice Crystal Size	0	0	0	0	0	0	0	-	-	0	0	X	0	-
4	Water Temp	1	1	1	1	2	1	1	1	1	1	1		12	12
	Wave Direction	1	1	1	1	1	1	1	-	-	1	1		9	9
	Wave Height	1	1	1	1	1	1	1	-		1	1		9	9
	Wave Period	1	1	1	1	1		1	-		1	1		9	9
	Salinity	1	1	1	1	2		1	1	1	1	1		12	12
	Current Speed	1	1	1	1	2	1	1	1	1	1	1		12	12
	Current Direction	1	1	1	1	2	1	1	1	1	1	1		12	12
	Water Pressure	1	1	1	1	2	1	1	1	1	1	1		12	12
	Ambient Light	1	1	1	1	1	1	1			1	1		9	9
	Transparency	1	1	1	1	1	1	1			1	1		9	9
	Ambient Noise	1	1	1	1	2	1	1	1	1	1	1		12	12
	Sound Speed	1	1	1	1	2	1	1	1	1	1	1		12	12
	Tidal Fluctuation	0	0	0	0	0	0	0			0	0		0	0
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
5	Water Temp	1	1	1	1	10	1	1	1	1	1	1		20	20
	Salinity	1	1	1	1	10	1	1	1	1	1	1		20	20
	Current Speed	1	1	1	1	10	1	1	1	1	1	1		20	20
	Current Direction	1	1	1	1	10	1	1	1	1	1	1		20	20
	Water Pressure	1	1	1	1	10	1	1	1	1	1	1		20	20
	Ambient Light	1	1	1	1	1	1	1			1	1		9	9
	Transparency	1	1	1	1	1	1	1			1	1		9	9
	Ambient Noise	1	1	1	1	10	1	1	1	1	1	1		20	20
	Sound Speed	1	1	1	1	10	1	1	1	1	1	1		20	20
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
6	Water Temp	1	1	1	1	8	1	1	1	1	1	1		18	18
	Salinity	1	1	1	1	8	1	1	1	1	1	1		18	18
	Current Speed	1	1	1	1	8	1	1	1	1	1	1		18	18
	Current Direction	1	1	1	1	8	1	1	1	1	1	1		18	18
	Water Pressure	1	1	1	1	8	1	1	1	1	1	1		18	18
	Transparency	1	1	1	1	1	1	1			1	1		9	9
	Ambient Noise	1	1	1	1	8	1	1	1	1	1	1		18	18
	Sound Spee	1	1	1	1	8	1	1	1	1	1	1		18	18
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0

TABLE A-3
HORIZONTAL SOUNDING BALLOON CAPABILITY MATRIX

		CHARACTERISTICS													
Layer	Parameters	Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Intensity	Temporal Sampling Intensity	Absolute X, Y Location Accuracy	Accuracy of Location in Vertical	Synchronization in Vertical	Synchronization in Horizontal	Transmission Lag	Deep Ocean Parameters Only	Deep Ocean Total Score	Coastal North America Total Score
1	Air Temp	0	1	1	1	4	1	1	1	1	1	1		13	13
	Air Press	0	1	1	1	4	1	1	1	1	1	1		13	13
	Wind Direction	0	1	1	1	4	1	1	1	1	1	1		13	13
	Wind Speed	0	1	1	1	4	1	1	1	1	1	1		13	13
	Dew Point	0	1	1	1	4	1	1	1	1	1	1		13	13
	Cosmic Radiation	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Ozone	0	1	1	1	4	1	1	1	1	1	1	X	13	-
	Cloud Tops	0	0	0	0	0	0	0	0		0	0	X	0	-
	Cloud Bases	0	0	0	0	0	0	0	0	-	0		X	0	-
	Cloud Amount	0	0	0	0	0	0	0	0	-	0	0		0	0
2	Atmos Elec	0	0	0	0	0	0	0	0	-	0	0		0	0
	Air Temp	0	1	1	1	2	1	1	1	1	1	1		11	11
	Air Press	0	1	1	1	2	1	1	1	1	1	1		11	11
	Wind Direction	0	1	1	1	2	1	1	1	1	1	1		11	11
	Wind Speed	0	1	1	1	2	1	1	1	1	1	1		11	11
	Dew Point	0	1	1	1	2	1	1	1	1	1	1		11	11
	Ice Crystal Size	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Cloud Tops	0	0	0	0	0	0	0	0	-	0	0	X	0	-
	Cloud Base	0	0	0	0	0	0	0	0	-	0	0	X	0	-
	Cloud Amount	0	0	0	0	0	0	0	0	-	0	0		0	0
3	Insolation	0	0	0	0	0	0	0	-		0	0		0	0
	Precip Rate	0	0	0	0	0	0	0	-	-	0	0		0	0
	Visibility	0	0	0	0	0	0	0	-		0	0		0	0
	Air Temp	0	0	0	0	0	0	0	-	-	0	0		0	
	Air Press	0	0	0	0	0	0	0		-	0	0		0	0
	Dew Point	0	0	0	0	0	0	0			0	0			0
	Atmos Elec	0	0	0	0	0	0	0	-		0	0		0	0
	Wind Speed	0	0	0	0	0		0		-	0	0		0	0
	Wind Direction	0	0	0	0	0	0	0			0	0		0	0
	Ice Crystal Size	0	0	0	0	0	0	0		-	0	0	X	0	-
4	Water Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wave Direction	0	0	0	0	0	0	0	-		0	0		0	0
	Wave Height	0	0	0	0	0	0	0			0	0		0	0
	Wave Period	0	0	0	0	0	0	0			0	0		0	0
	Salinity	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Water Pressure	0	0	0	0	0	0	0	0	0	0	0		0	0
	Ambient Light	0	0	0	0	0	0	0			0	0		0	0
	Transparency	0	0	0	0	0	0	0			0	0		0	0
	Ambient Noise	0	0	0	0	0	0	0	0	0	0	0		0	0
	Sound Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Tidal Fluctuation	0	0	0	0	0	0	0			0	0		0	0
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
5	Water Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Salinity	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Water Pressure	0	0	0	0	0	0	0	0	0	0	0		0	0
	Ambient Light	0	0	0	0	0	0	0			0	0		0	0
	Transparency	0	0	0	0	0	0	0			0	0		0	0
	Ambient Noise	0	0	0	0	0	0	0	0	0	0	0		0	0
	Sound Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
6	Water Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Salinity	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Water Pressure	0	0	0	0	0	0	0	0	0	0	0		0	0
	Transparency	0	0	0	0	0	0	0			0	0		0	0
	Ambient Noise	0	0	0	0	0	0	0	0	0	0	0		0	0
	Sound Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0

TABLE A-4
MANNED BUOY CAPABILITY MATRIX

Layer	Parameters	Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Intensity	Temporal Sampling Intensity	Absolute X, Y Location Accuracy	Accuracy of Location in Vertical	Synchronization in Vertical	Synchronization in Horizontal	Transmission Lag	Deep Ocean Parameters Only	Deep Ocean Total Score	Coastal North America Total Score
		CHARACTERISTICS													
1	Air Temp		1	1	1	9	1	1	1	1	1	1		19	19
	Air Press	1	1	1	1	9	1	1	1	1	1	1		19	19
	Wind Direction	1	1	1	1	9	1	1	1	1	1	1		19	19
	Wind Speed	1	1	1	1	9	1	1	1	1	1	1		19	19
	Dew Point	1	1	1	1	9	1	1	1	1	1	1		19	19
	Cosmic Radiation	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Ozone	1	1	1	1	13	1	1	1	1	1	1	X	23	-
	Cloud Tops	1	1	1	1	1	1	1	1	-	1	1	X	10	-
	Cloud Bases	1	1	1	1	1	1	1	1	-	1	1	X	10	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
2	Atmos Elec	0	0	0	0	0	0	0	0	-	0	0		0	0
	Air Temp	1	1	1	1	10	1	1	1	1	1	1		20	20
	Air Press	1	1	1	1	10	1	1	1	1	1	1		20	20
	Wind Direction	1	1	1	1	22	1	1	1	1	1	1		32	32
	Wind Speed	1	1	1	1	22	1	1	1	1	1	1		32	32
	Dew Point	1	1	1	1	10	1	1	1	1	1	1		20	20
	Ice Crystal Size	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Cloud Tops	1	1	1	1	1	1	1	1	-	1	1	X	13	-
	Cloud Base	1	1	1	1	4	1	1	1		1	1	X	13	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
3	Insolation	1	1	1	1	1	1	1	-	-	1	1		9	9
	Precip Rate	1	1	1	1	1	1	1	-	-	1	1		9	9
	Visibility	1	1	1	1	1	1		-	-	1	1		9	9
	Air Temp	1	1	1	1	1	1	1	-	-	1	1		9	9
	Air Press	1	1	1	1	1	1		-	-	1	1		9	9
	Dew Point	1	1	1	1	1	1	1	-	-	1	1		9	9
	Atmos Elec	1	1	1	1	1	1	1	-	-	1	1		9	9
	Wind Speed	1	1	1	1	1	1	1	-	-	1	1		9	9
	Wind Direction	1	1	1	1	1	1	1	-	-	1	1		9	9
	Ice Crystal Size	0	0	0	0	0	0	0	-	-	0	0	X	0	-
4	Water Temp	1	1	1	1	2	1	1	1	0	1	1		11	11
	Wave Direction	1	1	1	1	1	1	1	-	-	1	1		9	9
	Wave Height	1	1	1	1	1	1	1	-	-	1	1		9	9
	Wave Period	1	1	1	1	1	1	1	-	-	1	1		9	9
	Salinity	1	1	1	1	2	1	1	1	0	1	1		11	11
	Current Speed	1	1	1	1	2	1	1	1	0	1	1		11	11
	Current Direction	1	1	1	1	2	1	1	1	0	1	1		11	11
	Water Pressure	1	1	1	1	2	1	1	1	0	1	1		11	11
	Ambient Light	1	1	1	1	1	1	1	-	-	1	1		9	9
	Transparency	1	1	1	1	1	1	1	-	-	1	1		9	9
	Ambient Noise	1	1	1	1	2	1	1	1	0	1	1		11	11
	Sound Speed	1	1	1	1	2	1	1	1	0	1	1		11	11
	Tidal Fluctuation	0	0	0	0	0	0	0	-	-	0	0		0	0
	Chemical Factors	1	1	1	1	2	1	1	1	0	1	1		11	11
	Biological Factors	1	1	1	1	2	1	1	1	0	1	1		11	11
5	Water Temp	1	1	1	1	10	1	1	1	0	1	1		19	19
	Salinity	1	1	1	1	10	1	1	1	0	1	1		19	19
	Current Speed	1	1	1	1	10	1	1	1	0	1	1		19	19
	Current Direction	1	1	1	1	10	1	1	1	0	1	1		19	19
	Water Pressure	1	1	1	1	10	1	1	1	0	1	1		19	19
	Ambient Light	1	1	1	1	1	1	1	-	-	1	1		9	9
	Transparency	1	1	1	1	1	1	1	-	-	1	1		9	9
	Ambient Noise	1	1	1	1	10	1	1	1	0	1	1		19	19
	Sound Speed	1	1	1	1	10	1	1	1	0	1	1		19	19
	Chemical Factors	1	1	1	1	10	1	1	1	0	1	1		19	19
	Biological Factors	1	1	1	1	10	1	1	1	0	1	1		19	19
6	Water Temp	1	1	1	1	8	1	1	1	0	1	1		17	17
	Salinity	1	1	1	1	8	1	1	1	0	1	1		17	17
	Current Speed	1	1	1	1	8	1	1	1	0	1	1		17	17
	Current Direction	1	1	1	1	8	1	1	1	0	1	1		17	17
	Water Pressure	1	1	1	1	8	1	1	1	0	1	1		17	17
	Transparency	1	1	1	1	1	1	1		-	1	1		9	9
	Ambient Noise	1	1	1	1	8	1	1	1	0	1	1		17	17
	Sound Speed	1	1	1	1	8	1	1	1	0	1	1		17	17
	Chemical Factors	1	1	1	1	8	1	1	1	0	1	1		17	17
	Biological Factors	1	1	1	1	8	1	1	1	0	1	1		17	17

TABLE A-5
OCEANOGRAPHIC VESSEL CAPABILITY MATRIX

Layer	Parameters	Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Intensity	Temporal Sampling Intensity	Absolute X Y Location Accuracy	Accuracy of Location in Vertical	Synchronization in Vertical	Synchronization in Horizontal	Transmission Lag	Deep Ocean Parameters Only	Deep Ocean Total Score	Coastal North America Total Score
		CHARACTERISTICS													
1	Air Temp	1	1	1	1	9	1	1	1	1	1	1		19	19
	Air Press	1	1	1	1	9	1	1	1	1	1	1		19	19
	Wind Direction	1	1	1	1	9	1	1	1	1	1	1		19	19
	Wind Speed	1	1	1	1	9	1	1	1	1	1	1		19	19
	Dew Point	1	1	1	1	9	1	1	1	1	1	1		19	19
	Cosmic Radiation	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Ozone	1	1	1	1	13	1	1	1	1	1	1	X	23	-
	Cloud Tops	1	1	1	1	1	1	1	1	-	1	1	X	10	-
	Cloud Bases	1	1	1	1	1	1	1	1	-	1	1	X	10	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
2	Atmos Elec	0	0	0	0	0	0	0	0	-	0	0		0	0
	Air Temp	1	1	1	1	10	1	1	1	1	1	1		20	20
	Air Press	1	1	1	1	10	1	1	1	1	1	1		20	20
	Wind Direction	1	1	1	1	22	1	1	1	1	1	1		32	32
	Wind Speed	1	1	1	1	22	1	1	1	1	1	1		32	32
	Dew Point	1	1	1	1	10	1	1	1	1	1	1		20	20
	Ice Crystal Size	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Cloud Tops	1	1	1	1	4	1	1	1	-	1	1	X	13	-
	Cloud Base	1	1	1	1	4	1	1	1	-	1	1	X	13	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
3	Insolation	1	1	1	1	1	1	1	-	-	1	1		9	9
	Precip Rate	1	1	1	1	1	1	1	-	-	1	1		9	9
	Visibility	1	1	1	1	1	1	1	-	-	1	1		9	9
	Air Temp	1	1	1	1	1	1	1	-	-	1	1		9	9
	Air Press	1	1	1	1	1	1	1	-	-	1	1		9	9
	Dew Point	1	1	1	1	1	1	1	-	-	1	1		9	9
	Atmos Elec	1	1	1	1	1	1	1	-	-	1	1		9	9
	Wind Speed	1	1	1	1	1	1	1	-	-	1	1		9	9
	Wind Direction	1	1	1	1	1	1	1	-	-	1	1		9	9
	Ice Crystal Size	0	0	0	0	0	0	0	-	-	0	0	X	0	-
4	Water Temp	1	1	1	1	2	1	1	1	0	1	1		11	11
	Wave Direction	1	1	1	1	1	1	1	-	-	1	1		9	9
	Wave Height	1	1	1	1	1	1	1			1	1		9	9
	Wave Period	1	1	1	1	1	1	1		-	1	1		9	9
	Salinity	1	1	1	1	2	1	1	1	0	1	1		11	11
	Current Speed	1	1	0	1	2	1	1	1	0	1	1		10	10
	Current Direction	1	1	0	1	2	1	1	1	0	1	1		10	10
	Water Pressure	1	1	1	1	2	1	1	1	0	1	1		11	11
	Ambient Light	1	1	1	1	1	1	1			1	1		9	9
	Transparency	1	1	1	1	1	1	1		-	1	1		9	9
	Ambient Noise	1	1	1	1	2	1	1	1	0	1	1		11	11
	Sound Speed	1	1	1	1	2	1	1	1	0	1	1		11	11
	Tidal Fluctuation	0	0	0	0	0	0	0		-	0	0		0	0
	Chemical Factors	1	1	1	1	2	1	1	1	0	1	1		11	11
	Biological Factors	1	1	1	1	2	1	1	1	0	1	1		11	11
5	Water Temp	1	1	1	1	10	1	1	1	0	1	1		19	19
	Salinity	1	1	1	1	10	1	1	1	0	1	1		19	19
	Current Speed	1	1	0	1	10	1	1	1	0	1	1		18	18
	Current Direction	1	1	0	1	10	1	1	1	0	1	1		18	18
	Water Pressure	1	1	1	1	10	1	1	1	0	1	1		19	19
	Ambient Light	1	1	1	1	1	1	1			1	1		9	9
	Transparency	1	1	1	1	1	1	1			1	1		9	9
	Ambient Noise	1	1	1	1	10	1	1	1	0	1	1		19	19
	Sound Speed	1	1	1	1	10	1	1	1	0	1	1		19	19
	Chemical Factors	1	1	1	1	10	1	1	1	0	1	1		19	19
	Biological Factors	1	1	1	1	10	1	1	1	0	1	1		19	19
6	Water Temp	1	1	1	1	8	1	1	1	0	1	1		17	17
	Salinity	1	1	1	1	8	1	1	1	0	1	1		17	17
	Current Speed	1	1	0	1	8	1	1	1	0	1	1		16	16
	Current Direction	1	1	0	1	8	1	1	1	0	1	1		16	16
	Water Pressure	1	1	1	1	8	1	1	1	0	1	1		17	17
	Transparency	1	1	1	1	1	1	1	-	-	1	1		9	9
	Ambient Noise	1	1	1	1	8	1	1	1	0	1	1		17	17
	Sound Speed	1	1	1	1	8	1	1	1	0	1	1		17	17
	Chemical Factors	1	1	1	1	8	1	1	1	0	1	1		17	17
	Biological Factors	1	1	1	1	8	1	1	1	0	1	1		17	17

TABLE A-6
RECONNAISSANCE AIRCRAFT CAPABILITY MATRIX

Layer	Parameters	Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Intensity	Temporal Sampling Intensity	Absolute X, Y Location Accuracy	Accuracy of Location in Vertical	Synchronization in Vertical	Synchronization in Horizontal	Transmission Lag	Deep Ocean Parameters Only	Deep Ocean Total System	Coastal North America Total System
		CHARACTERISTICS													
1	Air Temp	0	1	1	1	6	1	1	1	1	1			15	15
	Air Press	0	1	1	1	6	1	1	1	1	1	1		16	17
	Wind Direction	0	1	1	1	1	1	1	1	0	1	1		9	9
	Wind Speed	0	1	1	1	1	1	1	1	1	1	1		9	9
	Dew Point	0	1	1	1	6	1	1	1	1	1	1		17	15
	Cosmic Radiation	0		1	1	1	1	1	1	0	1	1	X	9	
	Ozone	0	1	1	1	1	1	1	1	0	1	1	X	9	
	Cloud Tops	1	1	1	1	1	1	1	1		1	1	X	13	
	Cloud Bases	1	1	1	1	1	1	1	1		1	1	X	10	
	Cloud Amount	1	1	1	1	1	1	1			1	1		10	10
2	Atmos Elec	0	0	0	0	0	0	0	0	0	0	0		0	0
	Air Temp	0	1	1	1		1	1	1	1	1	1		16	16
	Air Press	0	1	1	1	7	1	1	1	1	1	1		16	16
	Wind Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Speed	0	0	0	0	0	0	0	0		0	0		0	0
	Dew Point	0	1	1	1	7	1	1	1	1	1	1		16	16
	Ice Crystal Size	0	0	0	0	0	0	0	0	0	0	0	X	0	
	Cloud Tops	1	1	1	1	4	1	1	1		1	1	X	13	
	Cloud Base	1	1	1	1	4	1	1	1		1	1	X	13	
	Cloud Amount	1	1	1	1	1	1	1	1		1	1		12	10
3	Insolation	0	0	0	0	0	0	0			0	0		0	0
	Precip Rate		0	0	0	0	0	0			0	0		0	0
	Visibility	0	0	0	0	0	0	0			0	0		0	0
	Air Temp	0	0	0	0	0	0	0			0	0		0	0
	Air Press	0	0	0	0	0	0	0			0	0		0	0
	Dew Point	0	0	0	0	0	0	0			0	0		0	0
	Atmos Elec	0	0	0	0	0	0	0			0	0		0	0
	Wind Speed	0	0	0	0	0	0	0			0	0		0	0
	Wind Direction	0	0	0	0	0	0	0			0	0		0	0
	Ice Crystal Size	0	0	0	0	0	0	0			0	0	X	0	
4	Water Temp	1	1		1	1	1	1	0	0	1	1		10	10
	Wave Direction	0	0		0	0	0	0			0	0		0	0
	Wave Height	0	0		0	0	0	0			0	0		0	0
	Wave Period	0		0	0	0	0				0	0		0	0
	Salinity	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Direction	0	0	0	0	0	0	0			0	0		0	0
	Water Pressure	0	0	0	0	0	0	0		0	0	0		0	0
	Ambient Light	0	0	0	0	0	0	0			0	0		0	0
	Transparency	0	0	0	0	0	0	0			0	0		0	0
	Ambient Noise	0	0	0	0	0	0	0	0	0	0	0		0	0
	Sound Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Tidal Fluctuation		0	0	0	0	0	0			0	0		0	0
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0		0	0
5	Water Temp	0	1	1	1	1	1	1	0	0	1	1		13	13
	Salinity	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Current Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Water Pressure	0	0	0	0	0	0	0	0	0	0	0		0	0
	Ambient Light	0	0	0	0	0	0	0			0	0		0	0
	Transparency	0	0	0	0	0	0	0			0	0		0	0
	Ambient Noise	0	0	0	0	0	0	0	0	0	0	0			
	Sound Speed	0	0	0	0	0	0	0	0	0	0	0			
	Chemical Factors	0	0	0	0	0	0	0	0	0	0	0		0	
	Biological Factors	0	0	0	0	0	0	0	0	0	0	0			0
6	Water Temp	0	0	0	0	0	0	0	0	0	0	0		0	0
	Salinity	0	0	0	0	0	0	0	0	0	0	0			
	Current Speed	0	0	0	0	0	0	0	0		0	0		0	0
	Current Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Water Pressure	0	0	0	0	0	0	0	0	0	0	0		0	0
	Transparency	0	0	0	0	0	0	0			0	0			0
	Ambient Noise	0	0	0	0		0	0	0	0	0	0		0	0
	Sound Speed	0	0	0	0		0	0	0	0	0	0		0	0
	Chemical Factors	0			0	0	0	0	0	0	0	0		0	
	Biological Factors	0			0	0	0	0	0	0	0	0		0	

TABLE A-7
SATELLITE CAPABILITY MATRIX

Layer	Parameters	Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Density	Temporal Sampling Interval	Absolute X, Y Location Accuracy	Accuracy of Location in Vertical	Synchronization in Vertical	Synchronization in Horizontal	Transmission Lag	Deep Ocean [illegible] Only	Deep Ocean Total Score	Coastal North America Total Score
		CHARACTERISTICS													
1	Air Temp	1	1	1	1	9	1	1	1	1	1	1		19	19
	Air Press	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Speed	0	0	0	0	0	0	0	0	0	0			0	0
	Dew Point	1	1	1	1	9	1	1	1	1	1	1		19	19
	Cosmic Radiation	0		0	0	0	0	0	0	0	0	0	X	0	-
	Ozone	1	1	1	1	13	1	1	1	1	1	1	X	23	-
	Cloud Tops	1	1	1	1	1	1	1	1	-	1	1	X	10	-
	Cloud Types	0	0	0	0	0	0	0	0		0	0	X	0	-
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
2	Atmos Elec	0	0	0	0	0	0	0	0	0	0	0		0	0
	Air Temp	1	1	1	1	10	1	1	1	1	1	1		20	20
	Air Press	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Direction	0	0	0	0	0	0	0	0	0	0	0		0	0
	Wind Speed	0	0	0	0	0	0	0	0	0	0	0		0	0
	Dew Point	1	1	1	1	10	1	1	1	1	1	1		20	20
	Ice Crystal Size	0	0	0	0	0	0	0	0	0	0	0	X	0	-
	Cloud Tops	1	1	1	1	4	1	1	1		1	1	X	13	-
	Cloud Base	0	0	0	0	0	0	0	0	-	0	0	X	0	
	Cloud Amount	1	1	1	1	1	1	1	1	-	1	1		10	10
3	Insolation	0	0	0	0		0				0	0		0	0
	Precip Rate	0	0	0	0	0	0			-	0	0		0	0
	Visibility	0	0	0	0	0	0			-	0	0		0	0
	Air Temp	1	1	1	1	1	1				1	1		9	9
	Air Press	0	0	0	0	0	0				0	0		0	0
	Dew Point	1	1	1	1	1	1				1	1		9	9
	Atmos Elec	0	0	0	0	0	0				0	0		0	0
	Wind Speed	0	0	0	0	0	0				0	0		0	0
	Wind Direction	0	0	0	0	0	0				0	0		0	0
	Ice Crystal Size	0	0	0	0	0					0	0	X	0	
4	Water Temp	1	1	0	1	1	1	[illegible]	1	[illegible]	1	1		9	9
	Wave Direction	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Wave Height	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Wave Period	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Salinity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Current Speed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Current Direction	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Water Pressure	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Ambient Light	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Transparency	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Ambient Noise	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Sound Speed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Tidal Fluctuation	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Chemical Factors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Biological Factors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
5	Water Temp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Salinity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Current Speed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Current Direction	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Water Pressure	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Ambient Light	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Transparency	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Ambient Noise	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Sound Speed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Chemical Factors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Biological Factors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
6	Water Temp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Salinity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Current Speed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Current Direction	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Water Pressure	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Transparency	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Ambient Noise	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Sound Speed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Chemical Factors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	Biological Factors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]

TABLE A-8
SHIP OF OPPORTUNITY CAPABILITY MATRIX

Layer	Parameters	Vertical Layer	Range	Accuracy	Duration	Vertical Sampling Interval	Time Sampling Interval	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] Time Lag	Derived Parameters	[illegible]	[illegible]
1	Air Temp		1		1	5								19	19
	Air Press				1	9		1	1	1	1			19	19
	Wind Direction	1		1	1	9	1	1	1	1	1	1		19	19
	Wind Speed	1		1	1	9	1	1	1	1	1	1		19	19
	Dew Point	1	1	1	1	9	1	1	1	1	1	1		19	19
	Cosmic Radiation												X		
	Ozone	1	1		1	13	1	1	1	1	1	1	X	22	
	Cloud Tops	1	1	1	1	1	1	1	1		1	1	X	13	
	Cloud Bases		1	1	1	1	1	1			1	1	X	13	
	Cloud Amount	1		1	1	1	1	1	1		1	1		1	13
2	Atmos Elec														
	Air Temp	1	1	1	1	10	1	1	1	1	1	1		20	20
	Air Press	1	1	1	1	1	1	1	1	1		1		20	20
	Wind Direction	1	1	1	1	22	1	1	1	1	1	1			22
	Wind Speed	1	1	1	1	22	1	1	1	1		1			22
	Dew Point	1	1	1	1	10	1	1	1	1	1	1			20
	Ice Crystal Size	0		0				0		0		0	X		
	Cloud Tops	1	1	1	1	4	1	1	1			1	X	13	
	Cloud Base	1	1	1	1	4	1	1	1			1	X	13	
	Cloud Amount	1	1		1	1	1	1	1			1		13	
3	Insolation	1	1	1		1	1							9	9
	Precip Rate													9	9
	Visibility													9	9
	Air Temp													9	9
	Air Press													9	9
	Dew Point													9	9
	Atmos Elec													9	9
	Wind Speed													9	9
	Wind Direction													9	9
	Ice Crystal Size												X		
4	Water Temp														11
	Wave Direction														
	Wave Height														
	Wave Period														
	Salinity													11	11
	Current Speed														
	Current Direction														
	Water Pressure													11	11
	Ambient Light														9
	Transparency														
	Ambient Noise														
	Sound Speed													11	11
	Tidal Fluctuation														
	Chemical Factors													11	11
	Biological Factors													11	11
5	Water Temp													13	13
	Salinity													13	13
	Current Speed														
	Current Direction														
	Water Pressure													13	13
	Ambient Light														
	Transparency														
	Ambient Noise														
	Sound Speed													13	13
	Chemical Factors													13	13
	Biological Factors													13	13
6	Water Temp														
	Salinity														
	Current Speed														
	Current Direction														
	Water Pressure														
	Transparency														
	Ambient Noise														
	Sound Speed														
	Chemical Factors														
	Biological Factors														

PARAMETER: AIR TEMPERATURE

PLATFORM	
Aircraft of Opportunity:	Can measure only at flight level with a platinum wire resistor that is part of a bridge network.
Buoy:	Can measure only at the surface with a platinum resistance thermometer or a thermistor.
Horizontal Sounding Balloon:	Can measure only at level it is floating in, with a rod or bead thermistor. It is planned to float balloons at six levels for the purpose of this analysis.
Manned Buoy:	Can have capability of launching rawinsonde and obtain measurements at all standard and significant levels.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	Assuming aircraft can reach at least 67,000 feet altitude over a point, measurements can be made at 13 levels by use of a dropsonde, eliminating standard levels from 30 mb to 10 mb.
Satellite:	Future capability (within 5 years) will be measurement both in clear and cloud covered regions using infrared measuring systems. Although present capability in clear regions only for 20 levels - otherwise the top of the clouds. It will not meet the absolute location accuracy requirement in the vertical because temperatures will be a mean for a layer not at a level.
Ship of Opportunity	Can have capability of launching rawinsonde and obtain measurements at all standard and significant levels.

PARAMETER: AMBIENT LIGHT

PLATFORM	
Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	Can be measured at required levels using photocells mounted on the mooring line. The primary problem will be biological fouling of the window with time.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	Can be measured at the required levels by lowering a calibrated photocell on a cable.
Oceanographic Vessel:	Same method as the Manned Buoy.
Reconnaissance Aircraft:	No capable of measuring this parameter.
Satellite:	Not capable of measuring this parameter.
Ship of Opportunity:	Can tow a photocell behind the ship to depth of about 300 feet.

PARAMETER: AMBIENT NOISE

PLATFORM	
Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	Can be measured at all required levels using calibrated hydrophones at each level on the mooring line. Appropriate filters and amplifiers are necessary to provide the measurement over the desired frequency band. Mooring line noise is a problem at the lower end of the frequency range.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	A calibrated hydrophone can be lowered to measure the ambient noise over given frequency bands. A problem here is the noise generated within the manned buoy.
Oceanographic Vessel:	Same method as the manned buoy but higher noise level of the vessel creates even more problems than the manned buoy.
Reconnaissance Aircraft:	No capability to measure this parameter.
Satellite:	No capability to measure this parameter.
Ship of Opportunity:	Ship noise and motion prevent a useful measurement of this parameter.

PARAMETER: ATMOSPHERIC ELECTRICITY

PLATFORM

Aircraft of Opportunity:	Can measure only at level at which it is flying by an antenna on the aircraft and an impedance voltage measuring circuit.
Buoy:	Can measure at the surface only with a one- or two-meter whip antenna with a radioactive button located on the tip as a pick up device. The voltage is measured between this antenna and ground by a high impedance voltage measuring circuit whose output can be digitized and transmitted.
Horizontal Sounding Balloon:	Cannot measure this parameter.
Manned Buoy:	Can measure at the surface only by same technique as buoy.
Oceanographic Vessel:	Can measure at the surface only by same technique as buoy.
Reconnaissance Aircraft:	Over a point, this parameter can be measured at flight level only by same technique as aircraft of opportunity.
Satellite:	Not capable of measuring in vertical layer required.
Ship of Opportunity:	Can measure at the surface only by same technique as on buoy.

PARAMETER: ATMOSPHERIC PRESSURE

PLATFORM

Aircraft of Opportunity: Can measure only at level at which it is flying by a bellows mechanically linked to a potentiometer.

Buoy: Can measure only at the surface by an aneroid or strain gage instrument.

Horizontal Sounding Balloon: Can measure only at level it is floating by diaphram gages (an aneroid baroswitch in particular). The plan is to have balloons floating at 6 levels.

Manned Buoy: Can have capability of launching rawinsonde and obtain measurements at all standard and significant levels.

Oceanographic Vessel: Same as Manned Buoy.

Reconnaissance Aircraft: Over a point can be measured at ~13 levels using a dropsonde.

Satellite: Does not have capability for measuring this parameter.

Ship of Opportunity: Can have capability of launching rawinsonde and obtain measurements at all standard and significant levels.

PARAMETER: BIOLOGICAL PARAMETERS

This includes a group of parameters for which we have ill-defined statements of requirements. These parameters are presently determined by taking water samples and analyzing them in a laboratory.

PLATFORM

Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	Not capable of measuring this general set of parameters.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	Can obtain water samples at desired levels using Nansen bottles and analyze the contents on board. Cannot meet the requirement for synchronization in the vertical.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	No capability for this parameter.
Satellite:	No capability for this parameter.
Ship of Opportunity:	Considered capable of taking water samples to a depth of 100 meters. Laboratory analysis capability is required on board.

PARAMETERS: CLOUD BASE AND CLOUD TOP

PLATFORM	
Aircraft of Opportunity:	Visual capability as good as or better than surface observer.
Buoy:	No capability for measuring.
Horizontal Sounding Balloon:	No measurement capability.
Manned Buoy:	Visual observation and rawinsonde temperature - dew point spreads.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	Visual observation.
Satellite:	Capable of measuring cloud tops - but not cloud bases.
Ship of Opportunity:	Visual observation and temperature - dew point spreads from rawinsonde information.

PARAMETER: CURRENT DIRECTION

PLATFORM

Aircraft of Opportunity: No ocean layer observing capability.

Buoy: Can measure at required levels using a current meter with a vane which orients itself with the flow of water past the instrument. The vane position is magnetically coupled through an aluminum pressure housing and compared with an internal magnetic compass.

Horizontal Sounding Balloon: No ocean layer observing capability.

Manned Buoy: A current meter similar to the buoy's can be lowered on a cable to determine current direction. The meter must be stopped at each level required for a period of time long enough to make a representative measurement. The synchronization requirement in the vertical cannot be met in this manner.

Oceanographic Vessel: Similar to Manned Buoy except the motion of the ship will preclude meeting the accuracy requirement.

Reconnaissance Aircraft: No capability for measuring this parameter.

Satellite: No capability for measuring this parameter.

Ship of Opportunity: The movement of the ship precludes measurement of this parameter within the range and accuracy requirements at any of the required levels.

PARAMETER: CURRENT SPEED

PLATFORM

Aircraft of Opportunity: No ocean layer observing capability.

Buoy: Can be measured by mounting current meters employing Savonius rotors at each level. The rotor turns are counted by magnetically coupling the rotation through the aluminum pressure case which creates a magnetic impulse or a switch closure.

Horizontal Sounding Balloon: No ocean layer observing capability.

Manned Buoy: A current meter similar to the buoy's can be lowered on a cable and stopped at required levels long enough to make a representative observation. The synchronization requirement in the vertical cannot be met in this manner.

Oceanographic Vessel: Similar to Manned Buoy except the motion of the ship will preclude meeting the accuracy requirement.

Reconnaissance Aircraft: No capability for measuring this parameter

Satellite: No capability for measuring this parameter.

Ship of Opportunity: The movement of the ship precludes measurement of this parameter within the range and accuracy requirements at any of the required levels.

PARAMETER: COSMIC RADIATION

PLATFORM	
Aircraft of Opportunity:	No measurement capability.
Buoy:	No measurement capability.
Horizontal Sounding Balloon:	No measurement capability.
Manned Buoy:	No measurement capability.
Oceanographic Vessel:	No measurement capability.
Reconnaissance Aircraft:	Can measure it at flight levels with a cosmic radiometer.
Satellite:	No measurement capability.
Ship of Opportunity:	No measurement capability.

PARAMETER: DEW POINT

PLATFORM	
Aircraft of Opportunity:	Can measure only at flight level with a carbon coated resistor.
Buoy:	Can measure only at surface using a device capable of producing a thermal electric or Peltier cooling effect to cool a stainless steel mirror to the dew point (saturation temperature).
Horizontal Sounding Balloon:	Can measure it only at level it is floating using a dew point hygrometer - plan is to fly balloons at 6 levels for purposes of this sensitivity essay.
Manned Buoy:	Can have capability of launching rawinsonde and obtain measurements at all standard and significant levels with a hygrometer.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	Assuming aircraft can reach 67,000 feet altitude (50 mb) over a point, we estimate this parameter can be measured using a dropsonde package containing a hygrometer at ~13 levels (eliminating levels from 30 mb to 10 mb, and some significant levels).
Satellite:	Future (5 year) capability to measure it at all levels in cloud free regions through use of a radiometer or spectrometer but limited to cloud top in cloud covered regions.
Ship of Opportunity:	Same as Manned Buoy and Oceanographic Vessel.

PARAMETER: ICE CRYSTAL SIZE

PLATFORM

Aircraft of Opportunity:	No measurement capability.
Buoy:	No measurement capability.
Horizontal Sounding Balloon:	No measurement capability.
Manned Buoy:	No measurement capability.
Oceanographic Vessel:	No measurement capability.
Reconnaissance Aircraft:	Over a point, can measure it only at flight level using a cold box.
Satellite:	No measurement capability.
Ship of Opportunity:	No measurement capability.

PARAMETER: INSOLATION

PLATFORM	
Aircraft of Opportunity:	Not capable of measuring this parameter.
Buoy:	A pyrheliometer can be mounted on the buoy to meet this requirement.
Horizontal Sounding Balloon:	No surface layer observing capability.
Manned Buoy:	Same as the buoy.
Oceanographic Vessel:	Same as the buoy.
Reconnaissance Aircraft:	Not capable of measuring this parameter at the surface.
Satellite:	The ability to infer the insolation at the surface of the earth from a satellite is not considered of sufficient accuracy to make this a meaningful observation in view of the requirement.
Ship of Opportunity:	Same as the buoy.

PARAMETER: OZONE

PLATFORM	
Aircraft of Opportunity:	No measurement capability.
Buoy:	No measurement capability.
Horizontal Sounding Balloon:	Possible to have ozonesonde on balloon and measure at 4 levels, 100 mb, 50 mb, 30 mb and 10 mb.
Manned Buoy:	Feasible to attach ozonesonde to rawinsonde balloon package and measure it at 13 levels (every 5000 feet from 40,000 to 100,000 feet).
Reconnaissance Aircraft:	Can be measured at flight levels with a spectrometer.
Oceanographic Vessel:	Same as Manned Buoy.
Satellite:	Capable of measuring at all required levels using a spectrophotometer and an ultraviolet back scatter technique.
Ship of Opportunity:	Same as Manned Buoy.

PARAMETER: PRECIPITATION RATE

PLATFORM

Aircraft of Opportunity:	Not capable of measuring this parameter.
Buoy:	Determined from sequential automated readings of a precipitation gauge.
Horizontal Sounding Balloon:	Not capable of measuring this parameter.
Manned Buoy:	Determined from sequential manual readings of a precipitation gauge.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	Not capable of measuring this parameter.
Satellite:	Not capable of measuring this parameter.
Ship of Opportunity:	Same as Manned Buoy.

PARAMETER: REFRACTIVE INDEX

PLATFORM

Aircraft of Opportunity:	Can be computed for flight level only.
Buoy:	Can be computed for surface only.
Horizontal Sounding Balloon:	Can be computed at 6 levels it is planned for balloons to fly.
Manned Buoy:	Can be computed from rawinsonde information.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	Can be computed at the 13 levels where measurements of temperature and dew point are made.
Satellite:	Temperature not measured at a level but within a layer - no capability for pressure measurement, hence no refractive index can be computed.
Ship of Opportunity:	Can be computed from rawinsonde information.

PARAMETER: SALINITY

This parameter is calculated from measurement of conductivity, temperature and pressure. Temperature and pressure measurements are required for other purposes, therefore, the conductivity measurement is the only necessary parameter to be measured specifically for salinity determination.

PLATFORM

Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	Can be determined for required levels by sensing conductivity with two toroidal-wound coils electromagnetically coupled by the sea water surrounding them, sensing temperature with a platinum resistance thermometer, and sensing pressure with a strain gauge. Salinity is computed from known relationships.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	A sensor package similar to that used on a buoy can be lowered to determine salinity at required levels. The rate of lowering is limited to $\leq$ 600 ft/min. so synchronization requirements in the vertical cannot be met.
Oceanographic Vessel.	Same as Manned Buoy.
Reconnaissance Aircraft:	No capability for observing this parameter.
Satellite:	No capability for observing this parameter.
Ship of Opportunity:	Same as Manned Buoy method but limited to about 100 meter depth (first 7 IAPSO levels).

PARAMETER: SEA STATE

PLATFORM	
Aircraft of Opportunity:	Can be visually estimated. Accuracy requirement cannot be met.
Buoy:	Can be determined from wave height and wind observations.
Horizontal Sounding Balloon:	Not capable of measuring this parameter.
Manned Buoy:	Can be visually estimated.
Oceanographic Vessel:	Can be visually estimated.
Reconnaissance Aircraft:	Can be visually estimated. Accuracy requirement ca[illegible] be met.
Satellite:	Can be determined using a radar scatterometer operating near vertical incidence at a wave length of the order of a meter.
Ship of Opportunity:	Can be visually estimated.

PARAMETER: SOUND SPEED

PLATFORM

Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	Sound speed can be determined from the salinity, temperature and pressure values using Wilson's equations or by instrumenting the mooring line with sound velocimeters.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	A sound velocimeter can be lowered from the buoy to the required levels. The vertical synchronization requirement cannot be met.
Oceanographic Vessel:	Same as the Manned Buoy.
Reconnaissance Aircraft.	No capability for measuring this parameter.
Satellite:	No capability for measuring this parameter.
Ship of Opportunity:	A sound velocimeter can be towed to a depth of about 100 meters (7 IAPSO levels). Zero scores are given for the vertical layer limitation and the inability to meet the vertical synchronization requirements.

PARAMETER: TOTAL CLOUD AMOUNT

PLATFORM

Aircraft of Opportunity:	Visual capability as good as or better than surface observer.
Buoy:	Can determine cloud cover with 180° camera equipped with an infrared sensing device.
Horizontal Sounding Balloon:	No observing capability.
Manned Buoy:	Visual observation.
Oceanographic Vessel:	Visual observation.
Reconnaissance Aircraft:	Visual observation.
Satellite:	Camera observation transmitted to ground receivers.
Ship of Opportunity:	Visual observation.

PARAMETER: TIDAL FLUCTUATION

PLATFORM

Aircraft of Opportunity:	Not capable of measuring this parameter.
Buoy:	A measurement may be made using a bottom-mounted pressure sensor. However, the best sensors available have about a 0.1% absolute accuracy. This means that the Coastal North American requirements of 0.1 foot accuracy cannot be met in water depths greater than 100 feet. The requirements for Deep Ocean tides are stated as 10% accuracy with range unknown. Deep ocean tides are apt to be of the order of a foot of variation and therefore the suggested instrumentation is not useful in depths greater than 100 feet. A measurement of lesser accuracy is considered to be of little or no value and a zero capability is given to the buoy.
Horizontal Sounding Balloon:	Not capable of measuring this parameter
Manned Buoy:	Not capable of measuring this parameter.
Oceanographic Vessel:	Not capable of measuring this parameter.
Reconnaissance Aircraft:	Not capable of measuring this parameter.
Satellite:	Not capable of measuring this parameter.
Ship of Opportunity:	Not capable of measuring this parameter.

PARAMETER: TRANSPARENCY

PLATFORM

Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	A photocell and a light source can be attached to the mooring line at the two required levels. The attenuation of light due to the water path will be a function of the photocell output. The light intensity should be monitored to detect changes in voltage for correction of the photocell output. Fouling due to marine organisms is a special problem here.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	Similar instrument package to that of a buoy but lowered on a cable to required levels.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	Not capable of measuring this parameter.
Satellite:	Not capable of measuring this parameter.
Ship of Opportunity:	An instrument similar to that used by a Manned Buoy can be towed behind the ship to a depth of 300 feet.

PARAMETER: VISIBILITY

PLATFORM	
Aircraft of Opportunity:	Can determine only at flight level.
Buoy:	No capability for determining it.
Horizontal Sounding Balloon:	No capability for determining it.
Manned Buoy:	Can determine it only at surface.
Oceanographic Vessel:	Can determine it only at surface.
Reconnaissance Aircraft:	Can determine it only at flight level.
Satellite:	Can determine it at various levels in cloud free regions only.
Ship of Opportunity:	Can determine it only at surface.

PARAMETER: WATER CHEMICALS

This includes a group of parameters for which we have ill-defined statements of requirements. Most of these parameters are presently determined by taking water samples and analyzing them in a laboratory.

PLATFORM

Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	Not capable of measuring this general set of parameters.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	Can obtain water samples at desired levels using Nansen bottles and analyze the contents on board. Cannot meet the requirements for synchronization in the vertical.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	No capability for measuring this parameter.
Satellite:	No capability for measuring this parameter.
Ship of Opportunity:	Considered capable of taking water samples to depth of 100 meters.

PARAMETER: WATER PRESSURE

PLATFORM

Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	Strain gauges can be mounted on the mooring line at the required levels.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	A strain gauge or Bourdon potentiometer can be mounted in a package lowered from the buoy. Cannot meet the requirement for synchronization in the vertical.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	No capability for measuring this parameter.
Satellite:	No capability for measuring this parameter.
Ship of Opportunity:	Considered capable of measuring water pressure down to 100 meters (7 IAPSO levels) using a strain gauge pressure element.

PARAMETER: WATER TEMPERATURE

PLATFORM	
Aircraft of Opportunity:	No ocean layer observing capability.
Buoy:	Platinum resistance units can be mounted on the mooring line at the required levels.
Horizontal Sounding Balloon:	No ocean layer observing capability.
Manned Buoy:	A thermistor or platinum resistance thermometer can be mounted in a package lowered from the buoy to the required levels. The requirement for vertical synchronization cannot be met.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	An expendable bathythermograph can be dropped from aircraft to provide water temperature readings to a depth of 1000 feet (10 IAPSO levels).
Satellite:	Infrared measurement techniques can be used to determine sea surface temperatures only. The required accuracy cannot be met however.
Ship of Opportunity:	An expendable bathythermograph can be used to obtain water temperature to a depth of 2500 feet (14 IAPSO levels).

PARAMETERS: WIND DIRECTION AND WIND SPEED

PLATFORM

Aircraft of Opportunity:	Can measure only at flight level by navigational equipment measuring ground speed and track accurately. Computing mechanisms can be placed on the aircraft to combine these measurements with true air speed and heading to give the wind vector.
Buoy:	Can measure it only at the surface with anemometers and wind vanes.
Horizontal Sounding Balloon:	Can measure only at level it is floating with tracking devices - planned to float balloons at 6 levels.
Manned Buoy:	Can have capability of launching rawinsonde and obtain measurements at all standard and significant levels.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	It can measure winds only at flight levels.
Satellite:	No wind measurement capability.
Ship of Opportunity:	Can measure at all standard and significant levels with rawinsonde launch capability.

PARAMETER: WAVE DIRECTION

PLATFORM

Aircraft of Opportunity:	Not capable of measuring this parameter.
Buoy:	The instrumentation will depend upon the buoy hull shape. On a discus buoy hull the direction can be determined from three pressure transducers located 120° apart. The record of the pressure variations at each of these transducers as a function of time will indicate the direction of propogation. The w[illegible] direction spectrum is also obtained from this measurement.
Horizontal Sounding Balloon:	Not capable of measuring this parameter.
Manned Buoy:	Obtained by visual observation.
Oceanographic Vessel:	Obtained by visual observation.
Reconnaissance Aircraft:	Not capable of measuring this parameter.
Satellite:	Not capable of measuring this parameter.
Ship of Opportunity:	Obtained by visual observation.

PARAMETER: WAVE HEIGHT

PLATFORM

Aircraft of Opportunity:	Not capable of measuring this parameter.
Buoy:	A gyroscopically stabilized accelerometer is used to measure only the vertical component of acceleration. Double integration of these acceleration values yields a time series of instantaneous displacement values that describe the ocean waves. The method assumes that the platform follows the ocean surface and cannot be applied to platforms such as spar buoys that have a large vertical damping coefficient.
Horizontal Sounding Balloon:	Not capable of measuring this parameter.
Manned Buoy:	Assuming this buoy to be a large spar buoy, the measurement may be made by attaching a pressure element at a depth on the hull greater than the largest wave expected. Another method is by means of a wave staff attached to the hull.
Oceanographic Vessel:	An arm or boom can be extended from the vessel with a resistance or capacitance probe extending through the surface of the water. The ship motion must be subtracted from the reading of this sensor by mounting a vertically stabilized accelerometer at the wave staff, double integrating its output and subtracting this signal from the wave staff signal. Another method involves mounting two vertically stabilized accelerometers below the water line on each side of the ship and double integrating to represent the ship's vertical motion. The change in water pressure on the hull is measured by two pressure sensors located at the accelerometers. The doubly integrated signal of each accelerometer is subtracted from the pressure sensor associated with it to provide a measure of the instantaneous wave elevation. The error due to roll is removed by differentially connecting the port and starboard outputs.
Reconnaissance Aircraft:	Not capable of measuring this parameter.

Satellite: Not capable of measuring this parameter.

Ship of Opportunity: Same as oceanographic vessel except that the accuracy requirement cannot be met due to the forward motion of the ship.

PARAMETER: WAVE PERIOD

PLATFORM	
Aircraft of Opportunity:	Not capable of measuring this parameter.
Buoy:	This parameter can be determined from the wave height trace.
Horizontal Sounding Balloon:	Not capable of measuring this parameter.
Manned Buoy:	Determined from the time series record of the wave height measurement.
Oceanographic Vessel:	Same as Manned Buoy.
Reconnaissance Aircraft:	Not capable of measuring this parameter.
Satellite:	Not capable of measuring this parameter.
Ship of Opportunity:	Determined from time series record of wave height measurement. A correction due to the forward motion of the ship must be applied. This motion will limit the capability of this platform to meet the accuracy requirement.

APPENDIX B
PLATFORM COST INFORMATION

Costs

The costs used in the cost effectiveness evaluation of alternative mixes of platform types, used to configure total marine data acquisition systems, were based upon projections and rationales for each platform type. The sources of the information and the rationales used are summarized here for each platform type.

Aircraft of Opportunity

Transoceanic commercial aircraft were considered here to project aircraft of opportunity capability scores. The present capability was extended to include the measurement of dew point at flight level. The cost estimated for purchase and installation of a dew point sensor was \$4000 and the expected lifetime was projected to be five years. No other costs were considered to be incurred by the marine data acquisition system.

Buoys

The source of information for buoy costs was the Technical Development Plan prepared by TRC as a part of the 1967 feasibility study. The procurement cost of 500 buoys (150 Deep Ocean and 350 Coastal North America) was estimated to be $\$250 \times 10^6$ or about \$500 K per buoy assuming a 40 foot discus-type buoy. The yearly operating cost of the 500 buoy system was estimated to be approximately $\$40 \times 10^6$ or \$80 K per year per buoy.

Thus the unit cost per ten years of operation would be:

$$\$500\ K + 10 \times \$80\ K = \$1.3 \times 10^6$$

Horizontal Sounding Balloons

The source of information was a report entitled "The Feasibility of a Global Observation and Analysis Experiment" published by the National Academy of Sciences, National Research Council in October 1965.

Several options were possible in projecting a horizontal sounding balloon system. A choice was made for a representative system to have instrumented balloons at six levels in the atmosphere (500, 300, 200, 100, 50 and 10 mb). The desired coverage was one balloon in each 500 mile square over the northern hemisphere. This requires a total of 2500 balloons aloft at any given time distributed over the six levels. The average lifetime projected for these balloons is six months at and below 100 mb and one year above 100 mb. To maintain the 2500 balloons aloft requires a total of 4500 balloons per year. The procurement costs range from $300 to $600 per balloon, depending on the flight level. The electronic packages on the balloons cost $800. Fifteen ground stations are required in the northern hemisphere for balloon launching operations. The satellites are required for tracking and readout. The resultant costs are shown below:

Balloons (4500 per year)	$ 1,500,000/year
Electronic packages (4500 per year)	3,600,000/year
Ground station operation (15 stations)	6,000,000/year
Total	$ 11,100,000/year
Satellites (2)	$ 29,000,000
Ground station initial costs	150,000
Total	$ 29,150,000

The ten-year unit costs considering a unit to consist of 2500 balloons airborne at all times is:

10 x $11,100,000 + $29,150,000 = $140,150,000.

Manned Buoys

The unit costs for manned buoys is based upon a moored buoy of the Seastation type described in a report entitled "Study of Moored Stable Platforms in Conjunction with Submarine Cables for Aviation Communications and Navigation Purposes in the Atlantic Ocean" prepared for The Ministry of Aviation by Seastation Telecommunications LTD, Greenwich and Birkenhead, dated November 1965. This manned buoy will house the crew of fifteen deemed necessary for operation and has adequate deck space for observational equipment including radiosonde launch and tracking facilities.

The initial cost per unit is approximately $\$5 \times 10^6$. It is assumed that 30 men are required per unit to maintain 15 aboard at all times. Ship time for shuttling crews and supplies is estimated as six days per month per buoy. The unit costs are therefore:

Initial procurement of buoy	\$ 5,000,000
Crew of 30 men @ \$10,000/year	300,000/year
Ship time of 6 days per month @ \$2500/day	180,000/year

Ten year operating costs are:

10 x \$480,000 + \$5,000,000 = \$9,800,000

This was rounded off to \$10 x 10^6 per 10 years.

Oceanographic Vessels

The sources of data were the costs of present day oceanographic vessels projected by Alpine Geophysical Associates and U.S. Coast Guard personnel to the 5-year state-of-the-art operation envisioned. The 10-year costs per oceanographic vessel were assumed to be:

Procurement cost for fully equipped oceanographic vessel		\$ 12,000,000
Operating cost @ \$900,000/year for 10 years		9,000,000
	Total	\$ 21,000,000

The 1967 TRC feasibility study included the assumption that two oceanographic vessels were required per grid point considering a maximum ship time at sea of 240 days per year. Part of the reasoning used was the long time spent in transit to reach the observation sites, particularly when the remote areas of the South Atlantic, South Pacific and Indian Oceans were included. In the present study we are considering only the northern hemisphere oceans with the predominantly large number of locations falling within 400 nautical miles of North America. For this reason we are considering that two sites can be manned with three ships and ignoring transit time. This assumption results in a conservatively low cost estimate for oceanographic vessels. With this assumption the unit cost to provide continuous coverage at a location at sea is 3/2 that of one vessel or \$31,500,000.

Reconnaissance Aircraft

The sources of data were personnel of the U.S. Air Force, U.S. Navy and U.S. Coast Guard interviewed on non-buoy observing equipment during the 1967 TRC feasibility study. The ten-year costs per unit are:

Procurement cost per aircraft	\$7,000,000
Yearly operating cost	\$1,400,000
Ten year total unit cost:	

$$\$7,000,000 + 10 \times \$1,400,000 = \$21 \times 10^6$$

Two aircraft were assumed to be required to have one aircraft per day operating at all times so that the unit cost used was $\$42 \times 10^6$

Satellites

The sources of data were government agency interviewees during the 1967 TRC feasibility study and TRC consultants. The projected costs for polar orbiting satellites with the projected five-year state-of-the-art capabilities used in the cost effectiveness evaluation were:

Initial procurement cost per satellite including launching cost = \$14,500,000

Ground station operation cost = \$5,000,000 per year for up to four satellites required for 100 percent coverage.

It was assumed that one replacement satellite would be required for each initial unit during the ten year period. Thus the ten year total cost for the four satellite system required for 100 percent coverage is:

$$4 \times 2 \times \$14,500,000 + 10 \times \$5,000,000 = \$166 \times 10^6$$

Ships of Opportunity

The source of the base cost data was the U.S. Coast Guard, NDBS DPO. It is understood that these costs were taken from a 1968 interagency investigation of potential future marine environmental data acquisition systems.

The unit cost for equipment for one ship of opportunity was projected to be \$95,000. The operating cost was projected to be \$185,000/yr. including two men per ship at \$10 K per year. Assuming replacement of the equipment once during the ten-year period results in a ten-year unit cost of:

$$2 \times \$95,000 + 10 \times \$185,000 = \$2,040,000 \text{ or about } \$2 \times 10^6$$

per unit per 10 years.

Summary

The above cost data were used in the cost effectiveness evaluation. Certain platforms, such as satellites and horizontal sounding balloons have ground support costs that can possibly be cost shared. Some cost sharing options were included in the evaluation. The above costs were considered to be representative for each of the platform types for purposes of the evaluation. The cost effectiveness model can be used to evaluate the alternative configurations of a marine data acquisition system with any revised or refined cost data available in the future.

APPENDIX C

THE COMPUTATION OF PLATFORM MIX EFFECTIVENESS CONSIDERING REDUNDANCY AND JOINT RELIABILITY EFFECTS

C-1.0 Introduction

The purpose of this appendix is to describe in detail two methods available for computing the total effectiveness of a mix of observing platforms throughout a prescribed geographical volume. The methods differ in the manner in which they treat redundancy among platforms.

When two or more observing platforms occupy the same geographical area, the possibility of redundant measurement of parameters exists. Redundancy is detected by comparing the observing capability of each of the platforms with one another, parameter by parameter and level by level.

The computation of the effectiveness of a mix of platforms must account for the redundancy of measurement that may exist among the platforms. In the method used for the cost-effectiveness analysis, effectiveness is computed utilizing only the non-redundant platform capabilities. In another method, the increased system reliability due to redundancy is incorporated into the effectiveness computations. The former method may be considered as a first order approximation to effectiveness and the latter, a second order approximation. Both methods are discussed herein.

In the cost-effectiveness model described in the main body of this report, the atmosphere-ocean domain has been divided into 7 layers. The layers are defined in Table 2-1. There were no stated operational requirements for Layer 7 in the Deep Ocean or Coastal North America requirement sets; hence, the cost-effectiveness analysis considered only the first 6 layers. For the purpose of this appendix, the number of layers is immaterial. A platform-mix effectiveness value is computed for each layer. The vertical dimension is then eliminated by computing a vertically averaged effectiveness for the mix. The layers may be weighted in the averaging process.

Two sets of composite, user requirements have been defined, one for the Deep Ocean area and another for the Coastal North America area. The details of these sets of requirements are given in Section 2.2. As far as the method for computing effectiveness is concerned, the details and number of requirement sets are unimportant.

Quite often a given mix of platforms will form a set of submixes when applied to a specific area; e.g., the Deep Ocean area. In one part of the Deep Ocean area, there will occur one combination of the platforms, in another, a different combination. This formation of submixes is due to the different areal coverage characteristics and mobility of the platforms.

In each submix it is necessary to assess the redundancy separately, to determine the fraction of the total area the submix occupies, and to compute a vertically averaged effectiveness.

The total platform mix effectiveness is expressed as an areally-weighted average of all the submix vertical average effectiveness values.

C-2.0 First Order Approximation to Effectiveness of a Redundant Platform Mix

We define the total effectiveness of a platform mix in a geographical volume to be

$$\bar{E} = \sum_{i=1}^{I} E_i \; A_i \qquad \text{(C-1)}$$

where I is the number of platform submixes and

$$E_i = \frac{\sum_{n=1}^{L} b_n E_{in}}{\sum_{n=1}^{L} b_n} \qquad \text{(C-2)}$$

is the vertically averaged effectiveness of Submix i with areal fraction A_i. The weight for Layer n is b_n for each of the L layers.

The layer effectiveness of Submix i comprising P platforms is given by

$$E_{in} = \sum_{m=1}^{P} \frac{C_{inm}}{C_{n\,max}} R_m \; S_m \qquad \text{(C-3)}$$

where m denotes a specific platform; R_m, the platform reliability; S_m, the platform survivability; C_{inm}, the non-redundant capability of platform m; and $C_{n\ max}$, the total possible capability in Layer n.

To compute the total effectiveness of a platform mix, the components and areal coverage of each submix it forms in the region of interest must be defined. These factors depend upon the number of each platform type in the mix, the areal coverage capability of each platform type, and the platform trajectories, if they move. The areal coverage capability of platforms has already been discussed in Section 2.4.1.4 of the main report. For some platforms, primarily the ones that do not move, there is a linear relationship between number of platforms and areal coverage because the platforms are never collocated. Satellites and reconnaissance aircraft also fall in this category. Ships of opportunity and aircraft of opportunity tend to follow fixed routes, which limits the areal coverage attainable by these platforms regardless of their number. A non-linear relationship between areal coverage and number of platforms must be defined for them because redundancy increases with the number of platforms. To simplify working with balloons, a system was defined that is assumed to give 100% areal coverage in the Deep Ocean area.

The platforms comprising a submix are determined by knowing where the platforms are or probably are. Buoys, manned buoys, and ocean vessels are stationary and their locations may be completely controlled. No combination of these platforms would ever logically be collocated because of their high mutual redundancy.

Horizontal sounding balloons, ships of opportunity, reconnaissance aircraft, satellites, and aircraft of opportunity all move. Of these, there is maximum control over reconnaissance aircraft, marginal control over balloons and satellites, and no control over ships of opportunity and aircraft of opportunity. In the mixes considered to date, the balloon system and the satellite system have each been designed to provide 100% coverage in the Deep Ocean area, hence, when they are mixed with some other platform in this area, they will always comprise a submix with that platform. The reconnaissance aircraft is usually flown to obtain atmospheric data in remote regions. We therefore exclude them in submixes with ships of opportunity, aircraft of opportunity, manned buoys, and ocean vessels, but not with satellites, balloons, or large buoy systems.

With the submixes defined, the next step toward computing the total effectiveness of a mix is to compute the layer effectiveness for all layers within a submix. Equation (C-3) indicates it is necessary to know the non-redundant platform capabilities. These are determined with the aid of Tables C-1 and C-2 which give the basic platform capabilities by layer and parameter for the Deep Ocean area and the Coastal North America area, respectively.

Assuming we are working in the Deep Ocean area, we mark the platforms in our submix on Table C-1. We select the platform with the highest reliability (reliability is indicated on the figure for each platform) and sum that platform's capability scores in Layer 1. This sum is the quantity C_{i11}. The platform with the next highest reliability is designated as Platform 2 (m = 2). The capability scores for Platform 1 are subtracted from those for Platform 2, parameter by parameter. The remainder, neglecting negative values, is summed over parameters to produce C_{i12}, the part of Platform 2 capability that is independent of Platform 1. If a third platform exists, the Platform 1 parameter scores are added to the Platform 2 remainder scores and the combined scores subtracted from the Platform 3 parameter scores. The new remainder summed over parameters is C_{i13}. New remainders are computed in this manner for the P platforms in the submix. In this study, the survivability for all platforms has been assumed equal to unity. The maximum possible layer capability scores $C_{n\ max}$ are given in the figures. For example, in the Deep Ocean area, the maximum capability for Layer 1 is $C_{1\ max} = 171$. Applying Equation (C-3), we may now compute E_{i1}.

The process described above is repeated for each of the six layers. The vertically averaged effectiveness of the submix is computed with Eqn. (C-2), using the six layer effectiveness values E_{in} and the layer weights b_n. The layer weights used in the main report are $b_1 = b_6 = 0.6$, $b_2 = b_3 = b_4 = b_5 = 1$.

A vertically averaged effectiveness is computed for all submixes of the original platform mix, each effectiveness is multiplied by its submix areal coverage, and the results are summed (Eq. C-1) to get the total system effectiveness $\bar{E}$.

Let us now consider a simple example to illustrate the computation of effectiveness of a redundant platform mix. Assume we have in the Deep Ocean area 100% coverage with buoys, 100% coverage with satellites, and 3% coverage with aircraft of opportunity. With this mix, we have two distinct submixes. In the first we have buoys

TABLE C-1
BASIC PLATFORM CAPABILITY IN THE DEEP OCEAN AREA, BY PARAMETER AND LAYER

Platform	Layer 1 Parameter Capability										Layer 2 Parameter Capability										Reliability
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Buoys	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	10	0.80
Manned Buoys	19	19	19	19	19	0	23	10	10	10	0	20	20	32	32	20	0	13	13	10	0.95
Ocean Vessels	19	19	19	19	19	0	23	10	10	10	0	20	20	32	32	20	0	13	13	10	0.95
Satellites	19	0	0	0	19	0	23	10	0	10	0	20	0	0	0	20	0	13		10	0.75
Horizontal Sound Balloons	13	13	13	13	13	0	13	0	0	0	0	11	11	11	11	11	0	0	0	0	0.70
Aircraft of Opportunity	9	9	9	9	9	0	0	10	10	10	0	0	0	0	0	0	0	13	13	10	0.95
Ships of Opportunity	19	19	19	19	19	0	23	10	10	10	0	20	20	32	32	20	0	13	13	10	0.95
Reconnaissance Aircraft	15	15	9	9	15	10	10	10	10	10	0	16	16	0	0	16	[illegible]	13	13	10	0.95
Max. Scores	19	19	19	19	19	23	23	10	10	10	15	20	20	32	32	20	16	13	13	10	
Max. Layer Score	171										191										

Platform	Layer 3 Parameter Capability										Layer 4 Parameter Capability															Reliability
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
Buoys	9	9	0	9	9	9	9	9	9	0	12	9	9	9	12	12	12	12	9	9	12	12	0	0	0	0.80
Manned Buoys	9	9	9	9	9	9	9	9	9	0	11	9	9	9	11	11	11	11	9	9	11	11	0	11	11	0.95
Ocean Vessels	9	9	9	9	9	9	9	9	9	0	11	9	9	9	11	10	10	11	9	9	11	11	0	11	11	0.95
Satellites	0	0	0	9	0	9	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75
Horizontal Sound Balloons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.70
Aircraft of Opportunity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
Ships of Opportunity	9	9	9	9	9	9	9	9	9	0	11	8	8	8	11	0	0	11	9	8	0	11	0	11	11	0.95
Reconnaissance Aircraft	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
Max. Scores	9	9	9	9	9	9	9	9	9	9	12	9	9	9	12	12	12	12	9	9	12	12	9	12	12	
Max. Layer Score	90										162															

Platform	Layer 5 Parameter Capability											Layer 6 Parameter Capability										Reliability
	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	
Buoys	20	20	20	20	20	9	9	20	20	0	0	18	18	18	18	18	9	18	18	0	0	0.80
Manned Buoys	19	19	19	19	19	9	9	19	19	19	19	19	19	19	19	19	9	19	19	19	19	0.95
Ocean Vessels	19	19	18	18	19	9	9	19	19	19	19	19	19	18	18	19	9	19	19	19	19	0.95
Satellites	0	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75
Horizontal Sound Balloons	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.70
Aircraft of Opportunity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
Ships of Opportunity	13	13	0	0	13	8	7	0	13	13	13	0	0	0	0	0	0	0	0	0	0	0.95
Reconnaissance Aircraft	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
Max. Scores	20	20	20	20	20	9	9	20	20	20	20	18	18	18	18	18	9	18	18	18	18	
Max. Layer Score	198											171										

TABLE C-2
BASIC PLATFORM CAPABILITY IN THE COASTAL NORTH AMERICA AREA, BY PARAMETER AND LAYER

Platform	Layer 1 Parameter Capability										Layer 2 Parameter Capability										Reliability
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Buoys	0	0	0	0	0					10		0	0	0	0	0				10	0.80
Manned Buoys	19	19	19	19	19					10		20	20	32	32	20				10	0.95
Ocean Vessels	19	19	19	19	19					10		20	20	32	32	20				10	0.95
Satellites	19	0	0	0	19					10		0	0	0	0	20				10	0.75
Horizontal Sound Balloons	13	13	13	13	13					0		11	11	11	11	11				0	0.70
Aircraft of Opportunity	9	9	9	9	9					10		0	0	0	0	0				10	0.95
Ships of Opportunity	19	19	19	19	19					10		20	20	32	32	20				10	0.95
Reconnaissance Aircraft	15	15	9	9	15					10		16	16	0	0	16				10	0.95
Max. Scores	19	19	19	19	19					10		20	20	32	32	20				10	
Max. Layer Score	105										134										

Platform	Layer 3 Parameter Capability										Layer 4 Parameter Capability															Reliability
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
Buoys	9	9	0	9	9	9	9	0			12	9	9	9	12	12	12	12	9	9	12	12	0	0	0	0.80
Manned Buoys	9	9	9	9	9	9	9		9		11	9	9	9	11	11	11	11	9	9	11	11	0	11	11	0.95
Ocean Vessels	9	9	9	9	9	9	9	9	9		11	9	9	9	11	10	10	11	9	9	11	11	0	11	11	0.95
Satellites	0	0	0	9	0	9	0	0	0		8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75
Horizontal Sound Balloons	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.70
Aircraft of Opportunity	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
Ships of Opportunity	9	9	9	9	9	9	9	9	9		11	8	8	8	11	0	0	11	9	8	0	11	0	11	11	0.95
Reconnaissance Aircraft	0	0	0	0	0	0	0	0	0		10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
Max. Scores	9	9	9	9	9	9	9	9	9		12	9	9	9	12	12	12	12	9	9	12	12	9	12	12	
Max. Layer Score	81										162															

Platform	Layer 5 Parameter Capability											Layer 6 Parameter Capability										Reliability
	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	
Buoys	20	20	20	20	20	9	9	20	20	0	0	18	18	18	18	18	9	18	18	0	0	0.80
Manned Buoys	19	19	19	19	19	9	9	19	19	19	19	17	17	17	17	17	9	17	17	17	17	0.95
Ocean Vessels	19	19	19	19	19	9	9	19	19	19	19	17	17	16	16	17	9	17	17	17	17	0.95
Satellites	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0.75
Horizontal Sound Balloons	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.70
Aircraft of Opportunity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
Ships of Opportunity	13	13	0	0	13	8	0	0	13	13	13	0	0	0	0	0	0	0	0	0	0	0.95
Reconnaissance Aircraft	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.95
Max. Scores	20	20	20	20	20	9	9	20	20	20	20	18	18	18	18	18	9	18	18	18	18	
Max. Layer Score	198											171										

and satellites covering 97% of the area, and in the second, we have buoys, satellites, and aircraft of opportunity covering 3% of the area.

The non-redundant Layer 1 parameter capabilities for Submix 1 are shown in Table C-3. They were obtained from Table C-1 in the following manner. Of the two platforms in Submix 1, buoys have the higher reliability; hence, buoys are assigned m = 1 and satellites, m = 2. In the column marked Layer 1 in Table C-1, buoys are seen to have capability only for Parameter 10. This capability, which has a value of 10, is entered in Column 10 in Table C-3 for buoys. We now subtract the buoy capability from the satellite capability in Table C-1. This eliminates the satellite capability of 10 for Parameter 10. The remaining satellite capabilities are entered in the corresponding locations in Table C-3. The buoy effectiveness in Layer 1 for Submix 1 is then given by

$$\frac{C_{111}}{C_{1\,max}} R_1 S_1 = \frac{10}{171} \times 0.80 \times 1 = 0.05$$

The corresponding satellite effectiveness is

$$\frac{C_{112}}{C_{1\,max}} R_2 S_2 = \frac{71}{171} \times 0.75 \times 1 = 0.31$$

The effectiveness of Submix 1 in Layer 1 by Equation (C-3) is

$$E_{11} = 0.05 + 0.31 = 0.36.$$

This value is entered in Table C-5 in the column for Layer 1 and the row for Submix 1. Corresponding Submix 1 effectiveness values for the other layers were computed in a similar manner and entered in Table C-5. By applying Equation (C-2) with the weights $b_1 = b_6 = 0.6$, $b_2 = b_3 = b_4 = b_5 = 1.0$, we compute the vertically averaged effectiveness of Submix 1 to be $E_1 = 0.53$. This value is entered in Table C-5 in the column marked E_i.

TABLE C-3
NON-REDUNDANT PLATFORM CAPABILITIES IN LAYER 1 FOR SUBMIX 1
OF THE ILLUSTRATIVE BUOY, SATELLITE, AND AIRCRAFT OF
OPPORTUNITY MIX IN THE DEEP OCEAN AREA

m	Submix 1 Platforms	Layer 1 Parameter Capabilities										R_m
		1	2	3	4	5	6	7	8	9	10	
1	Buoys										10	0.80
2	Satellites	19				19		23	10			0.75

The non-redundant Layer 1 parameter capabilities for Submix 2 are shown in Table C-4. In this submix, aircraft of opportunity have the highest reliability, buoys, the second highest, and satellites, the smallest. The capabilities for aircraft of opportunity in Table C-4 were taken directly from Table C-1. The second platform, buoys, contribute nothing new in this layer so the aircraft of opportunity capabilities are subtracted from the satellite capabilities. The resulting non-redundant satellite parameter capabilities are 10 for Parameters 1 and 5, and 23 for Parameter 7. These values are entered in the satellite row in Table C-4. The aircraft of opportunity effectiveness in Layer 1 for Submix 2 is given by

$$\frac{C_{211}}{C_{1\ max}} R_1 S_1 = \frac{75}{171} \times 0.95 \times 1.0 = 0.42$$

The corresponding buoy effectiveness is

$$\frac{C_{212}}{C_{1\ max}} R_2 S_2 = \frac{0}{171} \times 0.80 \times 1.0 = 0$$

For satellites we get

$$\frac{C_{213}}{C_{\ max}} R_3 S_3 = \frac{43}{171} \times 0.75 \times 1.0 = 0.19$$

The effectiveness of Submix 2 in Layer 1 by Eq. (C-3) is

$$E_{21} = 0.42 + 0 + 0.19 = 0.61.$$

This value is entered in Table C-5 in the column for Layer 1 and the row for Submix 2. Corresponding Submix 2 effectiveness values for the other layers were computed in a similar manner and entered in Table C-5. The vertically averaged effectiveness of Submix 2, using these values and Eq. (C-2) is computed to be $E_2 = 0.57$. This value is entered in Table C-5 in the column marked E_i.

TABLE C-4
NON-REDUNDANT PLATFORM CAPABILITIES IN LAYER 1 FOR SUBMIX 2
OF THE ILLUSTRATIVE BUOY, SATELLITE, AND AIRCRAFT OF
OPPORTUNITY MIX IN THE DEEP OCEAN AREA

m	Submix 2 Platforms	Layer 1 Parameter Capabilities										R_m
		1	2	3	4	5	6	7	8	9	10	
1	Acft of Oppor	9	9	9	9	9			10	10	10	0.95
2	Buoys											0.80
3	Satellites	10				10		23				0.75

TABLE C-5
NON-REDUNDANT LAYER EFFECTIVENESS, VERTICALLY AVERAGED
EFFECTIVENESS, AND AREAL COVERAGE FOR SUBMIXES 1 AND 2
OF THE ILLUSTRATIVE BUOY, SATELLITE, AND AIRCRAFT OF
OPPORTUNITY MIX IN THE DEEP OCEAN AREA

Submix	E_{in}						E_i	A_i
	1	2	3	4	5	6		
1	0.36	0.25	0.64	0.64	0.64	0.63	0.53	0.97
2	0.61	0.29	0.64	0.64	0.64	0.63	0.57	0.03

The total effectiveness of the original platform mix over the entire Deep Ocean area is, by Eq. C-1,

$$\overline{E} = E_1A_1 + E_2A_2 = 0.53 \times 0.97 + 0.57 \times 0.03 = 0.53 .$$

C-3.0 Second Order Approximation to Effectiveness of a Redundant Platform Mix

Redundancy implies an increase in platform-mix effectiveness because the reliability of the mix is increased for those parameters that are redundantly measured. The method for computing this increase, which is ordinarily a second order effect, is discussed below.

To determine the effect of redundancy on mix effectiveness, we must examine the parameter capabilities of each of the platforms in a submix and compute modified reliabilities for the redundantly measured portions of each parameter, depending upon the combination of platforms involved. The basic data to do this for the Deep Ocean area is found in Table C-1, and for the Coastal North America, in Table C-2.

To compute the modified reliabilities, we may consider reliability as the probability that a platform will perform its function. From basic probability theory, where two platforms are redundant, the probability that a parameter will be measured by one platform or in the event of failure of that platform, by a second platform is given by $R_{12} = R_1 + \overline{R}_1R_2$ where $\overline{R}_1$ denotes $(1 - R_1)$. Where three platforms are redundant, $R_{123} = R_1 + \overline{R}_1R_2 + \overline{R}_1\overline{R}_2R_3$. Where N platforms are redundant, the reliability is

$$R_k = R_{12\cdots N} = R_1 + \overline{R}_1R_2 + \overline{R}_1\overline{R}_2R_3 + \ldots \prod_{i=1}^{N-1} \overline{R}_i \, R_N. \qquad \text{(C-4)}$$

The layer effectiveness of a submix is now given by

$$E_{in} = \frac{\sum_{k=1}^{K} \sum_{p=1}^{Q} C_{inpk} \, R_k}{C_{n\,max}}, \qquad \text{(C-5)}$$

where R_k the reliability of a given combination of platforms is given by Eq. (C-4), p is the parameter number for the Q parameters in layer n, and C_{inpk} is the capability provided by platform combination k. Total effectiveness is computed from Eq. (C-1), (C-2), and (C-5).

To illustrate this method, let us choose the same mix used in the previous section. Again we have two submixes, one with buoys and satellites comprising 97% of the Deep Ocean area, and other with buoys, satellites, and aircraft of opportunity comprising 3% of the area.

The Submix 1 parameter capabilities for Layer 1, separated according to the various platform combinations possible between buoys and satellites, are shown in Table C-6. These values were extracted from Table C-1. Satellites alone provide all the capability except for Parameter 10 which is measured equally well by satellites and buoys. The reliability of the buoy-satellite combination is $R_3 = 0.80 + 0.20 \times 0.75 = 0.95$.

According to Eq. (C-5), the effectiveness of Submix 1 in Layer 1 is

$$E_{11} = \frac{0 \times 0.80 + 71 \times 0.75 + 10 \times 0.95}{171} = 0.37 .$$

This value is entered in Table C-8 for Layer 1, Submix 1. In a similar manner, the layer effectiveness was computed for the other layers and the values entered in Table C-8. The vertically averaged effectiveness of Submix 1, computed by means of Eq. (C-2) with the previously used layer weights, is 0.54. This value is entered in Table C-8 in the E_i column. Note this is only 0.01 larger than the corresponding value in Table C-5 which gives results for the method using only non-redundant capabilities.

The Submix 2 parameter capabilities for Layer 1, separated according to the seven platform combinations possible among buoy[illegible], and aircraft of opportunity, are shown in Table C-7. These values were extracted from Table C-1. Buoys alone make no independent contribution to the submix capability. Satellites make independent contributions through Parameters 1, 5, and 7. Aircraft of opportunity make independent contributions through Parameters 2, 3, 4, and 9. Satellites and aircraft of opportunity share a common capability of 9 for Parameters 1 and 5, and 10 for

TABLE C-6
PLATFORM COMBINATION CAPABILITIES AND MODIFIED RELIABILITIES IN LAYER 1 FOR SUBMIX 1 OF THE ILLUSTRATIVE BUOY, SATELLITE, AND AIRCRAFT OF OPPORTUNITY MIX IN THE DEEP OCEAN AREA

k	Submix 1 Platform Combinations	Layer 1 Parameter Capabilities										R_k
		1	2	3	4	5	6	7	8	9	10	
1	Buoys											0.80
2	Satellites	19				19		23	10			0.75
3	Buoys and Satellites										10	0.80 + 0.20 x 0.75 = 0.95

TABLE C-7
PLATFORM COMBINATION CAPABILITIES AND MODIFIED RELIABILITIES IN LAYER 1 FOR SUBMIX 2 OF THE ILLUSTRATIVE BUOY, SATELLITE, AND AIRCRAFT OF OPPORTUNITY MIX IN THE DEEP OCEAN AREA

k	Submix 2 Platform Combinations	Layer 1 Parameter Capabilities										R_k
		1	2	3	4	5	6	7	8	9	10	
1	Buoys											0.80
2	Satellites	10				10		23				0.75
3	Acft of Oppor		9	9	9					10		0.95
4	Buoys and Satellites											0.80 + 0.20 x 0.75 = 0.95
5	Buoys and Acft of Oppor											0.80 + 0.20 x 0.75 = 0.99
6	Satellites and Acft of Oppor	9				9			10			0.75 + 0.25 x 0.95 = 0.99
7	Buoys, Satellites and Acft of Oppor											0.80 + 0.20 x 0.75 + 0.20 x 0.25 x 0.95 = 1.00

TABLE C-8
LAYER EFFECTIVENESS, VERTICALLY AVERAGED EFFECTIVENESS, AND AREAL COVERAGE, INCORPORATING REDUNDANCY MODIFIED RELIABILITIES, FOR SUBMIXES 1 AND 2 OF THE ILLUSTRATIVE BUOY, SATELLITE, AND AIRCRAFT OF OPPORTUNITY MIX IN THE DEEP OCEAN AREA

Submix	E_{in}						E_i	A_i
	1	2	3	4	5	6		
1	0.37	0.26	0.67	0.64	0.64	0.63	0.54	0.97
2	0.61	0.34	0.67	0.64	0.64	0.63	0.58	0.03

Parameter 8. The three platforms all measure Parameter 10 with a capability of 10. Reliabilities for the various platform combinations were computed according to Eq. (C-4) and entered in Table C-7 in the R_k column.

The effectiveness of Submix 2 in Layer 1, according to Eq. C-5, is

$$E_{21} = \frac{0 \times 0.80 + 43 \times 0.75 + 37 \times 0.95 + 0 \times 0.95 + 0 \times 0.99 + 28 \times 0.99 + 10 \times 1.00}{171} = 0.61$$

This value is entered in Table C-8 for Layer 1, Submix 2. In a similar manner, the layer effectiveness was computed for the other layers and the values entered in Table C-8. The vertically averaged effectiveness of Submix 2, computed with Eq. (C-2) and the standard weights, is 0.58. This value is entered in Table C-8 in the E_i column.

The total effectiveness of the mix, from Eq (C-1) and the data in Table C-8, is

$$\bar{E} = E_1 A_1 + E_2 A_2 = 0.54 \times 0.97 + 0.58 \times 0.03 = 0.54.$$

This value is only 0.01 larger than the previously computed total effectiveness using the non-redundant capability method of the previous section. Because the differences tend to be small, the non-redundant method, which is easier to apply with manual computation methods, was used for the cost-effectiveness studies described in the main report.*

*The additional work done for this report (Section 4) was computerized, therefore, all future cost effectiveness work will incorporate redundancy-modified reliabilities.

APPENDIX D

COMPARISON OF COST EFFECTIVENESS RATIOS USING AGENCY - PROVIDED PARAMETER AND LAYER WEIGHTS

Definitions			
Abbreviations		Mixes	
HSB	= Hor Sound Bal	1	= 150 Buoys, 2500 HSB
AOO	= Acft of Oppor	2	= 150 Buoys, 4 SAT
SAT	= Satellites	3	= 150 Buoys, 100 SOO
RA	= Recon Aircraft	4	= 20 OV, 100 SOO, 10 RA
B	= Buoys	5	= 20 OV, 100 SOO, 10 RA 4 SAT, 60 AOO
SOO	= Ship of Oppor	6	= 137 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO
OV	= Ocean Vessel	7	= 127 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO, 10 MB
MB	= Manned Buoy		

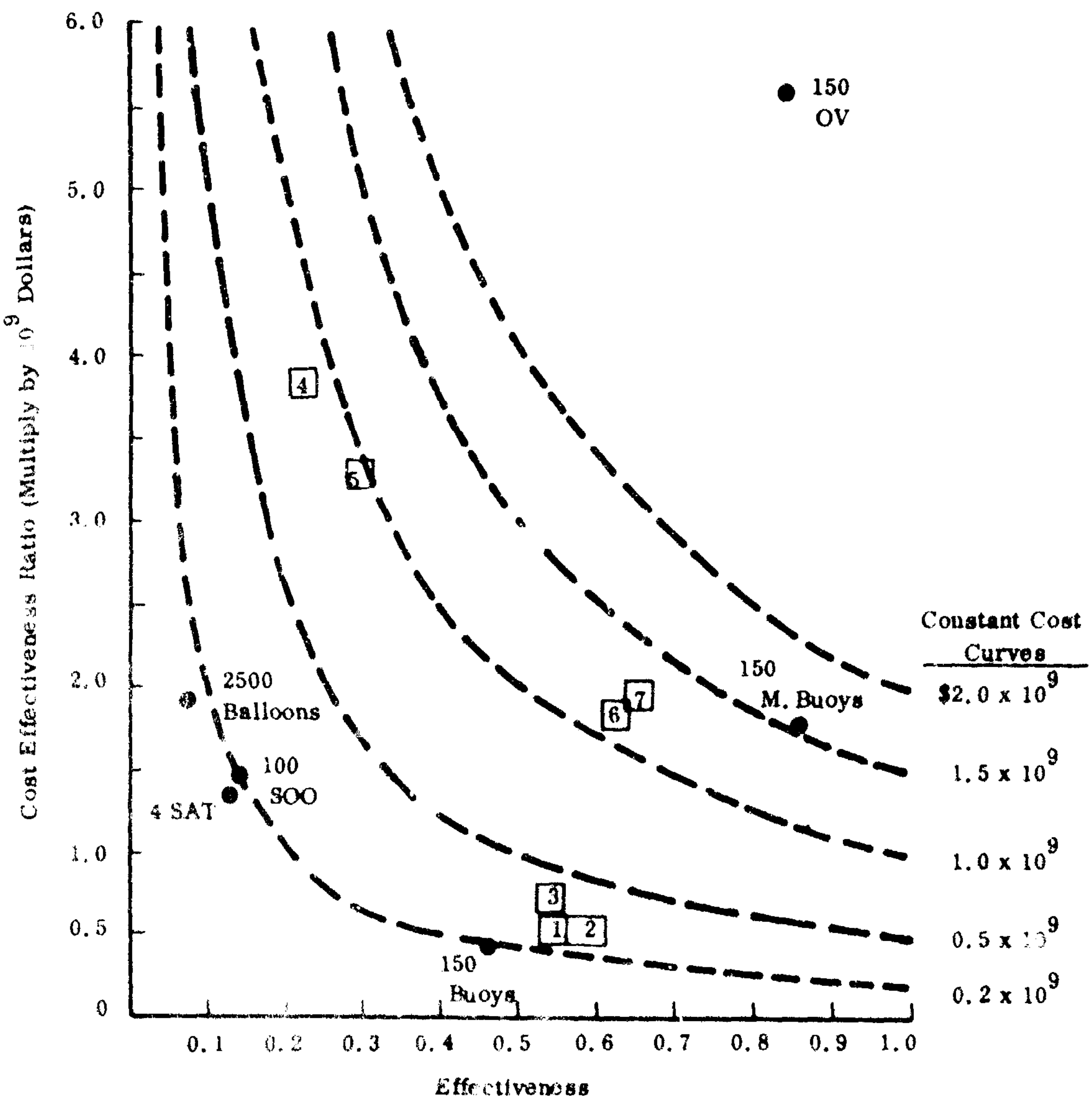


Fig. D-1. Comparison of Cost Effectiveness Ratios of Deep Ocean Systems Using Section 3 Parameter and Layer Weights

Definitions	
Abbreviations	Mixes
HSB = Hor Sound Bal AOO = Acft of Oppor SAT = Satellites RA = Recon Aircraft B = Buoys SOO = Ship of Oppor OV = Ocean Vessel MB = Manned Buoy	1 = 150 Buoys, 2500 HSB 2 = 150 Buoys, 4 SAT 3 = 150 Buoys, 100 SOO 4 = 20 OV, 100 SOO, 10 RA 5 = 20 OV, 100 SOO, 10 RA 4 SAT, 60 AOO 6 = 137 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO 7 = 127 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO, 10 MB

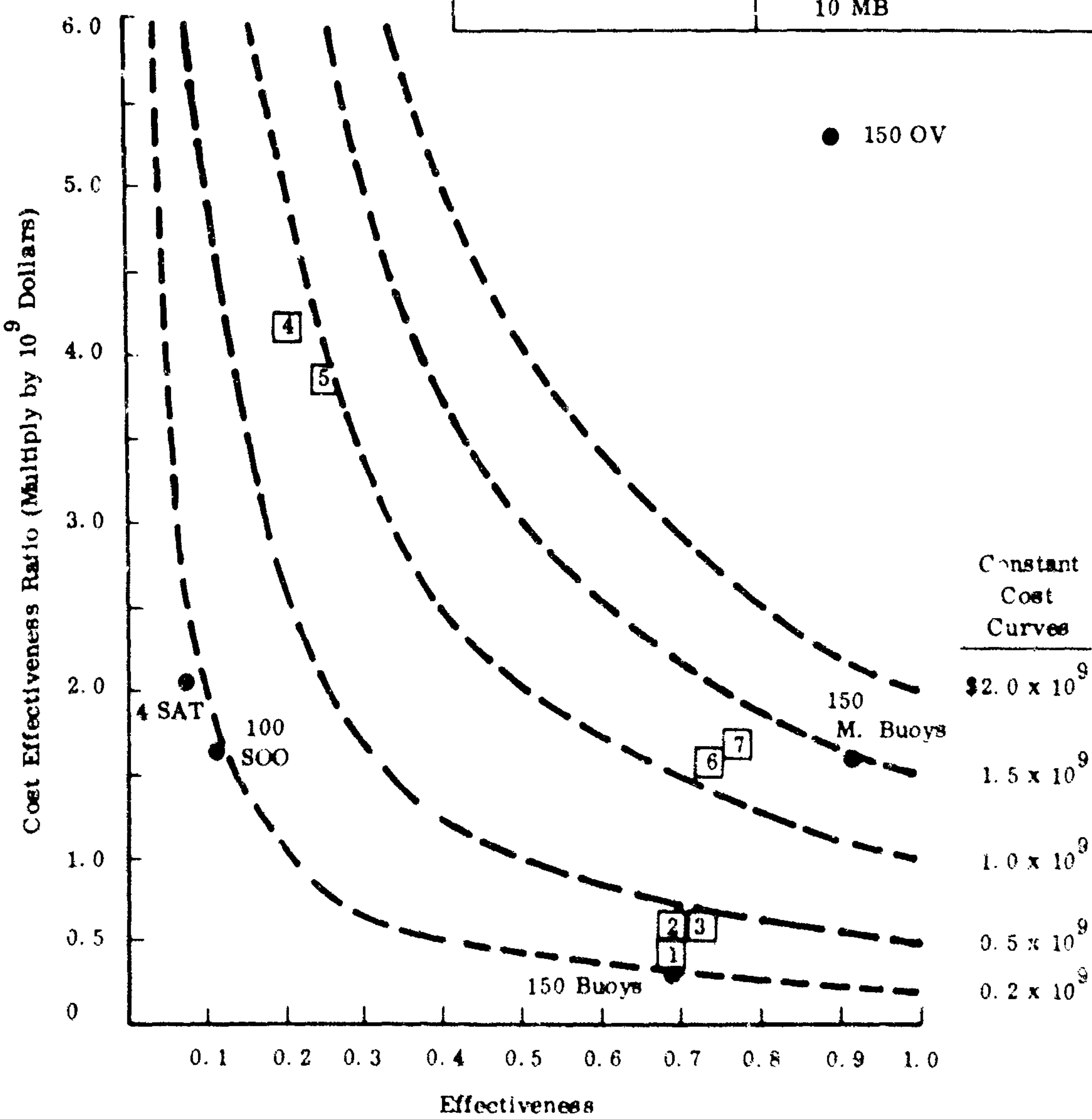


Fig. D-2. Comparison of Cost Effectiveness Ratios of Deep Ocean Systems Using BCF Parameter and Layer Weights

Definitions	
Abbreviations	**Mixes**
HSB = Hor Sound Bal AOO = Acft of Oppor SAT = Satellites RA = Recon Aircraft B = Buoys SOO = Ship of Oppor OV = Ocean Vessel MB = Manned Buoy	1 = 150 Buoys, 2500 HSB 2 = 150 Buoys, 4 SAT 3 = 150 Buoys, 100 SOO 4 = 20 OV, 100 SOO, 10 RA 5 = 20 OV, 100 SOO, 10 RA 4 SAT, 60 AOO 6 = 137 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO 7 = 127 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO, 10 MB

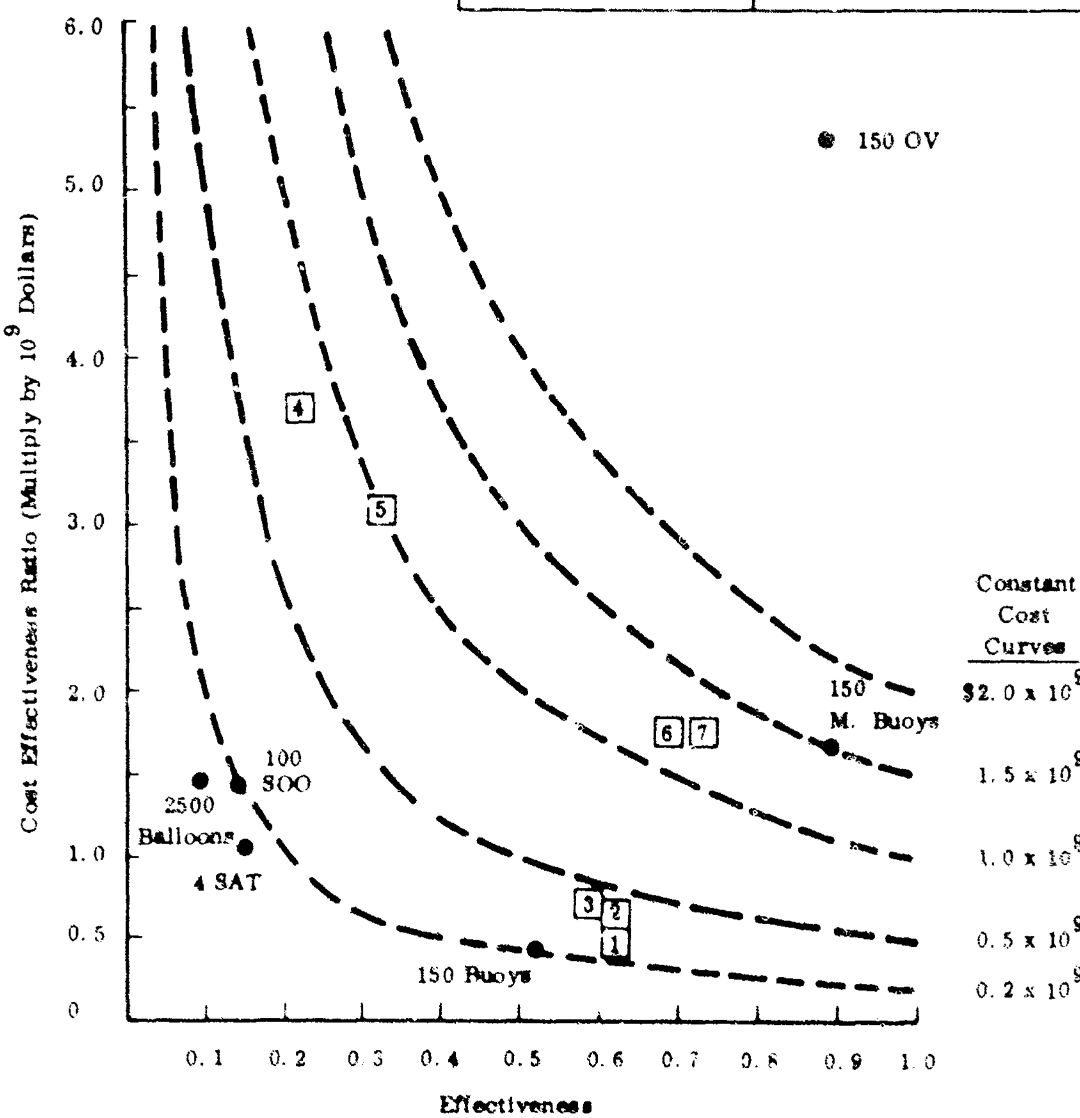


Fig. D-3. Comparison of Cost Effectiveness Ratios of Deep Ocean Systems Using ESSA Parameter and Layer Weights

Definitions	
Abbreviations	**Mixes**
HSB = Hor Sound Bal	1 = 150 Buoys, 2500 HSB
AOO = Acft of Oppor	2 = 150 Buoys, 4 SAT
SAT = Satellites	3 = 150 Buoys, 100 SOO
RA = Recon Aircraft	4 = 20 OV, 100 SOO, 10 RA
B = Buoys	5 = 20 OV, 100 SOO, 10 RA 4 SAT, 60 AOO
SOO = Ship of Oppor	6 = 137 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO
OV = Ocean Vessel	7 = 127 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO, 10 MB
MB = Manned Buoy	

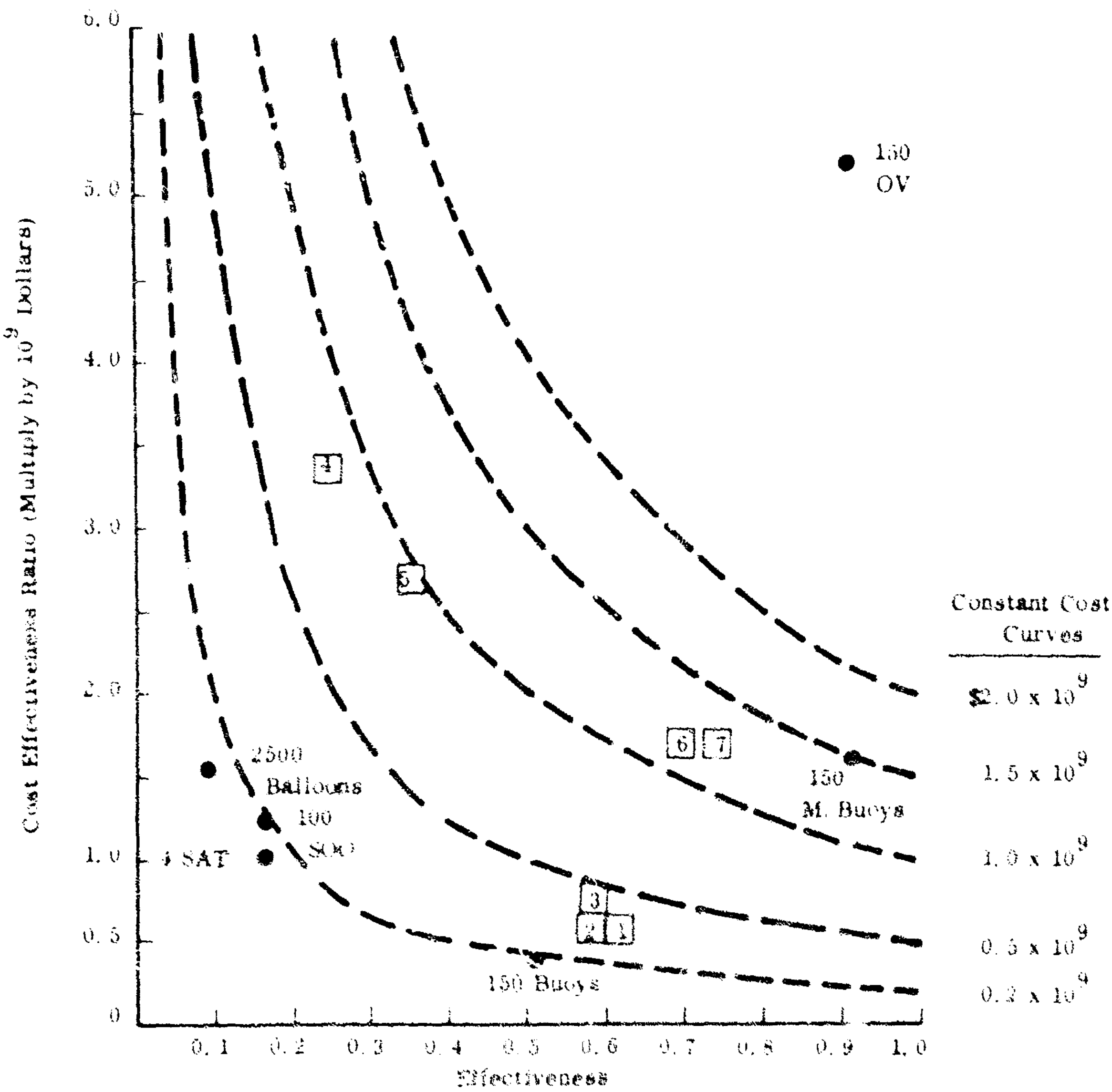


Fig. D-4. Comparison of Cost Effectiveness Ratios of Deep Ocean Systems Using U.S. Navy Parameter and Layer Weights

Definitions	
Abbreviations	Mixes
HSB = Hor Sound Bal	1 = 150 Buoys, 2500 HSB
AOO = Acft of Oppor	2 = 150 Buoys, 4 SAT
SAT = Satellites	3 = 150 Buoys, 100 SOO
RA = Recon Aircraft	4 = 20 OV, 100 SOO, 10 RA
B = Buoys	5 = 20 OV, 100 SOO, 10 RA 4 SAT, 60 AOO
SOO = Ship of Oppor	6 = 137 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO
OV = Ocean Vessel	7 = 127 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO, 10 MB
MB = Manned Buoy	

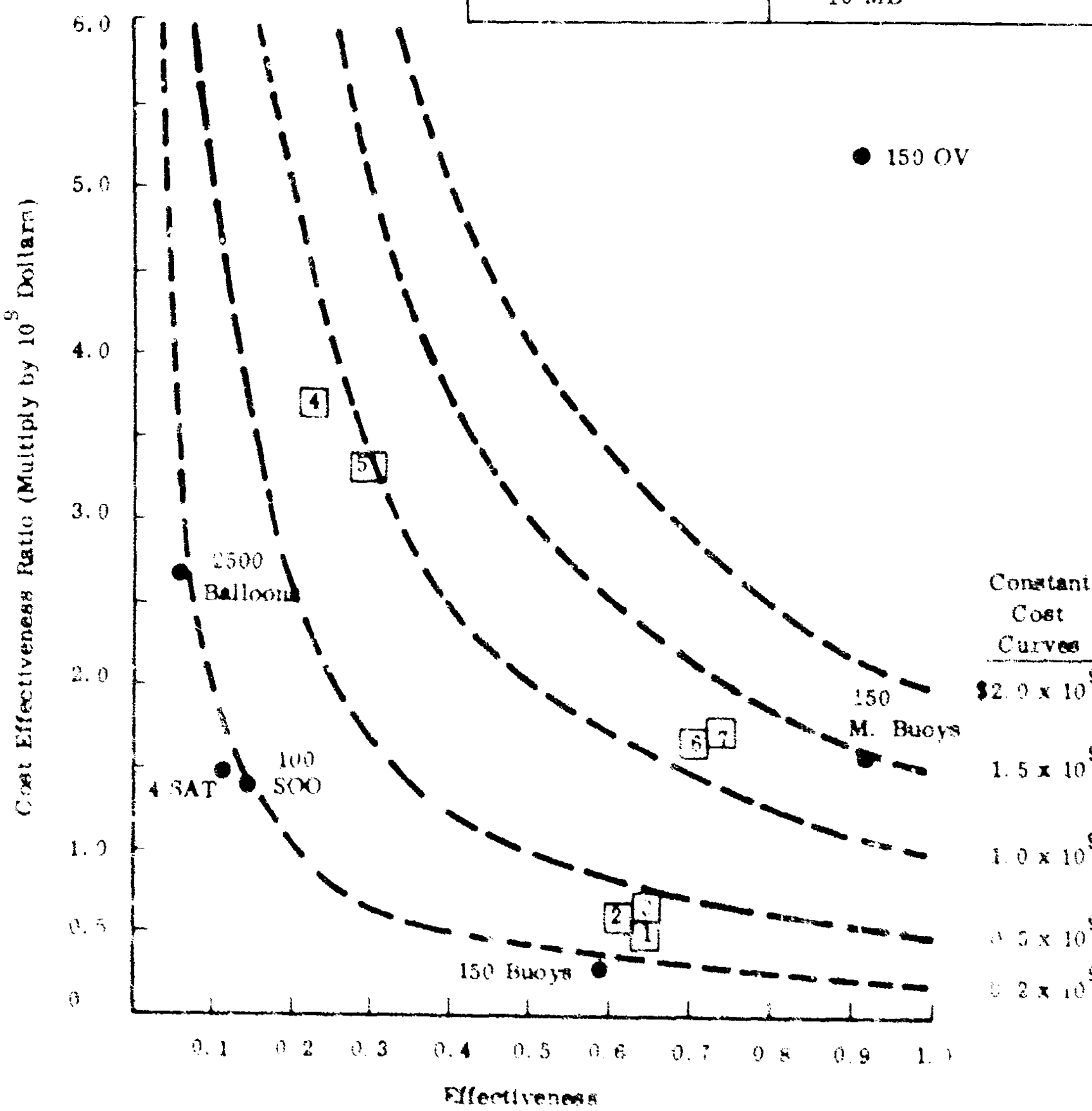


Fig. D-5. Comparison of Cost Effectiveness Ratios of Deep Ocean Systems Using USCG Parameter and Layer Weights

Definitions	
Abbreviations	**Mixes**
HSB = Hor Sound Bal	1 = 150 Buoys, 2500 HSB
AOO = Acft of Oppor	2 = 150 Buoys, 4 SAT
SAT = Satellites	3 = 150 Buoys, 100 SOO
RA = Recon Aircraft	4 = 20 OV, 100 SOO, 10 RA
B = Buoys	5 = 20 OV, 100 SOO, 10 RA 4 SAT, 60 AOO
SOO = Ship of Oppor	6 = 137 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO
OV = Ocean Vessel	7 = 127 B, 20 OV, 100 SOO, 10 RA, 4 SAT, 60 AOO, 10 MB
MB = Manned Buoy	

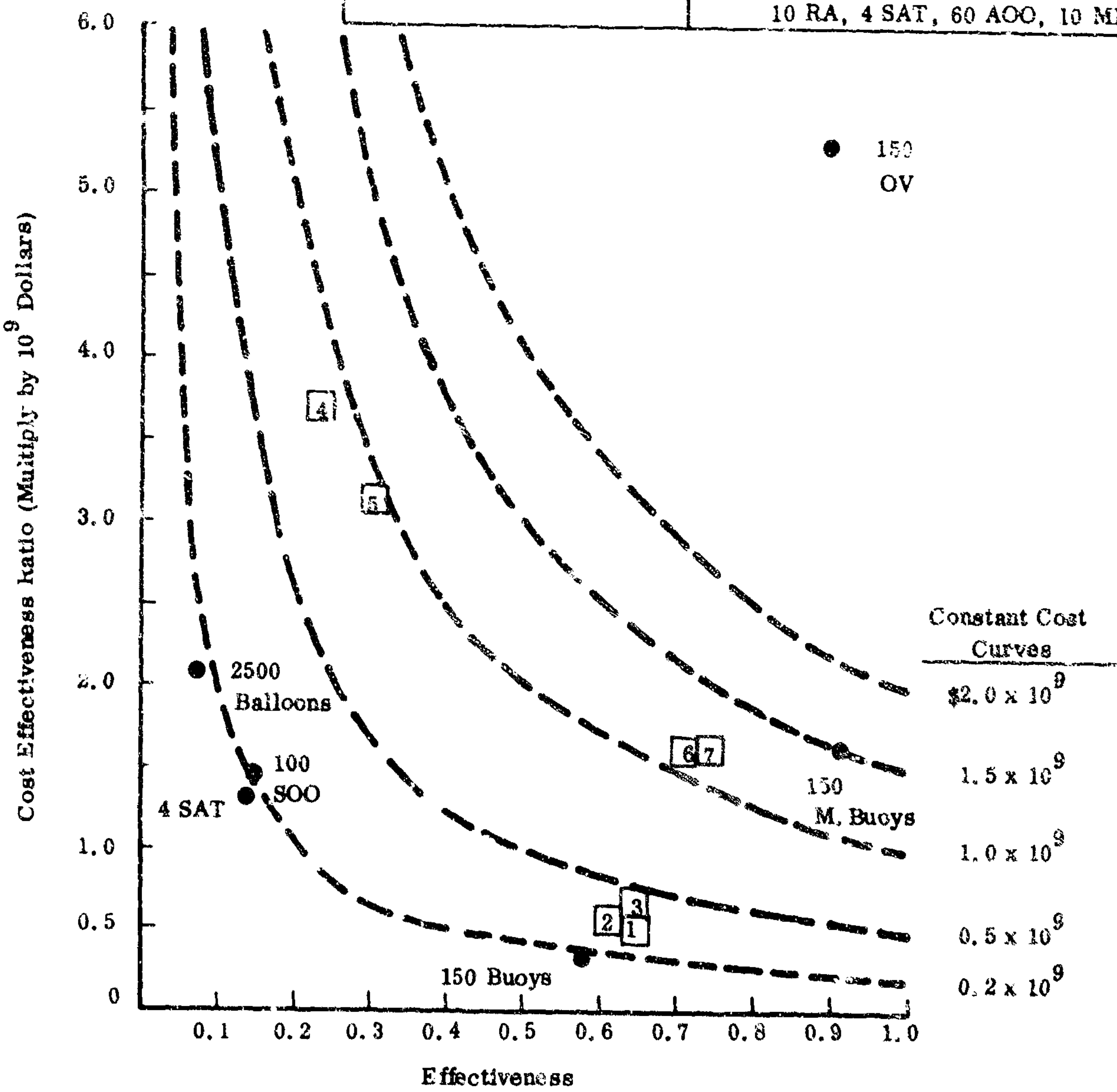
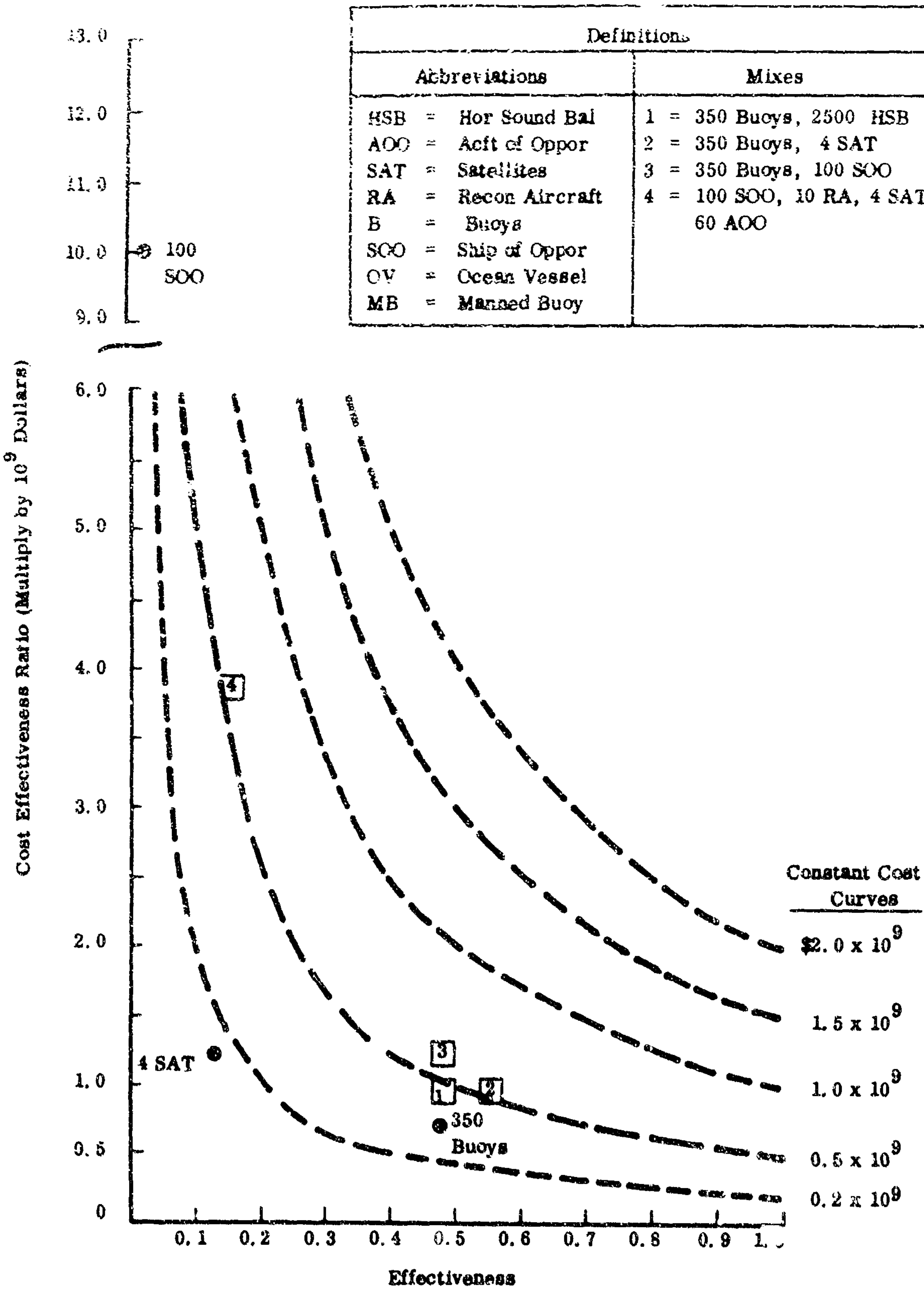


Fig. D-6. Comparison of Cost Effectiveness Ratios of Deep Ocean Systems Using Average of Four Agencies' Parameter and Layer Weights



Definitions

Abbreviations	Mixes
HSB = Hor Sound Bal	1 = 350 Buoys, 2500 HSB
AOO = Acft of Oppor	2 = 350 Buoys, 4 SAT
SAT = Satellites	3 = 350 Buoys, 100 SOO
RA = Recon Aircraft	4 = 100 SOO, 10 RA, 4 SAT 60 AOO
B = Buoys	
SOO = Ship of Oppor	
OV = Ocean Vessel	
MB = Manned Buoy	

Fig. D-7. Comparison of Cost Effectiveness Ratios of Coastal North America Systems Using Section 3 Parameter and Layer Weights

Definitions	
Abbreviations	**Mixes**
HSB = Hor Sound Bal AOO = Acft of Oppor SAT = Satellites RA = Recon Aircraft B Buoys SOO = Ship of Oppor OV = Ocean Vessel MB = Manned Buoy	1 = 350 Buoys, 2500 HSB 2 = 350 Buoys, 4 SAT 3 = 350 Buoys, 100 SOO 4 = 100 SOO, 10 RA, 4 SAT 60 AOO

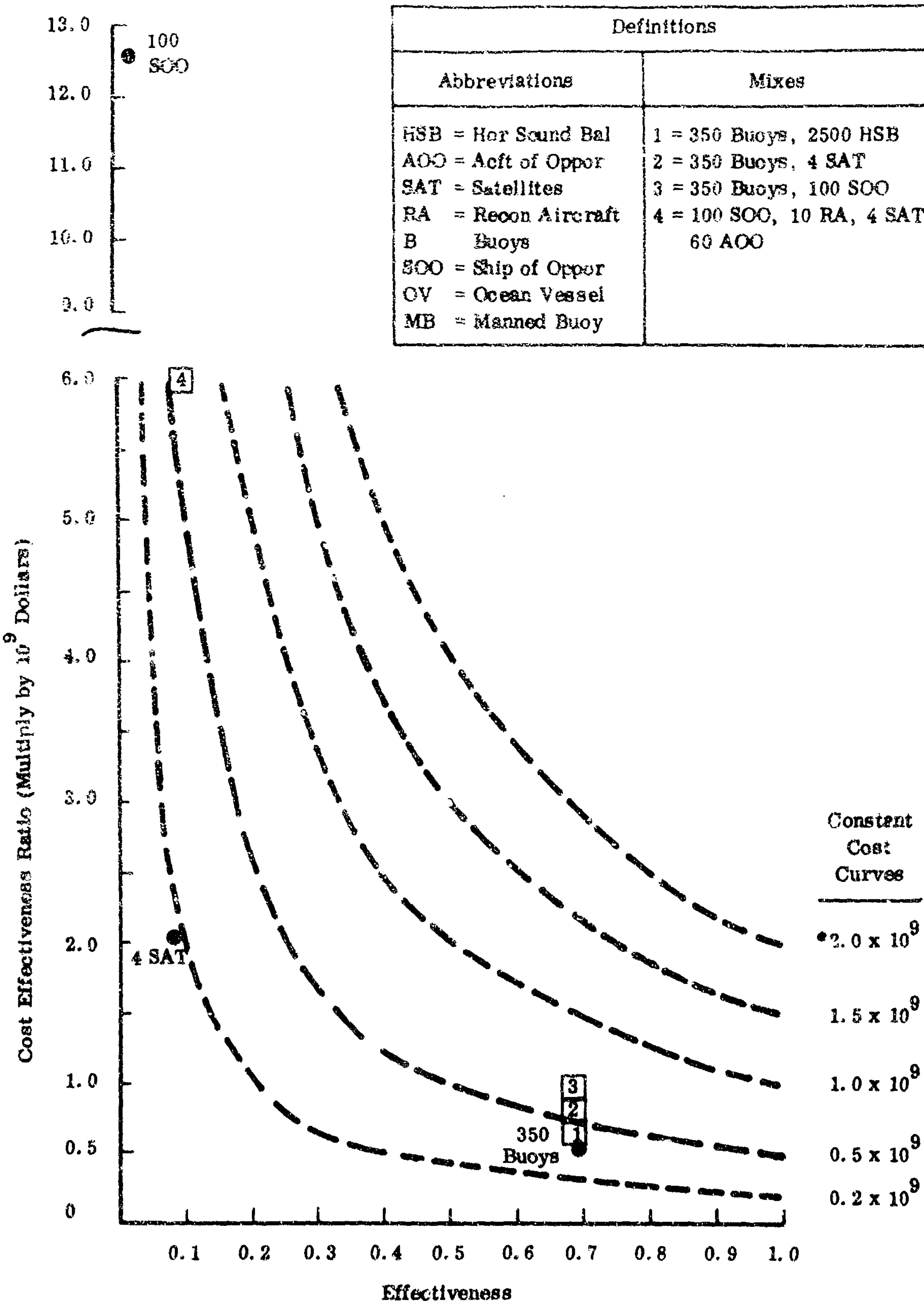
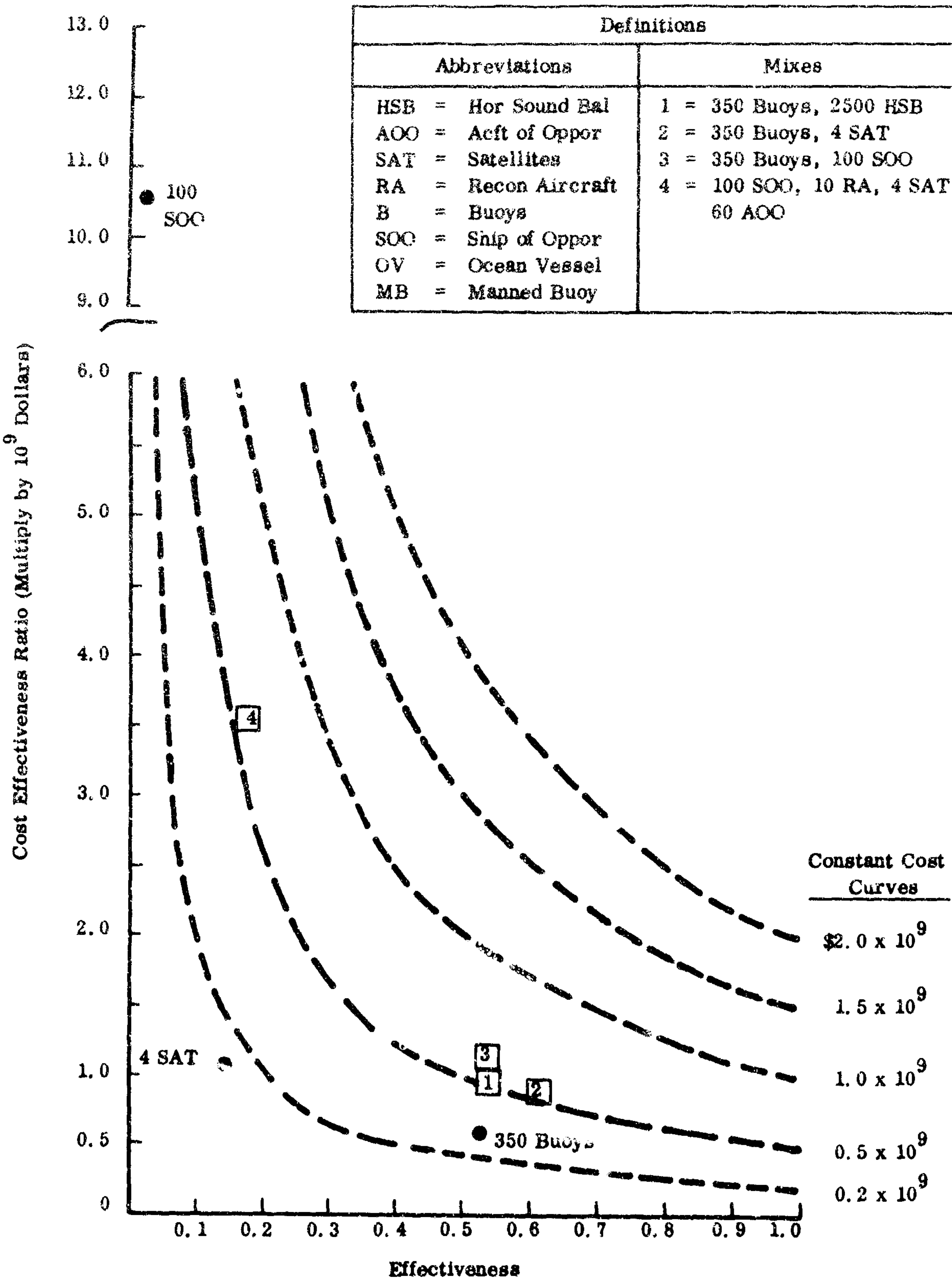
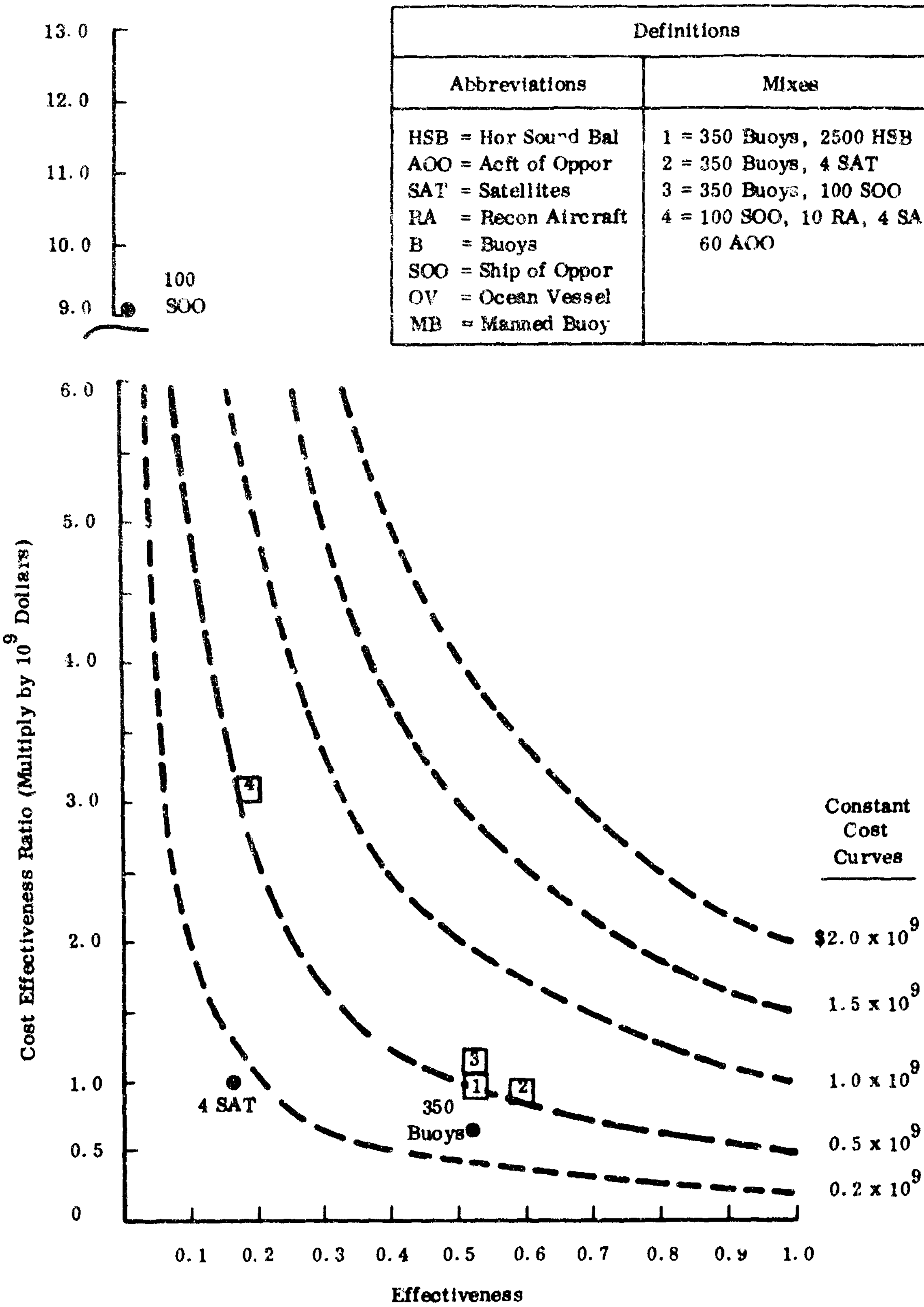


Fig. D-8. Comparison of Cost Effectiveness Ratios of Coastal North America Systems Using BCF Parameter and ayer Weights



Definitions	
Abbreviations	Mixes
HSB = Hor Sound Bal	1 = 350 Buoys, 2500 HSB
AOO = Acft of Oppor	2 = 350 Buoys, 4 SAT
SAT = Satellites	3 = 350 Buoys, 100 SOO
RA = Recon Aircraft	4 = 100 SOO, 10 RA, 4 SAT 60 AOO
B = Buoys	
SOO = Ship of Oppor	
OV = Ocean Vessel	
MB = Manned Buoy	

Fig. D-9. Comparison of Cost Effectiveness Ratios of Coastal North America Systems Using ESSA Parameter and Layer Weights



Definitions	
Abbreviations	Mixes
HSB = Hor Sou^d Bal AOO = Acft of Oppor SAT = Satellites RA = Recon Aircraft B = Buoys SOO = Ship of Oppor OV = Ocean Vessel MB = Manned Buoy	1 = 350 Buoys, 2500 HSB 2 = 350 Buoys, 4 SAT 3 = 350 Buoys, 100 SOO 4 = 100 SOO, 10 RA, 4 SAT 60 AOO

Fig. D-10. Comparison of Cost Effectiveness Ratios of Coastal North America Systems Using U.S. Navy Parameter and Layer Weights

Definitions	
Abbreviations	**Mixes**
HSB = Hor Sound Bal	1 = 350 Buoys, 2500 HSB
AOO = Acft of Oppor	2 = 350 Buoys, 4 SAT
SAT = Satellites	3 = 350 Buoys, 100 SOO
RA = Recon Aircraft	4 = 100 SOO, 10 RA, 4 SAT 60 AOO
B = Buoys	
SOO = Ship of Oppor	
OV = Ocean Vessel	
MB = Manned Buoy	

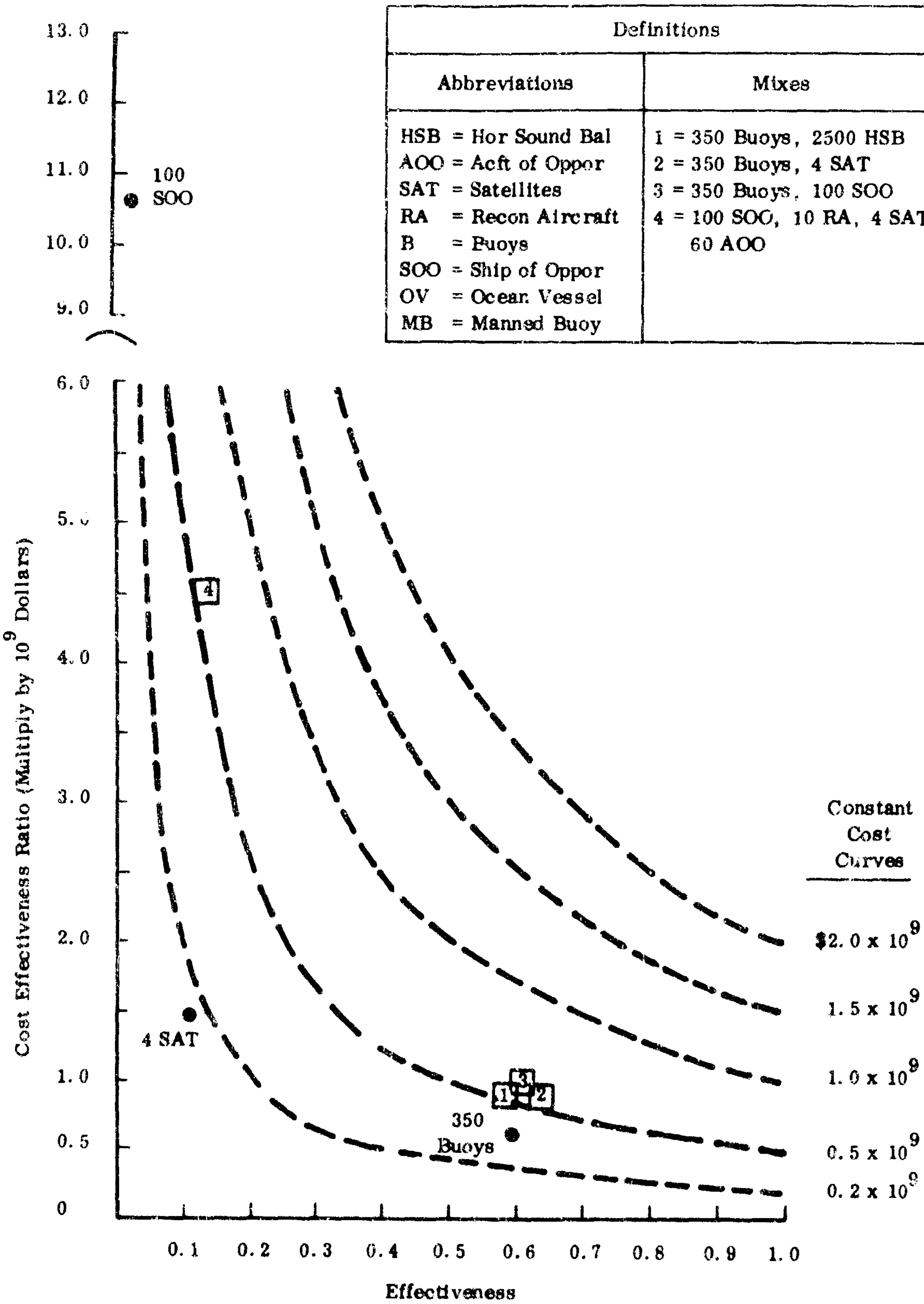


Fig. D-11. Comparison of Cost Effectiveness Ratios of Coastal North America Systems Using USCG Parameter and Layer Weights

Definitions			
Abbreviations		Mixes	
HSB	= Hor Sound Bal	1	= 350 Buoys, 2500 HSB
AOO	= Acft of Oppor	2	= 350 Buoys, 4 SAT
SAT	= Satellites	3	= 350 Buoys, 100 SOO
RA	= Recon Aircraft	4	= 100 SOO, 10 RA, 4 SAT 60 AOO
B	= Buoys		
SOO	= Ship of Oppor		
OV	= Ocean Vessel		
MB	= Manned Buoy		

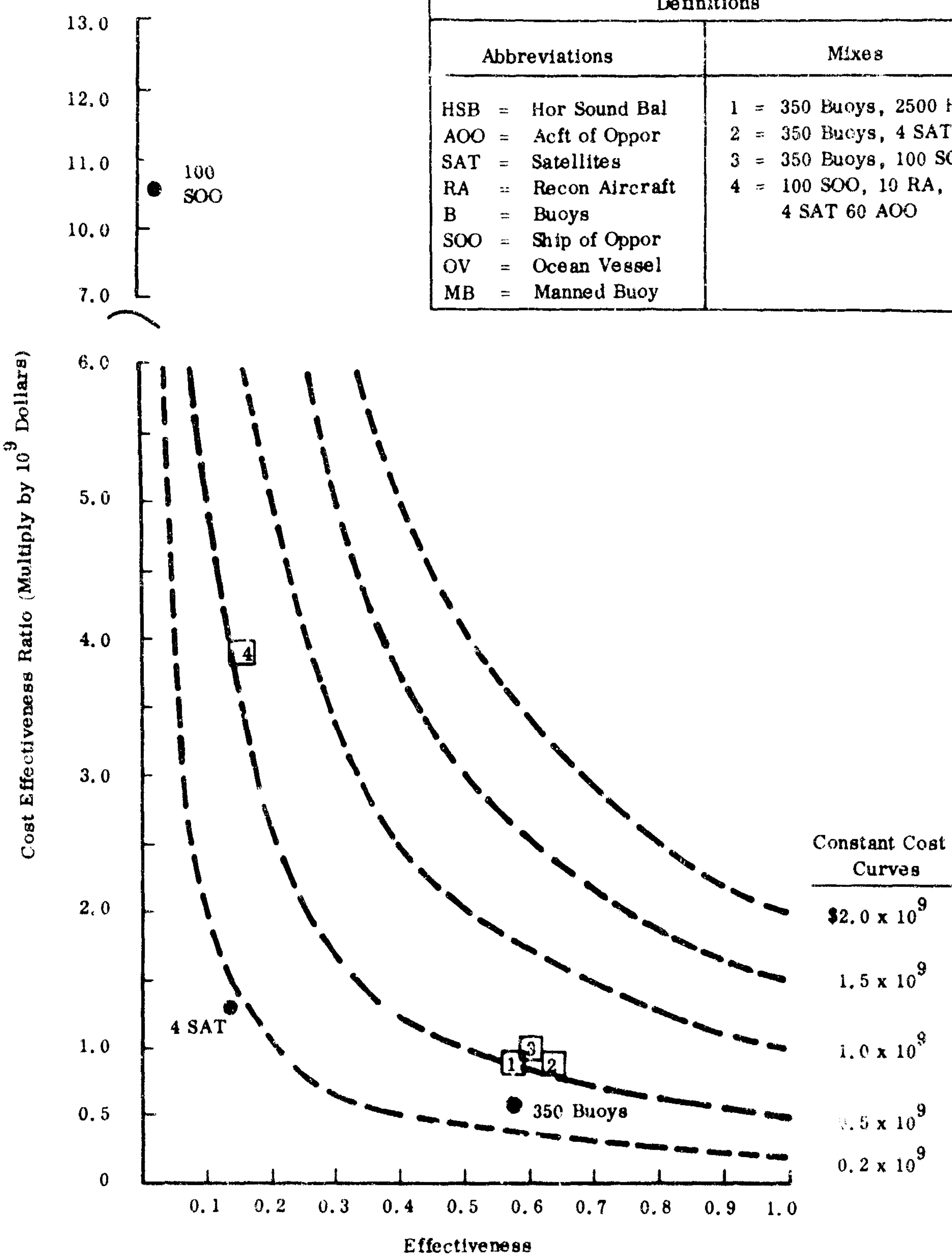


Fig. D-12. Comparison of Cost Effectiveness Ratios of Coastal North America Systems Using Average of Four Agencies' Parameter and Layer Weights

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ABSTRACT

The cost effectiveness analysis described in this report was carried out to assess the potential role of National Data Buoy Systems in the marine data acquisition system of the future and to determine the sensitivity of the NDBS design to complementary and competitive characteristics of other platform types in the national marine data acquisition system. A cost effectiveness model was designed to evaluate alternative mixes of buoy and now-buoy platforms against certain categories of stated data requirements provided by U.S. Government Agencies. Factors included in the effectiveness model include systems capability, reliability, survivability and areal coverage. The results showed that a system comprised solely of unmanned buoys was the most cost-effective system; however since an unmanned bouy system is ineffective in gathering data in the atmosphere above the ocean surface interface, complementary systems with upper air sounding capabilities would be required for effective data observations at all levels.

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