SYSTEMS ANALYSIS

OF

SHALLOW WATER BATHYMETRY

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by

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ABSTRACT

Shallow Water Bathymetry operations are currently performed using launches equipped with high-frequency active sonars. These operations are considered relatively expensive, and contribute to slow survey rates, poor area coverage, and hazardous navigational conditions.

Because of these undesirable operating conditions, the National Ocean Survey's System Analysis Division performed this independent objective study reported herein. The overall objective of this study was to identify alternative bathymetric systems, which might replace or complement the Launch-Sonar bathymetric operation. Such systems should allow for easy access to restricted areas, provide more detailed and greater area coverage and, at the same time, be cost effective to operate in waters of three fathoms or less.

FOREWORD

This report was prepared by the Systems Analysis Division of the Office of Marine Technology, National Ocean Survey/NOAA.

The studies presented began on June 1, 1977, and were concluded September 30, 1977. This work was a coordinated effort of the Systems Analysis Division (SAD, C64), Forecasting International, Ltd. (FI), Giannotti & Buck Associates, Inc. (G&B), Hydronautics, Inc. (HI), and GKY and Associates, Inc. (GKY).

The chief contributors to this program were: Dr. Juliani Gatzoulis (SAD), Mr. Nisenoff and Mrs. E. Bishop (FI), Dr. J. Giannotti (G&B), Mr. Clint Brown (HI), and Dr. K. Young (GKY).

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1.0 EXECUTIVE SUMMARY

1.1 Objectives:

The overall objective of this study was to identify alternative bathymetric systems which might replace or complement the Launch-Sonar bathymetric operation. Such systems should allow for easy access to restricted areas, provide more detailed and greater area coverage and, at the same time, be cost-effective to operate in waters of three fathoms or less.

However, a detailed work effort dealing in meeting the specific objectives of this study, was performed in order to accomplish this overall objective.

The specific objectives are briefly outlined below:

(A) establish a requirements data base for the evaluation of candidate shallow water bathymetry systems (Requirements);

(B) define NOS' near and long-term plans for shallow water bathymetry (NOS Plans);

(C) identify candidate systems for shallow water bathymetry and insure that no feasible alternative system competitive with Launch-Sonar was overlooked (Alternative Systems):

(D) define the operational domain characteristics of shallow water bathymetry systems (Domain Characteristics);

(E) develop a cost comparison study for the selected candidate shallow water bathymetry systems (Cost Study).

1.2 Findings;

1.2.1 General

(A) The results of this study indicate that it is essential that NOS continue bathymetric surveys in waters of three fahtoms or less. Figure 1 graphically justifies this finding.

(B) A composite bathymetric system which incorporates the best features of the acoustic and optical methods appears, from both operational and cost points of view, to be the best possible alternative. A plan for developing such a system is outlined in Section 7.0 of this report. The procedures used to grade and rank the system are discussed below.

The selected candidate systems were graded on each of the following factors:

- Operational cost
- Area coverage
- Operation in turbid waters

- Operation in clear waters
- Survey rate
- Accessibility to restricted areas
- Operational status
- Weather Constraints

The breakdown of the grading system was as follows:

Excellent	-	100
Good	-	75
Marginal	-	50
Poor or no data available	-	0

A grade of zero was assigned to any factor for which information was either not available or was difficult to assess on an intuitive basis. This was a conservative path to follow, but it was felt that it would result in a fair evaluation of all systems.

The grades were averaged and the systems were ranked on the basis of their overall average grades. The results of this grading and ranking procedure are shown in Table 1.

1.2.2 <u>Specific</u>:

(A) The work in defining the "operational requirements" of shallow water bathymetry, against which the selected candidate bathymetric systems were evaluated, revealed the existence of three categories of requirements: (1) Highly Desirable, (2) Desirable, and (3) Minimum Importance. The findings of these three categories are displayed graphically in Figure 1 and are briefly described below:

(1) Highly Desirable:

- Increase total linear nautical miles surveyed per year by 100 percent (9b).
- For a given sector, provide 50 percent actual coverage of bottom (3b).
- For a given sector, increase actual coverage of bottom from current level (3).
- For a given sector, ~~increase~~ Provide 100% actual coverage of bottom (3a).
- Continue surveying at least current number of linear nautical miles per year (9).

(2) Desirable:

- Resurvey changeable areas at least once every five years (4b).
- Maintain horizontal accuracy at at least present standards(2).
- Maintain at least current number of chart adequacy surveys per year (6).
- Increase number of chart adequacy surveys per year by 100 percent (6a).
- Maintain vertical accuracy at at least present standards (1).

- Change scheduling of resurveying changeable areas to regular basis (4).
- Increase total linear miles of survey per year by 1,000 percent (9a).
- Improve horizontal accuracy by 100 percent (2a).

(3) Minimum Importance:

- Resurvey changeable areas once per year (4a).
- Improve vertical accuracy by 100 percent (1a).
- Resurvey stable areas once each 50 years (5).
- Improve current level of responsiveness to urgent survey requests by 100 percent (8).

The numbers in parentheses (i.e., 9b, 3b, etc.) refer to their specific statements as presented in Table .

(B) The work in establishing the NOS priorities regarding the areas to be surveyed this year and the next five years revealed the following findings:

(1) Present NOS planning for hydrographic surveys allows great flexibility in reassigning priorities.

(2) Survey rates are found to be highly variable with adverse effects of shallow water, and weather obstructions, but other factors affecting the rate variability were not identified.

(3) At current survey rates, the shallow water regions of the United States are estimated to require a survey cycle time of greater than sixty (60) years if half of the present hydrographic field party capability is used.

(C) The work in identifying candidate bathymetric systems which might replace or complement the existing system (Launch-Sonar) for cost-effective bathymetric operations, revealed the following findings:

(1) In turbid waters Launch-Sonar remains the only reliable system, pending further developments in the R&D arena.

(2) In less turbid and clean waters, the airborne laser and photobathymetric systems have a clear advantage over launch sonar due to the larger area coverage, higher survey rates and potential for lower operational costs.

(3) The LANDSAT/MSS system should definitely be considered by NOS for the purpose of survey planning.

(4) Based on the ranking of the various systems, a composite bathymetric system, which would make use of the best features of the acoustic and optical methods, appears to be the best possible alternative, both from operational and cost points of view. A plan for developing such a system is outlined in Section 7.0 of this report.

(D) The work in establishing NOS' priorities dealing with the areas to be surveyed of depths of three fathoms or less within NOAA's concern and specifically establishing the domain characteristics of these areas, revealed the following findings:

(1) A rational ranking scheme is possible to direct field survey activities to high priority areas.

(2) The Gulf of Mexico Coast is of great concern.

(3) The South and Mid-Atlantic and Great Lakes are of moderate concern.

(4) The North Atlantic and Pacific Coasts are of little concern.

(5) The areas of great-to-moderate concern have been divided into 19 models (including the North Atlantic which is a borderline concern region) and the surveying success probabilities associated with three alternative survey systems have been assigned.

(6) As a generalization, launch operations are much less hampered by environmental factors than are alternative aircraft systems. In the same vein, airborne lasers are much less hampered by environmental factors than airborne photography.

(7) A preliminary set of water quality determinations has permitted consideration of the role of turbidity in laser and photographic contexts. This has been a major unknown factor and this study reduces the uncertainty associated with turbidity effects.

(E) The final step in achieving the overall objective of this study was to identify alternative bathymetric systems that operate cost effectively in shallow water bathymetry areas, allow for easy access to established restricted areas, and provide more detailed and greater area coverage. However, the lack of data for some of the systems and/or the inherent bias in the performance figures reported by the individuals or groups responsible for certain systems, made it very difficult to report realistic numerical values. This, however, did not prevent us from independently ranking all systems based on our objective judgment and evaluating the operational costs for at least three bathymetric systems.

Based on the analysis made in Section 6.5 of this report, the hydrographic operational performance characteristics of the east coast ships (PEIRCE, WHITING and MT. MITCHELL) and their launches, as illustrated in Figures 2 and 3 respectively, and also the total operating costs for ships and launch hydrography and the operating costs of the Hydrographic Field Parties (HFP) as illustrated in Figure 4, is concluded that for cost-effective shallow water bathymetric operations, NOS should:

(1) Cancel the shallow water bathymetric operations performed by the four launches of MT. MITCHELL and continue only MT. MITCHELL's hydrographic survey operations for turbid waters; and/or restricted areas where the HFP cannot operate according to NOS' existing priority schedule as presented in Table 13; and/or when the time-schedule allows, perform other nonbathymetric predetermined activities.

(2) Maintain WHITING and/or PEIRCE with the two and/or four launches to perform shallow water bathymetry for turbid waters; and/or restricted areas where the HFP cannot operate according to NOS' existing priority schedule as presented in Table 13; and/or, when the time-schedule allows, conduct other nonbathymetric predetermined activities.

(3) Maintain all HFP to perform shallow water bathymetric operations for turbid waters; and/or other areas having such environmental constraints that an optical bathymetric system or ship launch hydrography cannot cost-effectively operate according to NOS' existing priority schedule as presented in Table 13.

(4) Improve ship-launch hydrography and HFP operational performance by modernizing and automating their equipment. In addition, include the two launches from MT. MITCHELL in the HFP operations.

(5) Fully develop and operate an optical system (i.e., photobathymetry or Airborne-Laser System) to operate in nonturbid areas and under allowable environmental conditions according to the probability of success as presented in Table 21 of this report and also according to NOS' existing priority schedule as presented in Table 13; and/or when the time-schedule allows such system can be used for coastal mapping of other predetermined activities.

(6) Establish a well-coordinated and cost-effective operating schedule for the composite system (i.e., Ship-Launch Hydrograpby, HFP and optical system) to operate according to NOS' existing priority schedule and the probability of success as discussed in Tables 13 and 21, respectively, in this report.

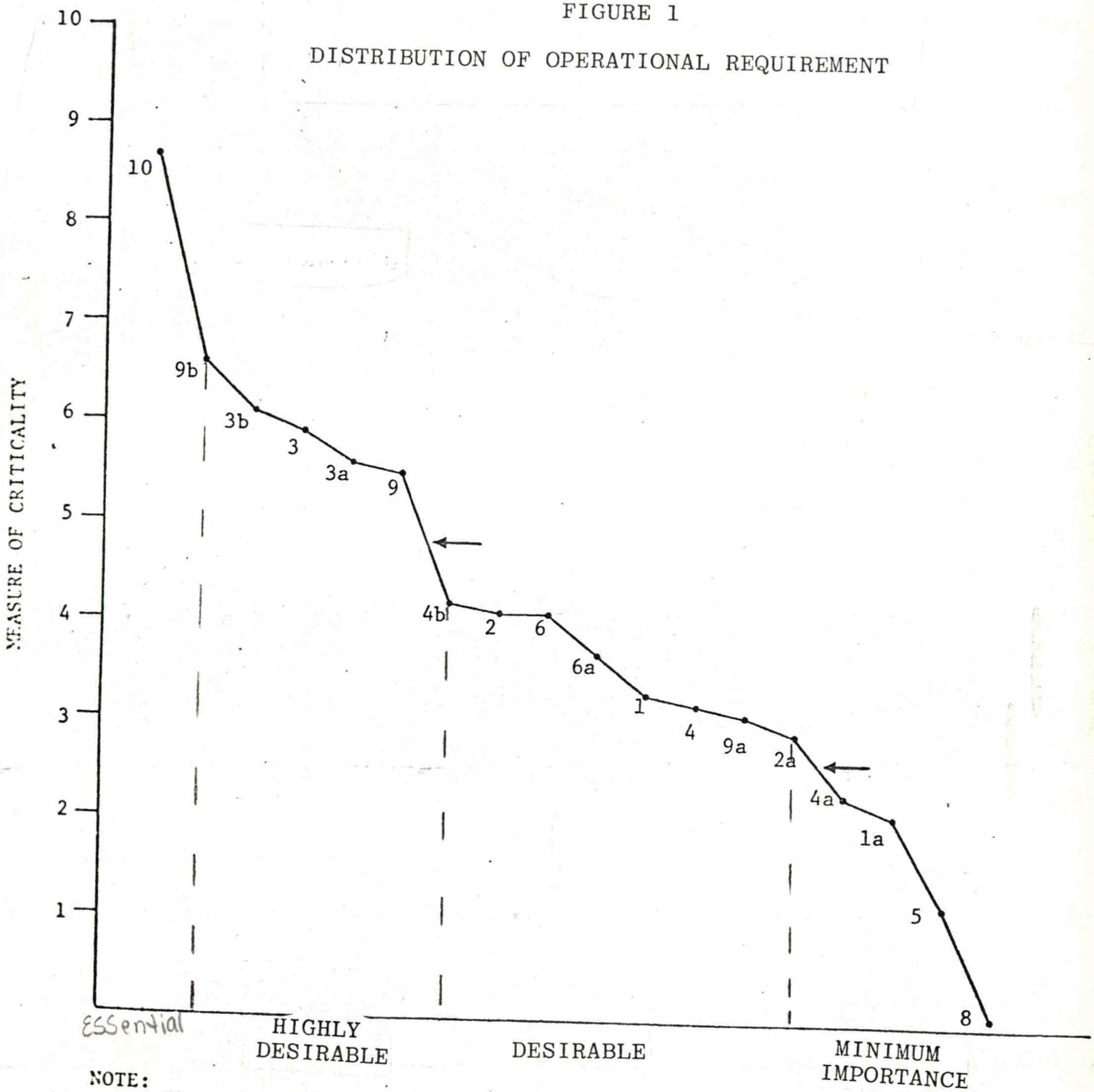
Table 1 <u>Evaluation and Ranking of Alternative Shallow Water Bathymetric Systems</u>

GRADES: 100 = Excellent; 75 = Good; 50 = Marginal; 0 = Poor, No Data

BENEFITS	LAUNCH SONAR	AIR PHOTO.	AIR LASER	AIR AC.SYS.	LANDSAT MSS	HYSURCH	AIRSHIP PLATFORM	COMPOSITE SYSTEM
Op. Cost	50	75	75	0	100	0	0	100
Area Coverage	50	75	75	75	100	75	75	100
Operation in Turbid Water	75	0	0	75	0	75	75	75
Operation in Clear Water	75	100	100	75	100	75	100	100
Survey Rate	50	100	100	100	100	75	100	100
Accessibility to Restr. Areas	50	100	100	100	100	50	100	100
Operational Status	100	100	50	0	100	50	0	50
Weather Constraints	50	50	50	0	50	50	75	50
Avg. Grade	62.5	75	68.75	53.12	81.25	56.25	65.62	84.37
RANKING	6	3	4	8	2	7	5	1

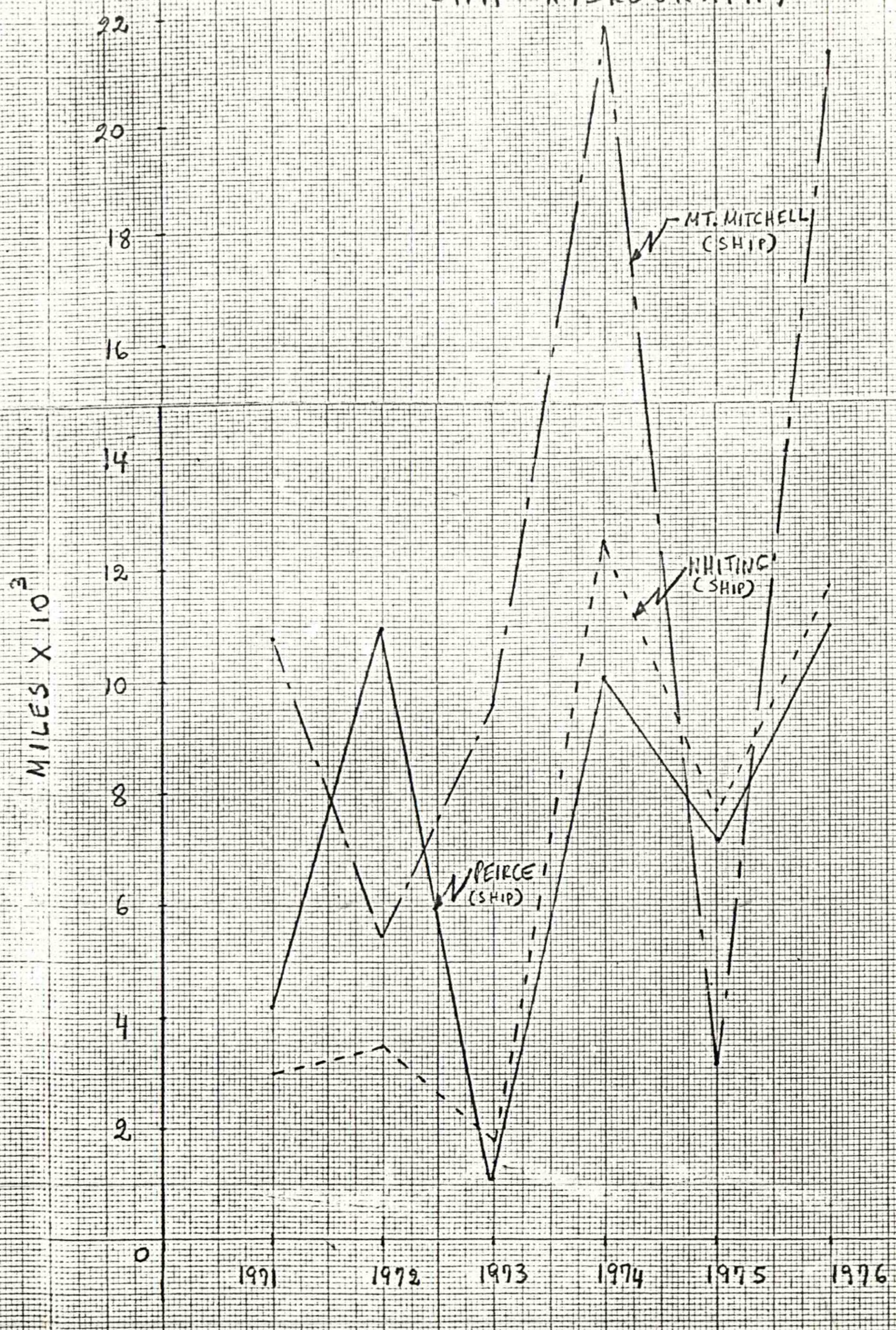
FIGURE 1

DISTRIBUTION OF OPERATIONAL REQUIREMENT



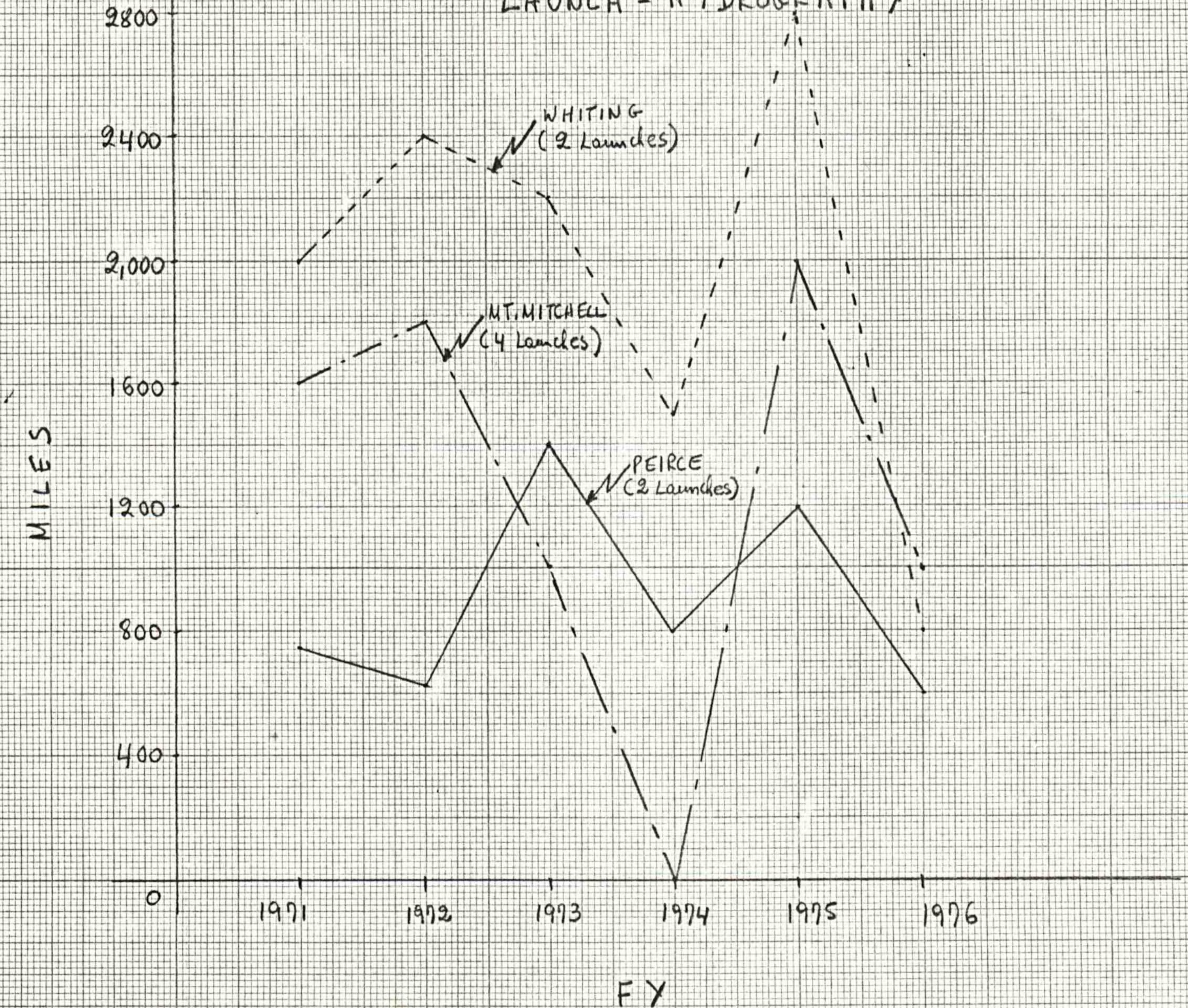
NOTE:
← Shows break between categories.

FIGURE 2
SHIP HYDROGRAPHY



SOURCE: ATLANTIC MARINE CENTER'S STATISTICAL DATA

FIGURE 3
LAUNCH - HYDROGRAPHY



SOURCE: ATLANTIC MARINE CENTER'S STATISTICAL DATA

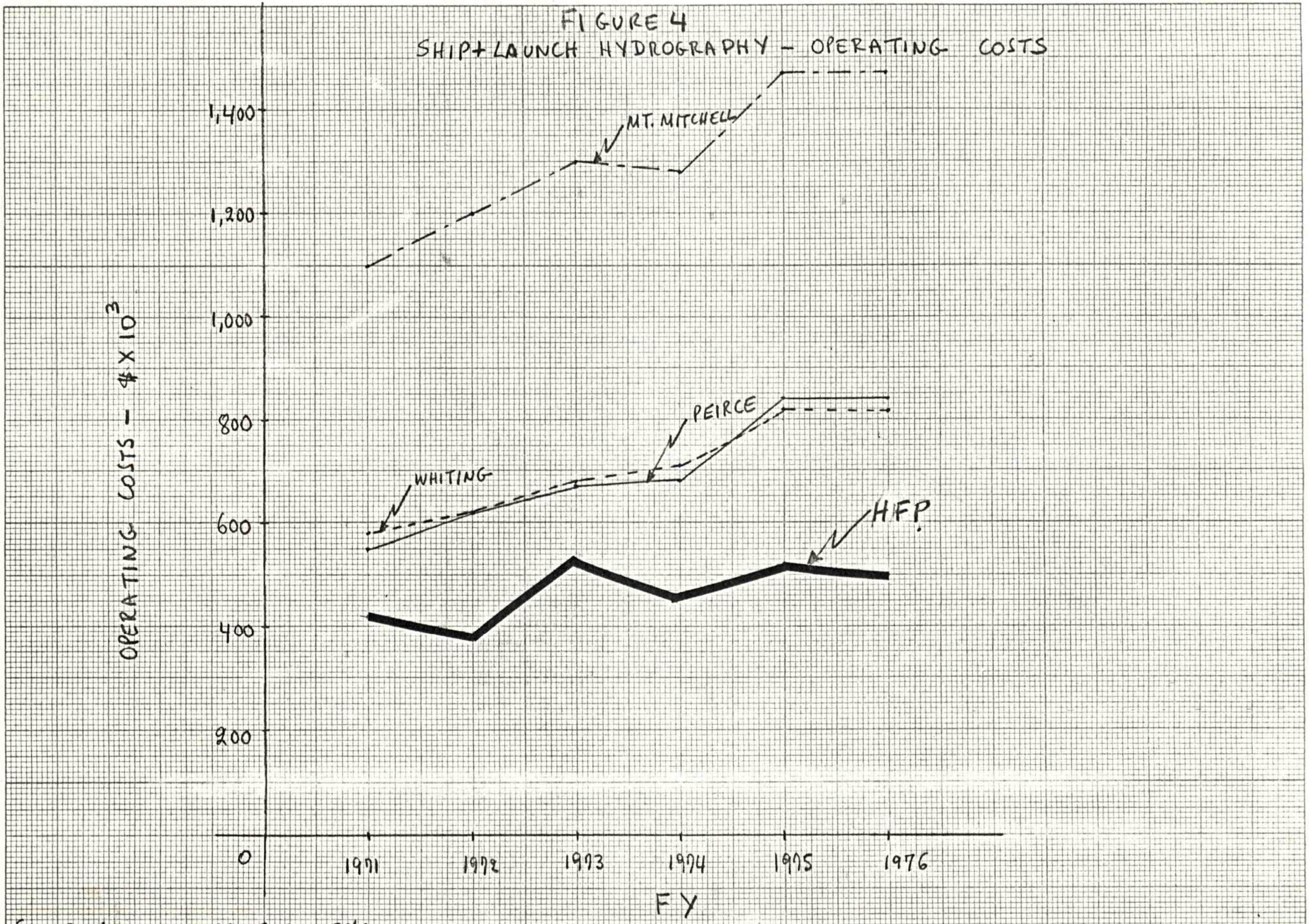


FIGURE 4
SHIP + LAUNCH HYDROGRAPHY - OPERATING COSTS

SOURCE: ATLANTIC MARINE CENTER'S STATISTICAL DATA

2.0 INTRODUCTION*

National needs require the improvement in present survey systems and techniques for acquiring and processing bathymetric data in support of changing navigational uses for nautical charts as well as ongoing and future scientific and engineering research and development.

The National Ocean Survey (NOS) of NOAA has established the need to modernize and update the coverage of the NOS' lake and oceanic coastal and harbor chart series; to expand the coverage of the small-craft series; to provide special purpose charts for major fishing areas; to provide engineering charts for those coastal areas susceptible to marine construction and engineering projects; and to introduce automated techniques in data handling, processing, compilation, and production in order to reduce the time interval between data acquisition and dissemination of new projects (charts) to the using public.

*Based on information supplied by W. L. Mobley, CAPT/NOAA.

3.0 BACKGROUND *

While charts were originally devised to enable mariners to travel safely from place to place, they are now used for a multiplicity of purposes, such as the planning of marine ventures, the exploitation of ocean resources, the management and use of the coastal zone, implementation of pollution control measures.

The largest user of the products and services provided by the nautical charting program is the Federal Government. Over 50 percent of the total production goes to satisfy defense requirements. Other Federal users include the U. S. Coast Guard, Army Corps of Engineers, National Marine Fisheries Services, etc. In addition to their navigation use, the charts are used for leasing of mineral rights, planning of public works, environmental protection/restoration actions, and ocean science development.

In the private sector, the largest user is marine shipping, which has formed an integral part of the national economy from colonial days to the present. In 1960, coastal merchant vessels transported a total of 681 million tons, earning revenues of over $6 billion, and it has predicted that the annual tonnage will rise to 900 million tons, with a value of $7 billion by 1980. Nautical charts are vital in safeguarding passengers and the huge volume of marine cargo from the many dangers besetting waterborne transportation. Other significant users from the private sector

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*Based on information supplied by W. L. Mobley, CAPT/NOAA.

include commercial fishermen who use charts to determine bottom conditions, potential feeding grounds, as well as for navigation and recreation boating. In the period extending from 1950 to 1974, the number of pleasure boats increased from approximately 3-1/2 million to over 9-1/2 million. This increase has markedly affected the requirement for nautical charting and has created the need to modernize existing charts and extend the entire coverage to include additional waterways used by the swelling millions of pleasure boatmen.

Charting is not a job that can be done once and then forgotten. In addition to natural changes, economic, socioeconomic, and technological changes cause the nautical charting program to be a dynamic and constantly-moving activity. Man busily and continually modifies his surroundings. He establishes new ports, straightens rivers, dredges channels, adds docks, builds bridges, deepens harbors, extends breakwaters, changes landmarks, lays underwater cables and pipelines, erects overhead powerlines, and fills in marginal lands. Natural changes occur from the interaction of wind and tide, the onslaught of storms and hurricanes, earthquake subsidence and emergence, from scouring on one hand and sediment deposition on the other. All of these changes, both natural and manmade, must be continually monitored, resurveyed, and recharted if safe and effective use of our waterways for commerce, recreation and defense is to continue.

Improved cartographic portrayal of a myriad of marine information will become increasingly important as the waterborne commerce increases. The recent establishment of directed traffic lanes, for entering and departing the busier ports of the United States is one of the newest safety measures used to separate shipping. These lanes are shown on approach charts to New York Harbor, Delaware Bay, San Francisco Harbor, Santa Barbara (California) Channel and Chesapeake Bay.

Over the past two decades, in the United States there has been a steady increase in the number of offshore oil wells in the Gulf of Mexico, along the west coast, and in Alaska. The huge oil well platforms are steadily advancing further into the sea, and each step seaward potentially increases their hazard to marine navigation. The Gulf of Mexico area is becoming so congested with oil well structures that the Federal Government has established "Shipping Safety Fairways" to help guide vessels safely through some 2,000 oil well structures which pose a problem to ocean shipping enroute to 29 ports in the Florida, Alabama, Mississippi, Louisiana and Texas area.

Shipping lanes are established and maintained on Lake Survey charts and statistics show that the collision rate on the Great Lakes is considerably lower than on any other United States waterway system.

All waters in the Great Lakes area of depths greater than 36 feet have been adequately surveyed; but surveys for inshore areas of depths less than 36 feet are 50 to 100 years old and very few resurveys have been accomplished.

It is extremely important to emphasize the resurvey of these inshore waters because Civil War era data used on charts of some coastal areas must be updated. This emphasis must be increased in the areas critical to navigation as the size and draft of the commercial ore boats sailing these waters increases. Also emphasizing the need for inshore surveys is the requirements of the operators of the rapidly-increasing fleet of recreational craft that ply these waters. In 1969, there were about 360,000 motor boats using lake waters, but by 1970 — just one year's time — this figure had increased to 435,000 users.

4.0 PROBLEM DEFINITION

New systems are needed to increase the effectiveness of our surveying systems. Ships with launches are very slow and inefficient to cover the very narrow but large areas of shallow water bordering the United States and its possessions.

At the present time, the bulk of this effort is conducted by hydrographic field parties which take care of inshore and shallow water surveys. These surveys are generally land-based surveys that employ small launches equipped with sonar sensors. There are five existing hydrographic field parties operating under the direction of the Marine Center in Norfolk. Four of the five field parties are dedicated to shallow water bathymetry while the fifth field party is involved in locating chart discrepancies. The size of the hydrographic field party can vary depending upon the nature and magnitude of the survey effort; however, the typical hydrographic field party has a five-man crew.

It has been demonstrated that field parties with launches are more efficient than ships with launches for surveying inshore areas, but the cost-inducing problem with the launch operation is, when the water gets shallow, the operational efficiency of the field party is hampered greatly by a number of factors including (2)

- hazardous navigation
- increased traffic congestion (especially in harbors and waterways)
- frequent, time-consuming turns and maneuvers
- greater detail to be charted
- damage to hulls and engines of launches and skiffs from grounding while operating in shoal conditions

These cost-inducing factors of operating the field parties, coupled with the slow survey rates, poor area coverage and hazardous navigational conditions has prompted NOS to give due consideration to other more advanced and perhaps more cost-effective systems for conducting shallow water bathymetry. The effort reported herein was aimed at identifying such systems as well as ranking them according to their relative merits, in a very objective and unbiased manner.

5.0 SHALLOW WATER BATHYMETRY

The operating areas at depths of three fathoms or less are defined as "shallow water bathymetry" (SWB) areas. The regimes of these coastal areas are as follows:

5.1 West Coast and Alaska

Water depths of less than 3 fathoms along the West Coast and Alaska are not normally surveyed except in the areas of flat bottoms where the tidal ranges permit surveying at higher water.

5.2 East Coast, Gulf and Great Lakes

Areas where water depths in this range, when surveying, is required are primarily encountered along the East Coast and Gulf, where numerous small craft for pleasure and commerce navigate. These areas cannot be effectively surveyed by conventional survey system or Bathymetric Swath Survey Systems (BS^3).

These factors point out the need for looking at alternative systems which might replace or complement the launch-sonar bathymetric operations. Such system(s) should allow for easy access to restricted areas, provide more detailed and greater area coverage, and at the same time, be cost-effective to operate.

6.0 DISCUSSION AND EVALUATION OF STUDY RESULTS

This section summarizes the work effort that was performed in meeting the predetermined specific objectives and, consequently, achieving the scope of the overall study. In addition, an analysis is made on the results obtained from this study, and their importance is discussed and evaluated in an unbiased and very objective manner — to the extent that is feasible.

6.1 Requirements:

In order to define the vague and uncertain so-called existing "requirements" on shallow water bathymetry, the Systems Analysis Division, together with Forecasting International (F.I.) Ltd., adopted a three-pronged approach of a literature survey, a series of interviews with knowledgeable NOS personnel and a requirements workshop. The workshop's analytic methodology overview is presented in Figure 5 and is also briefly discussed below:

6.1.1 Methodology:

A consensus workshop was conducted as a significant phase of this study to identify a "requirements data base" against which selected candidate bathymetric systems were evaluated.

This workshop was attended by knowledgeable representatives of NOS, who used proven workshop tools to measure "consensus" in a structured discussion of the mission needs and operational requirements for shallow water bathymetry.

The activities performed during the workshop were:

- a "scoring" of mission needs in terms of their perceived importance, both in the current time-frame and five years from now;
- "cross-support analysis" of mission needs in order to estimate the extent to which satisfaction of one mission need contributed to that of others;
- "cross-relevance analysis" of the operational requirements in terms of their contribution towards the satisfaction of mission needs.

These steps and the subsequent analysis applied to the data base gathered are presented in Figure 1 of this report.

6.1.2 Mission Needs:

The workshop participants were presented with a list of the Mission Needs referring to the total NOS bathymetry program as shown in Table 2. These mission needs had been developed from data gathered during the interviews and literature search and were centered around the basic NOS goal:

> "To provide navigation charts for the safe and efficient use of the Nation's waterways and marine environment by industry and the public."

The "average" score for each mission need was then calculated by summing the rows and again normalizing the range (0, 1) as presented in Figure 6. The resultant values were termed the "intrinsic values" (I) of the corresponding mission needs — i.e., a measure of their relative importance as perceived by the consensus judgment of workshop participants.

The results of these calculations for each of the two time-frames, 1977-8 and 1982-3, are shown in Table 3. These findings show very little change in the ranking or intrinsic evaluation of mission needs between time frames. There are two alternative theories to explain the lack of change. Either NOS personnel feel that the current mission priorities are a good and lasting set which will not change over time or they have not really considered the possibilities for change in missions in future years. Any further analysis of NOS requirements and priorities would benefit from further discussions of missions including interviews with the highest-level NOS personnel and management at the agency and department level.

The scale employed for quantifying the extent of the support relationship between NOS mission needs was as follows:

Major contribution	=	8
Considerable contribution	=	4
Some contribution	=	2
Negligible contribution	=	1
Complete independence	=	0

The contribution of one element of the set to another could have been either beneficial (positive) or detrimental (negative). In the case of NOS mission needs, all contributions were considered beneficial.

Following the workshop, the data accumulated during this voting were used to compute a "supportiveness" measure for each mission need, to assess the extent to which the satisfaction of one need contributes to the satisfaction of others. This "supportive value" (S) was computed using the cross-support voting data, in conjunction with the intrinsic values obtained from analysis of the mission needs ranking and scoring process as shown in Figure 2. Summation of these weighted values across each row then yielded the support value(S) for the mission need represented by that row. Thus S provides a measure of the value of that mission need in view of its contribution to the other mission needs.

These calculations were performed for 1977-8 and 1982-3 time periods. Once again the study team found no significant differences between the two time periods. Also, the supportiveness was very similar among the missions. Mission Need 2, "Provide navigational data for recreational boating" was judged the most supportive with Mission Need 5, "Provide bathymetric data for coastal zone studies" close behind. Missions 3 and 6 providing bathymetric data for mariculture and concerning the sea-land interface marine boundaries to support on-shore industrial development, respectively, tied for least supportive. However, the level of support was not high enough to be judged as significant as the intrinsic value.

A final set of calculations which combined the normalized intrinsic and support values resulted in the scale of mission weightings to be used in relating operational requirement options to mission needs. These calculations tested the sensitivity of the combined or "total mission need value" to various weightings of the support value. The team's analysis found that the pattern of mission needs was insensitive to the weighting used. Based on its total knowledge of the project, the team chose the I + .25S weighting as providing the most realistic balance between intrinsic and supportiveness values. The scoring of mission needs, used in this analysis is shown in Table 4 and 5.

6.1.3 Operational Requirements

The final phase of the workshop session addressed the question of the relevance to the mission needs of the various operational requirements for bathymetry in waters of three fathoms and less (SWB) being evaluated. This was accomplished by formulating sets of related options or variants (e.g., pertaining to vertical accuracy) whose individual and combined impacts on the 10 mission needs could be estimated either through direct voting during the workshop or through later calculation using workshop-derived data. Table 6 shows the list of SWB operational requirements as they were voted.

The workshop voted to eliminate Number 7, "Locate and record all potential hazards to navigation within an appropriate time period," based on its ambiguity and the opinion that this is really more a part of the NOS mission need than the SWB operational requirements necessary to fulfill those needs.

Using the consensor equipment as before, the workshop participants were then asked a series of questions in the format of "how would this option affect this mission?". For example, "what impact would performance of bathymetric surveys of waters of 3 fathoms or less with a 100 percent improvement of accuracy over current NOS standards have on the mission need to provide navigational data for commercial shipping?"

For this series of questions, the voting scale had the following meanings:

8 - High impact

4 - Moderate impact

2 - Low impact

1 - Negligible impact

0 - Totally independent

\+ - Beneficial impact

\- - Detrimental impact

As the basis for ranking the various requirements and set of associated requirement options, the evaluating team defined an index or measure of criticality. This measure established and permitted comparison of the average absolute impact of each option or option group. The formula for computation was as follows:

$$\text{Measure of Criticality} = \frac{\text{Effects of Improving+Effects of Degrading}}{\text{Number of Effects Measured}}$$

$$\text{Method of Computation} = \frac{\Sigma\text{Absolute Weighted Cross-Relevance Values of Options}}{\text{Number of Options Measured}}$$

Two examples of application of the formula to the SWB requirements options follow:

Example 1. Computation of the impact (criticality) of changing standards of accuracy for vertical measurement in bathymetric surveys in waters of 3 fathoms or less gives a criticality measure equal to:

$$\frac{2.05 + 4.5}{2} = 3.3 \text{ for 1977-78.}$$

Example 2. Computation of the impact of increasing standards of accuracy for vertical measurements in waters of 3 fathoms and less by 100 percent yields a criticality measure of 2.05 for 1977-78.

Criticality calculations for the requirement option groups yielded the schedule of operational groups in order of decreasing criticality of effect shown in Table 7. Note that there is no change in option order between time frames and only slight changes in the criticality index value.

6.1.4 Results

By considering the criticalities of both SWB operational requirement option groups and individual options, the team developed the list shown in Table 7. This list of rank-ordered against the maximum measure of criticality of 10 possible under the I + .25S weighting scheme.

Figure 7 provides a graphic display of the 1977-78 list. The graph shows a very good distribution which illustrates a separation into four parts occurring at the same index values originally chosen by the project team's judgment and thus serves to validate the results.

TABLE 2

NATIONAL OCEAN SURVEY
BATHYMETRIC MISSION NEEDS

1. Provide navigational data for commercial shipping.
2. Provide navigational data for recreational boating.
3. Provide bathymetric data for mariculture.
4. Provide bathymetric data for construction, dredging and other engineering studies.
5. Provide bathymetric data for coastal zone studies.
6. Provide bathymetric data concerning the sea-land interface marine boundaries to support on-shore industrial development.
7. Provide bathymetric data for pollution and other environmental studies.
8. Provide bathymetric data for other scientific research studies.
9. Survey all uncharted areas of the continental shorelines, Great Lakes and rivers within NOS jurisdiction.
10. Provide navigational and bathymetric data for commercial fishing.

	1977-1978		1982-1983	
RANK	NAME (#)	INTRINSIC VALUE	NAME (#)	INTRINSIC VALUE
1	Comm. Ship. (1)	.257	Comm. Ship (1)	.249
2	Rec. Boat. (2)	.165	Rec. Boat. (2)	.165
3	Comm. Fish. (10)	.136	Comm. Fish. (10)	.136
4	Con, Dred, Eng (4)	.084	Con, Dred, Eng (4)	.094
5	All Uncharted (9)	.081	Sea, Land Int. (6)	.083
6	Sea-Land Int. (6)	.078	All Uncharted (9)	.069
7	Coast Zone Studies (5)	.066	Coast Zone Studies (5)	.063
8	Poll.,Environ. (7)	.052	Poll., Environ. (7)	.053
9	Other Sci. Res. (8)	.045	Other Sci.Res. (8)	.046
10	Maricult. (3)	.036	Maricult. (3)	.042

TABLE 3

NOS MISSION NEEDS - RANKING AND INTRINSIC VALUES

Mission Needs M.N.	Intrinsic Value I	Weighted Support Value S	I+.05S	I+.1S	I + .25S	I+.5S	I + S
1	.26	.10	.27	.27	.29	.31	.36
2	.17	.12	.18	.18	.20	.23	.29
3	.04	.08	.04	.05	.06	.08	.12
4	.08	.10	.09	.09	.11	.13	.18
5	.07	.12	.08	.08	.10	.13	.19
6	.08	.08	.08	.09	.10	.12	.16
7	.05	.10	.06	.06	.08	.10	.15
8	.05	.09	.05	.06	.07	.10	.14
9	.08	.10	.09	.09	.11	.13	.18
10	.14	.11	.15	.15	.17	.20	.25

TABLE 4

SCORING OF MISSION NEEDS

1977-8

MISSION NEEDS M.N.	INTRINSIC VALUE I	WEIGHTED SUPPORT VALUE S	I+.05S	I+.1S	I + .25S	I+.5S	I + S
1	.25	.10	.26	.26	.28	.30	.35
2	.17	.12	.18	.18	.20	.23	.29
3	.04	.08	.04	.05	.06	.08	.12
4	.09	.10	.10	.10	.12	.14	.19
5	.06	.12	.07	.07	.09	.12	.18
6	.08	.08	.08	.09	.10	.12	.16
7	.05	.10	.06	.06	.08	.10	.15
8	.05	.09	.05	.06	.07	.10	.14
9	.07	.10	.08	.08	.10	.12	.17
10	.14	.11	.15	.15	.17	.20	.25

TABLE 5

SCORING OF MISSION NEEDS

1982-3

VOTING LIST

OPERATIONAL REQUIREMENT OPTIONS FOR BATHYMETRIC SURVEYS OF WATER 3 FATHOMS AND LESS

1. Maintain vertical accuracy of at least present standards.

1a. Perform vertical measurements with a 100% improvement of accuracy over current NOS standards.

1b. Perform vertical measurements with a 50% degradation of accuracy from current NOS standards.

2. Maintain horizontal accuracy of at least present standards.

2a. Perform horizontal measurements with a 100% improvement of accuracy over current NOS standards.

2b. Perform horizontal measurements with a 50% degradation of accuracy from current NOS standards.

3. For a given sector, increase actual coverage of bottom from current level.

3a. For a given sector, provide 100% actual coverage of bottom.

VOTING LIST

CONTINUATION OF OPERATIONAL REQUIREMENT OPTIONS FOR BATHYMETRIC SURVEYS OF WATERS 3 FATHOMS AND LESS

5. Resurvey stable areas once every 50 years.

6. Maintain at least current number of chart adequacy surveys per year.

6a. Increase number of chart adequacy surveys per year by 100%.

7. ~~Locate and record all potential hazards to navigation within an appropriate time period~~.

8. Improve current level of responsiveness to urgent survey requests by 100%.

9. Continue surveying at least current number of linear nautical miles per year.

9a. Increase total linear nautical miles of survey per year by 1000%.

9b. Increase total linear nautical miles of survey per year by 100%.

TABLE 6

OPERATIONAL REQUIREMENT OPTIONS FOR
BATHYMETRIC SURVEYS OF WATERS 3 FATHOMS AND LESS
(VOTING LIST)

VOTING LIST

OPERATIONAL REQUIREMENT OPTIONS FOR BATHYMETRIC SURVEYS OF WATER 3 FATHOMS AND LESS

3b. For a given sector, provide 50% actual coverage of bottom.

4. Change scheduling of resurveying changeable areas to regular basis.

4a. Resurvey changeable areas once each year.

4b. Resurvey changeable areas once every five years.

VOTING LIST

CONTINUATION OF OPERATIONAL REQUIREMENT OPTIONS FOR BATHYMETRIC SURVEYS OF WATERS 3 FATHOMS AND LESS

9c. Decrease total linear nautical miles of survey per year by 50%.

10. Discontinue surveying 3 fathoms or less waters.

TABLE 6

OPERATIONAL REQUIREMENT OPTIONS FOR
BATHYMETRIC SURVEYS OF WATERS 3 FATHOMS AND LESS
(VOTING LIST)

CRITICALITY 1977-78	CRITICALITY 1982-83	SWB OPERATIONAL REQUIREMENT OPTION GROUP EFFECT (#)
8.67	8.52	Continue bathymetric surveying of waters 3 fathoms and less. (10)
5.87	5.78	For a given sector, increase actual coverage of bottom in surveys of waters 3 fathoms and less. (3)
5.52	5.41	Change number of total linear nautical miles of survey per year of waters 3 fathoms and less. (9)
4.14	4.09	Change standards of accuracy for horizontal measurement in surveys of waters 3 fathoms and less. (2)
4.08	3.99	Change number of chart adequacy surveys per year of waters 3 fathoms and less. (6)
3.30	3.28	Change standards of accuracy for vertical measurement in surveys of waters 3 fathoms and less. (1)
3.23	3.21	Change method of determining when to resurvey changeable areas of waters 3 fathoms and less to regular basis. (4)
1.17	1.14	Change method of determining when to resurvey stable areas of waters 3 fathoms and less to regular basis. (5)
0.13	0.13	Increase level of responsiveness to urgent survey requests in waters 3 fathoms and less. (8)

TABLE 7

SWB OPERATIONAL REQUIREMENT OPTION GROUP EFFECTS
IN ORDER OF DECREASING CRITICALITY

TABLE 8

OPERATIONAL REQUIREMENT OPTION CATEGORIZATION AND RANKING FOR BATHYMETRIC SURVEYS IN WATERS OF 3 FATHOMS AND LESS BASED ON CRITICALITY ANALYSIS

CRITICALITY 1977-78	1982-83	SWB OPERATIONAL REQUIREMENT OPTION (#)
Essential (C = 8-10)		
8.7	8.5	Continue bathymetric surveying in waters 3 fathoms and less. (10)
Highly Desirable (C = 5-7.9)		
6.6	6.4	Increase total linear nautical miles surveyed per year by 100%. (9b)
6.1	6.0	For a given sector, provide 50% actual coverage of bottom. (3b)
5.9	5.8	For a given sector, increase actual coverage of bottom from current level. (3)
5.6	5.6	For a given sector, increase actual coverage of bottom. (3a)
5.5	5.4	Continue surveying at least current number of linear nautical miles per year. (9)
Desirable (C = 2.5-4.9)		
4.2	4.1	Resurvey changeable areas at least once every 5 years. (4b)
4.1	4.1	Maintain horizontal accuracy at at least present standards. (2)
4.1	4.0	Maintain at least current number of chart adequacy surveys per year. (6)
3.7	3.6	Increase number of chart adequacy surveys per year by 100%. (6a)
3.3	3.3	Maintain vertical accuracy at at least present standards. (1)
3.2	3.2	Change scheduling of resurveying changeable areas to regular basis. (4)
3.1	3.0	Increase total linear miles of survey per year by 1000%. (9a)
2.9	2.9	Improve horizontal accuracy by 100%. (2a)
Minimum Importance (C = 0-2.4)		
2.3	2.3	Resurvey changeable areas once each year. (4a)
2.1	2.1	Improve vertical accuracy by 100%. (1a)
1.2	1.1	Resurvey stable areas once each 50 years. (5)
0.1	0.1	Improve current level of responsiveness to urgent survey requests by 100%. (8)

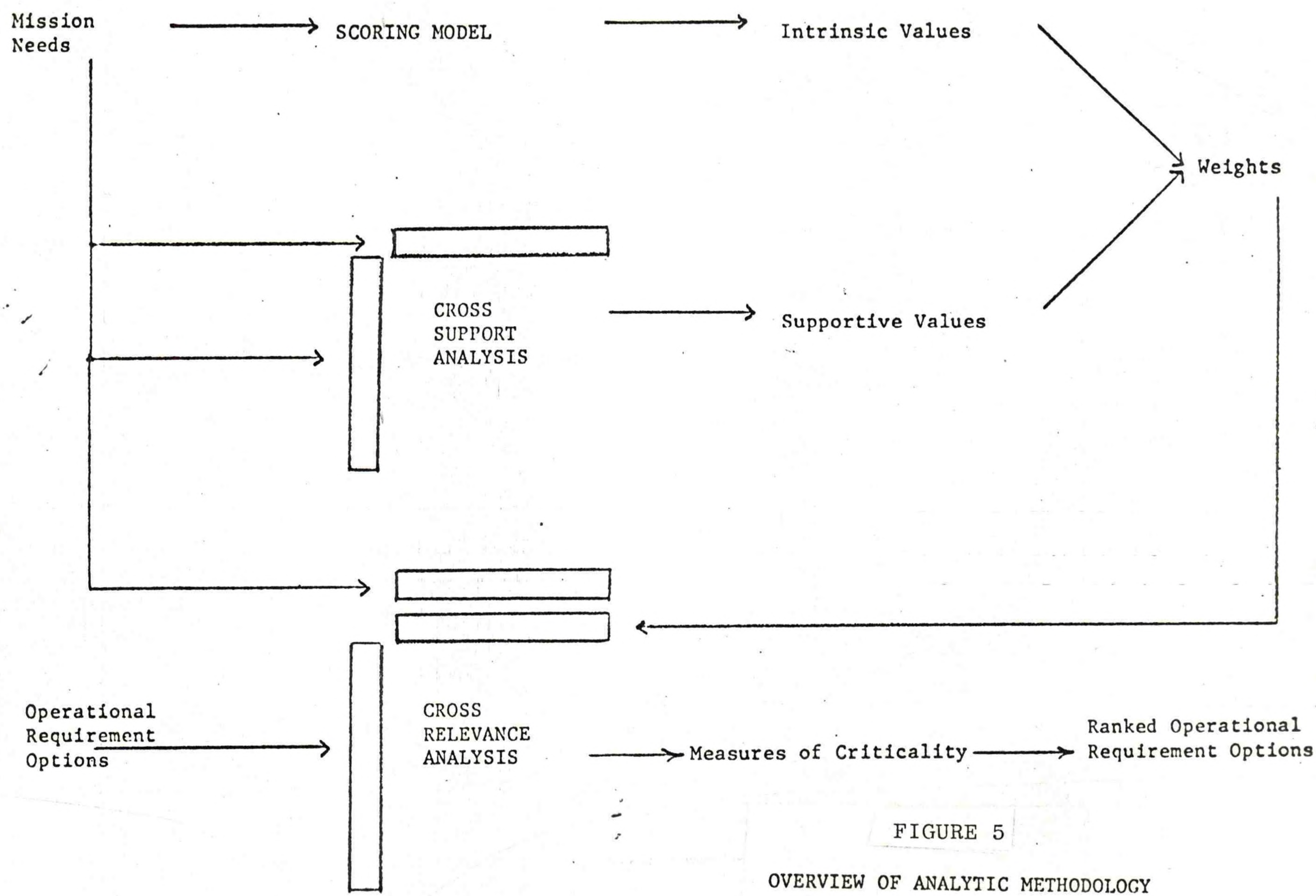


FIGURE 5

OVERVIEW OF ANALYTIC METHODOLOGY

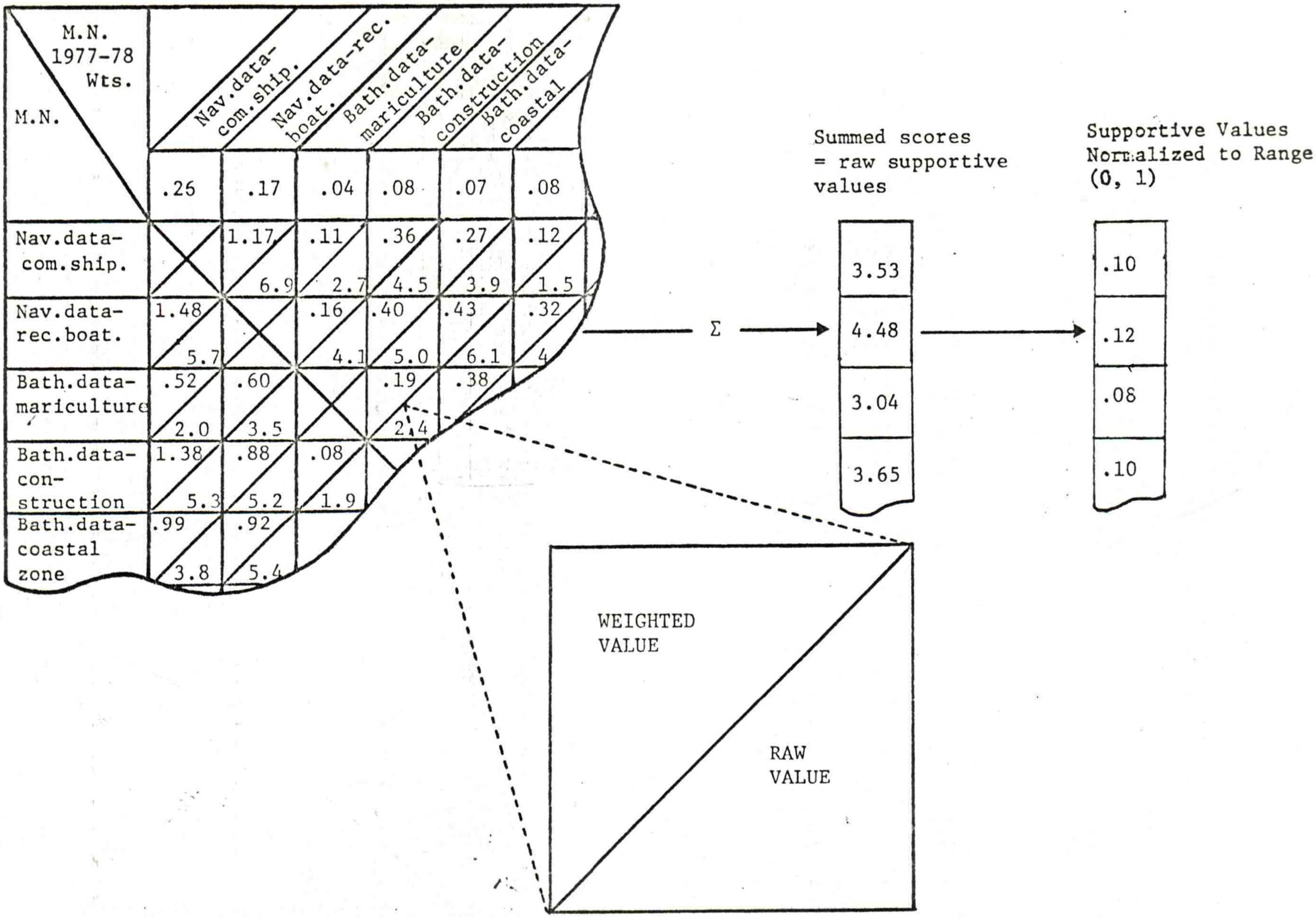


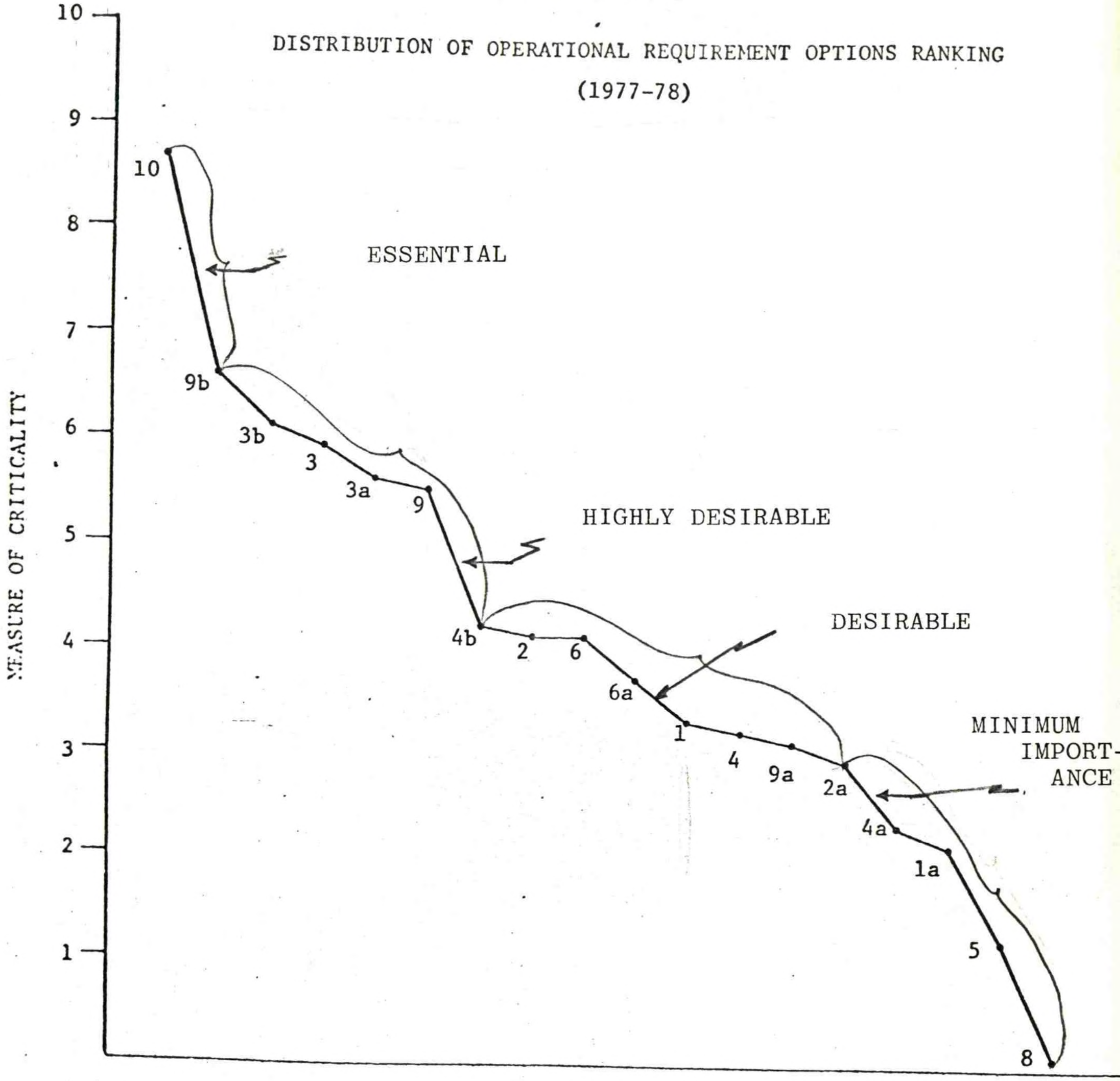
FIGURE 6

MISSION NEEDS CROSS-SUPPORT ANALYSIS METHODOLOGY

FIGURE 7

DISTRIBUTION OF OPERATIONAL REQUIREMENT OPTIONS RANKING

(1977-78)



NOTE:
← Shows break between categories.

6.2 Alternative Systems

The Results obtained from the Requirements Study, as discussed in the previous section (6.1) and presented in Table 8 and Figure 7 of this report, revealed that NOS' Highly-Desirable requirement for bathymetric surveying is to increase the total linear nautical miles surveyed per year by 100 percent. However, NOS' desire is to increase the productivity in terms of quality and thoroughness of coverage and, at the same time, decrease the expenditures involved in the presently-used conventional systems for hydrographic surveys.

In order to meet these Highly-Desirable requirements, the Systems Analysis Division, together with Giannotti & Buck Associates, Inc., conducted a systematic study to insure that no feasible alternative system competitive to Launch-Sonar was overlooked.

6.2.1 Methodology:

To insure that no alternative shallow water bathymetric system was overlooked, a systematic search was conducted through the technical literature and various U. S. private and foreign and government operations. The literature search produced over forty documents considered to contain information which was very relevant to the objectives of this study.

In addition to the literature search, personal interviews were conducted with individuals directly responsible for the development and/or applications of shallow water bathymetric systems. Some of these individuals were interviewed two or three times during the course of the study in order to obtain further information or clarification of comments made earlier in the study. The names of the people contacted, their organizations and their comments are well documented in the progress reports of the Systems Analysis Division of NOS during the study.

6.2.2 Results:

Table 9 presents a summary of the eight (8) systems which were defined as potential candidates for shallow water bathymetry. The list includes the Launch-Sonar system as it provides the frame of reference for evaluation and eventual ranking. The table also indicates the documents which contain detailed descriptions of each of these systems and their use as well as the names and organizations of the individuals contacted for the purpose of obtaining system information.

All of the alternative systems listed in Table 9 have one or more characteristic feature(s) which make them more attractive than the current launch-sonar operations. These advantages are listed next in a qualitative manner. At first, it was intended to quantify these advantages so that a clearer comparison with Launch-Sonar could be made. However, the lack of data for some of the systems and/or the inherent bias in the performance figures reported by the individuals or groups responsible for certain systems made it very difficult to report the realistic numerical values. This, however, did not prevent us from independently ranking all systems based on our own judgment, and the results are reported in Table 1 of Section 1.0 of this report. The additional benefits that can be obtained from each of the evaluated candidate systems are briefly outlined below:

(a) Airborne Photobathymetry:

1. Lower cost per square mile of survey.
2. More complete and detailed coverage of the area to be charted.
3. Performed in conjunction with coastal mapping operation.
4. The body of water and bottom to be charted is actually "seen" by the user.
5. Collision and grounding risk is avoided.
6. Higher survey rate.

(b) Airborne Laser:

1. Lower cost per square mile of survey.
2. More complete and detailed coverage of the area to be charted.
3. Collision and grounding risk is avoided.
4. Capable of performing both day and night operations.
5. Higher survey rate.

(c) Airborne Acoustic System:

1. Possibly lower cost per square mile of survey.
2. Possibly more complete and detailed coverage of the area to be charted.
3. Collision and grounding risk avoided.
4. Higher survey rate.

(d) LANDSAT/Multispectral Scanner:

1. Lower cost per square mile of survey.
2. More complete and detailed coverage of the area to be charted.
3. Collision and grounding risk is avoided.
4. Survey is performed in conjunction with other LANDSAT missions.
5. No platform or sensor manning is required.
6. Could provide support for effective survey planning with other systems.
7. The body of water and bottom to be charted is actually "seen" by the user.
8. Higher survey rate.

(e) HYSURCH Concept:

1. Grounding risk is reduced.
2. Higher survey rates.
3. More complete coverage of area to be charted.

(f) Airship Platform-Based System:

1. Possibly lower cost per square mile of survey.
2. More complete and detailed coverage of the area to be charted (assuming a camera or laser is mounted on the airship).
3. Collision and grounding risk is avoided.
4. Capable of performing, both day and night operations (assuming use of a laser system).
5. Higher survey rate.
6. Platform combines high stability with the ability to operate at any speed from 0 to 70 knots.
7. Platform can be used simultaneously for several oceanographic missions.

6.2.3 System Evaluation and Ranking

In order for photographic and laser bathymetry to be viable cost-effective tools, they could be used in conjunction with other tools having complementary characteristics. The use of sonar launches is the most common method of shallow water depth determination, but it is time and people consuming, expensive and can be hazardous. Thus, it should be reserved for areas that cannot be covered by other less demanding methods. An ideal system would appear as a composite system to include overflights (aircraft or satellite) using photographic and laser techniques with sonar launches reserved for a few ground truth measurements and those deeper, less hazardous areas unaccessible by optical methods.

In all probability, the optimal system would be some combination of the launch, photographic bathymetry, and some laser bathymetry method (with the laser wavelength being chosen for maximum penetration in the particular area of interest). One would expect that for different areas and different times of the year, the relative amount of use of each of the named devices would vary so that the bathymetric capability of NOS should include launch, photographic, and laser capabilities, so that these three techniques can be utilized in whatever portion is necessary to produce the optimum bathymetric survey.

(a) Composite System:

The benefits that can be obtained from a composite system are briefly described below:

1. Possibly lowest cost per square mile of survey.
2. Combines the best features of all sensors and platforms allowing for survey of shallow restricted areas; day and night operations; operation in relatively heavy weather; not limited by water turbidity.

3. The composite system would allow for improved planning of surveys by choosing the most desirable sensor to use in a given area ahead of time. Furthermore, it would free up costly aircraft time to be used in other missions where the need may be greater.

The plan for the development of such a composite bathymetric system is presented in Section 7.0 of this report.

SYSTEM	DESCRIPTION	RELEVANT DOCUMENTS (See Appendix A)	INDIVIDUALS CONTACTED (See Appendix B)	GENERAL COMMENTS
LAUNCH-SONAR	Acoustic sensor mounted on launches operated by field parties	38,36,43	Capt. Wayne Mobley, NOS C6 Lt. Cdr. R. Hopkins, NOS Fleet Operations Bathymetric Systems	1. Only alternative in turbid waters 2. Low survey rate and area coverage 3. Hazardous to operate 4. High operational costs 5. Accuracy could be improved. 6. System is operational
AIRBORNE LASER	Laser mounted on aircraft. Laser pulse is sent vertically downward. Time delay between light pulse reflected from the water surface and the one coming from the ocean floor yields water depth information	38,24,15,16, 22,30,17,23,43 31,4,24,11	Lt. Cdr. L. Goodman NOS, C 61	1. Competitive in relatively clear waters 2. Possibly more cost-effective to operate than launch-sonar 3. Accuracy could be improved. 4. System undergoing development.

TABLE 9

SHALLOW WATER BATHYMETRY SYSTEM CONFIGURATIONS

SYSTEM	DESCRIPTION	RELEVANT DOCUMENTS (See Appendix A)	INDIVIDUALS CONTACTED (See Appendix B)	GENERAL COMMENTS
AIRBORNE PHOTOBATHYMETRY	Camera mounted on aircraft. Steroscopic pictures are taken from the air and these are then analysed for depth information based on the difference in intensity of the received signals on the two images	33,28,7,29, 43	Cdr. J. Collins NOS, C34	1. Competitive in relatively clear waters 2. Possibly more cost-effective to operate than launch-sonar 3. Accuracy could be improved . 4. System is operational
AIRBORNE ACOUSTIC SYSTEM	Acoustic transmitter and receivers towed above the surface of the water by aircraft Acoustic signal penetrates water surface, and is reflected from the bottom back to the receivers,	23	G.D. Hickman, Private Consultant	1. Feasibility study showed that the system has severe limitations 2. Strictly a theoretical study

TABLE 9 (Continued)

SYSTEM	DESCRIPTION	RELEVANT DOCUMENTS (See Appendix A)	INDIVIDUALS CONTACTED (See Appendix B)	GENERAL COMMENTS
LANDSAT/ MULTISPECTRAL SCANNER (MSS)	Multispectral Scanner mounted on NASA'S LANDSAT Satellite yields green band data which is then translated into water depth	46,20,2,41,2, 34,41,37	Mr. J.C. Hammack, Deffense Mapping Agency, Hydrographic Center. Mr. Charles Bohn, Missions Utilization Office of NASA, Goddard Space Center. Mr. F. Polcyn, Envi-romental Research Institute of Michigan (ERIM)	1. Competitive in relatively clear waters 2. More area coverage than other Bathymetric systems. 3. Possibly more cost effective than launch-sonar. 4. System is operational
HYSURCH CONCEPT	Acoustic sensors mounted on high performance marine vehicles operating from a mother ship. Vehicles include air cushion vehicle surface effect ships, hydrofoils, planing hulls.	42,4	Dr. B.E. Olson, Chief Scientist of NAVOCEANO . Mr. H. Beck and Mr. H. Woodson, Ocean Engineering Group of NAVOCEANO Prof. P. Mandel, Ocean Engineering Dept., M.I.T. Mr. C.W. Pritchett, US Coast Guard Research and Development Center, Groton Connecticut.	1. Competitive with conventional launch-sonar as originally conceived 2. Platform costs are excessive . 3. Limited version is operational with NAVOCIANO

TABLE 9 (Continued)

SYSTEM	DESCRIPTION	RELEVANT DOCUMENTS (See Appendix A)	INDIVIDUALS CONTACTED (See Appendix B)	GENERAL COMMENTS
AIRSHIP PLATFORM - BASED SYSTEM	Photographic, Laser or Sonar System Mounted on an Air-Ship (BLIMP)	44		1. Could be competitive with launch and aircraft based systems 2. System is not operational, strictly a paper concept for bathymetry applications
COMPOSITE SYSTEM	Combined, launch-sonar laser, photo bathymetric and LANDSAT systems acting as part of an integrated package to optimize cost and effectiveness of bathymetric operations	See Volume II of this report	Prof. Jerome Williams, Environmental Sciences Dept., U.S. Naval Academy	1. System would be competitive in both turbid and clean waters. 2. System cost effectiviness could be optimized.

TABLE 9 (Continued)

6.3 NOS Plans

The results presented in Section 6.1 of this report revealed that NOS' highly-desirable requirement for bathymetric surveying is to increase the total linear nautical miles surveyed per year by 100 percent. To meet this requirement and the other highly-desirable requirements as presented in Table 8 of this report, a composite bathymetric system which incorporates the best features of the acoustic and optical methods, appears to be the best possible alternative system, as discussed in Section 6.2 of this report.

However, the NOS hydrographic planning regarding the area coverages for the surveys and the establishment of priorities of these areas, has to be determined.

This information has been obtained by the Systems Analysis Division together with Hydronautics, Inc., through a series of comprehensive interviews with NOS personnel. Through this approach, key policymaking individuals were contacted and information on the basic NOS policies and plans has been obtained. The near and far-term bathymetric system requirements, plans and policies dealing with coastal and inland shallow water areas of three fathoms and less depths have been determined.

6.3.1 NOS Hydrographic Survey Planning

The elements that are involved in establishing a bathymetric survey are discussed in this section.

The requirements for bathymetric surveys evolve as a result of the demands for up-to-date nautical charts. The chart demands originate from private individuals through personnel correspondence with NOS, industry, Federal, state and municipal requests and NOS Chart Adequacy Surveys. The analysts of the Marine Charts Division of the Office of Marine Surveys and Maps assess the chart demands and recommend the issuance of new charts as necessary. The chart recommendations reflect the collective opinions among the analysts.

The survey requirements are subject to the judgment of a small number of NOS personnel. They may, for example, have to weigh the urgency of a survey request from a prominent oil company establishing new facilities in Puerto Rico relative to a request by the U. S. Coast Guard for surveys on the coast of Maine needed in connection with plans for new deep-water ports. In this case, it may be an easy compromise as surveying in Maine may be restricted to summer months, so that Puerto Rico surveys can be carried on in the winter; however, many factors must be considered and the final decision is the result of subjective opinion of those individuals involved.

Based on the number of chart adequacies and/or inadequacies, together with the long-term charting plans of NOS, preliminary survey plans are established. These plans are submitted to "round table meetings" where the final survey plans are established. It should be noted that survey plans are tentatively established in advance of the meeting and finalized at the meeting. The "round table meeting" is chaired by the Associate Director of Marine Surveys and Maps or his deputy. These personnel act as moderators in establishing surveys priorities. Once the members of the "round table meetings" have completed their own background evaluations the meetings are called and survey priorities are set. The attendees of the "round table meetings" include personnel from Codes C2, C3, C32, C33, C4, C5, CAM and CPM. A graphical representation of the process for establishing the survey priorities is shown in Figure 8. There is a substantial amount of feedback and coordination between groups and the process is facilitated by the small size of the groups involved.

Upon establishment of surveying needs and priorities, ship time for the bathymetric surveys is requested through the Fleet Allocation Council. This Council in turn establishes a schedule for surveys, based on financial and manpower resources available and pre-existing ship commitments and schedules. Direction to the NOAA fleet comes from R.Adm. H. R. Lippold, Jr., Associate Director, Office of Fleet Operations.

The priority listings are also distributed to the Atlantic and Pacific Marine Centers. At the Atlantic Marine Center (AMC) there are, in addition to hydrography vessels, a certain number of shore-based hydrographic field parties, whose programs are spelled out specifica-ly in the planning documents.

Presurvey planning activities include establishing geodetic control, shoreline surveys and a tidal datum. Presurvey planning activities also require the coordination of the inputs of the Marine Surveys, Marine Chart, the Coastal Mapping and Oceanographic Divisions of Marine Surveys and Maps. The Marine Requirements Branch of the Marine Survey Division oversees the preparation of detailed project instructions for each survey. The Marine Requirements Branch reviews each divisional requirements and inputs the information into the project plans. This group also monitors the progress of underway surveys to assure compliance with project instructions and overall program objectives.

Project instructions, following a critical review and amended as necessary, are approved by the Marine Surveys Division and signed by the Associate Director, Office of Marine Surveys and Maps.

6.3.1.1 NOS Hydrographic Surveys:

It should be noted that NOS is conducting six types of bathymetric surveys, namely:

1. Navigable area surveys
2. Chart adequacy surveys
3. Wire drag surveys
4. Ship-hydrographic surveys
5. Hydrographic field party (HFP) surveys
6. Special surveys.

The nature and type of survey of several of the above surveys are obvious by name; however, several need further definition.

Navigable Area surveys are designed to provide contemporary hydrographic surveys for updating existing nautical charts or the construction of new charts. This type of survey serves to meet the charting requirements in areas of increased commercial interest where little or obsolete data exists.

Ship Hydrographic Surveys is a survey conducted in any area which the Commanding Officer of the survey ship will operate his ship. Any area in which the Commanding Officer will not operate his ship is designated an area for launch hydrographic surveying.

Hydrographic Field Party (HFP) Surveys are surveys conducted inshore and in relatively shallow waters. These surveys are landbased surveys that employ launches for their waterborne operations. It should be noted that there are no hydrographic field parties located on the west coast. The five or so existing hydrographic field parties operate under the direction of the Marine Center in Norfolk. One field party is employed in locating chart discrepancies. The size of the hydrographic field party can vary depending upon the nature and magnitude of the survey effort; however, the typical hydrographic field party has a five-man crew and one launch. A maximum of 10 launches are available for use; they range in length from 17 to 59 feet.

Special Surveys are surveys that are not unique in type; for example, they may be the navigable area surveys, but are given a higher priority than would be warranted under other circumstances. Special Surveys are responses to immediate and unforeseen needs that could not be and were not anticipated. An example of a currently-scheduled Special Survey is the Chart Deficiency Survey of the St. Johns River, Florida.

A deficiency survey is one planned to resolve inconsistencies on a chart reported by various users. Its exact procedure will, therefore, vary to suit the occasion but it generally is carried out by a single field party.

6.3.1.2 NOS Planning:

At present, NOS does not differentiate its bathymetry plans into near and long-term plans. Rather, there is a single reasonably flexible five-year plan which is constantly modified at intervals as close as six months. In crisis situations, a task force with high priority can be called into being to give much quicker response for small specific areas.

For new surveys such as those being conducted in Alaskan waters, a considerable amount of lead time from planning to implementation is required. This lead time may be as much as three years unless special urgency is required. There are five basic phases involved in conducting an inshore hydrographic survey:

1. Establish basic survey controls such as landmarks and shoreline references (geodetic survey).
2. Establish secondary controls for electronic or hydroreferencing.
3. Shoreline mapping and tidal gauging.
4. Field editing of shoreline manuscripts.
5. Launch hydrography.

In the normal cycle of events, the first three items can require three seasons; however, with advanced systems using satellite positioning, the basic phase times may be markedly shortened.

The plan is modified in accordance with both general and specific requirements. The general requirements are established by law and suggest an approximate 50-year resurvey period for the U. S. coastal waters. Experience and available funds determine the sequence and locations to be surveyed over the longer periods of time. More or less obvious requirements arise with growth in old or new coastal regions and provide priority for certain surveys. Alaskan oil development is an obvious example and growth of new marine industries in a region may produce requests (with congressional backing) for updated surveys.

Bathymetric Surveys are loosely categorized as pre or post-1940. The 1940 dividing line arises due to the development of the continuously-recording fathometer. Any survey completed after 1949 is considered a contemporary survey. Charts based on pre-1940 surveys are candidates for resurveys and reissue. The NOS is presently developing the Automated Charting System. This system is expected to be completed in 1981. In 1981, NOS also plans to adopt the nautical chart to the conventions established by the International Hydrographic Organization (IHO). Between now and 1981, NOS is not undertaking any major new charting programs, but instead is responding only to "brush fire" needs. However, some of these "brush fire" needs involve major surveying efforts, such as the surveying work underway in Alaska. The Atlantic and Pacific Marine Centers, upon receipt of the priorities and instructions, proceed to carry out the operations. If factors such as equipment breakdown, weather or scheduling difficulties require modifications of the survey plans, the operating centers request approval for changes through headquarters.

Once priorities are established, the survey sequence in a given area is selected by headquarters' personnel (C35) and the operational units, CAM or CPM. For example, in the Lake Erie surveys initial plans called for continuing efforts working to the east from past areas. However, because of agreements reached with the Canadians, higher priority was given to the Buffalo, NY, area and surveys were initiated there working to the west. Upon joining up with the earlier western surveys, the Lake Erie project will be finished.

Many areas designated on the priority listings will require several year's work for completion and it is often found that winter operations are not practical. In these cases, the decisions on launch party assignments will reflect the optimal use of the equipment as determined by common sense and the considerable past experience of the NOS personnel in conducting hydrographic surveys.

6.3.2 Survey Coverages:

The survey coverages for the past five years are presented as bar charts in Figures 9 and 10 in terms of linear nautical miles and square nautical miles. These figures represent the total coverages without regard to depth; annual coverages for depths of 3 fathoms and less were not available. The percentage of the total area of depths of 3 fathoms and less on any given survey is highly variable and depends primarily on the parcels selected. Hydrographic Field Party surveys of the south shore of Lake Erie conducted in 1976 were made out to depths of about 10 fathoms. For this particular site, the percentage of bottom at depths of 3 fathoms and less is less than 10 percent of the area surveyed. For surveys conducted in the Delaware Bay and other shallow waters, such as Currituck Sound, the area of 3 fathoms of water can be close to 100 percent of the total. Thus, to obtain a year-by-year estimate of the actual number of square nautical miles covered, all areas surveyed would have to have been measured off the individual charts available in the files at NOS. Estimates of time required to accomplish this work appeared to be unreasonable in view of the overall goals of the program and the practical constraints on time and cost.

In view of the unavailability of 3-fathom data, it was decided to attempt an analysis of the coverages of a moderate number of surveys to find a relationship between the depth of the survey and the monthly coverage both in terms of linear nautical miles and square nautical miles. The data were collected from surveys made at various sites along the eastern seaboard and Lake Erie. The basic data are presented in Table 10, and also in Figures 11 and 12, where monthly coverages are plotted as a function of water depth. An attempt is made to find a meaningful depth reference by showing a range (using bars) of depths covering the deepest 20 percent or so of the area. The data clearly show the wide variability of the surveying rates but appear to indicate an upper boundary of sorts. The very low values obtained in some cases are not always explainable, but often factors such as the presence of obstructions, islands or poor weather can be implicated. The effect of cold weather in survey operations is apparent in several of the surveys examined. The Lake Erie surveys, for example, show a marked drop in coverage during the month of October; the Baltimore Harbor surveys show a steady reduction in coverage from September through December, although the Christmas holidays may have had some impact on the December values.

The data shown in Figures 11 and 12 provide a more realistic basis for estimating survey launch performance than previously-made estimates. Commander James Collins of the NOS Coastal Mapping Division, has estimated the coverage for a single launch at 10 linear nautical miles (LNM) per day or about 220 LNM per month with an area coverage of about 8.7 square nautical miles (SNM) per month. In another analysis performed by GKY and Associates, Inc., they estimated typical coverages at 247 LNM and 5.4 SNM, although they noted that actual operations indicated a much lower average value.

6.3.3 Current and Far-Term Plans

The survey plans for the fiscal year 1978, as presented in Table 11, show the following areas: Lake Erie, Charleston Harbor, Gulf of Mexico, Beaufort Inlet, Pamlico Sound, Banana and Indian River, and Delaware Bay. Most of these areas are the scene of continuing surveys and apparently only Lake Erie, Beaufort Inlet and Charleston Harbor will be completed by the end of 1978. It is clear from the statements in the priorities letter that final decisions on the actual survey schedules come from the operational command at the Marine Centers. No specific plans are given for the square nautical miles to be covered during 1978; however, from the discussion in the previous section and Figures 9 and10, a total in the range of 1000 square nautical miles should be anticipated for hydrographic field parties. Because of the surveys of Lake Erie, Offshore Pamlico Sound, and the Gulf of Mexico, where launches operate out to depths of 10 fathoms or so, the substantial portion of the coverage will be for depths above 3 fathoms. It is estimated (but not measured) that the 3 fathoms and less areas would constitute less than 10 to 15 percent of the total coverage or less than about 150 square nautical miles during 1978.

In 1979, the additional area of Lake Borgne, Louisiana, the Upper Chesapeake and St. Marys River, Michigan, replace those areas completed in 1978. Once again, the normal coverages would be anticipated for this and subsequent years. If schedules are not met, the start of surveys of new areas would be delayed.

Reasons for the selection of one area over another for survey priority are not clearly defined, although justification for any survey can usually be made on the basis of updating obsolete surveys or because of increased traffic or industrial activity.

6.3.4 Discussion of Various Factors Affecting Survey Plans and Coverages

The extent of NOS hydrography is limited by the number of platforms that can be manned and operated, which is, in turn, dictated by the funds allocated for surveying purposes. Chart updates by resurveys are limited by the vastness of the coastline areas. Our study reveals that the East Coast and Great Lakes shallow water areas (i.e., less than 3 fathoms) cover approximately 20,000 square nautical miles. If it were assumed that two and one-half of the five Atlantic Marine Center Hydrographic Field Parties were dedicated to the continuous surveying of these areas, it is estimated that it would take nearly 67 years to complete a surveying cycle (assuming each launch covers 120 square nautical miles/year/launch).

It should be recognized that Hydrographic Field Parties cannot be totally dedicated to shallow water bathymetry. Rather, they are assigned to areas where ships and large survey craft cannot operate. Hence, the time required to survey all shallow water areas will be greater than the 67 years calculated. In fact, it may take two to three times that number of years to provide complete coverage of the shallow water areas using present facilities and techniques. In this regard, it can be seen from Figures 11 and 12 that the average survey rates could be substantially increased if all or most of the surveys could attain the values shown as the line marked "optimum limits of coverage." The cause of the wide variation in survey rates, even for areas of similar depth, is not at all clear, and it is suspected that equipment breakdown, inclement weather, or other manageable factors are at fault. Inspection of the data shown on Figures 11 and 12 would seem to indicate that a potential exists (by correction of or adaptation to the adverse factors) for increasing the shallow water (<3 fathoms) rates by a factor of two. Obviously, it would require additional investment to increase the reliability of equipment or to improve the weather performance of the present system. The alternative is, of course, to introduce a composite system as discussed in Section 6.2.3 and combine different operations as discussed in Section 6.5 of this report. In any case, it is certain that budgetary restraints limit the present system to a rather slow survey pace and condemn various shallow water areas to resurvey times approaching 100 years.

	Area	Survey Number	Survey Month/Year	Linear Nautical Miles Surveyed	Square Nautical Miles Surveyed	Minimum/ Maximum Depth, Ft.	Percent Area in Depths Less Than 1 fathom	2 fathoms	3 fathoms	4 fathoms	5 fathoms	Percent Greater than 5 fathoms	Notes
Chart 12304	Delaware Bay	OPR - 492	May '75	87.8	5.9	0-25	10		60	100			
			June '75	322.0	17.3	0-23	30	50	80	100			Obstructions
			July '75	165.0	8.6	0-7	90	100					
			July '75	310.0	16.0	3-28	10	85	95		100		Shoal Area
			Aug. '75	328.0	17.3	0-35	5	75			95	5	
			Sept. '75	232.0	12.7	0-15	10	85	100				
Chart 11476	Cape Canaveral to Bethel Shoal Banana and Indian River Survey	OPR - 499	June '76	159.0	5.9	0-9	20	100					
			July '76	82.0	2.9	0-8	50	100					
			Sept. '76	65.0	2.5	0-5	100						Obstructions
			Oct. '76	69.0	2.2	0-7	100%<7ft						Obstructions
			Nov. '76	91.0	3.5	0-7	100%<7ft						Obstructions
			Jan. '77	4.5		0-7	100%<7ft						
			Feb. '77	No Information		0-1	100%<1ft						Islands
Chart 12273	Chesapeake Bay	OPR - 510	June '74	121.0	7.1	0-6	100						Obstructions
			July '74	174.0	9.6	0-25	20	95	5%>2 fths				
			Aug. '74	111.0	6.0	0-35	40	70	80	20%>3 fths			
Chart 12204	Currituck Beach Light Bay to Wimble Shoals "Oregon Inlet" Survey	OPR -513	July '75	157.0	4.1	0-30	50	50%>18 ft					
Chart 12248	Chesapeake Bay Approaches to Baltimore Harbor - "Baltimore Harbor" Survey	OPR - 514	Sept. '75	310.0	11.1	0-33	25	75%>18 ft					Obstructions
			Oct. '75	322.0	10.0	0-42			50%>3 fths				Obstructions
			Nov. '75	387.0	5.6	0-33			90	10%>3 fths			Obstructions
			Dec. '75	70.0	2.0	0-33			95	5%>3 fths			Obstructions
Chart 14822	Lake Erie		Oct. '76	30.0	2.0	0-24	20	40	60	100			Obstructions
			June '77	932.0*	50.3*	0-57	1	3	8	10	90%>4 fths		
			July '77	556.0*	11.5*	0-38	15	25	40	60	40%>4 fths		
			Aug. '77	167.0*	7.5*	0-63	1	10	12	88%>3 fths			

*Estimated

TABLE 10

Profiles of Selected Surveys

Ranked Survey Priorities
A. Scheduled (First Priority) 1978 to 1982 1. Lake Erie 2. Charlestown Harbor 3. Gulf of Mexico 4. Beaufort Inlet, NC 5. Pamlico Sound, Offshore, NC 6. Banana and Indian Rivers, Florida 7. Delaware River 8. Lake Boyne, LA 9. Upper Chesapeake Bay 10. St. Mary's River 11. West Florida Coast 12. Currituck Sound, Offshore, NC 13. Currituck Sound, Inshore, NC 14. Delaware Bay (offshore) 15. Delaware Bay (inshore) 16. Pamlico Sound, Inshore, NC 17. Hudson River and NY Harbor B. Unscheduled (Second Priority) 18. Albemarle Sound, NC 19. Lake Ontario 20. Bogue Inlet (NC) 21. FLA Intracoastal Waterway (East) 22. FLA, Southwest Coast 23. Southern Long Island and NJ Coast 24. Lake Michigan -- Upstate New York Lakes 25. Raritan Bay 26. Rappahannock River 27. St. Lawrence River near Ontario 28. Gondiners and Peconic Bays, NY 29. Vermilion Bay, White and Ground Lake, LA -- Wisconsin Lakes

*Special case: inland lakes and rivers.

Source: Office of Marine Surveys and Maps, NOS draft memorandum pertaining to survey priorities, 1978 through 1982. Items 1 through 17 refer to scheduled hydrographic field party activity and Items 18 through 29 refer to unscheduled activity which is assumed to be second in priority to the scheduled activity. The listing is ranked.

TABLE 11

EXISTING PRIORITY SCHEDULE

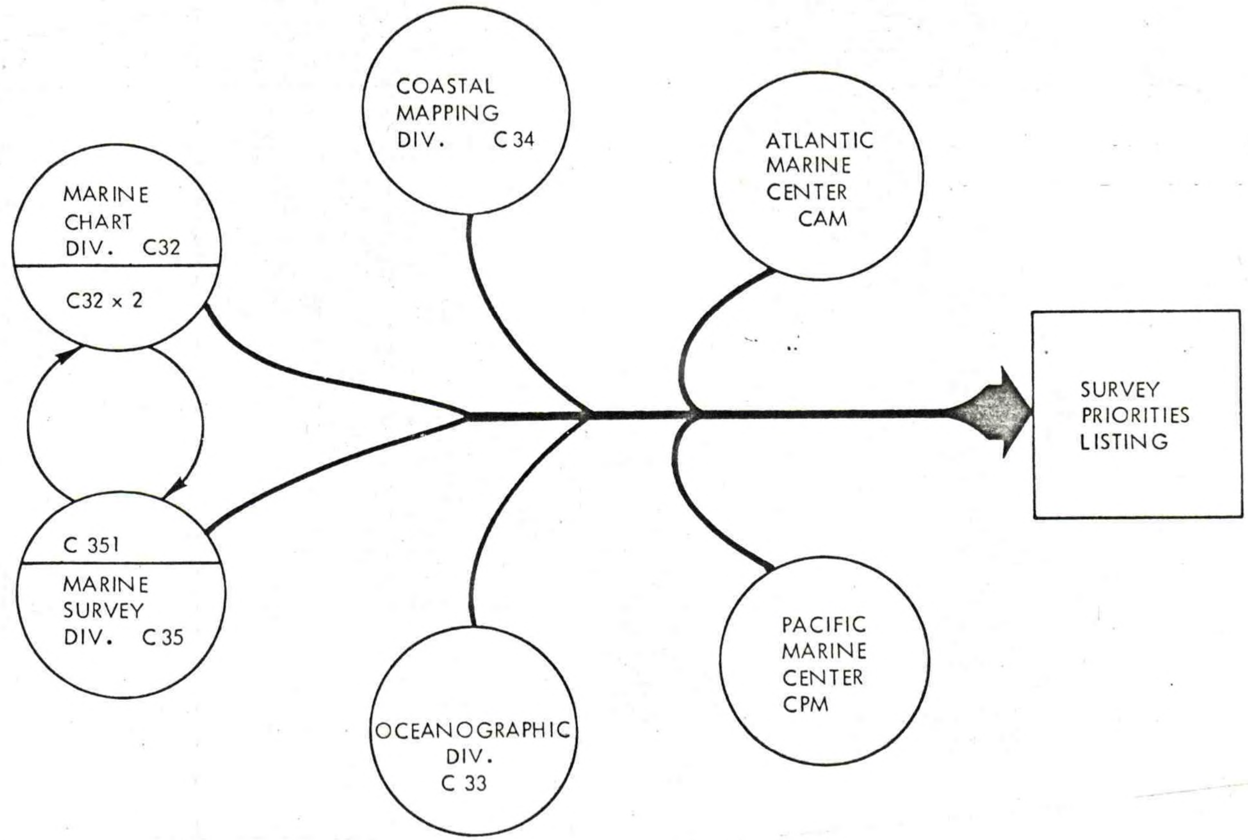


FIGURE 8

- REPRESENTATION OF THE FLOW OF ACTIVITY IN PREPARATION OF OCEAN SURVEY PRIORITIES

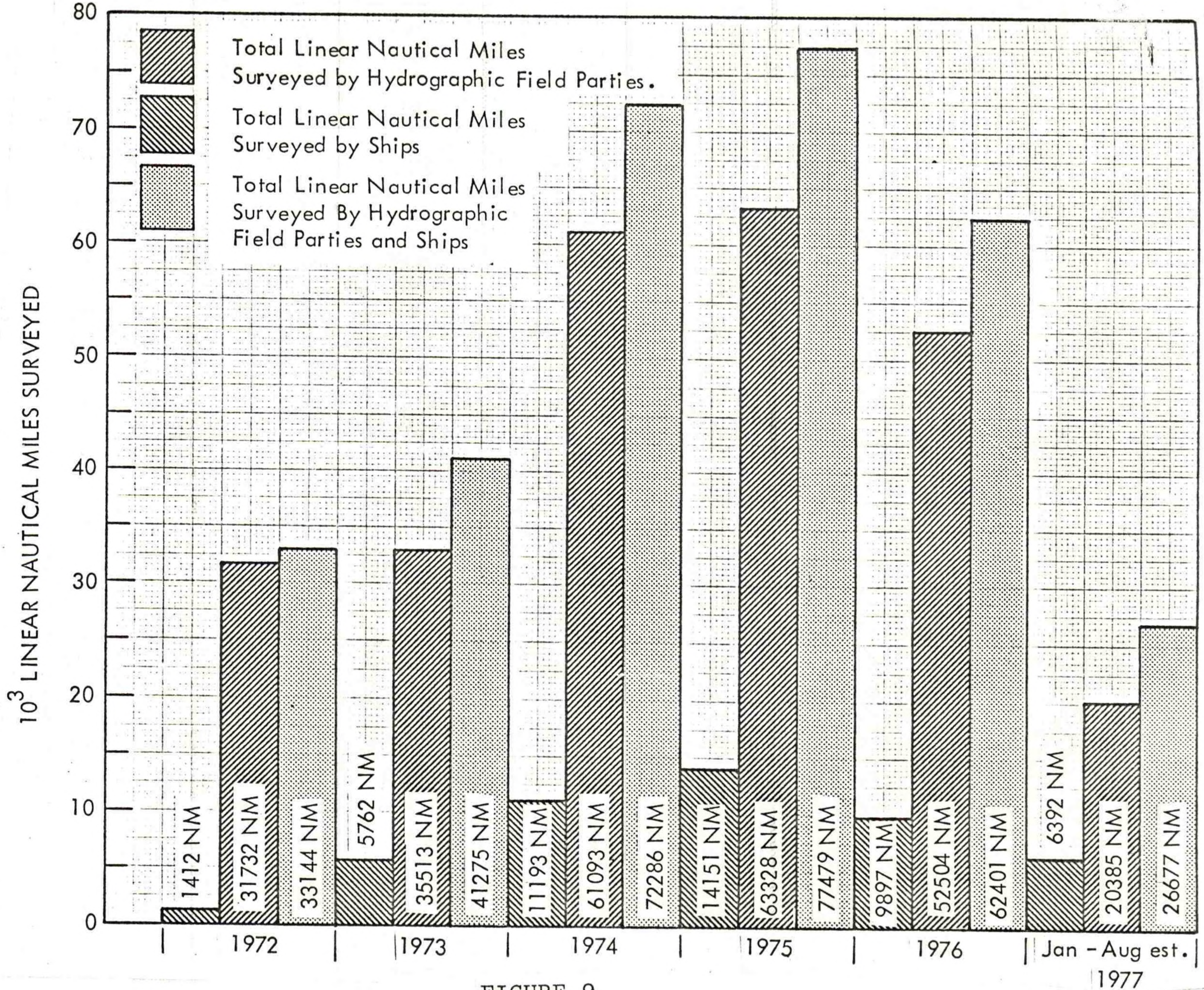


FIGURE 9

TOTAL LINEAR NAUTICAL MILES SURVEYED BY HYDROGRAPHIC FIELD PARTIES AND SHIPS BY YEAR

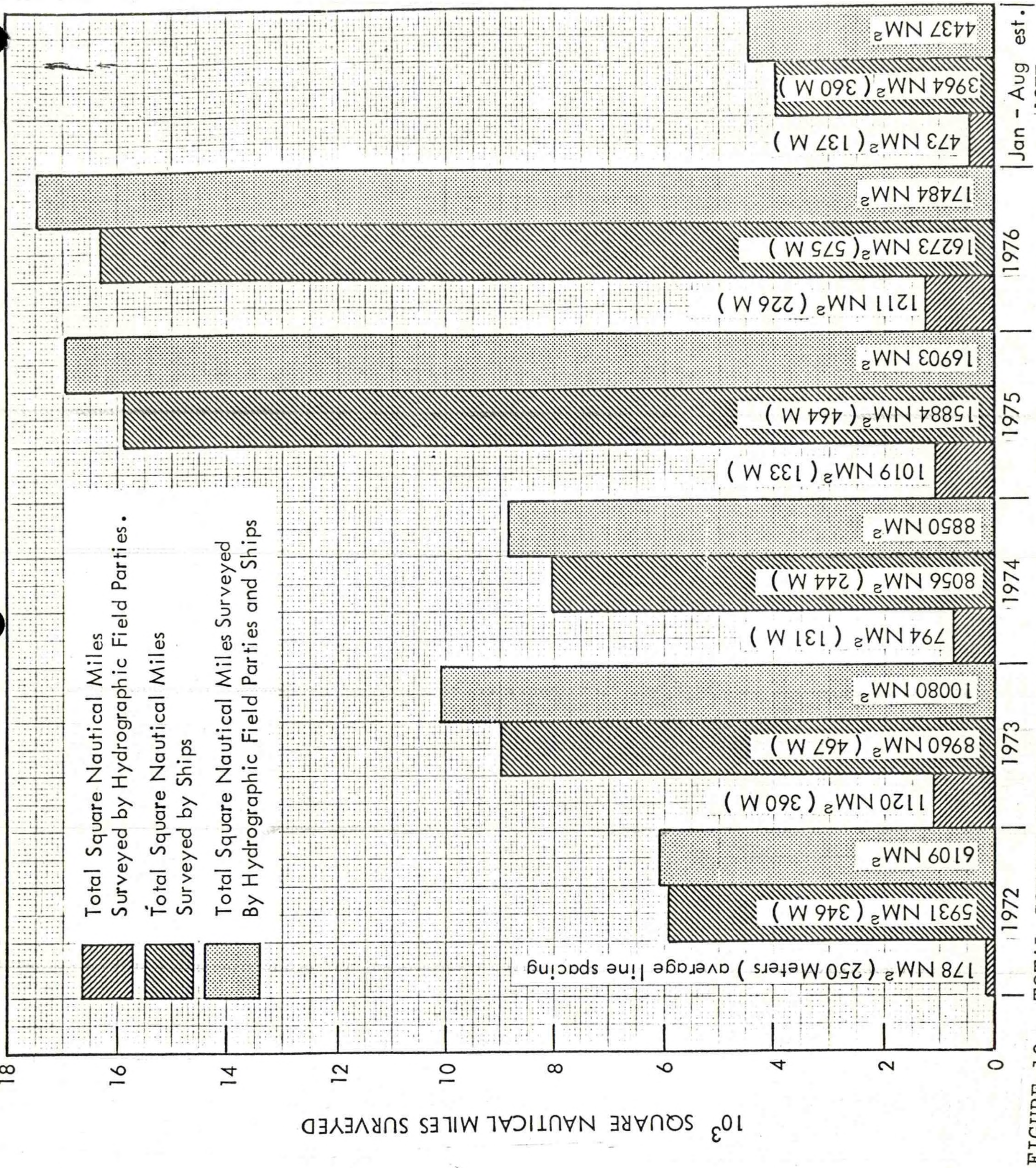


FIGURE 10 - TOTAL SQUARE NAUTICAL MILES BY HYDROGRAPHIC FIELD PARTIES AND SHIPS BY YEAR

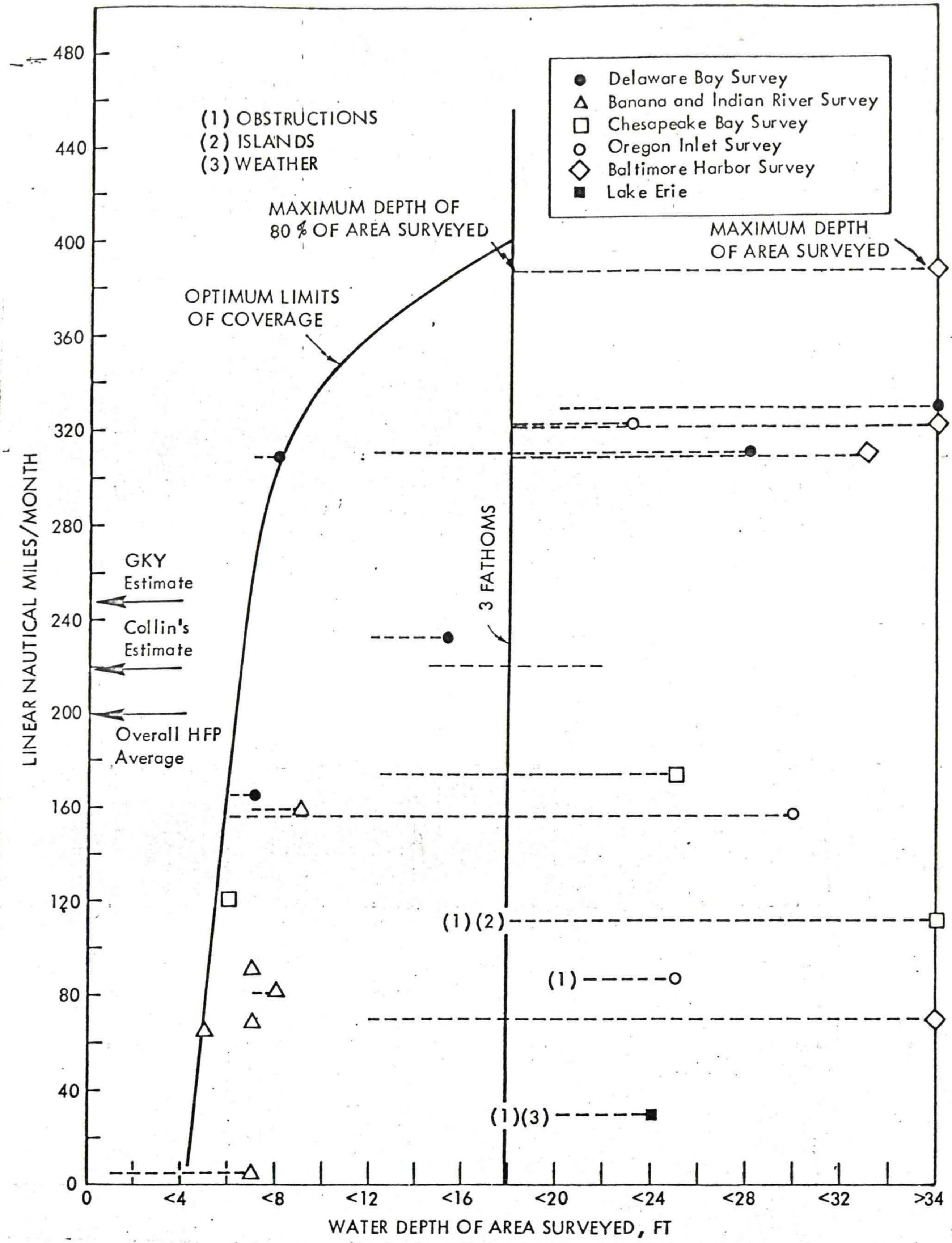


FIGURE 11

LINEAR NAUTICAL MILES SURVEYED PER MONTH IN SPECIFIC AREAS

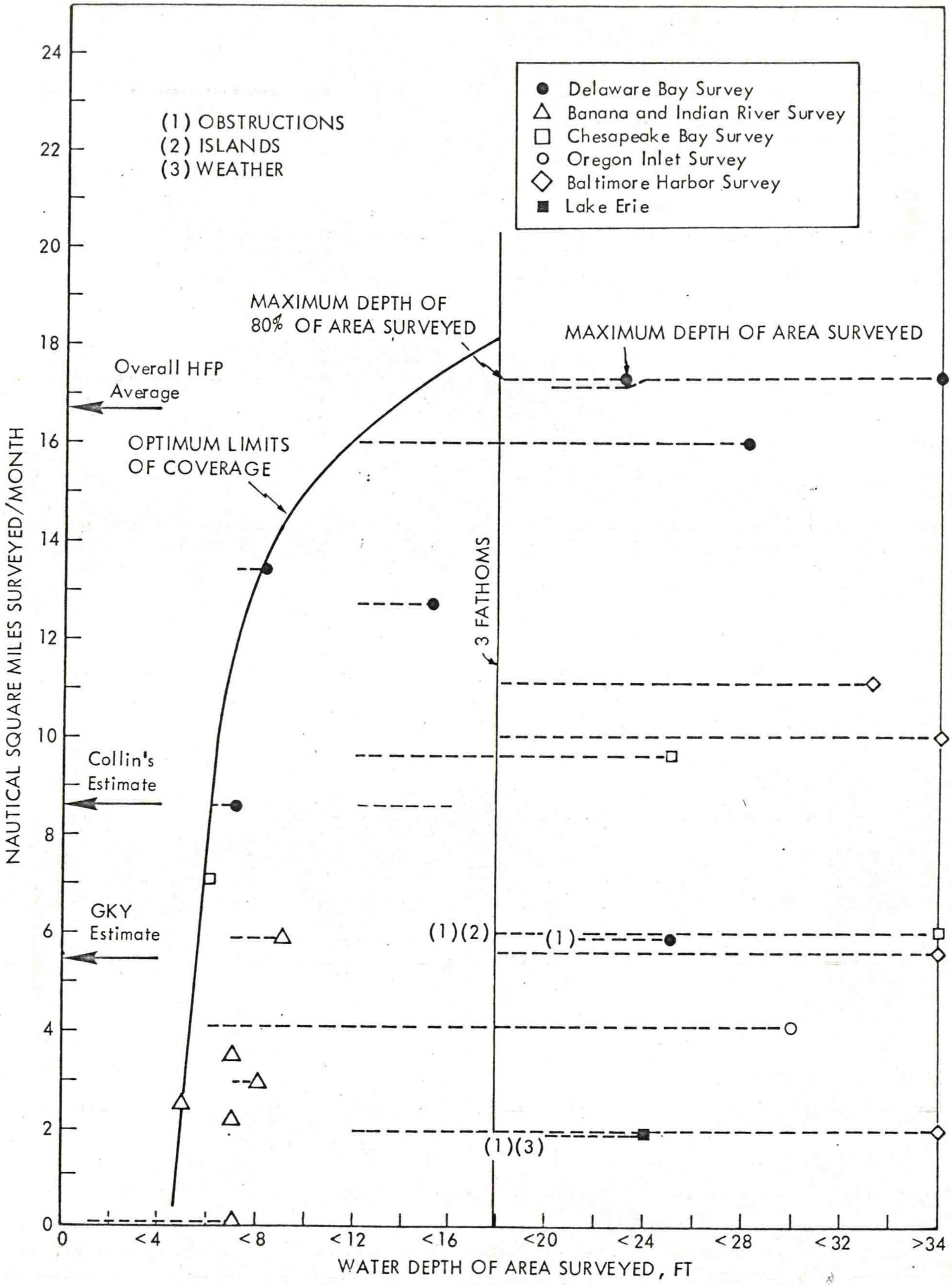


FIGURE 12

SQUARE NAUTICAL MILES SURVEYED PER MONTH IN SPECIFIC AREAS

6.4 Domain Characteristics

The information obtained from the previous Section 6.3 of this report dealt on NOS' hydrographic survey operations, the establishment of and the area coverages for the surveys and the determination of the priorities of these areas.

However, the establishment of the critical factors affecting the survey rates like water depth obstructions, weather, turbidity, appear to be very crucial. These factors play a very important role in selecting the bathymetric system to perform the required hydrographic survey.

The Systems Analysis Division, together with GKY and Associates, Inc., performed a study to determine specific environmental parameters that constrain the usage of the bathymetric systems.

6.4.1 Methodology:

The country was subdivided into 19 areas. For each area, the total shallow water area (three fathoms or less in depth) and the total shoreline were measured using NOS charts. Approximately 100 charts were analyzed.

The procedure was to measure the shoreline with a map measure. The areas were measured by counting grid cells and checked using 10 percent of the charts with a planimeter. The check indicated a bias which was adjusted. Errors in error measurement (in terms of cell counting vs. planimetering) are less than 10 percent.

The 19 areas were selected on the basis of homogeneous area/shoreline ratios and on the basis of general similarities of geography and settling.

A map locating the 19 areas is presented as Figure 13. In the course of the project, the 19 areas came to be called polygons. The reason for this designation is that straight line segments were developed to enclose the areas to form polygons. The coordinates of the polygon intersections were used to conduct a "lat-long" search of the Environmental Protection Agency's (EPA) STORET water quality data bank. The search was for turbidity information to use to estimate environmental constraints.

Table 12 gives the areas within each polygon and the amount of shoreline.

6.4.2 The NOS Concerns

The scheduling of launch surveys is a measure of the priorities of the agencies. The most current schedule is given in Table 13 and the survey areas are ranked. These rankings are keyed to polygons and averaged in Table 14. The polygon rankings are keyed to regions and within region averages are normalized with the results in Table 15. The normalization is done by dividing the reciprocal of the regional average ranks by the appropriate maximum reciprocal. The resultant normalized priorities may be considered to indicate the NOS concern for surveys within regions. The analysis gives:

Region	Normalized Priority	Concern Category
1. Gulf Coast	1	great
2. South Atlantic	.42	moderate
3. Mid-Atlantic	.51	moderate
4. North Atlantic	.33	little
5. Great Lakes	.46	moderate
6. Pacific Coast	0	little

The data give a high priority for the Gulf Coast. The normalized priorities are bunched between 0.42 and 0.51, over an interval of 0.09, and their closeness is considered justifiable for inclusion in the moderate concern category. The North Atlantic is out of the bunch, but still near enough to cause doubts as to how to categorize it. For the purposes of this report, the North Atlantic is considered to be of little concern.

6.4.3 Environmental Constraints:

This section summarizes the limitations imposed by the environment on the following alternative systems:

(a) Airborne Laser (Table 16)

(b) Airborne Photobathymetry (Table 17)

(c) LANDSAT Multispectral Scanner (Table 18)

(d) Launch-Sonar (Tables 19 and 20)

A discussion of the environmental considerations and thresholds for the design of the Composite Bathymetric System is presented below.

6.4.4 Environmental Considerations for Composite System Design

In recent years there has been a very large increase in the number of boats utilizing coastal waters. These vessels are both recreational and commercial in nature. Consequently, a strong requirement has developed for the accurate plotting of shallow water depths. Present day charts are in many cases inaccurate for many reasons. Previous surveys upon which the charts are based are in many cases quite old, and this coupled with the rapid accumulation of sediment associated with population pressures has caused shoaling of many areas previously deep. In addition, modern vessels often require greater depths for safe transits than has been the case in past years.

The classical methods by which depth surveys are accomplished require that small boats be used in relatively shallow waters. These small boats are expensive to operate, requiring large numbers of people and large amounts of time to cover relatively small areas. The boats are also required to operate under reasonably hazardous conditions associated with uncharted areas. Thus, there is a strong motivation to find an acceptable substitute for the use of small boats in determining shallow water bathymetry.

One such method is that utilizing photographic techniques. Stereoscopic pictures are taken from the air and these are then analyzed for depth information, based on the difference in intensity of the received signals on the two images. A typical system utilizes a very high resolution, high focal length aircraft camera with a suitable combination of filters and film type to accomplish maximum penetration in the area of interest. In relatively clean oceanic water, the system has been developed to a reasonably efficient point. Eastman-Kodak, for example, has succeeded in developing a new color film which seems ideally suited for maximum penetration in relatively clear oceanic water. At the same time, the Defense Mapping Agency has been utilizing satellite multispectral data, sequentially sampling small spectral bands of radiant energy. Thus, those spectral bands exhibiting the greatest penetration can be utilized as needed. The satellite data has the major limitation of resolution due to the great distance from the water surface and although these techniques seem to work reasonably well in clear oceanic water, it is doubtful they would be satisfactory for relatively dirty coastal water. Consequently, the only system of interest would be a filter-film system designed for the particular marine area to be measured with the satellite playing a supportive role for the purpose of overall survey planning.

Since the received signal, that is, the natural sunlight reflected off the bottom, is the basic data carrying signal, the amount of information available directly related to how well this reflected sunlight is recorded by the aircraft camera. Thus, the signal is related to the amount of cloud cover. A clear sky would seem to offer a more effective source than an overcast one since it is more concentrated. Also of interest are the surface conditions of the water. Different sea surface conditions will tend to reflect different amount of energy which would tend to either mask the signal coming from the bottom or else allow a smaller portion of the incident sunlight to penetrate the water. On the way down from the water surface to the bottom and then on the way back up again, the light is affected by the inherent water turbidity. The suspended particles in a coastal environment tend to scatter light a great deal and this scattering is wavelength dependent. Consequently, the choice of color film utilized in the coastal environment is very critical. The color of the bottom is also of import since a very low bottom reflectivity will produce a very poor signal in the aircraft. Therefore, it appears that in order to optimize a system of this type for a coastal environment, the surface reflectance, the average turbidity of the water column, and the bottom reflectance must be known in order to accurately interpret the data. This requires some ground truth information being acquired coincidentally with the overflight of the aircraft. However, this ground truth can probably be determined at a very few selected spots and the information would then be usable for the entire area.

It should be noted in passing that if there is an ice cover this system will not work and, therefore, the bathymetric photography method is limited to either areas warm enough so that ice does not form, or seasons wherein the temperature is high enough to preclude the formation of ice.

The natural parameters mentioned above are all dynamic so that their effect on the accuracy of the data obtained will not be a constant. This variation is tidal, diurnal, seasonal, weather, as well as area dependent. It turns out that the water column in an inshore area contains two separate particle populations. One of these populations is a permanent population of suspended particles which exists throughout the water column. The other is a population that is scoured from the bottom and resuspended as a result of tidal currents. This second cloud of particles only exists under conditions of high tidal currents, so that during periods of slack water, the particles will tend to settle back down onto the bottom. Consequently, photographs taken during periods of high tidal current will probably show a false bottom due to this particle cloud near the bottom.

There are also diurnal changes in the total environmental system produced by the altitude of the sun and changing wind systems as the air and/or water changes temperature during the day. Seasonal changes are also noted. During the fall, for example, the water tends to lose more of its turbidity load than at any other season of the year. Summertime appears to be the dirtiest time although it is not quite clear whether this is due to man's activity with small boats, the effect of runoff, or the increase of plankton populations in the water. Weather certainly has a strong effect, especially in the case of causing the water to be more turbulent, disturbing bottom sediments and putting them back in suspension. In addition, runoff directly following a rain storm will tend to cloud the water since this runoff contains a high concentration of suspended particulates. Lastly, the effect of man on a coastal area is very pronounced. In shallow areas, boats will tend to churn up the bottom and in addition, the activities of man bordering the marine areas will tend to cause an increase in turbidity. Construction and agriculture in particular are two activities that will increase the suspended sediment load of runoff to the environment.

It, therefore, becomes necessary to design an area specific system for maximum penetration. The suspended particle size will in large measure determine the choice of the wavelength while the filter choice will probably depend upon atmospheric conditions. This may not be as difficult as initially indicated since local areas may not be as different in terms of optimum film choice, but nevertheless, there is not doubt that film designed for maximum penetration in the open ocean is not suitable for use in turbid areas.

If a film-filter combination can be found which allows penetration on the order of two meters in relatively dirty waters, this would be a marked improvement over the small boat situation. The advantages of such a system are many: (1) a continuous record of the bottom is possible rather than just depths along a single line as are obtained with individual launches; (2) the navigation is much more accurate since points on land appear on the photographs also; (3) a much greater area can be covered in a much shorter time, with fewer personnel required.

The system is not without its drawbacks. It requires continuous ground truth and ideal weather conditions for use. In most middle latitude areas, probably the system could not be used one day out of three and maybe the percentage of use would be less than this. Unfortunately, the data analysis techniques and the system itself are not that well known and, therefore, this system would require a rather extensive research and development program. However, it would appear that the advantages of rapid coverage of large areas with an increase in accuracy of both navigation and bathymetric data would indicate that this new program would probably pay for itself in the long run. No cost estimates can be made at this time since it would appear that the system would have to be tried first to actually determine how many manhours are required to obtain a given amount of data so that a comparison with present methods can be made.

6.4.5 Discussion of Accuracy:

Table 21 gives the resultant success probabilities for each system by polygon. The locations of the polygons are given in Figure 14. It is seen that the relative probabilities favor launch over laser over photobathymetry. Furthermore, regional differences are noted. The table represents an evaluation of the success with which each of the three candidate systems can operate in areas of great to moderate concern. For completeness the north-eastern polygons (13 and 14) are included as they could be judged to be of little (as is suggested herein) concern or of moderate concern (since they are a borderline case). In operational deployment, forecasts could be used to deploy to alternative survey sites or to operate alternative measurement systems and thus increase overall mission "up" time.

The meteorologic probabilities P_o, P_1, P_2, P_3, P_4 and P_5 (as defined in Figure 14) are of a high level of accuracy and are based on long-term weather station analysis.

The upper and lower limits on P_2, P_3 and P_4 (the wind probabilities) impact the overall success probabilities in a major fashion. For laser and photobathymetric system, a lower wind speed of 5 is utilized to avoid the high reflectivity of calm water surfaces. High reflectivity is assumed to not be present with winds over five. This is rather subjective and is based on a consensus of NOS staff. Likewise the upper wind limit of 15 for photography is based upon two much scattering from rough sea state surfaces. This value is subjective, but is also based on expert opinion. Scattering is not the reason for an upper wind limit of 20 for the laser; the reason is that it is difficult to fly planes in high winds. This airplane wind constraint is probably less subjective than the others. However, clearly $P_2 < P_3$ which favors laser operations. The wind-induced wave scatter constraint of 15 for photography is rather binding.

The water quality success probabilities of P_6 and P_7 are based on actual water quality suspended solids data; that is, they have a realistic basis. However, the data are aggregated over large polygons and over time. Time aggregation is probably the biggest limitation at present. It is known that water quality varies seasonally. This will serve to increase P_6 in some seasons and decrease it in others. A subjective estimate of the accuracy of P_6 as it stands now would be $\pm$ 25 percent.

The value assumed for P_7 is $P_6/2$. Clearly this is a critical assumption since if P_7 could be made to approach P_6 (which is an estimate of the maximum upper limit of P_7), the laser and photographic systems would be more nearly the same, other factors being equal. The other factors restricting the photographic systems, in comparison to the laser system, would be the wind and the clear air days. Thus, if $P_2 \rightarrow P_3$ and $P_7 \rightarrow P_6$ the two airborne systems would approach equality of success probabilities ($P_L = P_P$) when the atmospheric conditions are clear.

However, P_L and P_P will usually be expected to be much less than the launch/sonar success probability, P_S, because of the water quality. In other words, P_L and $P_P < P_S$ because the water quality related success probabilities are usually less than one, P_6 and $P_7 < 1$.

The photobathymetric system success probability, P_P, is further penalized by the values of P_1 = the probability of aerial clear days. This probability, being based on long-term meteorologic data and predictable sun angles is an accurate estimate. To sum up, the status of the probability estimates is:

P_o: solid estimate based on long-term weather data

P_1: solid estimate based on long-term weather data

P_2: solid estimate based on long-term weather data

P_3: solid estimate based on long-term weather data

P_4: solid estimate based on long-term weather data

P_5: solid estimate based on long-term weather data

P_6: error $\simeq \pm$ 25 percent; needs refinement and time and space disaggregation

P_7: P_7 is assumed to equal $P_6/2$. An estimate of the range is $0 \leq P_7 \leq P_6$; thus, the maximum possible error on the order of 100 percent; a reasonable error estimate would be the same error as is associated with P_6, i.e., $\pm$ 25 percent.

Another possibility for estimation error is the possibility that the probabilities are not mutually exclusive. The most likely situation is that P_1 and P_2 have overlapping probabilities. In other words, a clear air day may tend to exclude high winds as a possibility on the same day. If such a situation exists (violation of the mutually-exclusive assumption), it would tend to increase the success probabilities for photobathymetric operations.

To sum up the most sensitive factors are the constraints associated with the wind (upper and lower levels) and P_6 and P_7. All other factors have errors that are insignificant by comparison.

AREA TO SHORELINE RATIOS
FOR GULF AND EAST COASTS

Polygon	A Surface Area	S Shoreline	A/S
1	1803.25	1901.4	.9484
2	1694.3	769.8	2.201
3	1455.7	2778.7	.5239
4*	2037.1	1159.5	1.7569
5	588.4	924.3	.6366
6	1517.6	811.2	1.8708
7	995.8	1998.1	.4984
8	2235.1	1443.6	1.5483
9a**	1115.0	4334.0	.257
9b & c**	679.0	3210.0	2.11
10	1645.5	1467.9	1.1210
11	1435.9	3553.5	.4041
12	723.3	2155.7	.3355
13	949.6	2404.2	.3950
14	463.8	3187.9	.1455

*Totals do not reflect data from chart 1269. Chart not available.

**a = Florida coast; b,c = Georgia, North and South Carolina coast.

TABLE 12

Areas and Shorelines

AREA TO SHORELINE RATIOS
FOR THE GREAT LAKES

Polygon	A* Surface Area (mi^2)	S* Shoreline (mi)	A/S
Ontario	110	203	.55
Erie	322	302	1.07
Huron	777	401	1.9
Michigan	487	802	.61
Superior	189	617	.31

*Figures include only shoreline in the U.S. and not Canada.

TABLE 12 (Continued)

Ranked Survey Priorities	Surveys are in These Polygons
A. Scheduled (First Priority) 1978 to 1982	
1. Lake Erie	16
2. Charlestown Harbor	9c
3. Gulf of Mexico	1 to 7
4. Beaufort Inlet, NC	9c
5. Pamlico Sound, Offshore, NC	10
6. Banana and Indian Rivers, Florida	9a
7. Delaware River	12
8. Lake Boyne, LA	3 and 4
9. Upper Chesapeake Bay	11
10. St. Mary's River	17
11. West Florida Coast	6, 7, 8
12. Currituck Sound, Offshore, NC	10
13. Currituck Sound, Inshore, NC	10
14. Delaware Bay (offshore)	12
15. Delaware Bay (inshore)	12
16. Pamlico Sound, Inshore, NC	10
17. Hudson River and NY Harbor	13
B. Unscheduled (Seoond Priority)	
18. Albemarle Sound, NC	10
19. Lake Ontario	15
20. Bogue Inlet (NC)	9c
21. FLA Intracoastal Waterway (East)	9a
22. FLA, Southwest Coast	7, 8
23. Southern Long Island and NJ Coast	12, 13
24. Lake Michigan	18
-- Upstate New York Lakes	*
25. Raritan Bay	13
26. Rappahannock River	11
27. St. Lawrence River near Ontario	15
28. Gondiners and Peconic Bays, NY	13
29. Vermilion Bay, White and Ground Lake, LA	2
-- Wisconsin Lakes	*

*Special case: inland lakes and rivers.

Source: Office of Marine Surveys and Maps, NOS draft memorandum pertaining to survey priorities, 1978 through 1982. Items 1 through 17 refer to scheduled hydrographic field party activity and Items 18 through 29 refer to unscheduled activity which is assumed to be second in priority to the scheduled activity. The listing is ranked.

TABLE 13

EXISTING PRIORITY SCHEDULE
WITH POLYGONS

Region	Polygons	Individual Survey Priorities	Average Survey Priority within a Polygon	Moving Average* Polygons 1 to 14	Polygon Rank
Gulf Coast	1. Texas Gulf	3	3	7.33	5
	2. Texas-LA Gulf	3, 29	16	10.12	8
	3. Miss. Delta	3, 8	5.5	8.12	6
	4. Mobile Area	3, 8	5.5	4.87	3
	5. Fla. Panhandle	3	3	4.62	2
	6. NW Florida	3, 11	7	7.25	4
	7. SW Florida	3, 11, 22	12	11.87	10
	8. Florida Keys	11, 22	16.5	14.62	11
South Atlantic	9a. East Florida	6, 21	13.5	18.37	15
	9b. Georgia	30	30	20.54	16
	9c. NC - SC	2, 4, 20	8.67	15.03	12
Middle Atlantic	10. NC Outerbanks	5,12,13,16,18	12.8	11.32	9
	11. Chesapeak Bay	9, 26	17.5	15.63	13
	12. Delmarva and NJ	7,14,15,23	14.75	17.56	14
North Atlantic	13. NY to Cape Cod	17,23,25,28	23.25	22.8	17
	14. Cape Cod to Maine	30	30	27.75	20
Great Lakes	15. Lake Ontario	19, 27	23	23	18
	16. Lake Erie	1	1	1	1
	17. Lake Huron	10	10	10	7
	18. Lake Michigan	24	24	24	19
	19. Lake Superior	30	30	30	21

*$\bar{x}_i = .25x_{i-1} + .5x_i + .25x_{i+1}$; this is done to smooth the data and account for overlaps at the boundaries.

TABLE 14

EXISTING POLYGON RANKINGS

Region	Polygons	Average of Ranks Within A Region	Normalized** Priority
Gulf Coast (Texas to Miami)	1 to 8	6.125	1
South Atlantic (Miami to NC Outer Banks)	9a, b, c	14.33	.42
Mid Atlantic (Outer Banks, Chesapeake Bay Delmarva, New Jersey)	10,11,12	12.00	.51
North Atlantic (New York to Maine)	13, 14	18.5	.33
Great Lakes (Ontario, Erie, Huron, Michigan, Superior)	15 to 19	13.2	.46
Pacific Coast*		----	0

*Based upon limited shallow water.
**Based on reciprocals.

TABLE 15

EXISTING PRIORITIES BY REGION

TABLE 16

ENVIRONMENTAL CONSTRAINTS FOR AIRBORNE LASER

WIND: Need few knots for mirror-like effect

Upper Limit: 15-20 kts.

RAIN: None

FOG: None

SEA STATE: Extreme - 4 to 6 ft. significant wave heights

Normal - 3 ft. or less

Lower Limit - Capillary waves must be present

TURBIDITY: $8 < \alpha d < 15 \rightarrow$ Upper Limit (Avg. $\alpha d = 12$);

α = attenuation coefficient, m^{-1}; d = depth in meters

Two factors affect turbidity:

(1) Suspended solids (scattering)

(2) Biological (scattering and absorption)

Biological turbidity is difficult to quantify

SUN: Effects unknown, sun increases background noise, currently work is underway to develop narrower filters to reduce problem

CLOUDS: Clouds help by reducing background noise

Source of Information: Literature and Lt. Cdr. L. Goodman of NOS.

TABLE 17

ENVIRONMENTAL CONSTRAINTS FOR AIRBORNE PHOTOBATHYMETRY

WIND: 15 kts > Speed > Calm

RAIN: None

FOG: None

SEA STATE: Ave. Wave Ht. = 2 ft.

TURBIDITY: $\alpha d \sim 12$; α = attenuation coefficient, m^{-1}; d = depth in meters

SUN: 20^{o} Optimum Angle

CLOUDS: Cloud free for optimum conditions

Source of Information: Literature and Cdr. J. Collins of NOS.

TABLE 18

ENVIRONMENTAL CONSTRAINTS FOR LANDSAT BATHYMETRY (SYSTEMS MSS AND MSS-5)

	MSS-4	MSS-5
Clear Water, Bright Bottom Max. Depth	20 m ± 10%	5 m ± 15%
Turbid Water, Sandy Bottom, Max. Depth	15 m ± 25%	4 m ± 20%

LIMITATIONS:

- Cloud-free day necessary for contouring
- Water transmittance must be constant
- Bottom reflectance must be constant

ACCURACY:

Based on NASA/Cousteau ocean bathymetry experiment, depths as deep as 20 meters (~ 10 fathoms) can be measured with an accuracy of better than 10%.

Source of Information: Mr. James Hammack of DMA.

ENVIRONMENT CONSTRAINTS	OPERATIONAL AREAS	MODES OF OPERATION				
	OPEN COAST		LARGE (OPEN) BAYS, SOUNDS		PROTECTED SMALL BAYS & RIVERS	
	ELECTRONIC	VISUAL	ELECTRONIC	VISUAL	ELECTRONIC	VISUAL
HAZE	0	1	0	1	0	1
FOG	2	2	2	2	2	2
RAIN LIGHT	0	1	0	1	0	1
RAIN HEAVY	1	2	1	2	1	2
WIND: 0-5 (Kts.)	0	0	0	0	0	0
WIND: 5-10 (Kts.)	1	1	1	1	0	0
WIND:10-20 (Kts.)	1	2	1	2	0	0
WIND:20-UP (Kts.)	2	2	2	2	1	1
SEA STATE:						
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	1*	1*	1*	1*	1*	1*
4	1*	1*	1*	1*	NA	NA
5	2	2	2	2	NA	NA

0 - No Constraints
1 - Limited Work
2 - No Work Accomplished
NA - Not Applicable

* Quality of work usually does not meet accuracy standards w/o considerable manual data inputs by hydrographers and verifiers

TABLE 19

ENVIRONMENTAL CONSTRAINTS FOR LAUNCH-SONAR FIELD PARTY/SHIP LAUNCHES

TABLE 20

% OF TIME SURVEY PARTIES CAN OPERATE DUE TO ENVIRONMENTAL, TOPOGRAPHICAL OR LOGISTICAL CONSTRAINTS (*)

(BEST GUESS)

TYPE OF OPERATION	BAYS, RIVERS	SOUNDS, LARGE BAYS	OPEN COASTLINE	COMBINATIONS OF ALL
SMALL LAUNCHES, FIELD PARTIES	40	10	5	30
HIGH SPEED LAUNCHES FIELD PARTIES	5	40	20	30
SMALL LAUNCHES SHIPBOARD	5	10	20	15

* ENVIRONMENTAL: Storm (wind), Sea Condition, Heat or Cold

TOPOGRAPHICAL: Differences between Bays, Rivers, Sounds, Open Coastline.

LOGISTICAL: Travel Times to and From Working Area, Down Time for Repairs/Maintenance, Set Up Time & Relocation Equipment, Other Survey Ops.

Source of Information: Capt. W. Mobley of NOS.

TABLE 21

Probability of Success for Alternative Bathymetric Systems

Polygon	Season	Sonar	Laser	Photo
1	Winter	86.0%	26.2%	1.5%
	Spring	76.0%	23.4%	1.3%
	Summer	93.0%	28.3%	2.3%
	Fall	95.5%	29.0%	2.6%
2	Winter	89.0%	26.0%	1.6%
	Spring	85.0%	26.0%	1.7%
	Summer	100%	28.2%	2.3%
	Fall	93.0%	28.7%	2.7%
3	Winter	96.0%	16.8%	.8%
	Spring	100%	17.9%	1.5%
	Summer	100%	14.3%	1.3%
	Fall	100%	16.5%	1.7%
4	Winter	94.0%	18.6%	1.1%
	Spring	95.0%	19.3%	1.7%
	Summer	100%	17.8%	1.4%
	Fall	99.0%	19.0%	1.8%
5	Winter	100%	54.3%	4.8%
	Spring	97.0%	53.9%	5.0%
	Summer	100%	46.2%	3.6%
	Fall	100%	52.5%	5.2%
6	Winter	100%	51.9%	5.6%
	Spring	100%	51.3%	5.4%
	Summer	100%	42.6%	2.0%
	Fall	100%	50.3%	2.0%
7	Winter	100%	48.5%	4.8%
	Spring	96.0%	48.3%	4.1%
	Summer	100%	39.8%	1.6%
	Fall	100%	45.4%	3.0%

TABLE 21 (Continued)

Polygon	Season	Sonar	Laser	Photo
8	Winter	100%	36.9%	3.4%
	Spring	100%	37.1%	2.0%
	Summer	100%	30.3%	1.0%
	Fall	98.5%	33.5%	2.0%
9a	Winter	100%	39.1%	2.6%
	Spring	99.0%	39.1%	3.4%
	Summer	100%	35.7%	1.2%
	Fall	100%	36.6%	2.4%
9b	Winter	98.0%	23.4%	2.0%
	Spring	90.0%	21.8%	1.8%
	Summer	100%	21.9%	1.4%
	Fall	100%	23.2%	1.8%
9c	Winter	98.0%	26.6%	2.2%
	Spring	90.0%	24.7%	2.2%
	Summer	100%	24.9%	1.6%
	Fall	100%	26.3%	2.0%
10	Winter	66.0%	14.4%	.4%
	Spring	67.4%	15.1%	1.4%
	Summer	76.6%	16.6%	.4%
	Fall	74.1%	16.6%	1.4%
11	Winter	86.4%	31.0%	2.8%
	Spring	84.1%	27.7%	2.2%
	Summer	95.0%	29.2%	1.2%
	Fall	95.0%	34.2%	3.2%
12	Winter	76.5%	28.2%	.8%
	Spring	73.0%	26.3%	2.5%
	Summer	95.0%	34.8%	.8%
	Fall	91.7%	34.1%	3.2%

TABLE 21 (Continued)

Polygon	Season	Sonar	Laser	Photo
13	Winter	68.1%	15.3%	.1%
	Spring	75.0%	16.6%	1.0%
	Summer	95.0%	22.4%	.5%
	Fall	82.2%	18.8%	1.0%
14	Winter	70.3%	23.5%	.06%
	Spring	72.4%	25.8%	1.6%
	Summer	93.6%	31.5%	1.0%
	Fall	78.8%	26.5%	.8%
15	Winter	--	--	--
Ontario	Spring	--	--	--
	Summer	95.0%	58.8%	7.5%
	Fall	95.0%	64.1%	2.0%
16	Winter	--	--	--
Erie	Spring	--	--	--
	Summer	95.0%	31.7%	3.1%
	Fall	86.4%	30.1%	.9%
17	Winter	--	--	--
Huron	Spring	--	--	--
	Summer	95.0%	38.5%	3.6%
	Fall	85.0%	35.0%	.9%
18	Winter	--	--	--
Michigan	Spring	--	--	--
	Summer	95.0%	63.4%	5.9%
	Fall	95.0%	65.2%	1.8%
19	Winter	--	--	--
Superior	Spring	--	--	--
	Summer	95.0%	47.6%	3.2%
	Fall	93.6%	49.5%	1.2%

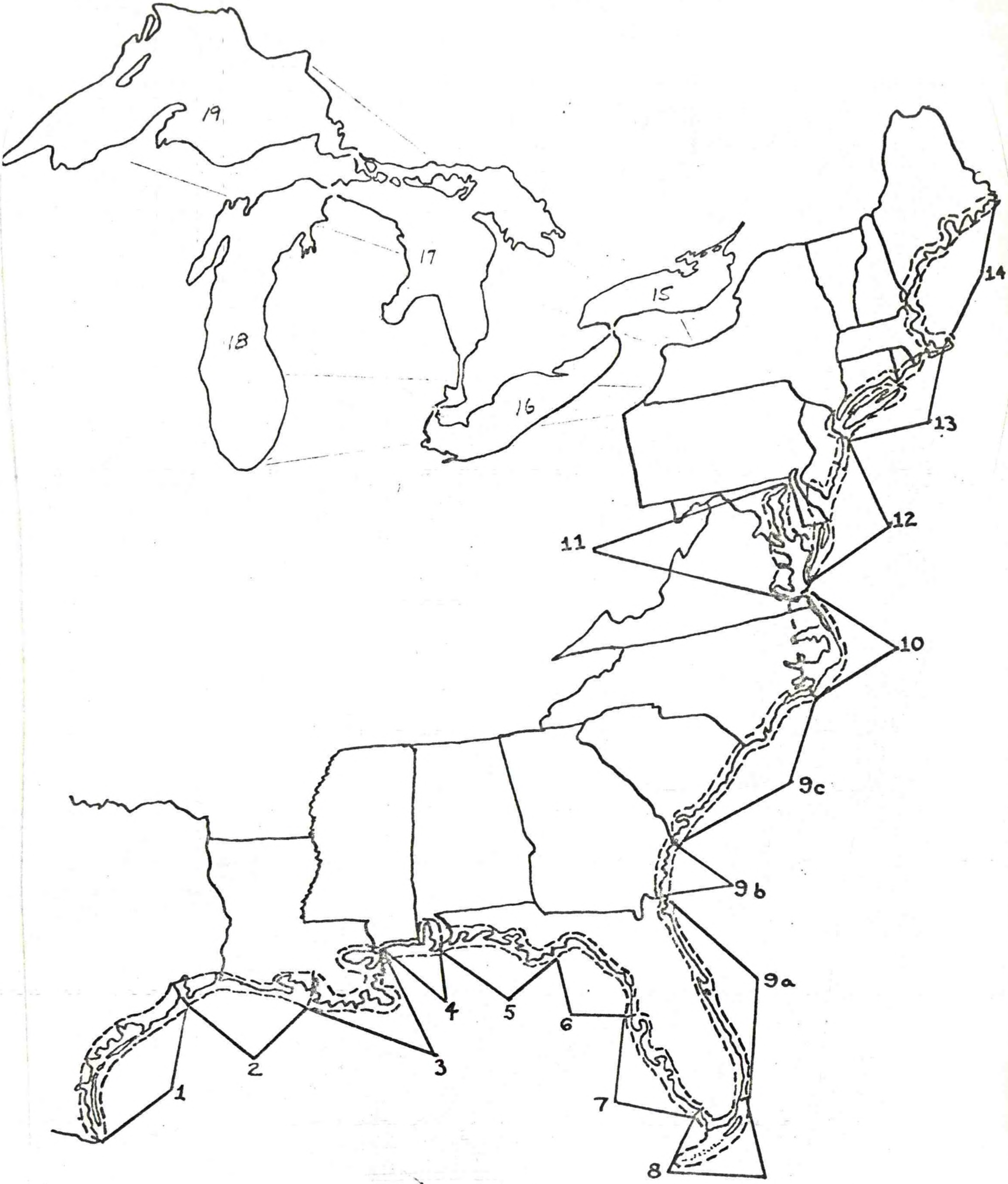


FIGURE 13

Location Map

Probability of Success for the Alternative Bathymetric Systems

Launch Sonar - $P_s = P_0 P_4$

Airborne Laser - $P_L = P_3 P_5 P_6$

Airborne Photo - $P_p = P_1 P_2 P_7$

where

P_0 = Probability of no fog

P_1 = Probability of aerial clear days

P_2 = Probability of (wind > 5 ≤ < 15)

P_3 = Probability of (wind > 5 ≤ < 20)

P_4 = Probability of (wind < 20)

P_5 = Probability of no rain

P_6 = Probability that laser can see 18 feet

P_7 = Probability that photo can see 18 feet

NOTE: The probability of Great Lakes operations in the winter and spring is taken to be zero.

FIGURE 14

PROBABILITY MODELS

6.5 Cost Study

As previously discussed, the overall objective of this study was to establish alternative bathymetric systems to operate cost effectively in waters of three fathoms or less.

As the final step in achieving this overall objective, the Systems Analysis Division performed the cost study discussed herein by evaluating the operating costs for at least three bathymetric systems (i.e., ship-launch hydrography, HFP and photobathymetry).

However, the lack of data for some of the systems and/or the inherent bias in the performance figures reported by the individuals or groups responsible for certain systems made it very difficult to report realistic numerical values. This, however, did not prevent us from independently ranking all systems based on our objective judgment.

6.5.1 Operating Costs:

Comparison of operational costs of various bathymetric systems, as is being pursued in this study, is an example of independent system costing as contrasted with "marginal" costing. If the concept of marginal costing was applied, then to total cost of operating the near-shore hydrographic launch operations over the complete life cycle of the systems would have been taken into account. Then those elements of the hydrographic fleet could be effectively replaced by, let's say, the airborne laser system or photobathymetry system, and would obtain the total cost of R&D, investment and operation of this new set of equipments meshed within all of the other operations. The difference in costs between these two or three total system costs would be the marginal costs of using airborne laser over photobathymetry over launch sonars. This is actually the preferred method of dealing with the relative cost savings that would result from introducing a new item or system into the operations. It attempts to insure that no item is overlooked and that all interactions have been accounted for.

Theoretically, one would have to do this problem over the complete time cycle associated with the research and development, initial investment, and operations to the end of the service life of at least the first batch of equipments. This is necessary to insure that the new equipments will be phased in efficiently without a disruption of current operations.

In this study, we essentially conducted the conditional problem of evaluating the operational cost for each of the systems, given that the research and development and initial investment can be considered by arguments outside of the basic cost comparison. In this sense, the tail end of life cycle costing was performed by considering only the operational costs and whatever maintenance, overhaul, and replacement of equipments are necessary to carry this through to the service life of all machine subsystems. Consequently, all previous costs and all associated system costs such as processing, mapping, etc., were ignored. This then is what is meant by "independent system costing" and it is, of course, much less complex than "marginal" costing. With this simplicity comes the danger of overlooking a number of terms or factors which could significantly alter the cost comparison. Consistency is perhaps the most important feature to be practiced by the systems analysis in this type of costing procedure. This is because it is so easy to bias this comparison. In independent system costing, one is looking for a term-by-term comparison of the cost of each system and then the sum of the differences to arrive at a net difference in cost. The concept of a cost comparison by taking ratios is really not appropriate here since there are many other cost terms within the overall system, and a ratio comparison or percentage comparison is misleading.

6.5.2 Cost Model

In the Systems Analysis Division a deterministic cost model has been developed by Dr. Gatzoulis and a computer program has been written by Dr. R. New and H. Beale, for the transformation of the deterministic cost model form to probabilistic form. This cost model represents the analytical systems model of the operating costs incurred by the selected candidate bathymetric systems. This model will eventually be employed as a managerial tool to evaluate candidate bathymetric systems, so as to choose the "best system." What is the "best" depends upon the criteria selected by judgment.

However, the cost comparison analysis of this study was performed using the rationale discussed herein and not this cost-model computer program, for matters of simplicity.

6.5.3 Bathymetric Surveys

NOS conducts the following types of bathymetric surveys, namely:

1. Navigable area surveys
2. Chart adequacy surveys
3. Wire drag surveys
4. Ship-Hydrographic surveys
5. Hydrographic Field Party (HFP) surveys
6. Photobathymetry

The nature and type of survey of several of the above surveys are obvious by name; however, the ones dealing with shallow water bathymetry (i.e., 4, 5, and 6) need further definition.

6.5.4 Ship Hydrography: Ship Hydrographic Survey is a survey conducted in any area where the Commanding Officer of the survey ship will operate his ship. Any area in which the Commanding Officer will not operate his ship is designated as an area for launch-hydrographic surveying.

It is apparent from Table 22 that west coast ships (RAINIER, FAIRWEATHER, and DAVIDSON) produce less linear nautical miles (LNM) of hydrography than east coast ships. (WHITING, PEIRCE, and MT. MITCHELL).

This is due mainly to the mode of hydrography (ship hydrography producing more LNM), the number of work areas during the year, and the locality. For example, conducting continuous ship hydrography in New York Bight and the southeast coast of the United States will obviously produce more miles of hydrography than a ship conducting many small near-shore hydrographic surveys in southeast Alaska.

NOAA hydrographic ships work approximately nine months of the year, which includes an average of 21 work days per month as presented in Tables 23 and 24, Class II NOAA ships (MT. MITCHELL, RAINIER, and FAIRWEATHER) generally carry four hydrographic launches, three of which are usually operating. Class III NOAA ships (WHITING, PEIRCE, and DAVIDSON) carry two launches, both of which are usually in use.

The ship characteristics are as follows: Class II NOAA ships are 231 feet in length, displace 1,660 tons, have a maximum speed of 14 knots, and generally carry a total of 70 officers and crew. Class III NOAA ships are about 170 feet in length, displace about 800 tons, and have a maximum speed of 13 knots. Class III ships generally carry a total of 35 officers and crew.

6.5.4.1 Ship and Launch Hydrography - Operating Costs:

Shallow water bathymetry is a very small part of the west coast operations because of the rapid shelving-off of the beaches and general lack of rivers, bays, etc. San Francisco Bay and Puget Sound are exceptions. In the east, the tasks of surveying the coastal regions with the numerous shallow bays, the Great

Lakes, the large rivers and smaller lakes and the Gulf of Mexico present the greatest areas of shallow water. Therefore, in this cost comparison study, the operating costs of the east coast ships (PEIRCE, WHITING and MT. MITCHELL) together with their launches, are taken into consideration and not the west coast ships (RAINIER, FAIRWEATHER and DAVIDSON). Table 25 represents a breakdown of the operating costs of the east coast ships together with their launches for FY 72.

It should be noted that a number of selected sources and/or individuals were contacted so an unbiased cost comparison could be made; however, only the following numerical values were obtained:

(a) From the Atlantic Marine Center's Annual Summary Report of FY 72, a breakdown of the operating costs was obtained, as presented in Table 25.

(b) From statistical data, covering the last five years of the east coast ships' operations, their operating costs were obtained as presented in Table 26. In addition, these operating costs, together with HFP operating costs are graphically displayed in Figure 4 of this report.

Therefore, the average operating costs per year for each of the east coast ships together with their launches is: PEIRCE = $673,320; WHITING = $682,480 and MT. MITCHELL = $1,276,360.

6.5.5 Hydrographic Field Parties: Hydrographic Field Party (HFP) Surveys are surveys conducted inshore and in relatively shallow waters (three fathoms or less). These surveys are landbased surveys that employ launches for their waterborne operations. It should be noted that there are no hydrographic field parties located on the west coast. The five or so existing hydrographic field parties operate under the direction of the Atlantic Marine Center in Norfolk, Virginia. One field party is employed in locating chart discrepancies. The size of the hydrographic field party can vary depending upon the nature and magnitude of the survey effort; however, the typical hydrographic field party has a five-man crew and one launch. A maximum of 10 launches are available for use; they range in length from 17 to 59 feet.

6.5.5.1 HFP Operating Costs:

Table 27 was formulated based on the information obtained from Lt. Cdr. Daniels from the Atlantic Marine Center, Norfolk, VA, on October 12, 1977, and provides the breakdown of the operating costs of one field party, five-man crew.

Consequently, the total operating costs for one field party results to $10,367 per month, or $124,404 per year.

Assuming that a three-launch 15-man party is used to conduct launch hydrography, the operating costs for a three-launch operation will result to $31,101 per month, or $373,212 per year.

It should be noted, that in order to make an unbiased cost comparison, a number of selected sources and/or individuals were contacted to obtain information regarding the operating costs of a three-launch party, 15-man crew. However, we were able to obtain cost data from the following four points of contact:

TABLE 28

HFP - TOTAL OPERATING COSTS

Point of Contact	Month	Year	Reference
• Cdr. Collins	$24,000	$288,000	Photobathymetry Report
• GKY and Asso., Inc	$30,000	360,000	Airborne-Laser Report
• Lt.Cdr. Daniels	31,101	373,212	FY 77 Actual Occurring Expenses
• Atlantic Marine Center (Capt. Mobley)	39,417	473,000	AMC Statistical Data of FY 1971-1976 (Figure 4)

6.5.6 Photobathymetry vs. Airborne-Laser

The use of photobathymetry as an underwater mapping technique has become increasingly more accepted during the past decade. Today's state of the art is such that underway areas can be routinely mapped photogrammetrically.

Photobathymetry is ahead of Airborne-Laser bathymetry in that the form is an operational system within NOS whereas the latter is still undergoing testing and development and is not yet ready for routine use.

However, this does not mean that Airborne-Laser system is excluded as a good candidate bathymetric system. On the contrary as discussed in the "Executive Summary," and Section 6.4 of this report, the Airborne-Laser system is much less hampered by environmental factors than Airborne-Photography.

It should also be noted that the Airborne-Laser system was excluded from the cost-comparison analysis, due to the lack of any reliable numerical values regarding its operating costs. Consequently, the cost study reported herein was restricted in comparing Ship-Launch Hydrography over HFP over photobathymetry's operating costs only, until such time arises, where reliable operating cost data can be obtained from the Airborne-Laser System.

Our study also indicates, as discussed in Section 6.2 and as presented in Table 9, that photobathymetry is (1) competitive in relatively-clear waters, (2) offers greater area coverage than other bathymetric systems, and (3) is possibly more cost effective than launch-sonar. To determine the latter, an attempt was made, to evaluate its operating cost data, since it is an operational system within NOS.

6.5.6.1 Photobathymetry - Operating Costs:

In order to conduct an unbiased cost comparison, a number of selected sources and/or individuals were contacted throughout the study; however, we were able to obtain information on photobathymetry's operating cost data from the following two sources:

(1) Based on Cdr. Collins' report, "A Cost Study of Inshore Bathymetry," the costs associated with mapping underwater areas photogrammetrically is $\$812/NM^2$. This average cost includes the cost of shoreline mapping and of locating shore survey control points. However, $\$438/NM^2$ for bathymetry operations is required based on Cdr. Collins' report.

(2) Based on Cdr. Carlen's memo to the Systems Analysis Division dated October 2, 1977, the following cost data were obtained:

1973 - South Coast of St. Thomas and St. John U.S.V.I.:

Labor costs for Marine Center compilation (not included: any field activities - aircraft, field parties, etc.)	$2,222

1977 - (Estimate) St. Croix, U.S.V.I.:

Field Party costs (labor, travel, supplies rentals, etc.) (not included: aircraft, office costs, etc.)	26,100

These above figures represent the cost of the project only; therefore, they do not provide complete cost data. However, it should be noted that Cdr. Collins stated that the cost of launch hydrography is possibly twice the cost of photobathymetry. However, this may be comparative costs of totally independent operations and it may not give a true picture of the cost in setting up a dual operation when one is already functioning. Having a launch complete the last 200 meters of survey lines in the Virgin Islands could be much less expensive than setting up a whole separate method of doing this work as was done.

It would appear that where one system such as launch hydrography must be available for depths greater than 18 feet and can work in depths less than 18 feet, that the cost of completing the work by launch should be compared with the additional cost of surveying the area by the new system rather than comparing independent costs per square mile of hydrography by the two systems.

6.5.7 Conclusions:

Based on the analysis made in this section, on the hydrographic operational performance characteristics of the east coast ships (PEIRCE, WHITING and MT. MITCHELL) and their launches, as illustrated in Figures 2 and 3 respectively, and also on the total operating costs for ships and launch hydrography and the operating costs of the Hydrographic Field Parties (HFP) as illustrated in Figure 4, is concluded that for cost-effective shallow water bathymetric operations, NOS should:

(1) Cancel the shallow water bathymetric operations performed by the four launches of MT. MITCHELL and continue only MT. MITCHELL's hydrographic survey operations for turbid waters; and/or restricted areas where the HFP cannot operate according to NOS' existing priority schedule as presented in Table 13; and/or when the time-schedule allows, perform other nonbathymetric predetermined activities.

(2) Maintain WHITING and/or PEIRCE with the two and/or four launches to perform shallow water bathymetry for turbid waters; and/or restricted areas where the HFP cannot operate according to NOS' existing priority schedule as presented in Table 13; and/or, when the time-schedule allows, conduct other nonbathymetric predetermined activities.

(3) Maintain all existing HFP to perform shallow water bathymetric operations for turbid water; and/or other areas having such environmental constraints that an optical bathymetric system or ship launch hydrography cannot cost-effectively operate according to NOS' existing priority schedule as presented in Table 13.

(4) Improve ship-launch hydrography and HFP operational performance by modernizing and automating their equipment. In addition, include the two launches from MT. MITCHELL in the HFP operations.

(5) Fully develop and operate an optical system (i.e., photobathymetry or Airborne-Laser System) to operate in nonturbid areas and under allowable environmental conditions according to the probability of success as presented in Table 21 of this report and also according to NOS' existing priority schedule as presented in Table 13; and/or when the time-schedule allows such system can be used for coastal mapping of other predetermined activities.

(6) Establish a well-coordinated and cost-effective operating schedule for the composite system (i.e., Ship-Launch Hydrograpby, HFP and optical system) to operate according to NOS' existing priority schedule and the probability of success as discussed in Tables 13 and 21, respectively, in this report.

TABLE 22

Miles of Launch and Ship Hydrography 1974-75
NOAA Ships

	Ship	Ship		Launch		Total	
		SNM	LNM	SNM	LNM	SNM	LNM
WEST COAST	RAINIER	335	2,104	315	5,619	650	7,723
			25	174	4,677	174	4,702
	FAIRWEATHER	1,587	5,399	250	4,071	1,837	9,470
		294	1,048	572	5,425	866	6,473
	DAVIDSON	.1	1.7	282	3,973	282	3,975
		286	1,537	189	2,522	475	4,059
EAST COAST	WHITING	857	9,698	151	2,362	1,008	12,060
		6,362	15,684	36	652	6,398	16,336
	PEIRCE	1,015	11,671	74	1,182	1,089	12,853
		4,438	14,392	14	150	4,452	14,542
	MT. MITCHELL	3,222	18,022	69	749	3,291	18,771
		3,687	23,224	93	1,327	3,780	24,551

SNM=Square Nautical Miles

LNM=Linear Nautical Miles

TABLE 23

Class II NOAA Ships Work Areas

Ship	Year	Area	% Ship	% Launch	Total Hydrography for Year % Ship	Total Hydrography for Year % Launch
MT. MITCHELL	1974				96	4
		Southeast Coast of U.S.	95	5		
		Baltimore Canyon	100			
	1975				95	5
		Cable Route Survey Caribbean	100			
		South Coast of Puerto Rico	69	31		
		New York Bight	100			
RAINIER	1974				27	73
		Strait of Juan de Fuca	78	22		
		Upper Cook Inlet		100		
		Southern Calif. Coast	18	82		
	1975					100
		Southern Calif. Coast		100		
		Upper Cook Inlet		100		
FAIRWEATHER	1974				57	43
		Strait of Juan de Fuca	98	2		
		Upper Cook Inlet	31	69		
		Southern Calif. Coast		100		
	1975				16	84
		Southern Calif. Coast	9	91		
		Shelikof Strait, Alaska	16	84		
		Southern Calif. Coast	24	76		

TABLE 24

Class III NOAA Ships Work Areas

Ship	Year	Area	% Ship	% Launch	Total Hydrography for Year % Ship	Total Hydrography for Year % Launch
WHITING	1974	Southeast Coast of United States	80	20	80	20
	1975				96	4
		Virgin Islands	85	15		
		New York Bight	100			
		Delaware-Maryland Coast	100			
PEIRCE	1974	Southeast Coast of United States	91	9	91	9
	1975	New York Bight	99	1	99	1
DAVIDSON	1974					100
		Commencement Bay, Washington		100		
		Prince William Sound		100		
		Orca Inlet, Alaska		100		
		Sumner Strait, Alaska		100		
		Skagway Harbor		100		
	1975				38	62
		Chart Adequacy Survey, Southern Calif.		100		
		Montague Island, Alaska	48	52		
		Northern Cook Inlet	45	55		
		Kachemak Bay, Alaska	52	48		
		Zaikof Bay, Alaska		100		
		Sergius Narrows, Alaska		100		

TABLE 25

OPERATING COSTS OF EAST COAST NOAA SHIPS

COST CATEGORIES	PEIRCE	WHITING	MT. MITCHELL
Wages	$250,218	$260,826	$483,474
Overtime	34,906	42,099	117,784
Penalty	700	1,453	400
Holiday Pay	1,781	2,001	6,253
Contractual Serv.	21,743	22,573	41,629
Com. Subs & Other	784	570	4,516
Trans. & Trans. Personnel	3,911	2,810	5,175
Trans. Things	88	385	750
Rents & Utilities	8,689	9,743	3,885
Other Contr. Serv.	8,303	6,594	10,114
Supplies Fuel	26,533	14,030	36,593
Supplies Other	29,114	34,184	63,427
Equip. Capital	6,670	11,819	31,980
Equip. Noncapital	2,952	869	5,004
Repair Services	95,214	93,545	153,732
TOTAL	$491,606	$503,501	$964,172

Source: Atlantic Marine Center Annual Summary of FY 72

TABLE 26

STATISTICAL OPERATING COSTS DATA

FY	PEIRCE 2 Launches	WHITING 2 Launches	MT. MITCHELL 4 Launches
1971	$558,000	$578,900	$1,132,900
1972	619,300	621,800	1,198,300
1973	666,600	676,400	1,290,400
1974	681,200	711,900	1,289,500
1975	841,500	823,400	1,470,700

TABLE 27

OPERATING COSTS OF A FIELD PARTY

COST CATEGORY	MONTH	YEAR
Wages and overtime	$3,628	$43,536
Commissioned Officer	1,205	14,460
Travel	2,468	29,616
Spare Parts	582	6,984
Repairs to Vessels	684	8,208
Other Equipment	121	1,452
Repairs to Vehicles	195	2,340
Diesel and Credit Card	146	1,752
Supplies - Vessels	211	2,532
Supplies - Miscellaneous	514	6,168
Cap. Inv. Vessels and Vehicles	613	7,356
TOTAL	$10,367	$124,404

Source: Lt. Cdr. Daniels, Atlantic Marine Center

7.0 COMPOSITE SYSTEM

7.1 A Plan for the Development of a Composite Bathymetric System

When using a composite system made up of both sonic and optical techniques, a new methodology would be required. A typical data gathering effort would appear to divide naturally into four phases:

Phase I - The first phase of a multifaceted bathymetric operation would involve a small boat to make water transparency measurements. From these measurements it then would be possible to select the optimum filter-film combination for the photographic system and the optimum laser wavelength to be used in order to achieve maximum penetration of the water column. In addition, these transparency measurements will allow prediction of maximum depths measurable with each method.

Phase II - After the system parameters have been specified by the launch activity described in Phase I, an aircraft overflight of the area of interest using the photographic tools may be accomplished. A large area can be covered in a short period of time, and from the photographs obtained, the regions too deep for photographic penetration may be easily delineated.

Phase III - Working with the results of Phases I and II, the optimum aircraft laser technique may be employed in the regions contiguous with the areas too deep for photography. In this manner, bathymetric data may be obtained for all the shallower areas leaving the deeper, less hazardous ones for the launches. It is possible that Phases II and III may be accomplished at the same time, as the individual techniques become more highly developed.

Phase IV - With the shallower areas well delineated, the sonar launches may now move in and measure depths in regions that are not only safer but also are probably more amenable to long straight runs, allowing the accumulation of more data in a shorter period of time. At this time also, the launches could acquire the ground truth data necessary for the calibration of the optical methods.

7.2 Present Problems

It is probably apparent at this point that the system described above does not exist. Not only are some of the hardware component nonexistent, but there is some basic environmental information that is lacking. The transparency measurements described in Phase I could be made today only with the expenditure of large sums of both time and money. What is needed is a device to measure the diffuse light attenuation coefficient as a function of wavelength in the visible spectrum. Only a few instruments of this type presently exist and they are not only designed to be used in clear oceanic water, but they are research devices not suitable for operational use. Because these instruments have never been used in dirty water, the optical properties of typical shallow water are not really known. The only data available are based on a very few isolated water samples and these data seem to show a maximum transparency around 540 nm.

7.3 Factors Affecting Transparency

The wavelength of maximum transparency is affected by suspended particles, plankton and dissolved coloring material. Suspended particles scatter light and the wavelength scattered most will depend on the particle size and composition. These particles also add color to the water depending on their mineral content, red indicating the presence of iron being a good example.

Plankton, primarily phytoplankton (plants), affect transparency selectively because they contain coloring pigments. These coloring pigments vary across the spectrum from red to blue-greem, depending upon the type of organism.

Dissolved coloring material is usually the result of some organic substance when found in the deep ocean, often taking on a yellow hue and called gelbstoff or yellow stuff for this reason.

In coastal waters this same yellow agent may be present but in addition, wastes of one form or another may add all sorts of exotic colors to the water. Thus, it may be seen that the absolute transparency and the color of maximum transparency may be affected by:

(1) recent rainfall

(2) nature of the watershed

(3) boat traffic

(4) proximity of industry

(5) wind history

(6) temperature

(7) season

(8) latitude

(9) time of day

and many other factors too numerous to mention. The point is that the chances of the wavelength of maximum transmission being the same for two different areas at two different times is probably small. Just how great the difference might be between any two water masses is unknown. If the differences were not too great, this would allow the use of a single filter-film combination and a single laser for all coastal waters.

7.4 Suggested Supportive Research

Whether the system described above is a cost effective one is difficult to determine at this time for two basic reasons. The first is that our knowledge of the optical properties of coastal waters is so meager that it is difficult to specify the system components. For example, it would be a lot easier if a system could be designed around a single wavelength of maximum transparency for all waters. But we do not know if this can be done with the amount of data presently available.

The second reason is that it is difficult to estimate costs because a large research program is necessary to supply data for optimum system development. Until these data start becoming available, it is not known how much of a development program is required.

The research program required to support the development of a photographic bathymetry system should include:

(1) The development of simple equipment for the measurement of the diffuse light attenuation coefficient as a function of wavelength. This equipment should be relatively easy to use and should be suitable for use aboard small craft such as sonar launches.

(2) The development of new filter-film combinations having maximum response in the region of maximum transparency of coastal waters. This may be a single combination or it may be many depending on the outcome of item (4) below.

(3) The development of a laser peaked in the region of maximum transparency of coastal waters. This may or may not be a tunable laser depending on the outcome of item (4) below.

(4) A large data gathering effort encompassing coastal areas from as many locations, seasons, etc., as possible. These data will be obtained using the gear developed in item (1) above.

7.5 Chances for Success

There is no guarantee that a system such as that described above would be economically feasible or even work at all. Unfortunately, a definitive answer cannot be obtained without an extensive research program to gather environmental data. The decision must be made then as to whether the data gathering effort would be worthwhile in itself even if it indicated that photographic bathymetry would not be worthwhile.

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9.0 DEFINITION OF TERMS

Actual Coverage of Bottom:	The percent of the bottom that is actually read and measured by a bathymetric survey system.
Airborne-Laser System:	A system that has a laser mounted on an aircraft. Laser pulse is set vertically downward. Time delay between light pulse reflected from the water surface and the one coming from the ocean floor yields water depth information.
Areas of Great-Moderate and Little Concern:	These areas are established as a function of the hurrican index and the population pressure index.
Bathymetry:	The science of measuring ocean depths in order to determine the sea floor topography.
Bathymetric System:	A system that provides ocean depth measurements.
Bathymetry vs. Hydrography:	On many bathymetric maps, the depth curves are much more styled and generalized than on a hydrographic survey. The scale is much smaller than on a hydrographic survey and much detail is lost or compromised.
Changeable Areas:	Oceanic areas which, because of natural or manmade forces such as bottom transiency, routine storm activity or industrial development, change bathymetric dimensions significantly and frequently. An example of a changeable area is the area of Wilmington, North Carolina.

Coastal Mapping: Photogrammetric mapping of the shoreline and adjacent land in preparation for charting.

Coastal Zone: A strip of land of indefinite width that extends from the seashore inland to the first major change in terrain features and which includes the marine boundary interface. The coastal zone is the site of a diverse group of studies.

Composite System: A system combining the operation of launch-sonar, laser, photobathymetric and LANDSAT systems and acting as part of an integrated package to optimize cost and effectiveness of bathymetric operations.

Consensus Workshop: A mechanism of proven value for improving the accuracy of intuitive judgments or forecasts. Issues are discussed by a panel of experts meeting together, who vote upon specific questions previously prepared in a structured manner.

Cost-Effectiveness Analysis: Such analysis would take either of two equivalent forms. For a given desired level of effectiveness the least cost would be implied, or for a specified budget level, the alternative or combination of them, will be established, which maximize effectiveness. But in either case, the total systems analysis will require numerous substudies.

Cost-Relevance Analysis: A technique similar to that of cross-support, but which evaluates members of one set of elements in terms of their relative contributions to members of a second set. For example, one could assess the relevance (potential contribution) of members of a set of R&D projects, toward the fulfillment of a set of national or agency objectives.

Cross-support Analysis: A technique for determining the relative value of members of a set of like elements, in terms of their mutual interdependence. For example, in a set consisting of a number of R&D projects, a measure of cross-support would be the extent to which work on one project would support, or contribute to, another project in the set.

Desirable, Highly Desirable, Minimum Importance: The divisions given to the measures of criticality for those operational requirement options which did not rank as "essential." These divisions are suggestsion only and are based on analysis of the ranking graph. Divisions match the groupings found on that graph and also roughly equate to a division of the total ranking array (0-10) into categories corresponding to the logarithmic distributions used throughout the analysis.

Horizontal Accuracy: The accuracy of a bathymetric measurement on the horizontal plane based on the accuracy of routine survey horizontal controls. The present NOS standard for horizontal accuracy provides for an allowable error $\pm$ 5 to 7.5 meters (chart scale dependent). Therefore, a depth measurement on the chart may be actually located anywhere within a 10 to 15-meter seaure area around the point at which it is plotted.

Environmental Constraints: Conditions that are exclusive of those that are more technical or system oriented, such as platform size constraints. They are concerned with meteorological and water quality conditions.

Geodetic: Signifying basic relationship to the earth in which the curvature of its sea level surface is taken into account.

Geodetic Control:	A system of control stations established by geodetic methods.
Grid Cells:	1/8 of an inch squares, which is equal to one square nautical mile on a 1,000 to 80,000 scale chart.
Hydrography;	That science which deals with the measurement and description of the physical features of the oceans, seas, lakes, rivers, and their adjoining coastal areas with particular reference to their use for navigational purposes.
Hydrographic Survey:	A survey of a water area, with particular reference to submarine relief, and any adjacent land.
Hydrographic Field Party:	Typically the party of a 5-man crew performing landbased surveys that employ small launches equipped with sonar sensors for their waterborne operations.
Hurrican Index:	The index of each polygon is the average probability that a hurricane with winds > 73 miles/hr will occur near a polygon.
Intrinsic Value (I):	Applied to mission need areas measures the relative value of individual mission need to the total NOS bathymetric program. Intrinsic value does not include any measure of the supportiveness of fulfillment of one mission need to satisfaction of any other mission need.
Latitude-Longitude:	Coordinates used in defining the boundaries of a polygon (latitude-longitude).

LANDSAT/Multispectral Scanner System (MSS): The system that has multispectral scanner mounted on NASA's LANDSAT satellite, and yields green band data which is then translated into water depth.

Launch Sonar System: The system that has acoustic sensor mounted on launches and operated by field parties.

Linear Nautical Miles: A measure of distance using the nautical miles as a measure. NOS often measures surveys by number of linear nautical miles surveyed. This measurement represents the total linear miles contained in the survey sounding lines rather than any measure of area.

Mariculture (aquiculture): Farming the sea. The workshop participants felt that commercial fisheries (including fish farming), because of their importance, should be considered separately from mariculture. Examples of mariculture would include oyster, mussel and shellfish farms and shrimp, prawn and eel farms.

Measure (Index) of Criticality: The total criticality or importance of an operational requirement option to fulfillment of NOS missions. This index utilizes measurements of the effects of changes in possible operational specifications or "options" on satisfaction of NOS mission needs.

Mission Need: A statement of need for bathymetric data to satisfy an overall NOAA/NOS mission. The sum of the separate NOS mission needs represents the total NOS bathymetric program. All mission needs are derived from the overall NOS goal of "providing navigation charts and aids for the safe and efficient use of the nations waterways and marine environment by industry and the public" (cited from NOAA Hearings before a Sub-Committee of the Committee on Appropriations of the House of Rep., 1977).

Operational Requirement: (also referred to as "requirement")	Operational specifications which must be met to fulfill the NOS missions in shallow water bathymetry. The present investigation arrayed a number of possible requirements or "options" in order of their criticality to NOS missions to determine whether any ranked as "essential" or true operational requirements.
Photobathymetry (Airborne System):	The system has camera mounted on an aircraft. Stereoscopic pictures are taken from the air and these are then analyzed for depth information based on the difference in intensity of the received signals on the two images.
Planimeter:	Instrument used to determine the areas of an irregular figure by tracing the perimeter of that figure.
Polygon:	Multisited figure used to establish boundaries around an area in which water quality data is desired.
Population Index:	Covers a wide range of usage factors. This includes fishing, recreation boating and commerce. The index is assumed to be proportional to the population and inversely proportional to the square of the distance people have to travel to get to the resource.
Requirements:	Refer to "Operational Requirements."
Shallow Water Areas:	The areas in which there are depths of three fathoms or less, over a bottom which is not rocky.
Square Nautical Miles:	A measure of area whose dimensions are one linear nautical mile by one linear nautical mile.

Stable Areas: Areas whose bathymetric dimensions do not change significantly or frequently over time. Such areas may be subject to very gradual changes. Example of stable areas are the middle of the Long Island Sound and the Coast of Florida.

Success Probability: The estimate of the percentage of the time successful field operations can be carried out as they pertain to meteorological and water quality conditions.

Supportiveness or Supportive Value: A term whose interpretation varies with the particular set of elements being evaluated. However, in each instance, the meaning expresses in some fashion the strength of the linkage between each pair of elements.

Systems Analysis: Is the inquiry to aid a decision maker choose a course of action by systematically investigating his proper objectives, comparing quantitatively where possible the costs, effectiveness and risks associated with the alternative policies, strategies, systems for achieving them.

Time Aggregation: Pertains to the exact location of the sampling stations in the time period over which observations were collected.

Turbidity: Concentration of suspended solids in water measured in mm/ltr.

Vertical Accuracy: The accuracy of a bathymetric measurement on the vertical plane. The current NOS standard for vertical accuracy allows an error of $\pm$ 1 foot in waters to depths of 11 fathoms. Therefore, the actual depth at any point may vary $\pm$ 1 foot of the measurement shown on the NOS chart.

Water Quality Data: Amount of suspended solids in water, measured in mm/ltr.

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Concept of photobathymetry is wrong. Juli thinks we measure difference in intensity of received signals on each photo, and that we need different film filter combinations for different areas.