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# Benefits and Costs of Loran-C Expansion in the Hawaiian Islands

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16. Abstract

This study assesses the benefits and costs to the marine community of the expansion and/or retention of the Central Pacific LORAN-C chain. Included are projections through the year 2000 for user and government costs and benefits, user populations, traffic flows and trade patterns. User populations are defined in terms of large and small commercial vessels, fishing and commercial sport fishing vessels and pleasure craft. Trade and traffic flows are characterized by principal commodity, vessel type, origin, destination and vessel routing.

Measures of comparative system value include benefit/cost ratios, benefits and costs per vessel mile, and benefits and costs per square mile cf signal coverage. Also included are case studies of marine groundings in the Hawaiian archipelago, studies of current and future directions of the fishing industry in the Hawaiian Islands and future trends for recreational boating in the region.

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# PREFACE

This study of the benefits and costs of the expansion of the current LORAN-C coverage in the Hawaiian Islands and Central Pacific was performed by the Transportation Systems Center (TSC) for the United States Coast Guard, Office of Navigation under PPA CG-121. The Coast Guard Project Manager was LT. T.M. Brown of the LORAN Branch. Special thanks are due him for his help and support during the course of the study.

The initial concept for this project and much of the preliminary planning and guidance was provided by the late CDR. B.C. Mills of the LORAN Branch. His insights and patient direction supplied a pleasurable background for the overall study. The benefits of his experience as well as his review, comments, and recommendations will be greatly missed.

Much of the data base development and preparation was performed by Input-Output Computer Services, Inc. (IOCS) of Waltham, MA. In particular, a substantial contribution to this study was due to the efforts of Mr. Andreas Tzioumis of IOCS who was responsible for Appendixes C, D, and E and parts of Sections 4 and 5.

Many individuals in the Hawaiian Islands interrupted their schedules and gave freely of their knowledge and experience. Their contributions are acknowledged and appreciated. CAPT. V.R. Robillard of the Fourteenth Coast Guard District, Stanley N. Swerdloff, Hawaii Division of Fish and Game, Svein Fougner, Western Pacific Regional Fishery Management Council, and Chuck Johnson of the "Hawaii Fishing News" were particularly generous in their time, efforts and interest in the development of the study.

The persistence and cheerful patience of Dorothy Clinton for her support during the drafting of this study is recognized with gratitude.

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## EXECUTIVE SUMMARY

The issue regarding the expansion of LORAN-C in the Hawaiian Islands is addressed in this study. As well as a conventional benefit/cost analysis, this study also provides much of the background data and other underlying elements which contribute to an expansion decision. In addition to quantified benefits and costs to the users and operators of the system, this study considers the current and future growth of the islands, their economy, and other factors contributing to the utilization of LORAN-C by the maritime community.

The Hawaiian Archipelago consists of two separate geographic regions. The main Hawaiian Islands at the eastern end comprise the centers of population and commerce. The Northwest Hawaiian Islands extending 1200 nm to the northwest of the main islands consist of a series of small isolated islets and shoals which are, by and large, uninhabited. LORAN-C coverage of the archipelago is presently provided by the Central Pacific chain; however, assured coverage only includes the northwest Hawaiian Islands and adjacent waters. There is limited coverage of the main Hawaiian Islands.

When the Central Pacific chain became operational in 1961, it was a military system designed to meet the requirements of national defense. As a result, civil maritime needs were not involved in the design of the system. Since military effectiveness was the principal issue, civil benefits and costs were not considered. The proposed expansion of the Central Pacific chain addresses the principal civil traffic areas in order to provide navigational fix coverage to those regions of high traffic density heretofore uncovered. Further, as part of the expansion decision the requirements of the civil user are arrayed against the current and projected user benefits, system operator costs and user costs.

Three decision options are considered: expansion of the Central Pacific chain; retention and status quo; and by implication, termination of the system. Two expansion alternatives are addressed: the first involves reconfiguring the system by adding another station at Kauai in the main Hawaiian Islands. This alternative provides additional coverage to the south and slightly more coverage to the northeast. The second alternative relocates the present Kure transmitter eastward to Midway Island in the Northwest Hawaiian Islands thereby increasing coverage eastward into the principal North American trade routes. Investment and operating costs for these alternatives are considered as well as the operating costs for the Central Pacific chain. Investment costs for the Central Pacific chain are considered sunk and do not enter into the analysis. Benefits attributable to all three alternatives are determined.

The following conclusions have been drawn with respect to the costs, benefits, and other elements affecting the decision structure.

- Under the most optimistic set of assumptions the Central Pacific (CENPAC) chain which currently provides LORAN-C coverage of the Hawaiian Islands is marginally justifiable on the basis of costs and benefits to the civil marine users. This chain was designed to meet the requirements of the defense community and does not provide benefits to that area of the Hawaiian Islands where the greatest civil maritime activities lie. A benefit/cost time stream for the Central Pacific chain and the alternatives is shown in Figure 1.

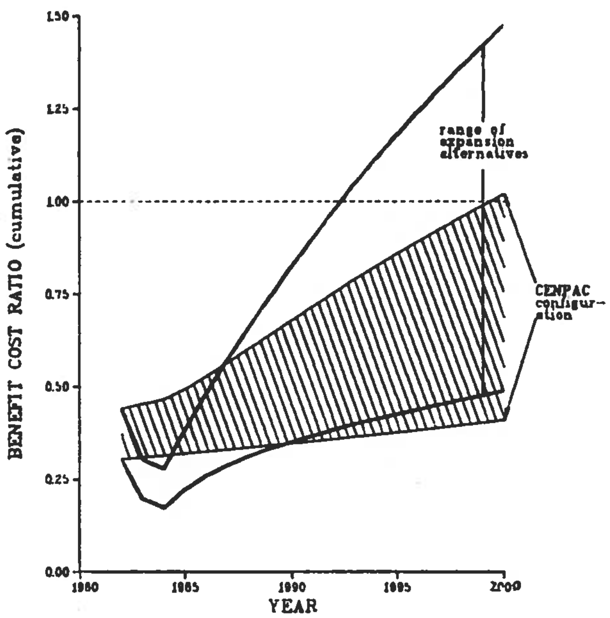



Figure 1: LORAN-C BENEFIT/COST TIME STREAM

- The benefit/cost relationships of the configurations designed to extend LORAN-C coverage narrowly favor system expansion since those alternatives show slight improvement over the Central Pacific chain. However, these relationships do not reach a level considered sufficient to warrant either an investment decision or futher study. The benefit/cost ratio for the reconfigured chain with a master station on Kauai is

1.25 while the ratio for the chain with a repowered and relocated station on Midway Island is 1.47.

- Benefits to U.S. fishing vessels drive the results. However, the uncertainties associated with these benefits are such that under the worst case assumptions for the Central Pacific chain the accrued benefits do not reach a level sufficient to pay back operating expenses. Similar conclusions can be drawn with respect to the minimum benefit/cost relationships for the expansion alternatives.

- Because of the limited civil utility of the Central Pacific chain and the less than favorable benefit/cost relationships for the expanded chains, no overriding case for either system expansion or retention can be made. Although, if the Central Pacific system is retained for reasons other than benefit/cost considerations its worth will be enhanced through expanded coverage.

- The benefits for the expansion alternatives are similar and, in the aggregate, present little discernable difference. However, using other criteria such as costs and benefits per vessel mile and per square mile of coverage, it is apparent that the Midway relocation alternative provides greater benefits to a greater number of users at slightly lower costs. On this basis it is the preferred alternative.

- The principal beneficiaries of coverage from the Central Pacific chain are foreign flag fishing and foreign flag cargo vessels. The Kauai reconfiguration will provide additional benefits to these groups of users; the Midway relocation alternative will benefit the U.S. flag users the most by providing coverage to the North America - Hawaii traffic.

- The benefit/cost ratios for all alternatives including the Central Pacific chain tend to be insensitive to major events which cause changes in benefits. The prevention of a major navigation-related marine disaster through expanded LORAN-C coverage will not raise the benefit/cost relationships to a level sufficient to justify a positive investment decision.

- Vessel groundings occur throughout the entire Hawaiian Archipelago. However, the frequencies and severities are low and the greatest numbers occur within the main Hawaiian Islands. In the shoal areas of the archipelago to the west of the main Hawaiian Islands fewer groundings occur but they are of greater severity. LORAN-C coverage from the Central Pacific chain is available in the latter area but not in the former.

Based on historic data some quantitative benefits can be attributed to expanded coverage.

- Although most Coast Guard benefits from expanded LORAN-C coverage cannot be quantified, substantial qualitative benefits can result. These benefits are in improved capability in the enforcement of laws and treaties, particularly the enforcement of the Fishery Conservation Management Act, in the marine environment protection mission and in search and rescue operations. With respect to search and rescue some quantitative benefits can also be derived from LORAN-C expansion through improved navigability. These benefits can result in savings in helicopter/fixed wing operations. However, helicopter upgrading with self-contained navigational capability can yield similar benefits without LORAN-C expansion. Since this upgrading is already planned for FY82-83, no LORAN-C benefits have been assigned.

- The advent of NAVSTAR GPS in 1987-1988 could significantly affect the number of ships that equip with LORAN-C. This, in turn, would lower all projected benefit/cost ratios thereby making all system alternatives investigated even less promising. Some large marine operators have already indicated their intent to defer the acquisition of any additional radionavigation receivers until the presumed availability of NAVSTAR GPS.

# 1. INTRODUCTION

## 1.1 General

This study of the benefits and costs of additional LORAN-C coverage in the Hawaiian Islands was conducted by the Transportation Systems Center (TSC) under the sponsorship of the U.S. Coast Guard, Office of Navigation. This study is in partial fulfillment of the requirement for an assessment of the needs for expanded LORAN-C coverage in the extracontinental regions of the United States as laid down in the Federal Radionavigation Plan. In this plan the issues of the expansion of LORAN-C in the Eastern Caribbean, Hawaii, and the Northern Regions of Alaska are left unanswered pending the results of a study of the benefits and costs of expanded coverage in each of these areas. A previous study has addressed the Eastern Caribbean; a future study will consider the Alaska expansion. This study considers additional LORAN-C coverage in Hawaii.

## 1.2 Scope and Objectives

The issue of the expansion of the current Central Pacific LORAN-C Chain is addressed in this report. Other alternative systems (Omega, Transit, NAVSTAR GPS) are considered where appropriate but in less detail. Inasmuch as expanded LORAN-C or NAVSTAR GPS would not be available in Hawaii until the mid or late 1980's, the data presented are based on projections and trends derived from an analysis of current operations. Where uncertainties exist, ranges of values are shown. Whenever possible benefits are quantified in terms of dollar savings; however, when quantification is not possible, qualitative benefits are noted.

The objective is to provide an early indication of the requirements, if any, for enhanced coverage of LORAN-C in the region surrounding the major Hawaiian Islands. The principal elements considered are the benefits and costs to the maritime user and to the government. The costs of the system are considered both in terms of the operational costs of the current Central Pacific chain and the additional capital and operational costs associated with expanding and reconfiguring this chain through the addition or relocation of transmitter stations. Both benefits and costs are considered within a framework of the marine operations in the region. Included are a determination of the marine population expressed as traffic and trade into and through the area of current and expanded LORAN-C coverage. Also considered are the origins and destinations of all marine traffic both in terms of Hawaii-specific traffic as well as that traffic which transits the area, but which is nevertheless, a beneficiary of the LORAN-C system.

Other principal users and beneficiaries of the expanded or reconfigured system are the Hawaiian fishing industry and the Federal Government. While the current contribution of the fishing industry is less than 0.2 percent of the Gross State Product, there is a concerted, coordinated drive to expand this industry by the year 2000 to a level of nearly eight times its current state. The role and possible contribution of expanded LORAN-C in meeting this goal is considered as a possible benefit area. Also considered are the benefits to the government, particularly the Coast Guard, in terms of improved mission capability and operational effectiveness, mainly in the Search and Rescue element. Finally, the role and possible benefits in the reduction of navigation-related maritime incidents due to enhanced LORAN-C signal coverage is addressed and quantified.

## 1.3 Assumptions and Approach

Since this is principally an operational study of benefits and costs, alternative LORAN-C system configurations and capabilities are included only as they relate to these determinations. Approximate system coverage is more important in this study than technical system capabilities and constraints. Therefore, the configurations shown are used for illustration and for developing estimated benefit and cost data. A more precise study of these alternatives for the purposes of developing detailed specifications and characteristics could be the subject of a future effort if required by the results of this analysis. At this time, it is the principal intent to provide meaningful cost and benefit estimates of the potential for system expansion.

Civil marine users are assumed to be the principal beneficiaries although Coast Guard air and marine users are also considered. Of the civil marine users, only those vessels (both U.S. and foreign flag) engaged in U.S. trade or calling at Hawaiian or Mainland U.S. ports were considered. Foreign vessels engaged in foreign trade or transiting through the LORAN-C coverage areas were outside of the scope of this study. It is probable that these vessels would also derive benefits from LORAN-C system expansion.

Under the ground rules of this study, civil aviation users are assumed to be outside the area of interest. Further, as the FAA has certified Omega to replace LORAN-A as the externally referenced radio aid to navigation for use in the oceanic enroute phase of navigation (Reference 1). FAA certification of the aviation use of Omega is obtained only upon request by the individual airlines. Such certification is restricted to the region between 70$^{o}$N and 45$^{o}$S. Military users were not considered because the stated DOD position assumes that LORAN-C will be phased out in favor of NAVSTAR GPS when the latter system becomes operational (Reference 1).

Only coverage provided by LORAN-C ground wave is considered. At this time the quality of coverage from LORAN-C sky waves is unknown and a definition of their utility for navigation will require a program of monitoring and surveying beyond the scope of this study.

The users of the LORAN-C signal in other than radionavigation applications were not considered although current indications are that this population may be considerable. Among this group are the scientific and technical users of the precise time component of the LORAN-C signal. Also not considered are those users of the communication applications of LORAN-C.

NAVSTAR GPS is assumed to be fully operational by the end of 1988 (Reference 1) while the LORAN-C expansion alternatives would be in place and operational by 1985. However, current estimates indicate that the NAVSTAR GPS date may slip, while the LORAN-C expansion date is contingent on an early decision together with prompt congressional action.

## 2. BACKGROUND

The current Central Pacific (CENPAC) LORAN-C Chain became operational in 1961. The original rationale for the installation of LORAN-C in Hawaiian waters was governed by the requirements for national defense and military effectiveness. Costs were a secondary issue. Further, since civil entities were not involved, nor were they at that time a potential user of the system, a conventional benefit/cost analysis was not performed.

At the time of initial conceptualization and installation of the CENPAC Chain, the needs of the military governed its configuration and coverage. Thus, current coverage of LORAN-C in the Hawaiian Islands is geographically optimized for military requirements but not necessarily civil needs. The CENPAC Chain provides coverage to the west of the main Hawaiian Islands, and includes most of the islets and shoals comprising the Archipelago; it extends on the south to Johnston Island and includes the open sea areas to the west and south of the main islands.

The declassification of LORAN-C made two radionavigation systems available for civil use. These systems, LORAN-A and LORAN-C, provided similar coverage of local waters. Neither covered the main islands and, of the two, LORAN-C provided considerably greater regional coverage. Further, LORAN-C provided vastly improved accuracy and reliability. In 1974 LORAN-C was designated as the government-provided navigation system for the coastal regions of the Continental United States, Gulf of Alaska and the Great Lakes. At that time a schedule was promulgated which provided for the orderly phase out and termination of the LORAN-A system. No specific mention was made regarding the expansion of LORAN-C into the insular regions of the U.S., specifically Puerto Rico and Virgin Islands in the Eastern Caribbean and the main Hawaiian Islands. Nor was any mention made regarding the reconfiguration or expansion of the Alaska chains so as to incorporate the Coastal Confluence Zone north of the Bering Strait and Seward Peninsula.

The 1977 edition of the National Plan for Navigation, raised the issue of LORAN-C expansion into the above areas (Reference 2). This issue was reiterated in 1979 in the Federal Radionavigation Plan, the successor document to the National Plan for Navigation. Further, in the Federal Radionavigation Plan the U.S. Coast Guard is specifically tasked with recommending for or against LORAN-C expansion in areas of the U.S. Coastal Confluence Zone outside the Continental United States and Southern Alaska.

Heretofore, system investment decisions were made either based on the needs of the military, as with the Central Pacific LORAN-C Chain, or as a question of national policy as was the case with LORAN-C expansion and reconfiguration in the continental Coastal Confluence Zone and Great Lakes. For the first time, expansiion decisions now include requirements of the civil user arrayed against the current and projected user benefits, system operator costs, and user costs. In the Central Pacific LORAN-C configuration the needs of the military were the driving factors in the decision structure and, as a result, system coverage excludes those areas of major civil maritime traffic. The proposed Central Pacific expansion configurations, on the other hand, address the principal traffic areas and provide signal coverage to those regions of high traffic density heretofore not covered.

In FY80, the Transportation Systems Center addressed the needs, benefits, and costs of the civil maritime radionavigation user in the Eastern Caribbean (Reference 3). The results of that study of LORAN-C alternatives indicated that the payback period of benefits to costs did not occur until late in the system life cycle. Further, that study indicated that under the most optimistic set of assumptions and expansion alternatives selected, the system was only marginally cost-beneficial (Benefit/Cost ratios $\leq$1.6). In some of the system configurations considered, the net life cycle benefits did not exceed the life cycle costs. The study results were used as the basis for a subsequent decision by the Secretary of Transportation not to expand LORAN-C into this region.

The study of the expansion of LORAN-C in the Hawaiian Islands addresses similar issues. The question to contend with now, however, is whether to expand, terminate, or continue a system which provides partial coverage and some benefits to the civil maritime community although the coverage may not be focused on the needs of the majority of users or potential users. The following sections provide the assumptions and basis for the subsequent analysis and findings.

# 3. CHARACTERIZATION OF THE HAWAIIAN ISLANDS

## 3.1 The Hawaiian Archipelago

### 3.1.1 General

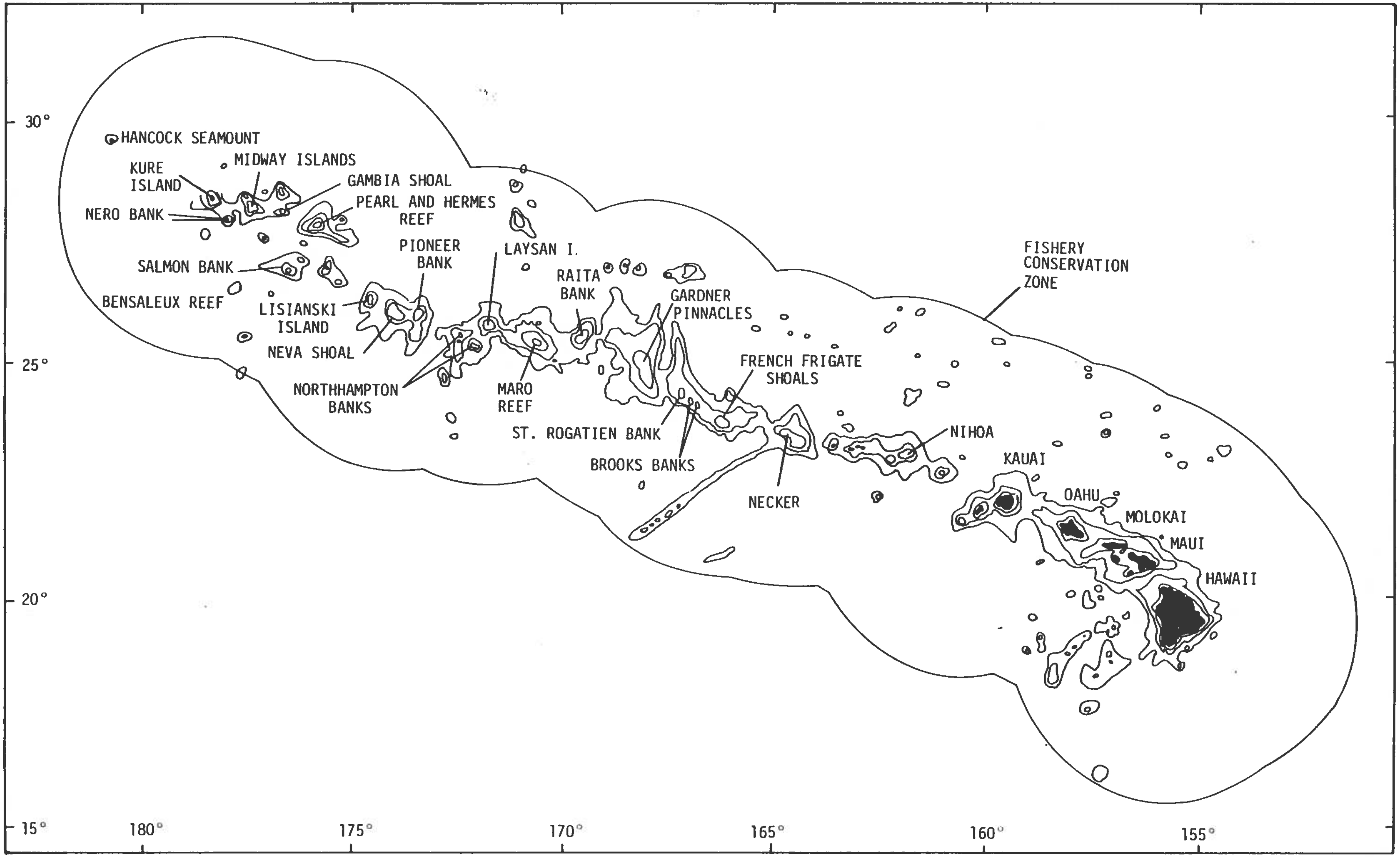
The Hawaiian Islands comprise an archipelago consisting of a series of volcanic islands, islets, reefs, and shoals extending 1400 nautical miles along a northwest, southeast axis. The principal islands are in order of size, Hawaii, Maui, Oahu, Kauai, and Molokai and are located on the eastern extremity. The archipelago extends from 154°49'W (Cape Kumukahi on the Island of Hawaii) to 178°20'W (Kure Island). In a north-south direction, it extends from Ka Lae on the Island of Hawaii, the southernmost point in the the United States (18°45'N) to Kure Island (28°30'N) (Reference 4). Most of the islands are surrounded by a narrow coastal shelf which drops off rapidly to great depths. Figure 3-1 is a chart showing the major islands, shoals, banks and islets. Also shown on this chart is the 1000 fathom curve which by its proximity to the shoreline indicates the narrowness of the offshore coastal shelf. All islands in the archipelago are part of the State of Hawaii except for the Midway Islands which are part of the naval defensive sea area and are reserved for purposes of national defense.

### 3.1.2 Coastal Confluence Zone (CCZ)

The Coastal Confluence Zone is characterized as a region of moderate maritime traffic and reasonable proximity to the coastline and, as such, is an area which requires more precise and more reliable navigation aids than the high seas. The Coastal Confluence Zone of the United States is that region extending from the harbor entrance to 50 nm offshore or to the edge of the continental shelf (100 fathom curve), whichever is greater. The designation of a Coastal Confluence Zone in its strictest interpretation is applicable both to major land masses (Continental United States) and to island groups (Hawaii and Puerto Rico/Virgin Islands). In this zone, transoceanic traffic patterns tend to converge, inter-island or inter-port traffic exists in patterns that are essentially parallel to coastlines and ships of lesser range tend to confine their operations. Movement of traffic in the CCZ may be point-to-point as in coastwise or foreign trade; directed, in the sense of fishing or survey vessels; or casual, in the sense of recreational craft (Reference 2). In the Hawaiian Islands, the Coastal Confluence Zone extends approximately 50 nm offshore since the 100 fathom curve generally begins a few hundred yards offshore due to the rapid and steep dropoff. Thus the CCZ would follow the shoreline of the islands and extend the length of the archipelago.

### 3.1.3 Fishery Conservation Zone (FCZ)

The Fishery Conservation Zone (FCZ) was established by the Fishery Conservation and Management Act of 1978 and delineates a




COURTESY HAWAII DIVISION OF FISH AND GAME

Figure 3-1

HAWAIIAN ARCHIPELAGO

region wherein the United States exercises fishery management jurisdiction. Generally this region is defined as a zone 200 nm seaward from the baseline from which the territorial sea is measured (Reference 5). Figure 3-1 shows the FCZ for the Hawaiian Archipelago. It extends from 200 nm east of the Island of Hawaii to 200 nm to the northwest of Kure Island so as to include the Hancock Seamount. This encompasses an area of approximately 648,000 sq. miles and is an area over which the Coast Guard exercises jurisdictional control in its mission of enforcement of maritime laws and treaties.

## 3.2 Principal Ports and Harbors

Honolulu, on Oahu, is the capital of the state, the center of population and the largest commercial deep water facility in the Islands (Figure 3-2). It is located on Mamala Bay on the south side of the Island. This bay extends from Diamond Head on the East to Barbers Point on the West. The Port of Honolulu handles approximately 96 percent of the oceanic traffic and serves as the distribution point for the majority of the marine commerce destined to or originating from the other islands. There are 42 major piers, wharves and other docking facilities in the Port of Honolulu and vicinity; 31 of these facilities are in the Port of Honolulu proper. The balance are in the various basins and lagoons bordering Mamala Bay. Three of these facilities are at Barbers Point serving the petroleum refinery and shipping operations there. Also located on Mamala Bay is the U.S. Naval Base at Pearl Harbor which has been established as a defensive sea area and is closed to commercial traffic.

The other principal ports in the Hawaiian Islands are Hilo and Kawahae on Hawaii, Port Allen and Nawiliwili on Kauai, Kahului on Maui and Kaunakakai on Molokai. Of these, Kahului and Hilo are the largest in terms of numbers of facilities and capabilities; all are equipped to handle barge traffic as well as petroleum offloading and bunkering.

## 3.3 Principal Trade Routes

### 3.3.1 Oceanic Trade Routes

The oceanic trade routes between the Hawaiian Islands and continental land masses and other islands can be grouped into four quadrants. The northern quadrant consists of the traffic from Alaska and the West Coast of the United States and Canada; the eastern quadrant traffic is from the Panama Canal and the West Coast of South America. Traffic in the south-southwestern

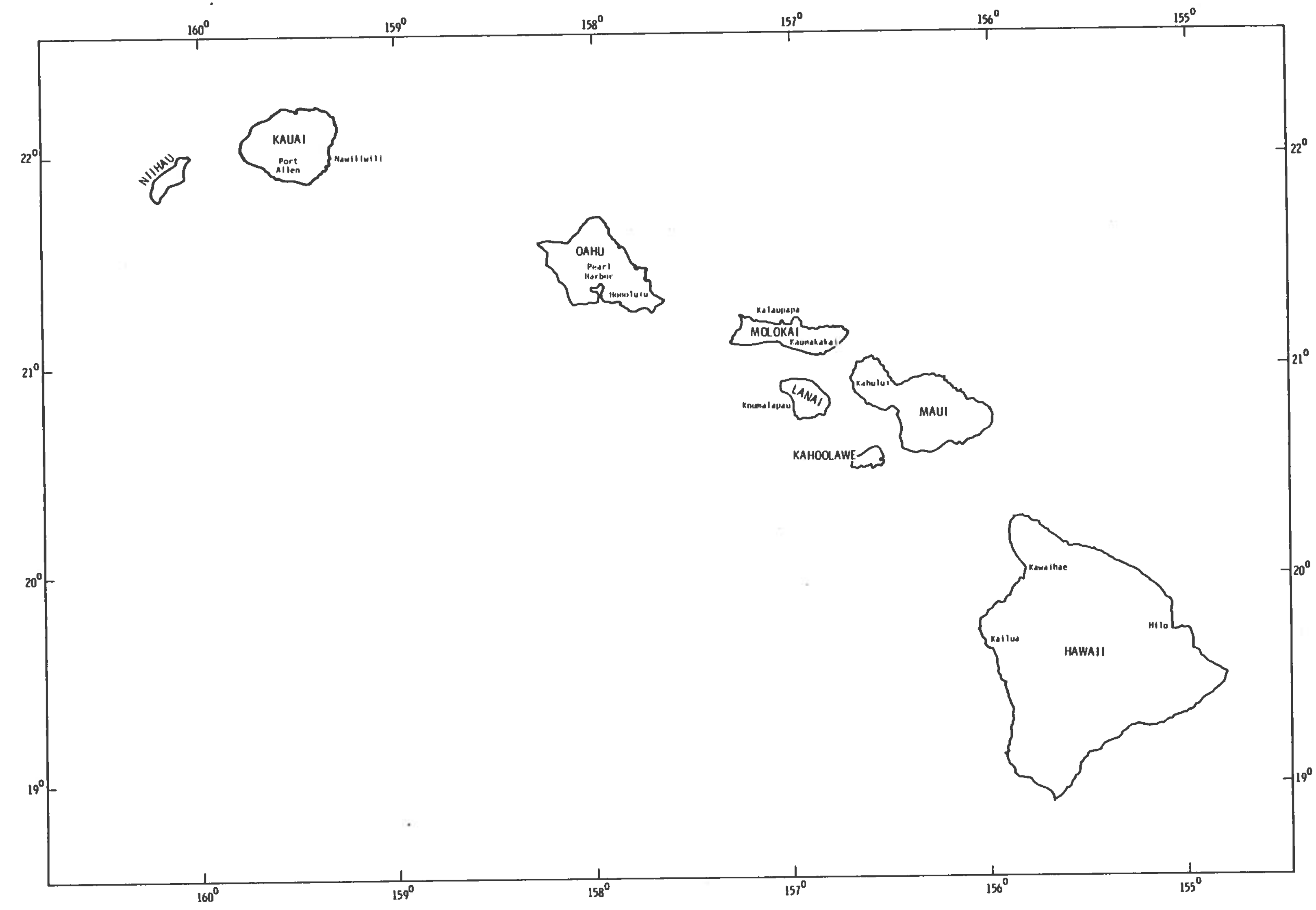



Figure 3-2

PRINCIPAL PORTS AND HARBORS

quadrant is from Australia, New Zealand and other Pacific Islands such as American Samoa, Fiji, Cook and Society Islands. The western quadrant traffic is from Southeast Asia, the Orient and Soviet Union. Included in this quadrant is traffic from Singapore, Indonesia, Philippines, Japan, Taiwan, and Korea. Also included is traffic from the Trust Territories such as Guam and the Marianias Islands. The track lines for these trade routes are shown in Figure 3-3. When multiple track lines are shown, i.e., Japan or Alaska, alternate routes are available. Since this chart is based on a Mercator projection, these routes should appear as slightly curved lines. For ease in portrayal, rhumb lines are used and thus represent an approximation of the route.

In addition to oceanic traffic which is either destined for or originates from the Hawaiian Islands, there are also trans-Pacific trade routes which are used by transient traffic between the west coast of the United States and the southern and western Pacific ports. These trade routes pass through either the major islands or the archipelago proper, or else are in close proximity to the Islands. They are also shown in Figure 3-3. Only one route, the Seattle to Australia route, goes between the islands of Kauai and Oahu. Most of the remaining trade routes pass to the north of the Islands principally the Southeast Asia - California routes. On the other hand, only two routes pass to the south of the Islands and they represent the Australia - California traffic. These trade routes were subsequently used to develop a characterization of oceanic traffic and to provide a basis for the determination of system benefits.

### 3.3.2 Inter-island Trade Routes

Honolulu is the principal port of the Hawaiian Islands and most oceanic and interisland traffic either originates or terminates there. Oceanic cargo may be offloaded at Honolulu and transshipped by barge to the adjacent islands. Sometimes a vessel is partially offloaded at Honolulu and then continues to subsequent ports in the islands. The interisland trade routes are shown in Figure 3-4. Some of the traffic is made up of multiple barge loads with multiple destinations. One or more barges will be left at an intermediate port while the principal load continues on to its final destination. On the return trip, the process is reversed.

Most of the barge traffic tends to follow the coastal trade routes and more circuitous interior channels between the islands. On the other hand, larger vessels will sail direct via the open waters to their destination. In either case, navigation or piloting is performed visually and augmented by radar.

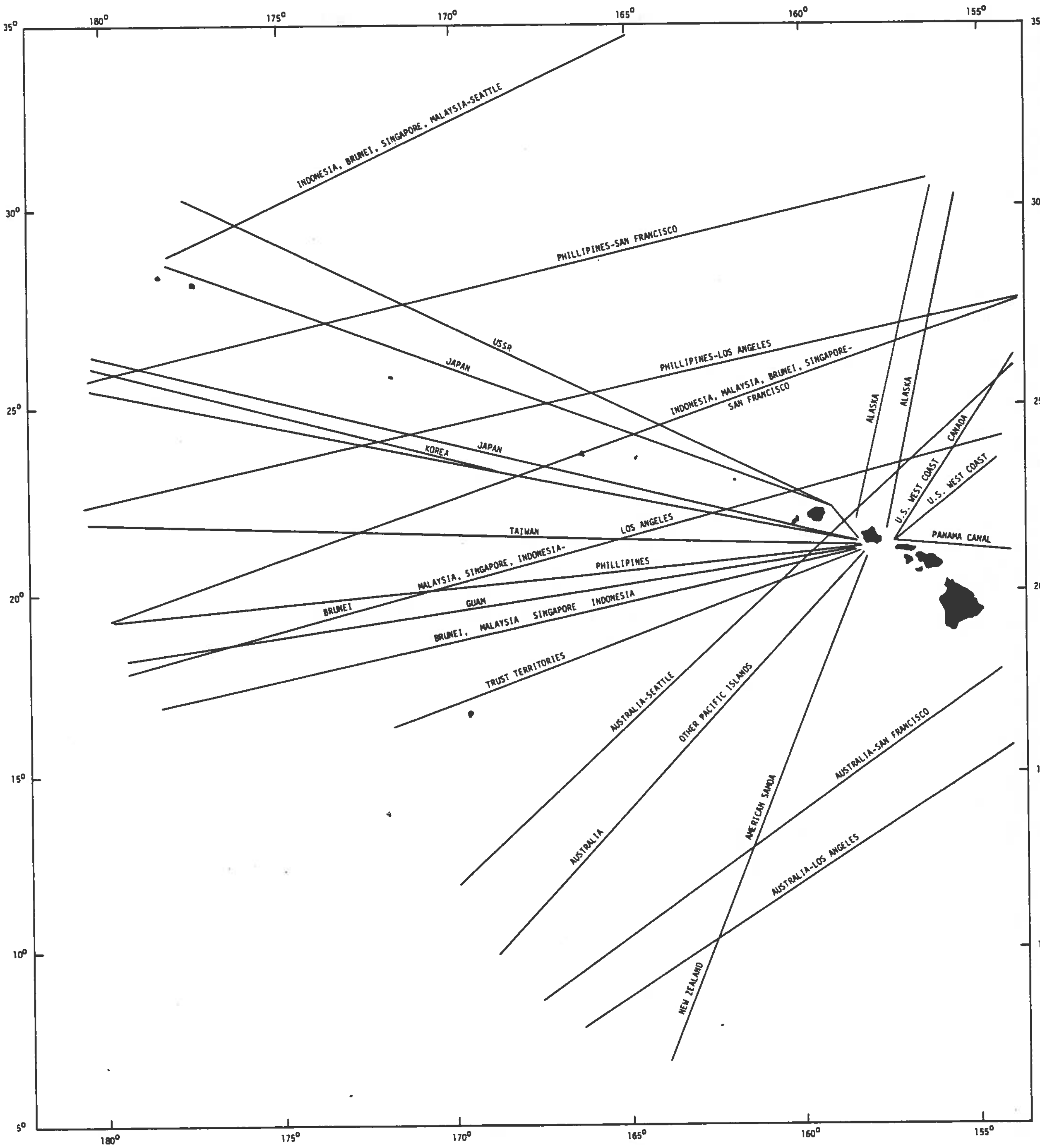



FIGURE 3-3

OCEANIC TRADE ROUTES

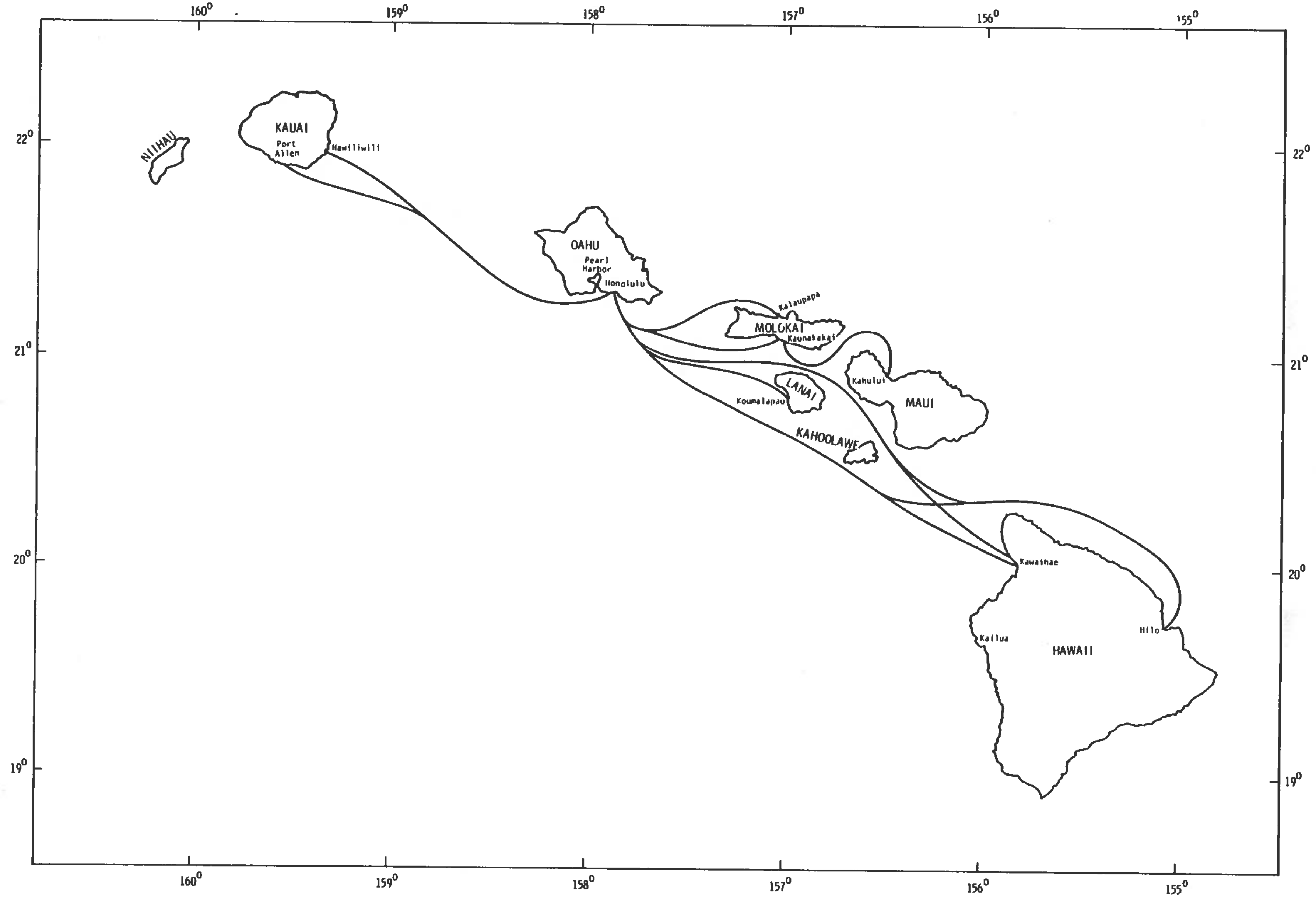



FIGURE 3-4
INTER-ISLAND TRADE ROUTES

## 3.4 Ocean Basin Environment: Weather and Climate

### 3.4.1 General

The ocean basin environment of the Hawaiian Islands is marked by a tropical climate which is unusually favorable for the mariner. Adverse effects such as severe storms are rare, short-lived, and do relatively limited damage (References 4,6).* Overall the climatic features are dominated by trade winds whose influences are felt throughout all seasons, by uniform temperatures in all regions and by extreme variations in rainfall between adjacent areas. The following is a discussion of those elements of the Hawaiian weather and marine environment which impact upon the mariner and safe navigation.

### 3.4.2 Wind

Overall, the wind is the dominant characteristic of Hawaiian weather. The trade winds blowing from a northeast direction are not only persistent and predictable but also account for approximately 70 percent of the wind distribution. The Pacific Anticyclone (Pacific High) is the source of the Hawaiian trade winds. Circulation around this cell is in a clockwise direction, which, together with a slight deflection of the surface winds away from the high pressure region account for the northeast trade winds that dominate the area. The trade winds have an average velocity of 13 knots and are marked by seasonal variations. They are strongest and most persistent during the summer months; between January and March they are least frequent and sometimes disappear for an entire month. The greatest effect upon the mariner from the trade winds is in the channels between the islands. There the winds tend to be funneled and accelerated as they pass between the steep coastal slopes of the islands. This funneling effect tends to increase the wind velocities by 5 to 20 knots or more. The effect of this acceleration upon the channel waters is to develop choppy waves which in time become rough and confused. While this effect is not critical for ocean going vessels, it can be hazardous for small craft (Reference 7). The strongest trades are in the Alenuihaha Channel between Maui and Hawaii. Other regions where the winds accelerate greater than 20 knots include the Kaiwi Channel between Oahu and Molokai, and the Pailolo and Kalohi Channels between Maui, Molokai and Lanai.

*Subsequent to the draft of this report, hurricane Iwa struck the islands of Kauai and Oahu in November 1982 causing major damage.

Kona (leeward) winds are strong south or southwesterly winds accompanying shifts in the weather pattern. When these shifts occur, the trade winds disappear and are replaced by winds from the opposite direction. Because of the shift in direction, the normally leeward slopes of the islands become windward slopes. Kona winds are usually associated with storms, heavy rainfall and cloudiness. Areas which have no rain when the trade winds are blowing are deluged. This weather pattern is associated with a tropical low and cold front advancing from the west. The impact upon the mariner of Kona weather is to cause heretofore safer shores and anchorages to become unsafe for small craft.

### 3.4.3 Storms and Visibility

The effect of storms, lows and accompanying reductions in visibility are minimal upon the mariner and marine navigation. Thunderstorms in Hawaii are uncommon and are generally associated with cold fronts and Kona lows. When they do occur, they are mild and of short duration. Hail seldom occurs. Waterspouts are formed occasionally, generally during the Kona season and are associated with cumulonimbus clouds and thunderstorms. When a waterspout funnel is formed, it rarely touches the surface of the water and therefore is of little danger to the mariner. Hurricanes and typhoons sometimes visit the islands, however their force usually has been attenuated. The Hawaiian Islands lie at the extremes of the West North Pacific typhoon area and the East North Pacific hurricane area and those tropical storms that do appear have been greatly dissipated. Of the two types of storms it is more probable that the hurricanes would reach the islands. These storms are bred off the North American coast and travel westward. Most often however, they recurve to the east or die before reaching the Islands. Reduced visibility due to thick weather and fog to the extent that it interferes with shipping is almost unknown. Reductions in visibility that do occur are generally attributable ?rto rain and mist. In nearly thirty years of record keeping there have been no recorded days when the visibility dropped to one quarter mile or less. Visibility less than 2 miles is recorded less than 1 percent of the time and is generally confined to the winter months.

### 3.4.4 Currents

The effect of currents upon the mariner is not pronounced nor should it impact greatly upon maritime navigation. The currents surrounding the Hawaiian Islands are extremely variable. They are the product of many forces and are difficult to define except in general terms. There is a prevailing westward oceanic drift caused by the north Pacific equatorial current. The prevailing trade winds tend to drive the surface current in a westerly direction thereby enhancing the effect of the overall westward drift. Tidal currents are weak and reversing in the channels, but tend to rotate around the islands, generally in a clockwise direction. The maximum velocity of the current is 1.5 knots with an average of about 0.5 knots.

3.5 Marine Navigation in the Hawaiian Islands

The ability to navigate in Hawaiian waters and in the oceanic regions surrounding the Islands is a function of the generally favorable weather conditions in the area and of the availabilities of electronic and visual navigation aids. The impact of weather and the ocean basin environment upon marine navigation is slight as was discussed in Section 3.4. The greatest effect is from the trade winds and Kona weather which can be hazardous to small craft operators but would be slight with respect to oceanic traffic. In addition, the Hawaiian region is characterized by deep water with the relative absence of shoals except extremely close inshore or in certain areas of the archipelago. Because of the benign weather and hydrographic conditions and the relative proximity and topography of the islands, most mariners rely on a combination of visual and radar piloting for inter-island sailings. The generally high, rugged coastlines of the islands provides good and well defined radar returns (Reference 4). Landfalls at a distance of 20 to 30 miles is not uncommon; some navigators report radar contact at 40 miles.

For open water and trans-Pacific navigation by large and small ocean going vessels, long range and global electronic navigation sytems are generally used. Ground wave LORAN-C signals from the Central Pacific Chain are available up to 1000 miles to the west of the principal Islands. Omega signals are available from four stations, with a fifth, Norway, generally usable at nightime. Transit is available and used although time between fixes is approximately 90 minutes in Hawaiian waters. A complete discussion of radionavigation systems and user requirements is given in Sections 6.2 and Appendix A.

Celestial navigation is frequently used by many of the oceanic vessels which operate from Hawaii and transit the Pacific. The generally fair weather and absence of cloud cover favor the use of this means. In particular, the recreational boater, specifically those engaged in ocean sailing and ocean racing such as the Transpac and Clipper Cups races, tend to opt for the more traditional methods, particularly celestial.

Radiobeacons are not available in the Hawaiian Islands. However, a calibration beacon is available upon request at Diamond Head on Oahu. No other marine radionavigation aids are available in the Hawaiian Islands.

# 4. ECONOMY OF THE HAWAIIAN ISLANDS

## 4.1 Overview

The purpose of this section is to present an overview of Hawaii's economy, emphasizing the elements or activities that affect marine operations.

The Hawaiian economy will remain relatively small in size regardless of future growth rates. Economic growth, among other inputs, requires land, natural resources, technology and a pool of specialized labor. Hawaii is deficient in the first two inputs, which are the limiting elements to achieving high growth rates. In particular, the growth of the Hawaiian economy will reflect land limitations imposed by the size of the islands. An accelerated growth of any one activity will have a negative effect on other ones. For instance, a high growth rate of the construction industry due to high demand for hotels, industrial or commercial parks and residential housing will drain land away from agricultural usage. For example, sugar acreage harvested declined from 100,600 acres in 1979 to 97,400 acres in 1980 while construction activity has been on the rise. The implication of this competition for scarce resources is that expansion of one activity may raise the level of trade and marine operations, while contraction of the other may lower both trade and marine operations.

In 1980, the Gross State Product (GSP) of Hawaii was valued at 11.4 billion dollars, an increase of 1.21 billion dollars from 1979. Table 4-1 indicates the major income producing activities for the economy that produced goods and services in 1980 valued at 10.67 billion dollars. Total Federal outlays ranked first, accounting for 30.9 percent of the income produced. The tourist industry generated 3.0 billion dollars, ranking second (28.1 percent) among all income-producing activities. Manufacturing sales ranked third, accounting for 2.5 billion dollars or 23.4 percent of the total income produced.

Table 4-2 shows the performance of Hawaii's economy from 1970 through 1980. As Table 4-2 indicates, GSP and per capita personal income more than doubled in that period. However, these gains were largely offset by rising prices, as is indicated by the Honolulu Price Index (equivalent to the Consumer Price Index), which from 1970 to 1979 rose 79 percent. In 1970, foreign trade totaled 225.9 million dollars, of which 77 percent represented imports and the balance was exports. In 1980, foreign trade exceeded 2.0 billion dollars and imports rose from 77 percent to 91 percent, indicating a higher deficit in the balance of payments.

In 1970, 9.61 million tons of cargo were shipped via sea to or from Hawaiian ports. Incoming cargo accounted for 77.6 percent, or 7.46 million tons. In 1980, total cargo accounted for 15.0 million tons, representing a net increase of 5.39 million tons

TABLE 4-1. MAJOR INCOME PRODUCERS
(1978 - 1980)

| ITEM | AMOUNT IN BILLIONS 1978 | 1979 | 1980 |
|---|---|---|---|
| Visitor Expenditures | $2.19 | $2.62 | $ 3.00 |
| Manufacturing Sales | 1.48 | 1.86 | 2.60 |
| Federal Nondefense Outlays | 1.34 | 1.66 | 1.90 |
| Federal Defense Outlays | 1.21 | 1.31 | 1.40 |
| Construction Completed | 1.06 | 1.34 | 1.60 |
| Diversified Agriculture | .13 | .15 | .17 |
| Total | $7.41 | $8.94 | $10.67 |

Source: Reference 8, 9, 10

TABLE 4-2
HAWAIIAN ECONOMIC INDICATORS

| YEAR | STATE PRODUCT IN $ MILLION | PER CAPITA PERSONAL INCOME IN DOLLARS | UNEMPLOYMENT RATE IN PERCENT | HONOLULU PRICE INDEX* | MANUFACTURING IN $ MILLIONS | FOREIGN TRADE IN MILLIONS | | SEA TRANSPORTATION IN 1,000 TONS | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | IMPORTS | EXPORTS | INCOMING | OUTGOING |
| 1970 | $ 4,259 | $ 4,599 | 4.9 | 114.2 | $ 761.4 | $ 174.7 | $ 51.2 | 7,464.7 | 2,146.1 |
| 1971 | 4,562 | 4,785 | 6.9 | 118.9 | 805.4 | 223.6 | 46.4 | 7,094.4 | 2,345.2 |
| 1972 | 4,989 | 5,078 | 7.7 | 122.8 | 804.9 | 244.3 | 60.4 | 7,631.8 | 2,392.3 |
| 1973 | 5,572 | 5,529 | 7.2 | 128.3 | 935.9 | 340.1 | 72.8 | 8,203.1 | 3,084.4 |
| 1974 | 6,276 | 6,130 | 7.9 | 141.9 | 1,537.6 | 621.5 | 113.1 | 8,581.2 | 2,575.1 |
| 1975 | 6,970 | 6,711 | 8.3 | 155.0 | 1,318.3 | 784.4 | 94.0 | 8,644.3 | 3,114.7 |
| 1976 | 7,537 | 7,134 | 9.8 | 162.8 | 1,231.6 | 915.1 | 66.2 | 9,240.6 | 2,981.4 |
| 1977 | 8,189 | 7,669 | 7.4 | 171.0 | 1,299.4 | 1,042.0 | 98.3 | 9.545.4 | 3,101.8 |
| 1978 | 9,092 | 8,465 | 7.8 | 184.2 | 1,483.3 | 1,184.5 | 137.8 | 9,800.8 | 3,200P |
| 1979 | 10,161 | 9,248 | 6.3 | 204.7 | 1,890.9 | 1,334.6 | 176.1 | 10,250P | 3,325P |
| 1980 | 11,375 | 9,787 | 5.0 | 228.5 | 2,611.7 | 1,841.2 | 174.4 | 11,250P | 3,740P |

*1967 = 100

P = Projected

Source: Reference 8, 9, 1Ø

over the 10 year period. The principal commodities imported are crude oil, automobiles, lumber, machinery and equipment, transportation equipment, furniture and household durables, metals and other industrial commodities. Hawaii exports refined petroleum, pineapple (fresh and canned), sugar, scrap metal, papaya, coffee, veal and textile garments.

The remainder of this section is a description of the most important economic elements affecting marine operations.

## 4.2 Economic Elements Affecting Marine Operations

### 4.2.1 Agriculture

The gradual development of service-oriented industries coupled with competition for land use, is changing the role of agriculture. Though agriculture contributed nearly one billion dollars in value in 1980 (in Table 4-1, some items are included under manufacturing), the production of traditionally important products, such as sugar and pineapple, has declined. Sugar production in 1971 exceeded 1.22 million tons, while in 1980 it was at 1.02 million tons. Similarly, pineapple production in 1970 was 820,000 tons, while in 1980 it was 657,000 tons. Figures 4-1 and 4-2 show production for sugar and pineapple, respectively. Although diversified agriculture (includes all other products and livestock with its products, except sugar and pineapple) has increased by 11.7 percent since 1975, its total sales in 1980 amounted to only 171.9 million dollars. The largest component of diversified agriculture is livestock products, accounting in 1980 for sales amounting to 81.2 million dollars.

Given these trends, it can be assumed that the level of exports will not change substantially in the near future. However, the level of imports will depend on local population growth rates and on the visitor industry. Using a regression analysis it was estimated that the defacto population (number individuals in the state at any given day) will be 1,383,000 in 2000, up 32.6 percent from 1980. It can be postulated that demand for imported agricultural products, will rise by a similar rate over the twenty-year period.

The net result of the defacto population growth will be reflected in increased marine traffic activity. The U.S. mainland can be expected to remain the major supplier of agricultural products. The magnitude of the traffic increase is presented in Appendix C.

### 4.2.2 Tourism

Tourism is the second most important source of income for Hawaii. Table 4-3 shows various data pertinent to the visitor industry. As Table 4-3 indicates, the industry grew at an annual average rate of 13.8 percent from 1960 to 1980, while during the 1970-80

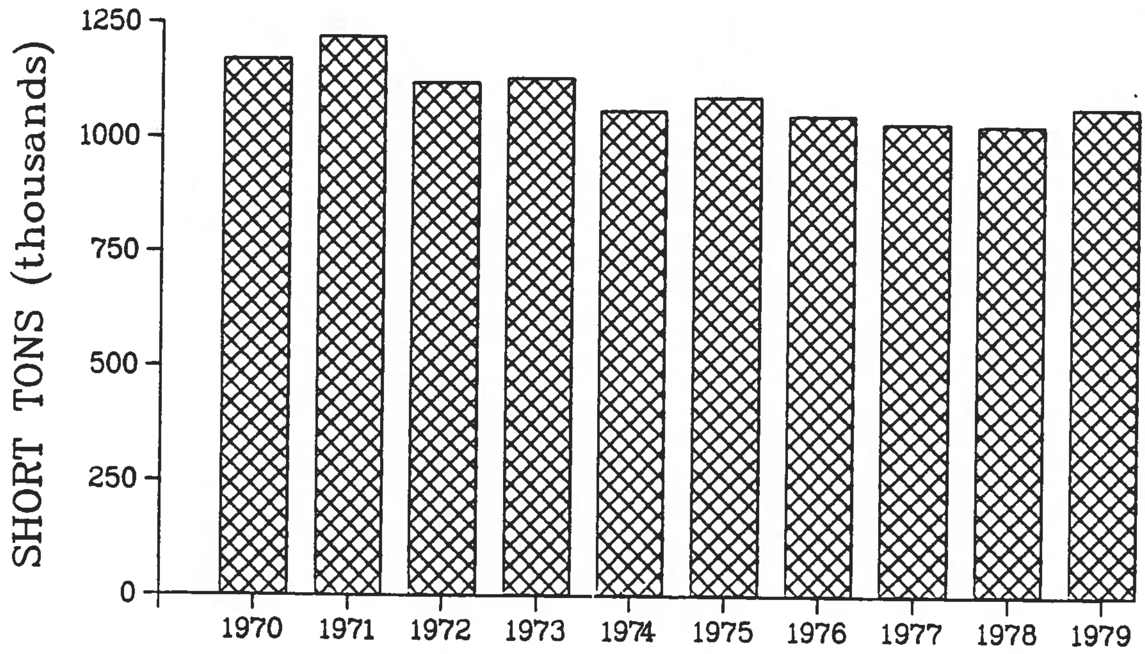



FIGURE 4-1
PRODUCTION OF SUGAR

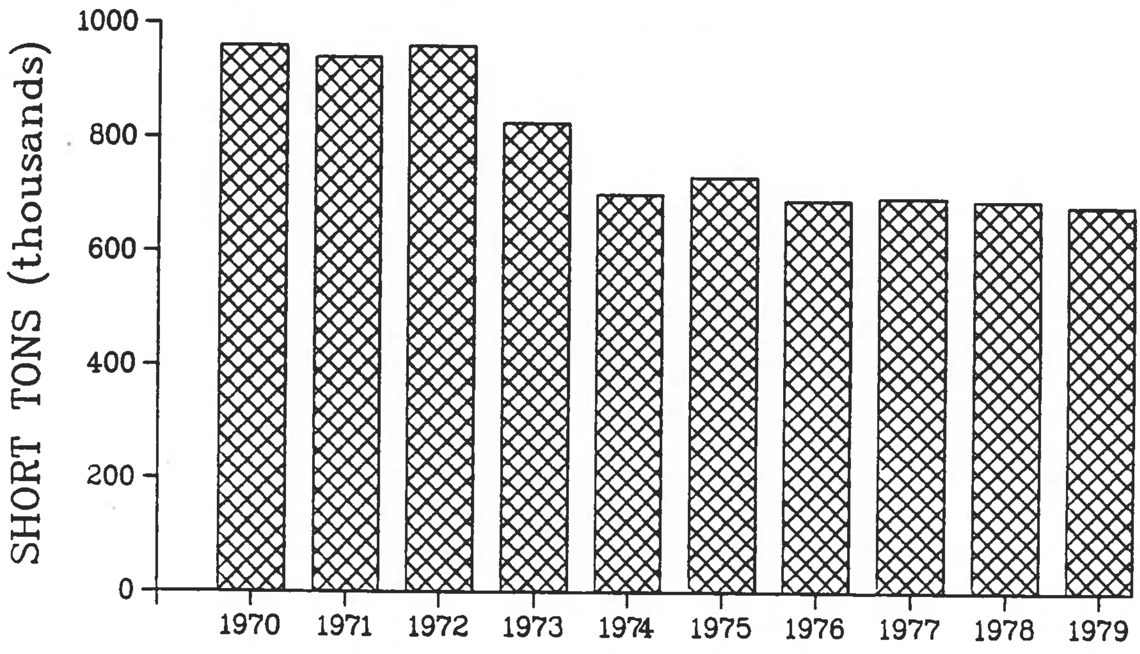



FIGURE 4-2
PRODUCTION OF PINEAPPLE

Source: Reference 8, 9, 10

## TABLE 4-3. ANNUAL VISITORS TO HAWAII

| | 1960 | 1970 | 1979 | 1980 | ANNUAL PERCENTAGE CHANGE AVERAGE 1960-70 | 1970-80 | 1960-80 | 1979-80 |
|---|---|---|---|---|---|---|---|---|
| Total Visitors Staying Overnight or Longer | 296,517 | 1,746,970 | 3,960,531 | 3,934,504 | 19.4 | 8.5 | 13.8 | -0.7 |
| Total Westbound Visitors | 250,795 | 1,326,135 | 3,139,455 | 3,046,132 | 18.1 | 8.7 | 13.3 | 3.0 |
| Total Eastbound Visitors | 45,722 | 420,835 | 821,076 | 888,372 | 25.0 | 7.8 | 16.0 | 8.2 |
| Average Daily Census | 11,797 | 36,943 | 98,676 | 96,497 | 12.1 | 10.1 | 11.1 | 2.2 |
| Hotel Occupancy Rates (Percent) | | | | | | | | |
| Oahu | 75.3 | 74.1 | 77.1 | 71.7 | | | | |
| Neighbor Islands | NA | 64.8 | 70.2 | 62.6 | | | | |
| Hawaii County | 67.5* | 68.3 | 62.0 | 52.7 | | | | |
| Maui County | 64.8* | 66.7 | 73.0 | 66.2 | | | | |
| Kauai County | 63.3* | 58.0 | 76.5 | 69.0 | | | | |
| Total Visitor Expenditures ($ Millions) | 131.0 | 595.0 | 2,620 | 3,000 | 16.4 | 11.4 | 16.9 | 14.5 |

*1962 data.

Source: Reference 8, 9, 10

period the growth rate decreased to 8.5 percent per year. Since both westbound and eastbound visitors travel to Hawaii primarily by air, the visitor industry creates almost no marine traffic except for three trips made by large cruise ships which sail from the West Coast to the Orient via Honolulu. Plans call for three more cruise ships to provide services between the west coast ports and Hawaii. However, no firm date of operations has been established nor has the number of sailings been decided. One U.S. cruise ship, the S.S. Oceanic Independence, now makes weekly trips year-round sailing the following itinerary: Honolulu, Hilo, Kona, Maui, Kauai.

The tourist industry is important to Hawaii's overall economy because it not only affects the level of demand for goods and services but also determines to a large extent the level of construction activity. Hawaii imports most of the needed construction materials from the mainland and, thus, changes in construction activity affect marine traffic. In addition to creating a demand for goods and services, the visitor industry also creates a demand for marine-related attractions such as commercial sport fishing. As of 1979, 100 commercial sportfishing vessels (charter boats) operated in the state. The base of the majority of the boats is the Honokakau harbor in Kailua-Kona, Hawaii which is the center of commercial sport fishing. Charter vessels usually fish for half to a full-day (12 hours) and operate within 20 nm from shore.

In 1980, the number of visitors declined by 0.7 percent (from 1979) due to a drop in the westbound traffic. Furthermore, in 1980, spending in real terms increased by 2.5 percent below the average annual rate in the past decade. A further decline in visitors is also projected for 1981. Data from the first six months of 1981 show that the industry will experience a reduction of 1.6 percent from its 1980 level. These declines are attributable to poor economic conditions on the mainland, escalating jet fuel costs and increased competition from other resort areas around the world. The state and private industry have undertaken an aggressive advertising program in many markets to attract more visitors. The success of the program, however, will largely depend on improved employment opportunities, rising real personal incomes and other monetary factors on the mainland.

### 4.2.3 Fishing

The fishing industry in the last 20-30 years has not changed in any substantial manner, and as a result, Hawaii imports increasing quantities of fish to meet the demand of its canning industry, its growing population and tourist industry. Hawaii, recognizing the economic importance of a healthy fishing industry, launched a program to assess the factors inhibiting its further growth. The publication of the state planning document, "Hawaii Fisheries Development Plan (1979)," was the first step toward the definition of the problems and constraints associated with the fisning industry and its real potential (Reference 11).

According to estimates presented in this document, the 1978 income derived directly from the harvesting sector accounted for less than 0.2 percent of the GSP, while the contribution of the whole fishing industry to GSP did not exceed 0.8 percent.

Five tuna species (skipjack, yellowfin, bluefin, bigeye and albacore) accounted for 75 percent of the total landings in 1978, while bottomfish accounted for 13.5 percent. The balance represented all other species combined. The majority of the commercial fishing boats take daily trips, sailing up to 50 nm from the shores of the major islands. Only four large multi-purpose and 27 albacore vessels (the latter operation commenced in 1978 on an experimental basis) fish in the Midway Islands (1000-1400 nm from Honolulu), where it is claimed that there is an abundance of resources.

The stock of migratory species such as tuna and mahimahi is limited within the current range of operations. Consequently, current landings of those species do not represent the actual potential of the resource that could be harvested. Further, due to fishing pressure on the non-migratory inshore stocks, there appears to be a decline in the productivity of vessels.

In 1978, commercial, semi-commercial and recreational vessels landed 13.3 million pounds of fish valued at 12.2 million dollars. However, the potential of the fisheries within the Hawaiian region is estimated at 74 to 118 million pounds per year. Of the additional 61 to 104 million pounds per year, 47 to 71 million pounds represent tuna species. The balance consists of all other species combined.

To harvest the additional 61 to 104 million pounds per year, another 185 large fishing vessels must be added to the current fleet. The Hawaiian Fisheries Development Plan estimated that the Gross State Income could be increased in 1990 by 53 million dollars and, in 2000, by 92 million dollars (in 1979 prices). "The present discounted value of direct income derived from the projected increase in catch was estimated to be 168 million dollars through the year 2000" (Reference 11).

However, if the above stated direct benefits, as well as the expected indirect benefits, are to occur, several constraints inhibiting the growth of the industry must be overcome. The principal constraints are associated with limited dock space, availability of support facilities (such as fuel and cold storage), vessel financing, marketing and product promotion and price of fuel.

Assuming that these constraints are overcome, fishing operations will change dramatically. Tuna operations will be expanded to the Northwestern Hawaiian Islands (NWHI), 1500 nm from Honolulu, while bottomfish, lobster and other species will also be sought in distances up to 1500 nm from Honolulu.

### 4.2.4 Petroleum Imports and Refining

Hawaii's largest manufacturing activity is petroleum refining. In 1980 this activity accounted for an estimated 1.1 billion dollars out of total manufacturing sales that exceeded 2.5 billion dollars. The two refineries, Hawaiian Independent Refinery, Inc. and Chevron USA, Inc. are located at Campbell Industrial Park in Leeward Oahu and have a combined capacity of 100,000 barrels per day. The crude product for the refineries is shipped from Alaska, Indonesia, Brunei, Malaysia, Singapore and Africa. The majority of the refined product is consumed locally, while the balance is shipped to the west coast, Trust Territories and American Samoa.

Negotiations are underway concerning establishment of a third refinery with a capacity of 50,000 barrels per day. If the negotiations are successful, an increase of one-third above the current and projected tanker traffic can be expected. Similarly, it can be expected that sales would be increased approximately 33 percent above current levels.

### 4.2.5 Diversified Manufacturing

Traditional manufacturing establishments in Hawaii, such as processed food and construction related-materials have an important place in the manufacturing sector. However, during the recent past they have neither generated substantial income nor provided increased employment opportunities. The principal gain of the manufacturing industry has come from oil refining, while other segments such as iron, steel, concrete, garments and textiles have suffered due to increased competition from other Asian nations and high inflation rates.

In the case of iron, steel and concrete, production levels are determined to a large extent by the performance of the construction industry. In real terms the construction industry is growing at a very moderate pace. Additionally, competition from foreign producers and high inflation rates have contributed to a sluggish demand for these products. The two major cement establishments have a combined capacity of 600,000 short tons. Production in 1980 was down to 379,000 short tons from 469,000 short tons in 1979. Production data from the first six months of 1981 indicate a further decline.

One industry that seems to be on the rise is the electronics manufacturing industry. Several electronics firms have started operations in Hawaii and the state is involved in marketing efforts to attract more firms. Manufacturing of electronics does not require great amounts of materials, the final product is light in weight and small in volume, and shipment costs relative to the value of the product are low. Hawaii, due to its proximity to Far East markets, seems to be in an advantageous position for attracting electronics firms. This industry however, will not have any substantial impact on marine traffic due to small amounts of materials used and small size of the finished product.

In conclusion, diversified manufacturing is not expected to affect future marine operations in any substantial manner.

### 4.2.6 Construction

Hawaii imports most of the needed construction materials from the mainland and, hence, variations in construction activity affect marine operations. Most of the materials from the mainland are shipped to Hawaii via tugs and barges which comprise a substantial portion of the traffic between U.S. mainland and Hawaii. In the next twenty years this traffic is expected to grow moderately, and parallel the construction industry.

The construction industry accounted for 1.60 billion dollars in 1980, an increase of 260 million dollars from 1979. In 1960 and 1970 the construction industry contributed 15.8 and 18.4 percent to the GSP, while its 1978, 1979 and 1980 contributions amounted to 10.3, 13.2 and 13.7 percent. Construction output (measured in 1972 dollars) reached its peak in 1974 and 1975 when it totaled 865.1 and 820.3 million dollars.

In general, the construction industry feels the financial strain during recessions, through tight credit and rising interest rates. The construction industry in Hawaii is not an exception to this rule, though recession cycles in Hawaii lag behind those in the mainland by one year to 18 months. Due to high inflation rates, expensive mortgages and a rising residential inventory, the growth of the industry has been moderate.

Improved general economic conditions, however, will aid the recovery of the construction industry through increased demand for residential housing, and commercial and industrial buildings. Finally, improved real incomes on the mainland will benefit the visitor industry by increasing travel to Hawaii and thus indirectly raising the demand for hotels.

### 4.2.7 Other Activities

Since 1975, Hawaii has expressed interest in establishing a manganese nodule processing plant in Hilo, Hawaii. Manganese nodules are black, pea-to-potato-sized concretions that have grown on the sea floor and are primarily composed of metal oxides.

Several international consortia have shown interest and have conducted some preliminary mapping and field tests. One of the potential areas for commercial development is situated 1,100 miles from the Island of Hawaii. Though the technology for ocean mining is relatively new, it is legal issues that constrain commencement of ocean mining operations. In light of the rich metal deposits to be found in the oceans, jurisdictional problems over the high seas and distribution of the resources have been hotly debated at the United Nations for several years. Furthermore, the prospects for any settlements in the near future are slim.

According to a transportation scenario developed by the Hawaii Department of Planning and Economic Development, if the processing plant is located in Hilo, four tugs and barges will make 110 trips to transport three million metric tons of nodules per year (Reference 12). Further, 110 additional trips will be made to export the finished product. However, due to uncertainties associated with ocean mining operations, the abovementioned trips were not considered in the traffic projections presented in Appendix C, and their omission will not affect the overall results of this study.

# 5. VESSEL TRAFFIC AND POPULATION

## 5.1 Introduction

This section provides an estimate of the marine traffic which originates at or is destined for the Hawaiian Islands as well as the trans-Pacific traffic which operates in the vicinity of the Hawaiian Islands. Also included is an estimate of the current users of LORAN-C in this region as well as those additional users who will acquire receivers should the system be expanded. This section also contains a projection of traffic, vessel populations, and LORAN-C users through the year 2000. Only summaries are presented. Appendixes C, D, and E show the data sources, methods used to derive the traffic and population estimates as well as detailed tables presenting this information.

Two concepts, vessel traffic and vessel population, are very often used in this analysis and they require some further clarification. Traffic refers to vessel movements from port to port. Traffic is a dynamic concept because it changes over time and reflects time-dependent trade among nations. Vessel population, on the other hand, refers to the number of vessels causing the traffic to occur. Vessels whose movements are such that they have no destination, but rather habitually return to the same port (e.g., fishing vessels), or are random in nature (e.g., tramp vessels) are difficult to estimate. Because of this latter limitation only vessels with definite origins and destinations were deemed to generate traffic.

## 5.2 Marine Users of Navigation

Estimates were developed for civil vessels who operate within or to the Hawaiian Islands and who were potential users of LORAN-C. Military vessels were not included since the DOD position is to phase out LORAN-C in favor of NAVSTAR GPS when the latter system becomes available in the late 1980's. Vessels were further identified as U.S. flag and foreign flag vessels. Because of limitations of the data base, no attempt was made to identify U.S. owned foreign flag vessels (flags of convenience). Under the requirements of this study, only vessels engaged in U.S. trade or calling at U.S. ports were considered. Foreign vessels who operate or transit the area were not included. Discussed below are the major categories of vessels used in this study.

- o Large Commercial Vessels. These are the large oceangoing cargo, tank and passenger vessels greater than 1600 GT principally engaged in Pacific and world-wide operations. Also included in this category are government-owned vessels and vessels engaged in resource exploration, oceanography, hydrography, and other special operations where accurate radio-location determination is important and cost is relatively minor in importance.

- Small Commercial Vessels. This category consists of the smaller vessels (less than 1600 GT) whose operations are not only inter-island but oceanic as well. Included in this category are ocean going tugs and barges, small cargo and coastal vessels. Because the data base for foreign flag vessels did not differentiate by type of operations, foreign fishing vessels were included in this category.

- Commercial Fishing and Commercial Sport Fishing. Commercial fishing vessels are those vessels habitually engaged in fishing operations from which the captain and crew derive their principal source of income from the landing of fish. Commercial sport fishing vessels are vessels available for charter or hire by tourists and private parties and any income derived from the landing of fish is supplemental to the basic mode of operation. Because of the variable nature of the tourist industry in Hawaii, commercial sport fishing operators frequently engage in commercial fishing when charter operations decline. Further, there are a large number of subsistence fishing vessels whose operators engage in part-time activities as a means of supplementing their income. This latter category of fishing vessels was considered as part of the recreational boating category, although many of these operators have commercial fishing licenses. Only U.S. flag fishing vessels were considered; foreign flag fishing vessels were included in the small commercial vessel category (see above). A detailed analysis of the Hawaii fishing industry is given in Appendix D.

- Recreational Boats. This category of vessels consists of cabin cruisers, sailboats and yachts whose principal operations are in pursuit of leisure time activities. Considered in this category are all boats required to be registered by the State of Hawaii which includes all motorboats and sailboats over eight feet in length. Also included are documented yachts. Part of the recreational boat traffic are U.S. mainland and foreign registered boats which cruise to Hawaii.

- Other. Included in this category are users of LORAN-C but not necessarily users of navigation. Precious coral dredging, diving and ocean floor mining of manganese nodules are typical. These are activities wherein the vessel requires positional information rather navigational information.

## 5.3 Vessel Traffic

### 5.3.1 Data Sources

The data used in the determination of vessel traffic were derived principally from the Department of Commerce, Foreign Trade Division of the Bureau of the Census, and the State of Hawaii, Department of Transportation, Harbors Division. These statistics were supplemented with information provided by many shipping companies operating vessels in the study area. A list of contacts is shown in Appendix F.

The Bureau of the Census compiles its statistics from U.S. Customs documents which contain vessel, movement, and cargo information of all U.S. vessels engaged in foreign trade and foreign vessels engaged in U.S. trade (Reference 13). This information is obtained from manifest documents supplied to the U.S. Customs by vessel masters and shipping agents. The Bureau of the Census utilizes this information to compile monthly traffic statistics by U.S. port.

These statistics served as the principal data source used to estimate the following traffic and population components:

- Foreign flag vessels generating revenue traffic between U.S. mainland ports, foreign ports, and Hawaii.
- U.S. flag vessels generating revenue traffic between foreign ports and Hawaii.

The statistics compiled by the Hawaii Department of Transportation, Harbors Division were utilized to estimate the following traffic:

- U.S. flag vessels operating between U.S. mainland and Hawaii and U.S. flag vessels operating within the Hawaiian Islands.

The traffic representing foreign vessels which do not make trade transactions (load or discharge cargo), but call in Hawaii for replenishment or medical reasons was obtained from the "Bunker Log Book" from the U.S. Customs, Hawaii District.

### 5.3.2 Oceanic Traffic

The estimated revenue traffic for 1979 between U.S. mainland including Alaska and Hawaii, and Hawaii and foreign ports was derived from Table C-1. The following discussion summarizes these data. As this table indicates, the direct oceanic traffic consisted of 2,727 moves. Nearly forty percent of this traffic was between U.S. mainland and Hawaii, while the remainder was between Hawaii and foreign ports. Of the oceanic traffic (2,727 moves), U.S. flag vessels accounted for 1,154 moves or 42 percent, the balance was handled by foreign flag vessels.

Of the traffic between U.S. mainland and Hawaii, over 80 percent was handled by U.S. flag vessels, with U.S. flag large cargo vessels accounting for approximately 50 percent of the moves. Virtually all of the large cargo traffic originated or terminated at west coast ports (principally, Los Angeles, San Francisco, Portland and Seattle), the balance represented traffic having origin or destination at Gulf ports or East Coast ports. However, this may not represent the total Hawaii - mainland traffic since many of the East Coast and Gulf vessels which transit the Panama Canal declare this port as their origin or destination on their customs documents.

The large tank vessel traffic between U.S. mainland and Hawaii generated an estimated 96 moves. This traffic flow consisted of North Slope crude product from Alaska to Oahu. The refined product was consumed locally or transported to west coast ports. Other petroleum flows consisted of diesel or special products from the mainland to Hawaii.

Approximately 220 moves were made by U.S. tugs/barges between the west coast ports and Hawaii. The tugs/barges principally carried construction materials from the Pacific northwest ports to Honolulu, while pineapple and raw sugar was shippped as backhaul. Foreign tugs/barges did not account for any of this traffic.

The revenue traffic between foreign ports, non-continental U.S. ports and Hawaii was estimated at 1,668 moves most of which, 83 percent, was handled by foreign vessels, the balance by U.S. Approximately 51 percent represented traffic between Japan and Hawaii, mostly small cargo vessels. These small cargo vessels are generally fishing vessels which provided product for the Honolulu tuna canneries. The traffic between the Pacific Islands and Hawaii consisted of 121 moves ranking second, while the Panama Canal - Hawaii traffic ranked third with 95 moves.

Large cargo vessels comprised approximately 23 percent, or 383 moves, of the total Hawaii-foreign port traffic. Of this traffic, foreign flag cargo vessels handled 60 percent of the volume. Crude petroleum product from Southeast Asia generated 92 moves which represented 6 percent of the Hawaii-foreign port traffic. Over 96 percent of this petroleum was handled by foreign tankers.

Among the small (non-tug) commercial vessels sailing in foreign trade, U.S. and foreign flag small cargo and tankers, and "other" vessels generated a total of 1,087 moves the majority of which were made by foreign small cargo vessels.

The ports of Hilo, Kahului, and Nawiliwili - Port Allen handled an insignificant portion of the total direct oceanic traffic, (less than 4 percent). The port of Honolulu, on the other hand, accounted for majority of the traffic, approximately 96 percent.

Most of the cargo is unloaded in Honolulu and then transshipped to other Hawaiian ports, principally via tugs/brages. Sometimes the oceanic cargo is partially unloaded in Honolulu and then the vessel continues on to other ports in the main Hawaiian Islands for further off loading.

In addition to the direct oceanic revenue traffic, two other traffic categories were estimated: (a) non-revenue traffic - generated by vessels which call in Hawaii for repair, replenishment, medical care for the crew and (b) through traffic - generated by vessels which do not call in Hawaii but transit the area enroute to either U.S. west coast ports (Los Angeles, San Francisco, and Seattle) or Australia, Singapore, Brunei, Malaysia, Phillipines, Indonesia and Guam. Both of these categories of traffic would be, nevertheless, users and beneficiaries of LORAN-C.

The non-revenue traffic consisted of an estimated 817 moves, 85 percent of which was made by Japanese fishing vessels. Due to the long periods that these vessels stay on the high seas, they call periodically in Hawaii to replenish their supplies and rest the crew. The through traffic category consisted of 391 moves, the majority of which (331) were handled by foreign flag carriers. A detailed discussion of these categories is given in Appendix C.

### 5.3.3 Inter-Island Traffic

Inter-island traffic was estimated to be 4,794 moves, nearly all of which (99 percent) was handled by U.S. vessels. Tugs/barges comprise the bulk of this traffic. The 786 moves made by the U.S. large cargo vessels represent traffic which was attributable to Matson Navigation Company vessels, the principal inter-island carrier. Included in the large cargo vessel traffic was also the traffic generated by the U.S. cruise ship S.S. Oceanic Independence which sails year-round in inter-island tourist trade.

### 5.3.4 Traffic Patterns and Densities

Using the vessel tracks for oceanic sailings described in Section 3.3.1, major traffic patterns were developed. These traffic patterns reflect only those oceanic vessel moves associated directly with the Hawaiian Islands and include both revenue and non-revenue producing operations. Not included were oceanic traffic which may transit the area but would not call at any Hawaiian ports. The traffic was segregated into four principal patterns: West Coast of North America, Panama Canal and South America, South Pacific and Western Pacific. This traffic was further segregated by origin or destination. When the origin/destinations of the traffic was unknown or unspecified it was assumed to be distributed proportionately among the traffic patterns. Where traffic originated from the same general area, certain simplifying assumptions were made, as for example, Indonesia includes Brunei, Malaysia and Singapore. The traffic by region was separated by U.S. and foreign flag. The results of this analysis are shown in Figure 5-1.

In Figure 5-1, traffic flows are proportionately weighted as shown by the size of the arrows. Thus, over 50 percent of the Hawaii oceanic trade is with Western Pacifc countries followed by approximately 32 percent with the West Coast of North America. Panama Canal and South Pacific regions account for nine and six percent respectively. Further, it is significant to note that in the Western Pacific trade pattern less than eight percent of the transactions are carried by U.S. flag vessels. This trend is also prevalent among South Pacific and Panama Canal vessel traffic. On the other hand, this tendency is reversed with respect to North American traffic wherein U.S. flag vessels comprise over eighty percent of the traffic.

## 5.4 Vessel Population

### 5.4.1 Commercial Vessels

During 1979, the number of large commercial vessels customarily operating in support of U.S. trade in Hawaii was estimated at 240 vessels, three-fourths of which were cargo vessels. Of the total cargo vessels engaged in this trade, two-thirds were foreign flag; while among the tank vessels 75 percent were of foreign registry. The U.S. tank vessels principally carried crude oil from Alaska and refined product to U.S. west coast ports. The foreign flag tank vessels carried mostly crude oil from Singapore, Brunei, Indonesia and other Southeast Asia ports to the two refineries at Barbers Point.

Approximately 27 U.S. flag tugs operate in the trade between U.S. west coast ports and Hawaii as well as in inter-island trade. Three foreign flag tugs were also identified as customarily operating between Hawaii and foreign ports.

In addition to 240 large tank and cargo vessels and 30 tugs, another 373 vessels of various types were identified as having called in Hawaii more than once. Of those, approximately 300 were fishing vessels principally of Japanese registry. The balance represented small cargo and tank vessels and other vessel types.

### 5.4.2 Fishing and Commercial Sport Fishing

It is difficult to identify and characterize the U.S. commercial fishing vessels since many recreational boat owners have commercial fishing licenses yet do not engage in fishing as a full time occupation. For purposes of this study, only vessels which fish more than half to one day a week on a regular basis are considered as commercial fishing vessels. The balance are considered as recreational boats. The U.S. fishing vessels were classified into three categories: (a) full-time large commercial

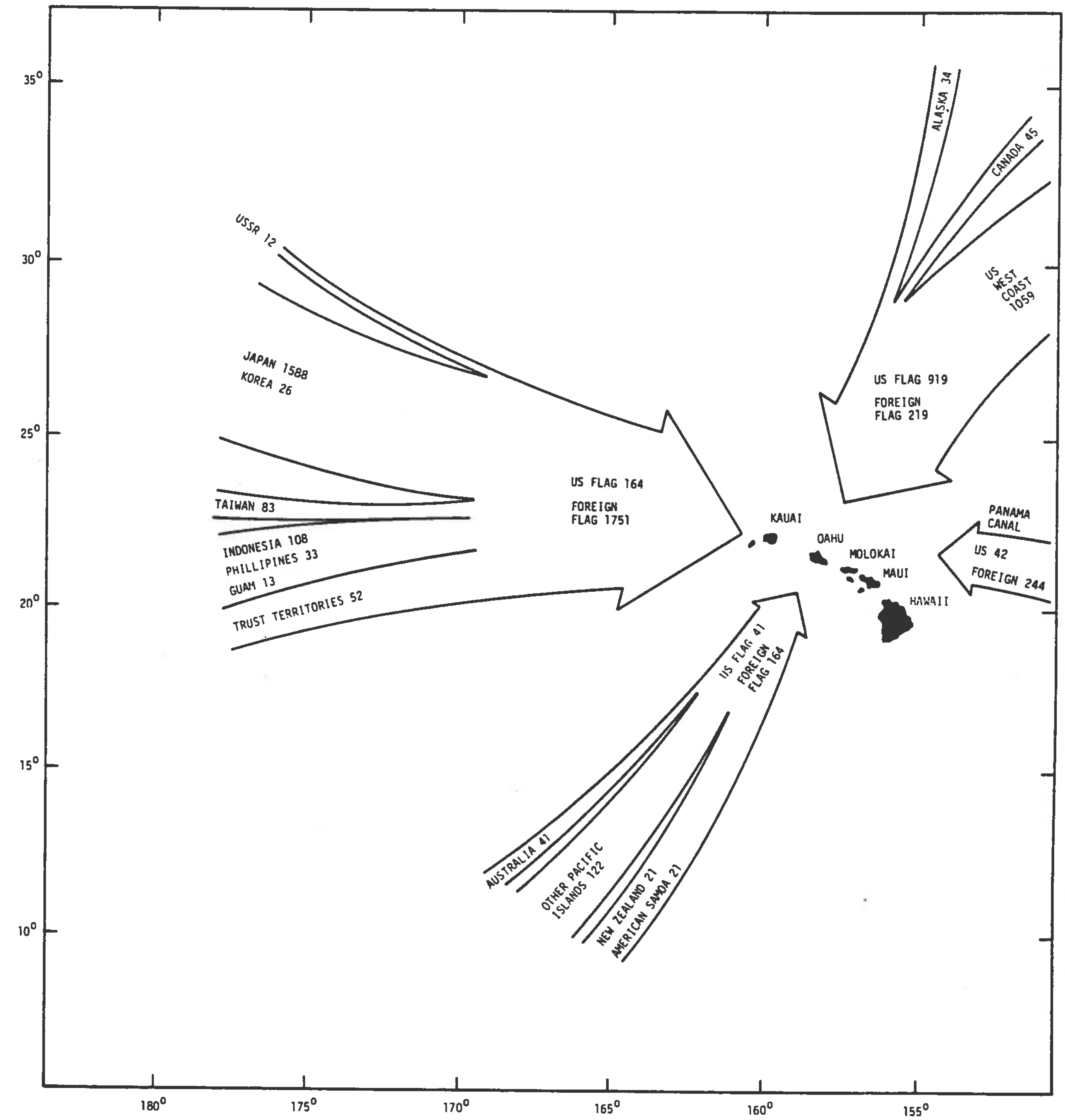



FIGURE 5-1
TRAFFIC PATTERNS AND FLOWS - 1979

fishing vessels, (b) other smaller fishing vessels (semi-commercial/subsistence) and, (c) commercial sport fishing vessels. The first category refers to those vessels whose operator and crew members derive their primary source of income from the fish they sell. The second category are vessels used by their owners to fish half to a full day per week. Part or all of the catch is sold to supplement their income or is retained for private consumption. The third category include charter vessels principally engaged in the sport fishing industry. The population of the fishing vessels was estimated to consist of 342 boats. Of these, 56 represent full-time large commercial vessels; 186 semi-commercial/subsistence and; 100 commercial sport fishing.

### 5.4.3 Recreational Boats

Included in this group were all pleasure boats which are registered or documented in the State of Hawaii such as sailboats, power boats, and yachts. The number of these boats was estimated at 12,326. Approximately 6208 boats or 50 percent of the total population were between 16 and 26 feet, while 4365 boats or 35 percent were smaller than 16 feet. Only three percent were greater than 40 feet.

The total number of recreational boats operating year-round in Hawaii was obtained by adding to the local population the U.S. and foreign registered transient boats. An estimated 1,100-1,200 and 105 foreign recreational boats sail to Hawaii per year. Thus, the total recreational boat population was estimated to be approximately 13,500-13,600.

## 5.5 Projected Traffic and Populations

The direct oceanic traffic will increase by 653 moves over the next twenty years. This estimate is based on MARAD projections and discussions with state economic planners and shipping companies (Reference 14 and Appendix F). Table C-13 in Appendix C shows the direct oceanic traffic for the year 2000. This appendix also contains tables showing the traffic for 1985, 1990, and 1995. As Table C-13 indicates, the total traffic will consist of 3,380 moves, an increase of 24 percent from 1979.

The U.S. mainland - Hawaii traffic will account for 68 percent of the additional traffic, the balance being traffic between Hawaii and foreign ports. This former traffic was estimated to consist of 1,500 moves or an increase of 441 moves from 1979. On the other hand, the Hawaii-foreign port traffic will consist of 1,880 moves, an estimated increase of 212 moves from 1979.

U.S. flag vessels will account for 46 percent of the total oceanic traffic, the balance of the traffic will be handled by foreign flag vessels. Most of the projected traffic increase will occur in the large cargo, tanker and tug/barge vessel types which will account for an increase of 542 moves out of the total 653.

Since the non-revenue traffic is not a contributing factor to the Hawaii economy, it will reflect world-wide rather than Hawaii trade conditions and probably increase more modestly over the next twenty year period. In 1979 this traffic consisted of 817 moves, by 2000 it could reach 1010. On the other hand, the through traffic could experience a dramatic increase. Since this traffic principally consists of crude oil flow from the far east to the west coast, it is probable that it may double or even triple as older petroleum sources become depleted and new regions become suppliers.

Indications are that nearly all of the inter-island traffic will continue to originate and terminate in Honolulu. By the year 2000 this traffic is projected to principally consist of 6,044 tug/barge, 1,139 large cargo, and 62 large tanker moves. All of the tug/barge traffic will be handled by U.S. flag tugs and nearly all (99 percent) of the 1,200 remaining moves will be generated by U.S. flag vessels. In addition, an estimated 32 tugs will operate between U.S. and Hawaii, as well as accommodating inter-island traffic.

Table 5-1 shows the expected population of fishing and recreational vessels. The number of fishing vessels operating in 2000 is projected to be 641. Of those, 210 will be large modern vessels engaged in full-time fishing, 140 will be commercial sport fishing and the remaining 291 will be semi-commercial recreational boats.

Projections in regard to full-time commercial fishing vessels were derived from the state planning document "Hawaii Fisheries Development Plan" (Reference 11). A detailed discussion of limitations and constraints, number of vessels by fishery and other pertinent data is presented in Appendix D. Projections for the smaller fishing vessels were based on information provided by state and industry officials and current operations. Commercial sport fishing vessel projections were developed using tourism growth trends and information provided by owners, operators, and representatives of the commercial sport fishing community.

The number of recreational boats registered and documented in Hawaii is projected to increase from 12,326 in 1979 to over 15,000 in 2000, an estimated increase of 140 boats per year. This estimate is based on an examination of historical boat population data, dock space availability, credit cost and availability, discussions with recreational boat experts, and current boat sales. Detailed data on recreational boating are given in Appendix E.

Due to lack of adequate berthing facilities to accommodate large vessels, approximately 88 percent of the projected increase will be under 26 feet. In addition to lack of dock space, current tight credit conditions have made money both expensive and scarce thereby affecting the larger boat purchases. The 26 to less than

| VESSEL TYPE | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| Full-Time Large Commercial Fishing Vessels | 94 | 140 | 171 | 210 |
| Other Smaller Fishing Vessels (Semi-Commercial/Recreational) | 212 | 239 | 265 | 291 |
| Commercial Sport Fishing | 110 | 120 | 130 | 140 |
| Recreational Under 16 Feet | 4772 | 5111 | 5450 | 5789 |
| Recreational 16 to less than 40 feet | 8014 | 8364 | 8714 | 9064 |
| Recreational over 40 feet | 380 | 391 | 402 | 413 |

TABLE 5-1
FISHING AND RECREATIONAL VESSEL POPULATION PROJECTIONS
1985-2000

40 feet boat category is projected to increase by 10 percent while the 40 to 65 feet and over 65 feet categories are projected to grow slightly, one and one half percent, respectively.

Discussions with dockmasters in Hawaii and an examination of past trends revealed that transient vessel population has not changed appreciably in the last several years. Thus, it is estimated that this population component will probably remain at its current level, 1100-1200 U.S. and 105 foreign flag vessels.

## 5.6 LORAN-C Users - Current and Projected

Most of the large commercial vessels engaged in shipping operations with the U.S. have already acquired LORAN-C or other authorized receivers to enter the U.S. Coastal Confluence Zone (Reference 15). In addition, 20 of the 27 U.S. tugs which operate between U.S. mainland and Hawaii and in the inter-island trade are equipped with LORAN-C receivers. The seven tugs which do not carry LORAN-C operate exclusively in the inter-island trade and they utilize piloting and dead reckoning.

Availability of expanded LORAN-C coverage will have the greatest impact upon the fishing and recreational boating community. At the present time LORAN-C coverage is limited to that region from Kauai westward including the northwest Hawaiian Islands. However, the majority of the fishing and recreational vessels operate in the waters off Oahu and Hawaii where coverage is limited to a single line of position and hence only a small fraction of these users are so equipped. Currently there are 31 full-time large commercial fishing vessels and five or six large recreational boats with LORAN-C receivers. These fishing vessels operate in the northwest Hawaiian Islands where they utilize LORAN-C for both navigation and enhancement of fishing operations.

Table 5-2 shows LORAN-C user projections from 1985 to 2000. All large commercial vessels will be equipped with LORAN-C or other authorized receivers. All of the tugs operating in the U.S. mainland and Hawaii trade will have LORAN-C receivers as well as nearly 90 percent of the tugs which are exclusively engaged in inter-island trade. LORAN-C user projections for the fishing and recreational vessels were developed according to two assumptions. The first is that LORAN-C coverage is not expanded, while the second assumes that LORAN-C coverage is expanded as indicated in this study.

The fishing population shown in Table 5-2 is based on the assumption that future fishing operations will expand toward the northwest Hawaiian Islands. The numbers shown reflect the additional vessels which will operate in this region. With respect to expanded LORAN-C coverage, a major group of new users will be drawn from the fishing community. This additional group will be those local operators whose principal fishing areas are in the near vicinity of the major Hawaiian Islands and to the south of Hawaii.

TABLE 5-2
PROJECTED LORAN-C USERS: 1985-2000

| VESSEL TYPE | CURRENT LORAN-C USERS | CURRENT LORAN-C COVERAGE | | | | EXPANDED LORAN-C COVERAGE | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1985 | 1990 | 1995 | 2000 | 1985 | 1990 | 1995 | 2000 |
| Large Commercial | 240 | 246 | 251 | 257 | 263 | 246 | 251 | 257 | 263 |
| Tugs | 20 | 24 | 26 | 28 | 30 | 24 | 26 | 28 | 30 |
| Fishing | 31 | 62 | 115 | 146 | 185 | 171 | 255 | 337 | 424 |
| Recreational* | 236-406 | 236-406 | 236-406 | 236-406 | 236-406 | 491-661 | 643-813 | 814-984 | 1006-1176 |
| TOTAL | 527-697 | 568-738 | 628-798 | 667-837 | 714-884 | 932-1102 | 1175-1345 | 1436-1606 | 1723-1893 |

*Included in these estimated are 230-400 recreational vessels registered in the continental U.S. but sail to Hawaii.

As indicated in Table 5-2, under current LORAN-C coverage, very few recreational boats are expected to acquire LORAN-C receivers. With respect to expanded LORAN-C coverage, the additional recreational users will be those larger boat owners whose vessels, because of their range and size, have the capability for inter-island cruising.

# 6. RADIONAVIGATION SYSTEMS AND ALTERNATIVES

## 6.1 Introduction

The current and near term planned mix of radionavigation coverage in the Central Pacific is, or will be, provided by four principal systems: LORAN-C, Omega, TRANSIT and NAVSTAR GPS. The performance characteristics of these systems is provided in Appendix A. This section briefly describes these systems to provide a framework against which the characteristics of LORAN-C can be compared. Principally however, this section is concerned with LORAN-C both in terms of the coverage currently provided and the coverage expected to be provided by several proposed alternative configurations.

The LORAN-C coverage diagrams have been supplied by the Coast Guard and are presented for illustrative purposes as a means of determining the amount of future costs and benefits expected to be derived from system expansion. The proposed LORAN-C coverages and configurations shown are estimates and should be used only for comparisons among alternatives. a rigorous technical design and development study of these alternatives is beyond the scope of this report and should be the subject of future activity if the decision is made that further system development is warranted.

The underlying approach used in developing these alternatives was to provide coverage for those areas where coverage does not now exist and which are areas of significant itinerant traffic. these are areas which not only surround the principal islands but which are also to the north and east of these islands. by implication an additional alternative was also considered, namely that of a null set, which would entail termination of the existing central pacific chain should benefits, costs and other measures prove that it has marginal utility.

## 6.2 Current SYSTEMS

### 6.2.1 LORAN-C

LORAN-C is a pulsed, hyperbolic radionavigation system, operating in the 90-100 khz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of rf energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The measurements of time-difference (TD) are made by a receiver which compares a zero crossing of a specified rf cycle within the pulses transmitted by master and secondary stations within a chain. (Reference 1).

Coverage provided by a chain is defined by the signal to noise ratio and geometric fix accuracy limit. This signal to noise ratio is determined based upon the predicted signal strength from the transmitting station, modified to reflect the conductivity of the path traveled, and compared with noise to provide relative signal strength or signal to noise ratio (SNR). A SNR of one to three is used in the coverage definition. The geometric fix accuracy limit is a contour which shows where a receiver, capable of furnishing TD readings with a standard deviation of 0.1 $\mu s$ will provide a two line of position (LOP) fix accuracy of 0.25 nm, 2 drms (95 percent confidence). (Reference 16). This definition is used throughout this report in describing LORAN-C coverage.

The Central Pacific (CENPAC) LORAN-C chain provides fix coverage of the Hawaiian Archipelago extending from the Kauai channel westward to nearly the Midway Islands in the western portion of the island chain. The extent of this coverage is approximately 944,000 square miles. The geometry associated with this coverage is shown in Figure 6-1. In addition a single LOP is available as far to the east as 150$^{o}$W and as far to the west as 171$^{o}$E. However, since a single LOP does not constitute a fix, this additional coverage will not be considered in this study.

The basic configuration of the CENPAC chain is a triad with secondary stations at Upolu Point on the Island of Hawaii, and Kure Island at the western extremity of the archipelago. The master station is on Johnston Island, approximately 735 miles to the southwest of Honolulu. All three stations have 625 ft antennas and a peak radiated power of 275 kW. Listed below are the personnel complements for the three stations.

| | OFFICER | WARRANT OFFICER | ENLISTED |
|---|---|---|---|
| Johnston Island | 0 | 1 | 8 |
| Kure Island | 1 | 1 | 18 |
| Upolu Point | 0 | 1 | 10 |

The monitor station is collocated with the LORAN-C station on Johnston Island; the control station is located at Kaneohe, Hawaii in the same facility as the Omega Station.

6.2.2 Omega

The Omega system is a very low frequency (VLF) global navigation system operating in the 9-14 kHz band. It was developed by DOD to meet the need for a world-wide general navigation system and is now operated by the Coast Guard.

Omega utilizes CW phase comparison of skywaves from pairs of stations. The stations transmit time shared signals in four frequencies: 10.2 kHz, 11 1/3 kHz, 13.6 kHZ and 11.05 kHz. In addition to these common frequencies, each station transmits a unique frequency to aid station identification and to enhance

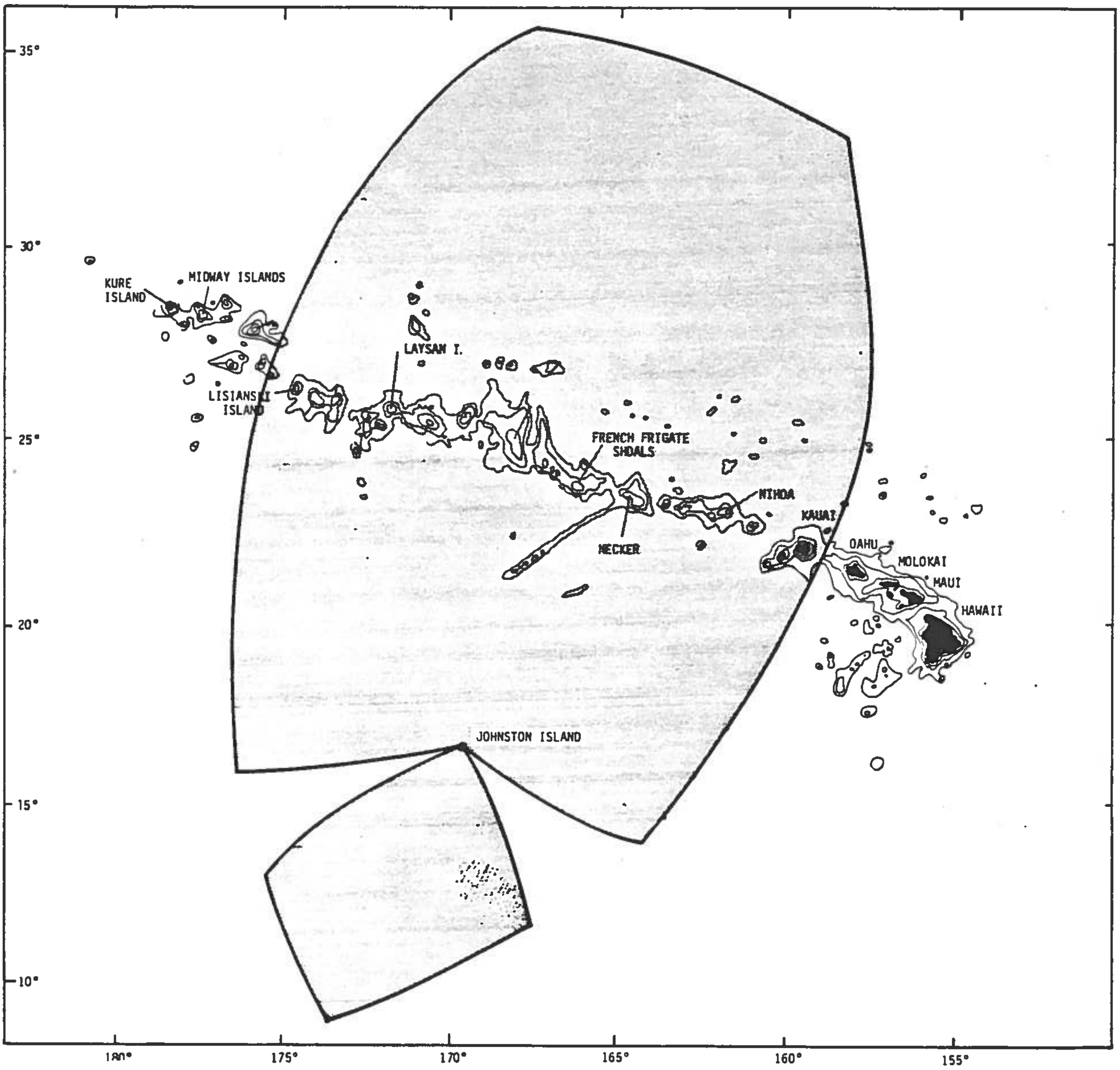



FIGURE 6-1
CENTRAL PACIFIC LORAN-C
FIX COVERAGE

performance. The system is composed of eight transmitting stations situated throughout the world, six of which are operated in partnership with other nations.

The inherent accuracy of the OMEGA system is limited by the accuracy of the propagation corrections that must be applied to the individual receiver readings. The corrections may be obtained in the form of predictions from tables or automatically in computerized recievers. The system has a design goal of 2 to 4 nm (95 percent CEP). This depends on location, station pairs used, time of day, and validity of the propagation corrections. Other operational characteristics include 95 percent operating time for each station including scheduled off the air time and three station availability, world wide, 95 percent of the time.

In the Hawaiian Islands coverage is provided by the following stations:

Norway (A)
North Dakota (D)
La Reunion (E)
Australia (G)
Japan (H)

Coverage contours for these stations are given in Appendix A. The most promising LOP station pairs on the basis of lowest total fix error, based on preliminary data for both day and night readings, are AE - DH (Reference 17). No readings were available for Australia (Station G). When this station is operational it will provide a very strong, reliable signal for the Hawaiian region and will probably be used as one of the station pairs in the future.

### 6.2.3 TRANSIT

TRANSIT (SATNAV) is a space-based navigational system operated by the U.S. Navy primarily to meet military needs. It is available for civil use and is widely used by both U.S. and foreign flag operators (>20,000 users). The system consists of five satellites in 600 nm polar orbits. The phasing of the satellites is staggered to minimize time between fixes for users. In addition, the TRANSIT system consists of four ground-based monitors. The monitor stations track each satellite while in view and provide the tracking information necessary to update satellite orbital parameters every 12 hours.

The satellites broadcast ephemeris information continuously on approximately 150 MHz and 400 MHz signals. One frequency is required to determine a position with a maximum error of 500 m. However, by using the two frequencies, higher accuracy can be attained (35m). A receiver measures successive doppler, or apparent frequency shifts of the signal, as the satellite approaches or passes the user. The receiver then calculates the geographic position of the user based on knowledge of the satellite position that is transmitted from the satellite every two minutes, and a knowledge of the doppler shift of the satellite signal. Also, vessel course, speed, and time must be known to determine position accurately.

Coverage is world wide, but not continuous, and mean time between fixes varies from an average of 110 minutes at the equator to 30 minutes at 80°. In the regions of the Hawaiian Islands mean time between TRANSIT fixes is approximately 90 minutes. Due to non uniform orbital precession Transit satellites are not in evenly spaced orbits. Hence a user can occasionally expect periods of between 6 and 11 hours when a fix is not available.

## 6.3 Future Systems - NAVSTAR GPS

NAVSTAR GPS is a space-based radionavigation system being developed by the Department of Defense under Air Force management. The concept is predicated upon accurate and continuous knowledge of the spatial position of each satellite to the user. Each satellite transmits its ephemeris data. This is periodically updated by the master control station based upon data obtained from the monitors. The fully deployed operational system is intended to provide highly accurate positional information in three dimensions and precise time and velocity information on a global basis continuously, to an unlimited number of properly equipped users. It will be unaffected by weather and will provide world-wide coverage with a common grid reference system. While the system was initially conceived to meet the requirements of a wide spectrum of military missions, current policy calls for civil availability with a degradation in system accuracy required to protect national security interests.

The major issues confronting the civil use of NAVSTAR GPS are the accuracy of the supplied signal and the costs of the user equipment. Because NAVSTAR GPS has the capability of providing high positional accuracy on a global basis it can supplement LORAN-C, Transit, and Omega. Thus the potential for many civil users is high. However, it is a developmental system with full operational capability not expected until 1987. In 1983 a preliminary recommendation from DOD/DOT regarding the future navigation system mix (including the role of NAVSTAR GPS) is expected. In 1986 a decision at the national level will be made. This decision will then become the basis for navigational system implementation. Until that time the civil role of NAVSTAR GPS can only be surmised.

## 6.4 LORAN-C Expansion Alternatives

Improved coverage and coverage in areas where it does not now exist is limited by lack of suitably located islands to serve as transmitter sites. The alternatives that are presented are based on expediency and tend to be compromises between required coverage and available sites. Two LORAN-C alternatives are considered for purposes of evaluating the costs and benefits of increased LORAN-C coverage. These alternatives are: the installation of an additional station at Kauai, and the relocation of the existing Kure station to Midway Island. Given a timely approval, it is assumed that these alternatives could be operational by 1985. The characteristics and coverages are discussed below.

### 6.4.1 Kauai Reconfiguration

This configuration entails the installation of an additional station at the Navy's Pacific Missile Range Facility on Kauai, while retaining the existing three stations at Upolu Point, Johnston Island and Kure Island. Further, the master station would be transfered from Johnston Island to Kauai. The effect of this reconfiguration is to extend coverage to the south and west while providing minimal additional coverage to the northeast. The fix coverage for this configuration is shown in Figure 6-2. An antenna height of 700 ft and a radiated power output of 800 kw is assumed.

This reconfigured chain covers an area of $1.77 \times 10^6$ square miles of which $0.8 \times 10^6$ square miles are attributable to the additional station at Kauai. As well as regional coverage of most of that area surrounding the major islands, this additional station provides coverage of the South Pacific trade routes to and through the Hawaiian Islands. There is also a slight amount of coverage of the North American trade routes. The AC&I costs of this additional station are $4.6 million; the additional OE costs are $0.323 million per year, both costs are in 1982 dollars.

### 6.4.2 Midway Relocation

This alternative involves the transfer of the existing Kure Station 40 nm eastward to the naval station at Midway Island. Since the rationale for this move is to extend chain coverage eastward, the transmitter would be optimized by increasing radiated power to provide greater additional coverage. A principal assumption underlying this alternative is that the Kure station can not be taken off the air while it is being relocated, since uninterrupted signal coverage must be available. Thus four transmitters must be provided while stations are being moved. A new, fully manned and equipped station must be operational at Midway before the Kure station ceases transmissions.

The relocation to Midway Island would entail certain savings in logistics and manpower as well as changes in operations and mission requirements. The assumptions associated with these savings and changes include:

- o Logistic support to the Midway Station as well as berthing, messing and personnel support facilities will be provided by the Navy on a reimbursable agreement with the Coast Guard.

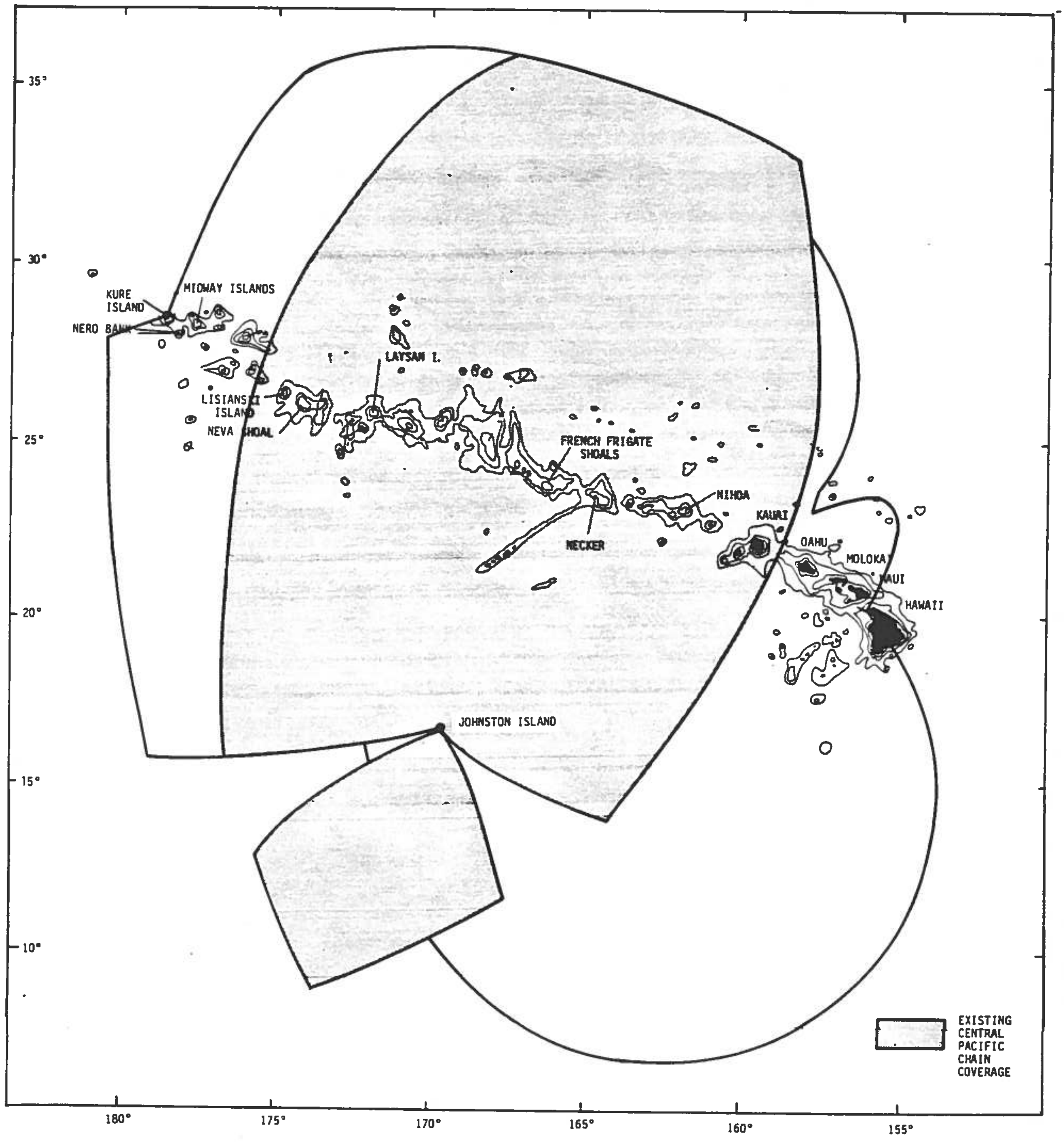



Figure 6-2
LORAN-C Fix Coverage
Kauai Reconfiguration

- o Station personnel complement at Kure (1-1-18) could be reduced to (0-1-10) by relocation to Midway. These savings amount to approximately $140 thousand, annually.
- o The biweekly Coast Guard flight to Kure accomplishes two purposes: (1) it provides logistic support to the LORAN-C Station and (2) it furnishes a fishery patrol under the Coast Guard's enforcement of laws and treaties (ELT) mission. While the movement of the Kure station to Midway will eliminate the requirement for most, if not all, of the logistic support flights, the requirement for fishery conservation patrols will remain. If anything, the latter requirement may increase due to probable changes in Pacific tuna, porpoise and billfish regulations. (Reference 18). Hence, no aircraft saving through the elimination of the logistics flights can be attributed to this move.

The new station to be located at Midway Island is assumed to consist of a high power solid state transmitter. This transmitter would provide an output of approximately 800 kW into a 700 ft antenna. This new transmitter facility would modify the existing CENPAC chain and provide fix coverage as shown in Figure 6-3. This coverage is based on the geometric accuracy definitions and contraints discussed previously.

This relocated chain provides coverage of 1.18 X $10^6$ square miles of which 0.2 X $10^6$ square miles are due to the relocation and repowering of the Kure Station at Midway Island. This relocation would provide additional fix coverage to the east and include all of the major islands, except the east coast of Hawaii. Further, it would provide coverage to the northeast including the approaches to the Hawaiian Islands from the North American trade routes. The AC&I costs for the Midway relocation are assumed to be $4.0 million; the assumed OE costs for Midway are $0.440 million per year including the savings attributable to personnel reductions. Both costs are in 1982 dollars. A full cost discussion is given in Section 7.

Two additional variations of this alternative are possible. These include the movement of the Kure Station to the former LORAN-A site at French Frigate Shoals or the retention of the current Kure site and the increase of the radiated power of the transmitter. The move to French Frigate Shoals would shift the eastern edge of the CENPAC signal approximately 750 nm eastward without an additional increase in power. This option would provide greater eastward signal coverage than the Midway relocation alternative, but would entail both the disadvantages of relocating a station while assuring continuous signal coverage (temporary four station operation) plus the problems of staffing and supplying a remote site (current Kure problems). The latter option of retaining the Kure site while using a high power transmitter (800 kW) would not provide full coverage of the major islands. Further, this option would require the utilization of

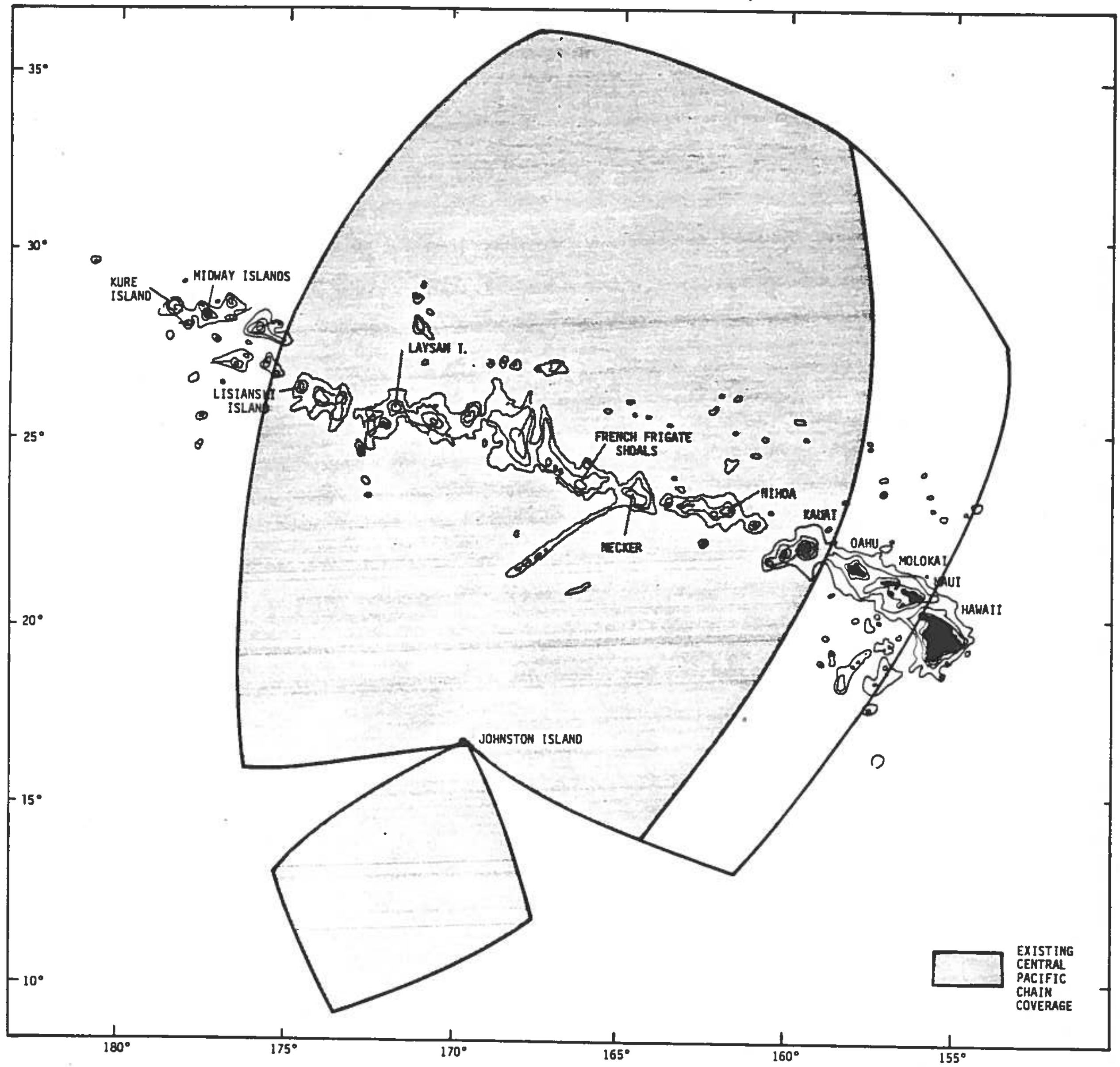



Figure 6-3
LORAN-C Fix Coverage
Midway Relocation

two transmitters to assure stated coverage during the changeover period. Neither of these options was considered further since there was no major apparent advantage to be gained from either configuration.

### 6.4.3 Comparison of Alternatives

Using the traffic patterns and traffic densities discussed in Section 5.3 together with the coverage diagrams given in this section, the relative capabilities of the CENPAC Chain and the two expansion alternatives were determined. In this analysis, both traffic coverage and area coverage were used as measures of comparative system capability. The traffic figures used were those expected to be generated in the year 1985. To provide a basis for comparison both for area and traffic covered, the Hawaiian Region was assumed to extend from $150^{o}$W to $180^{o}$W and from $5^{o}$N to $36^{o}$N. Considered in this region were large and small oceanic vessels and interisland vessels. Both U.S. and foreign flag vessels were included, however only those vessels whose activities were in support of U.S. trade were considered. All vessels were included regardless of whether they used LORAN-C or not since the purpose of this comparison was to measure the potential capabilities of the two systems as compared to the existing CENPAC chain. The results of this determination are shown in Figure 6-4. As can be seen, area coverage and traffic coverage are not identical, but vary as a function of traffic density.

With respect to area coverage as defined above, the CENPAC chain covers less than one-third of the region with the Midway relocation alternative encompassing slightly more (38 percent). On the other hand, the Kauai reconfiguration covers over half of the region. Of equal, if not greater importance however, is the relative amount of traffic which can use the signal from the various alternatives. Currently the CENPAC chain provides a usable signal to approximately 23 percent of the oceanic andinterisland traffic. This consists principally of the Western Pacific and Far East traffic as well as a small fraction of the interisland traffic between Oahu and Kauai. With regard to the Kauai and Midway alternatives, both provide coverage to approximately 99 percent of the region's commercial traffic although some of the traffic due east of Oahu is covered only briefly. Overall, it would appear that of the two expansion alternatives, the Midway configuration provides some traffic coverage using a lesser amount of additional area coverage. On the other hand, if greater area coverage is the criterion, then the Kauai configuration would be the more favorable alternative.

If fishing trips are added to the traffic, the results will tend even more favorably toward the expansion alternatives. Since the number of fishing trips greatly exceed the total traffic considered and since the Kauai and Midway configurations provide coverage of all of the fishing grounds, then these alternatives would cover over 99 percent of the maritime activity. On the

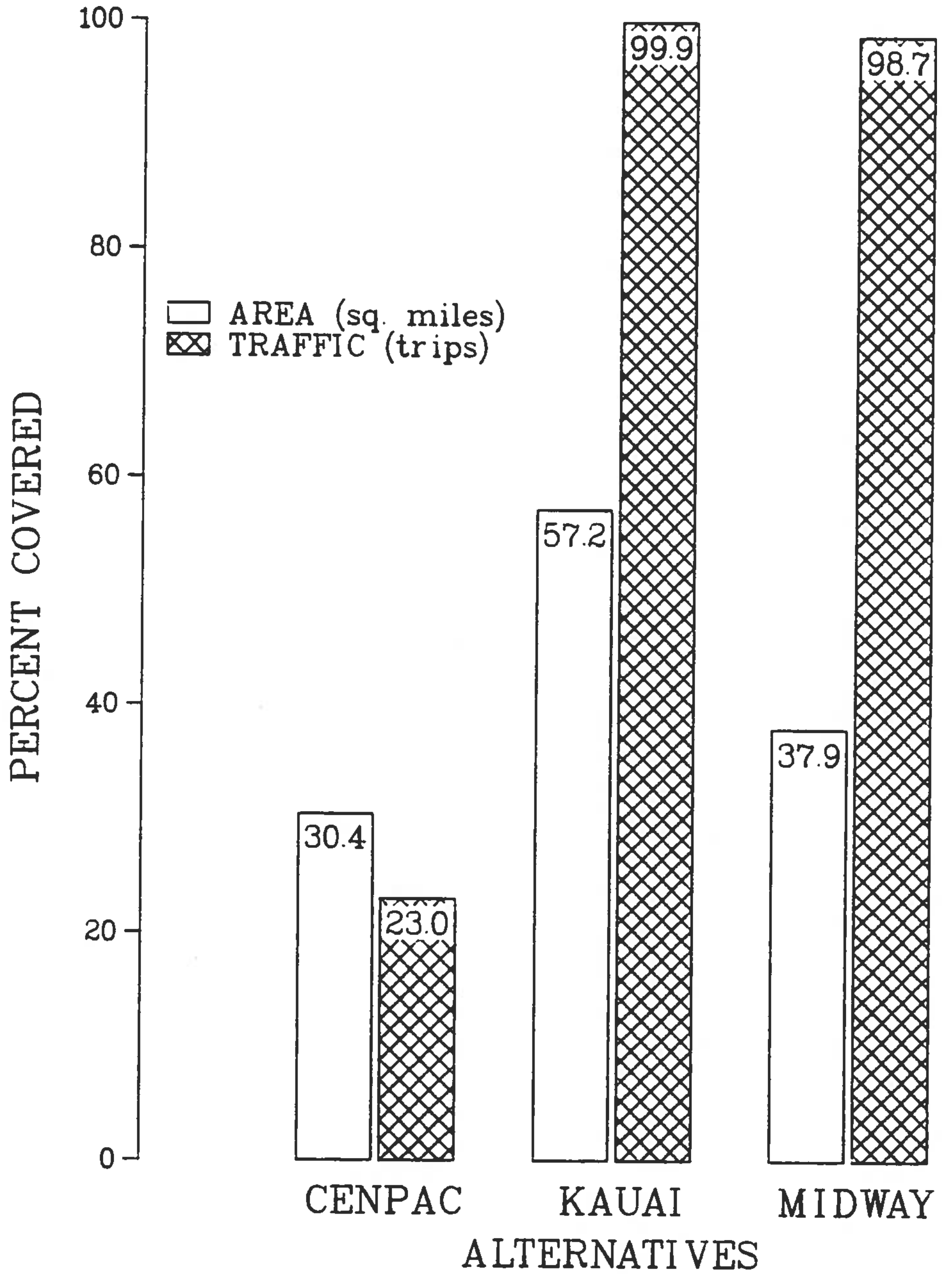



Figure 6-4

PERCENT OF AREA AND TRAFFIC COVERED

other hand, since few fishing trips are made to the regions of current LORAN-C coverage, the relative amount of traffic covered by the CENPAC chain with respect to the increased total traffic is drastically reduced (to approximately three percent).

# 7. LORAN-C SYSTEM AND USER COSTS

## 7.1 Approach and Assumptions

Using Coast Guard supplied estimates, station costs for the various LORAN-C system configurations were determined. In the case of expansion alternatives, station costs were assumed to consist of investment costs (AC&I) and annual operating expenses (OE). With respect to the CENPAC Chain, station costs consisted solely of OE costs. The investment costs included the transmitter, timing and control equipment; antennas, buildings and power; communications and test equipment; and costs associated with the installation and check out of the stations. In the case of the Midway relocation, the cost of the disestablishment of the Kure station is also included. Not included are the costs associated with the site such as land acquisition (if non-government land were involved), or abnormal site access and preparation. Commercial power was assumed to be available on Kauai. Navy-supplied power was assumed to be adequate on Midway.

The total investment costs were assumed to be obligated over a two year period and were equally allocated between each year. OE costs were accrued at the full rate in the year the station became operational. With respect to the relocation of the Kure station to Midway an overlap of one year was assumed while the Midway station became operational and the Kure station ceased transmission. During this period, OE costs for both stations were accrued.

For purposes of the determination of costs and benefits and for the development of cost streams, 1982 was assumed to be the base year.

Life cycle costs reflected station operations through the year 2000 in accordance with Reference 1.

Discounted dollars were used throughout this analysis for evaluating alternatives. A discount rate of ten percent was used to determine present value costs in accordance with OMB circular A-94 (Reference 19) and DOT guidance for regulatory evaluations (Reference 20).

AC&I costs for the existing CENPAC Chain were considered sunk and hence did not enter into the analysis. Only OE costs were considered for this configuration. These latter costs were based on initial outlays for FY80. These costs were then inflated to FY82 dollars using an inflation rate of 10 percent per year.

Costs for the Kauai reconfiguration and the Midway relocation consisted of CENPAC OE costs plus the additional AC&I and OE costs associated with the addition or relocation of the station.

## 7.2 System Costs

### 7.2.1 Station Total Costs

Cost comparisons for the CENPAC and the two expansion alternatives are shown in Figure 7-1. This figure shows the cumulative costs in discounted dollars through the year 2000 for the three configurations. With respect to total costs, the CENPAC is the least cost option as would be expected; the Kauai configuration the most costly. Considering only OE costs, the Midway alternative is the least cost option being slightly less (by $500 thousand) than CENPAC. The lowered cost for this alternative is attributable to the personnel reductions gained by the shared use of Navy facilities at Midway. On the other hand, the OE costs for the Kauai configuration reflected the additional costs due to four station operation. Overall, solely on a least cost basis, continuation of the CENPAC chain appears the preferred alternative; however, other criteria must be used as well.

### 7.2.2 Unit Area Costs

The cumulative dollar costs per square mile of coverage area are shown in Figure 7-2. In this assessment, the cost per square mile for the Kauai configuration is least while the CENPAC chain is greatest. Since the Kauai alternative adds approximately 830,000 square miles to the overall coverage area, the net effect of this addition has been to reduce the overall unit coverage cost.

On the other hand, the cost per square mile of the Midway alternative is slightly less than the CENPAC configuration since the additional coverage gained is offset in part by the net additional cost. In Figure 7-3, the net effects of Kauai and Midway can be seen. In this figure, the additional coverage gained is shown as a function of the incremental costs (i.e., total costs minus CENPAC costs). The additional unit area cost of the Midway expansion is nearly 60 percent greater than the Kauai unit area expansion costs. However, these incremental costs must be weighed against the number of vessels in the area to provide an additional measure of system worth.

### 7.2.3 Costs per Vessel Mile

While absolute costs and cost per unit area can be used to evaluate relative merits between systems, the amount of traffic within each coverage area more accurately reflects the utility of the system. The cost per unit of traffic was used to develop this measure of system utility. In this case, vessel miles were defined by not only the number of vessels operating within a given configuration, but also the distance that these vessels travel within the coverage area. Using the oceanic trade routes discussed in Section 3.3 and the traffic volumes defined in

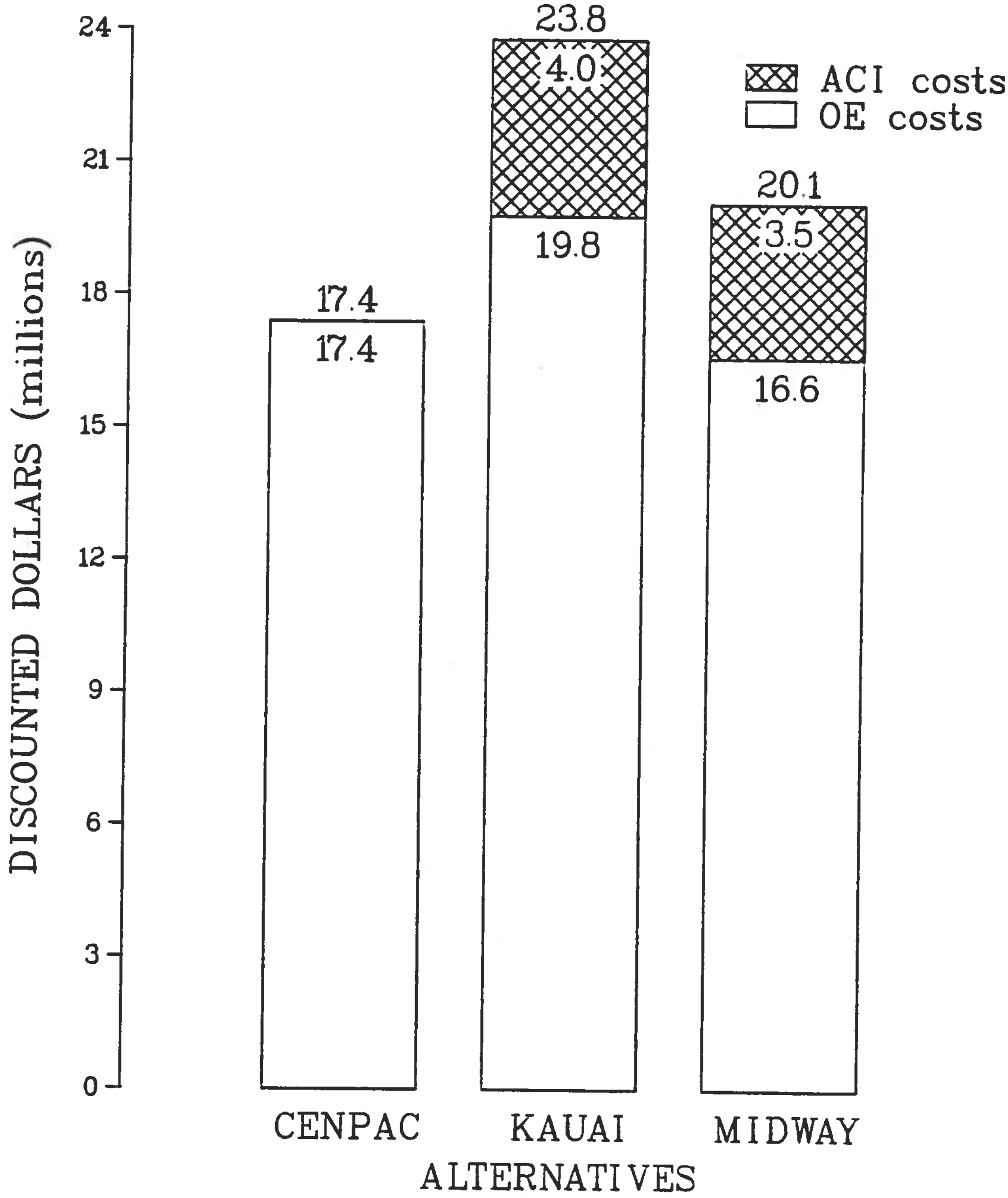



FIGURE 7-1
SYSTEM ALTERNATIVE COSTS
(Cumulative through Year 2000)

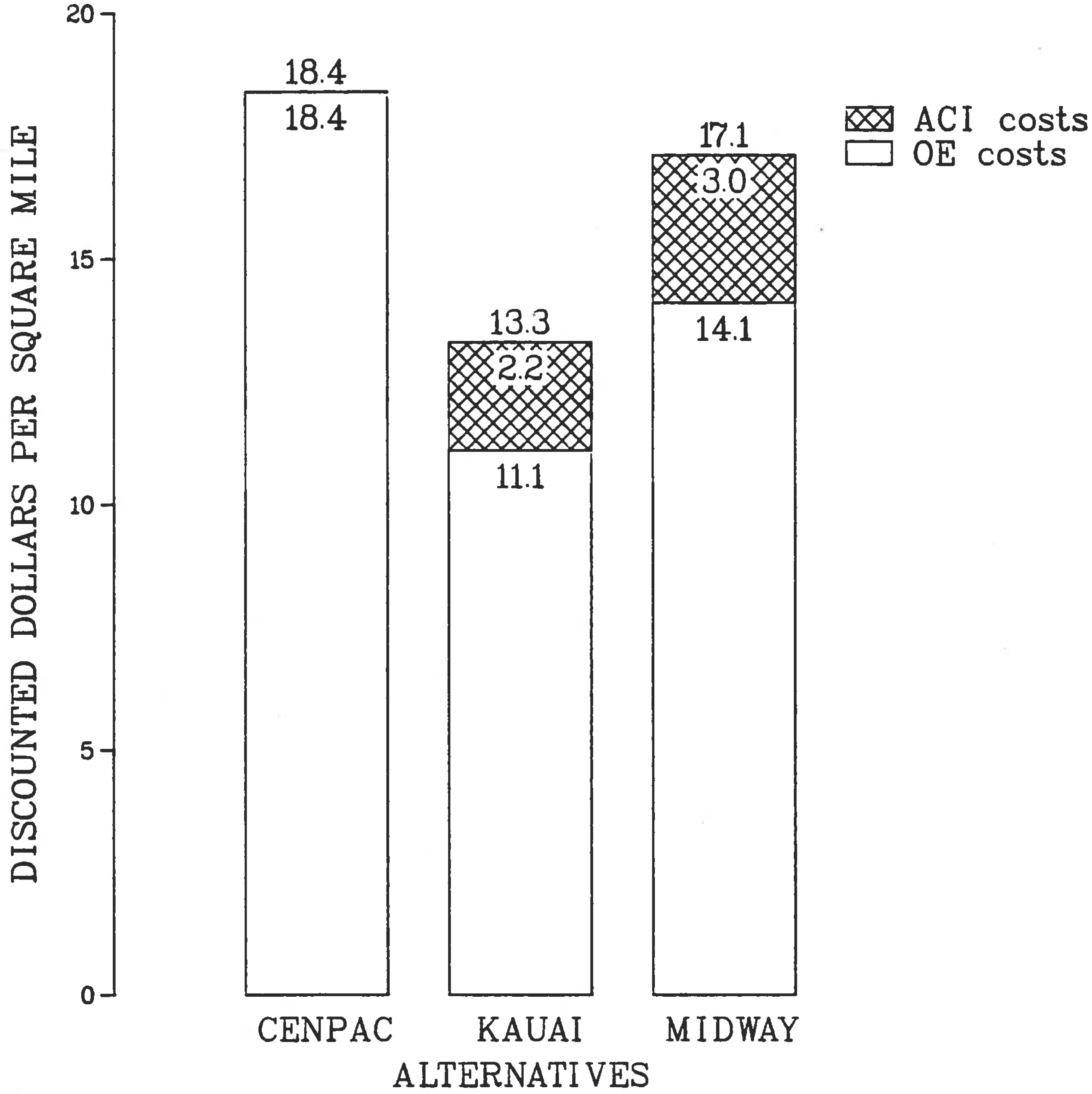



Figure 7-2

SYSTEM ALTERNATIVES: COST PER SQUARE MILE OF COVERAGE
(cumulative through year 2000)

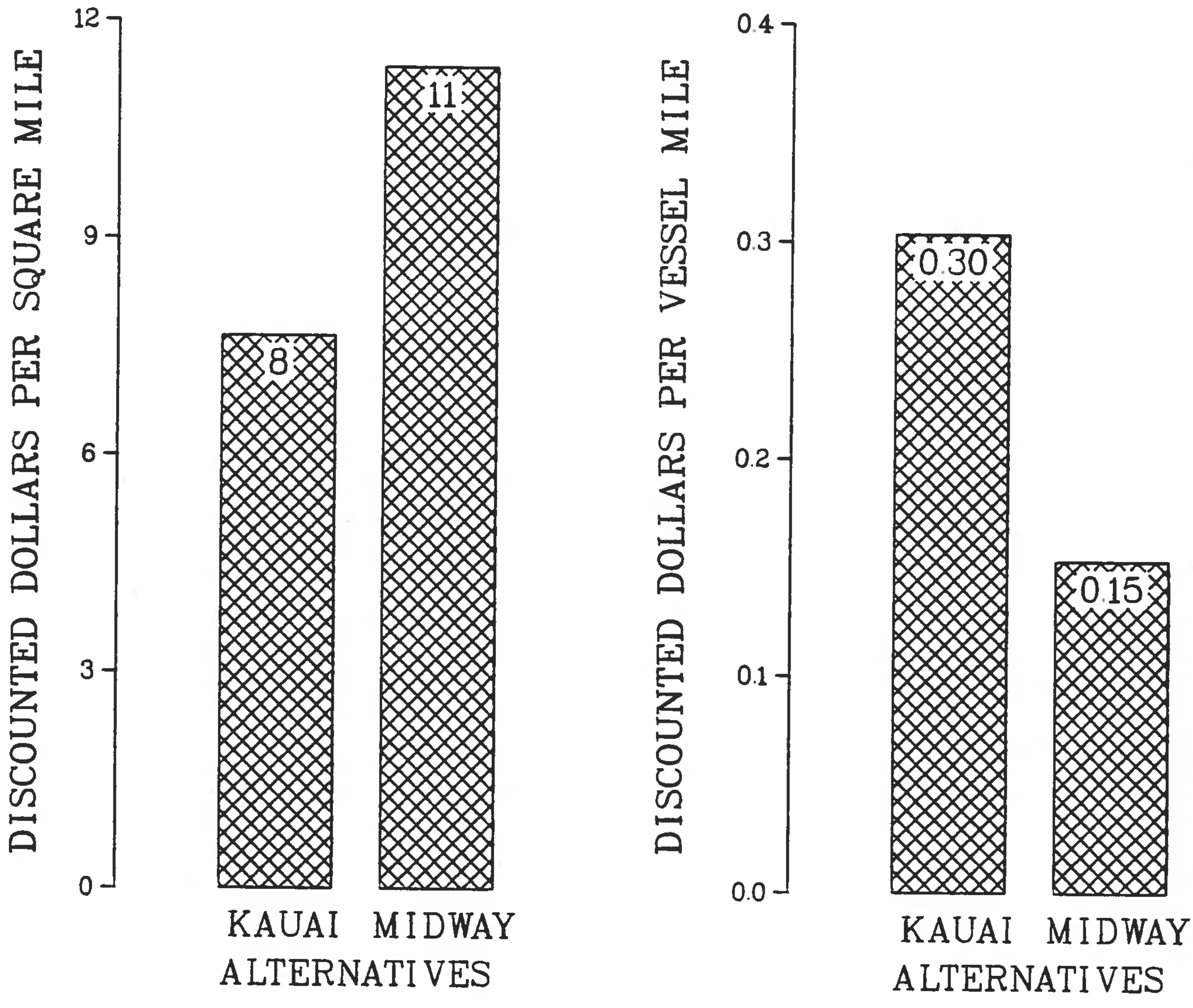



FIGURE 7-3
SYSTEM ALTERNATIVES: ADDITIONAL COVERAGE
VS ADDITIONAL COSTS
(Cumulative through Year 2000)

Section 5.3, together with geometric overlays of the various system alternatives, the distances that each vessel would have traveled were determined for each configuration. Only through and direct oceanic traffic to Hawaii was considered since the vessels comprising this traffic were the more likely users of LORAN-C. Interisland or fishing traffic was not included in this determination. These vessel miles were aggregated for each year and then cumulated through the year 2000 using traffic projections from Section 5.5. The results of this determination are shown in Figure 7-4 where system costs are plotted as a function of cumulative vessel miles. In this figure it can be seen that the Midway relocation appears to be the most cost-favorable option, with the status quo (CENPAC chain) as the least favorable. The Kauai alternative is nearly the same on a cost per vessel mile basis as the CENPAC option. These results would indicate that Midway provides a sufficient amount of traffic coverage and should be regarded as the most promising among the three alternatives using the criterion of potential vessel utilization of LORAN-C.

## 7.3 Receiver Costs

LORAN-C receiver costs were determined based upon a summary of manufacturers' and distributors' selling prices and discussions with representatives at trade shows and exhibitions. LORAN-C receiver prices have been under downward pressure over the past several years with many discounts and sales incentives being offered. Coupled with a lowered price structure, the level of sophistication of the receivers has risen as competition has increased. All of these events has served to place low cost LORAN-C radionavigation equipment in the price range of not only the serious recreational boater but also the cost-sensitive commercial fisherman. Further, the price of the high cost, high value receivers such as those used by the major ocean-going vessels has also dropped substantially while improving markedly overall navigational performance and capability. On the basis of price and performance characteristics, LORAN-C receivers appear to fall into four categories. The prices used to derive these categories are generally list prices or if special sales or discounts were advertised those were used for guidance in defining the groups. In all instances, installation costs were not included, nor were accessories such as power supplies, conversion packages and plotters unless they were integral with the receiver.

These categories, the price ranges and the general characteristics are listed below:

- Group I - Low Cost Receivers. Under $1000

  Receivers in this category are generally basic receivers and are somewhat limited in flexibility and function. The readout display from these receivers is in time difference coordinates (TD's) which require interpolation and plotting

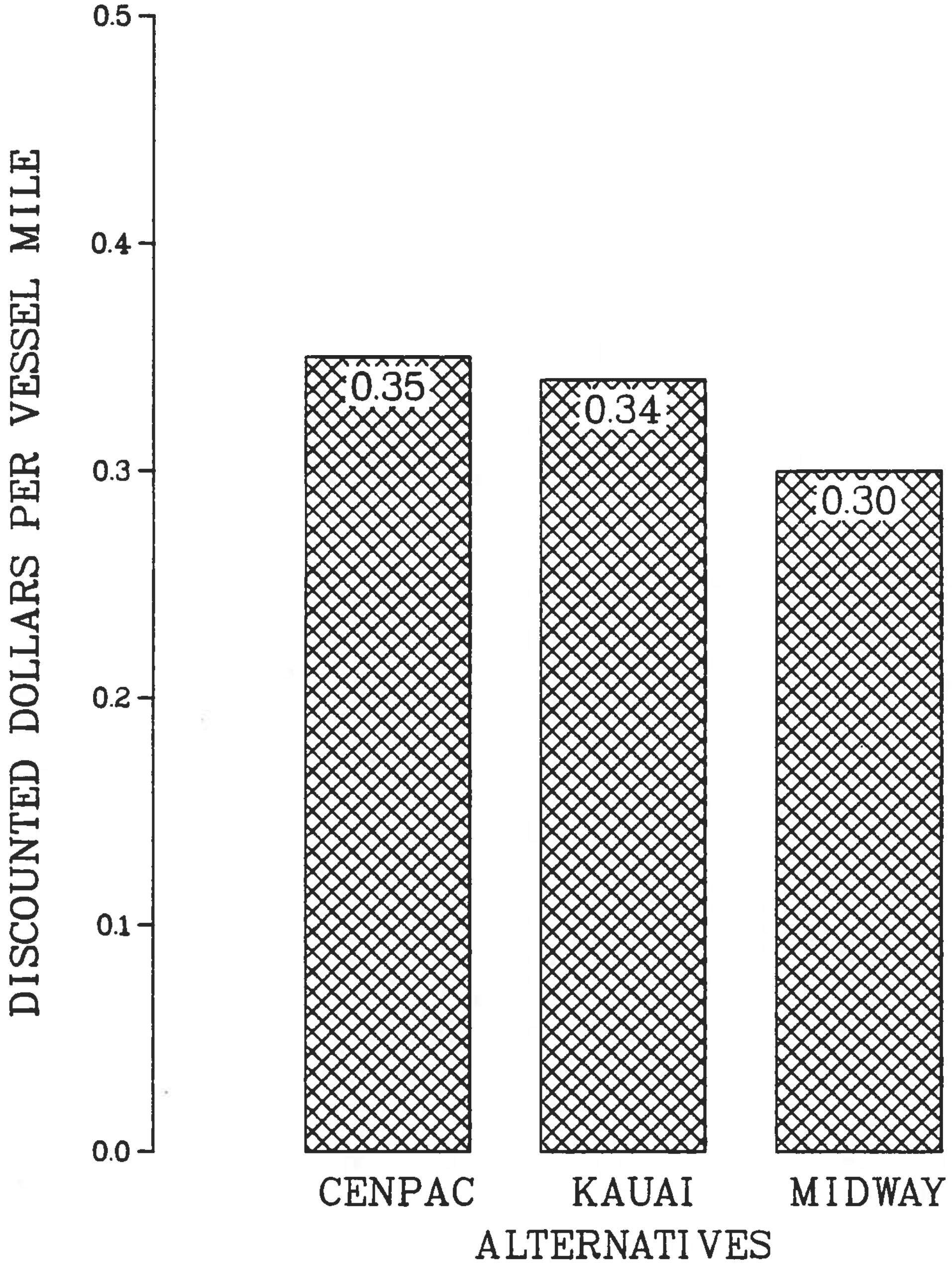



FIGURE 7-4
SYSTEM ALTERNATIVES: COST PER VESSEL MILE
(Cumulative through Year 2000)

on LORAN-C overprinted charts. The overall performance is adequate for most navigational functions including the ability to accurately return to prolific fishing grounds. These receivers are targeted for the low cost market including the recreational boater and the small commerical and subsistence fishing operators.

o Group II - Moderate Cost Receivers. $1000 - $2000 range

Receivers in this price category are general purpose receivers of greater sophistication and capability than the low cost receivers in Group I. Signal acquisition is fully automatic as is the tracking of the master and the secondaries in the selected LORAN-C chain. Internally and externally adjustable notch filtering is included for suppression of encountered interference. Readout display is in time difference coordinates in all models surveyed. Most have storage capability for retention and recall of previous TD coordinates. Some receivers have the capability for developing steering information between pre-programmed destinations. The options available for most of these receivers include navigational computers, track plotters and remote readout displays. These receivers would be purchased by all categories of users with options added to tailor the units to meet the particular requirements of the operators.

o Group III - High Cost Receivers. Greater than $2000

Receivers in this group range from a low of $2000 to greater than $5000. The price range tends to reflect the level of flexibility and the number of functions integral to the set. Many of the sets in this range have Latitude/Longitude converters either as part of the receiver or available as a higher cost version. Similarly, navigational computers are also included in many of this group. These computers have the capability of processing and displaying: vessel heading in degrees, bearing to preprogrammed destinations or waypoints, cross track error, distance to go, time to go, and vessel speed over the ground. Displays are generally LCD or LED although CRT displays are used in some of the higher cost receivers. Service and maintainability is improved with modular construction used in most units; repairs are made by replacing modules. The most probable purchasers of this category of receivers would be the high value commercial users particularly the large, ocean going vessels, and the major fishing operators. Also included among these users are the cost insensitive recreational boat owners particularly the owner of large power boats and yachts.

o Group IV - Special Purpose Receivers. Greater than $5000

These receivers are generally in the $5000 to $10,000 range, although some can reach nearly $26,000. This application is for those users who require a precision navigation capability beyond that normally demanded by the usual commercial or recreational operator. Particular applications for these units are in offshore positioning and survey work where the optimal accuracy inherent in the LORAN-C system must be exploited. Further, some of these receivers can be used in vessel monitoring applications wherein the vessel's position is automatically transmitted to a dispatcher or control location for purposes of operational location and control. Some of these receivers can be equipped for range/range navigation as well as modified for cross chain operation. Because of their specialized applications, this receiver group is considered only peripherally in the study.

## 7.4 User Purchase Strategies

Based on data collected from the Hawaii marine community and discussions with principal users, certain conclusions and judgements can be drawn with respect to the purchase and utilization of LORAN-C receivers both under current conditions and if the Central Pacific chain is expanded. These results are summarized in Table 7-1 for the current and expanded options. In addition, this table also indicates current and future alternative navigation systems, their users and potential users. The rationale underlying this table is discussed below.

- Most of the large marine operators, particularly the ocean going vessels currently employ a combination of LORAN-C and TRANSIT, LORAN-C and OMEGA or TRANSIT alone in Trans-Pacific crossings. Many of these vessels also call at U.S. mainland ports and those that are over 1600 GT are required by regulation to be equipped with LORAN-C, TRANSIT or other approved electronic navigation equipment (Reference 15). Thus, future purchases of LORAN-C receivers would be replacements for those already installed. Further, many current users of LORAN-C have indicated a desire to defer system upgrading until NAVSTAR GPS becomes available, confining current purchases to replacement of defective and worn-out units.

- The inter-island operators, including the tug/barge operators use visual piloting augmented by radar almost exclusively. The generally favorable weather conditions and good visibility impose few constraints upon inter-island operations such that visual means generally suffice. Many of the inter-island vessels, particularly all those which are also engaged in traffic to the continental United States, are already equipped with LORAN-C, yet discussions with those operators indicate that they would probably not use it in inter-island operations. Thus, it is believed that the new receiver market for these users would be slight with purchases being confined to the replacement market.

TABLE 7-1
USER PURCHASE STRATEGIES

| USER | CURRENT NAVIGATION SYSTEM OR TECHNIQUE | | | | | FUTURE NAVIGATION SYSTEM | |
|---|---|---|---|---|---|---|---|
| | CENPAC LORAN-C | TRANSIT | OMEGA | CELESTIAL | DEAD RECKONING PILOTING | EXPANDED LORAN-C | NAVSTAR GPS |
| LARGE COMMERCIAL | X | X | X | X | X | P* | P |
| SMALL COMMERCIAL | | | | | | | |
| OCEAN GOING | X | X | X | X | X | P* | P |
| INTER-ISLAND | * | | | | X | * | |
| FISHING > 30 FT COMMERCIAL | P NORTHWEST HAWAIIAN | P | | | X | P | P |
| SPORT FISHING | | | | | X | | |
| RECREATIONAL POWER > 60 FT | X | X | X | | X | P | P |
| POWER 40-60 FT | | | | X | X | | |
| SAIL | | | | X | X | | |
| OTHER | | | | | | | |
| PRECIOUS CORAL | P | P | | | | P | P |
| SEA BED MINING | | P | | | | P | P |

P = POTENTIAL USER X = CURRENT USER *CURRENTLY INSTALLED BUT NOT USED

- o Few commercial fishermen currently have LORAN-C installed mainly due to the lack of coverage in the fishing areas close to the major islands (Appendix D). Those whose operations are in the Northwest Hawaiian Islands where there is coverage are the principal users of LORAN-C. With the current thrust of the Hawaii fishing industry toward the exploitation of this latter area, it is probable that the receiver market will grow for this user category regardless of whether LORAN-C is expanded or not.

- o Foreign fishing vessels, principally Japanese, fishing in the Central and Northern Pacific use Transit to improve their operating capability (Reference 21). Hence the precedent exists for receiver purchases of this latter system by U.S. fishermen if their operations expand as predicted in the Hawaii Fisheries Development Plan.

- o Recreational boaters who currently operate in the Hawaiian Islands use visual means for interisland cruising regardless of whether the boat is power or sail. Discussions with many recreational boat owners indicated a tendency to maintain a status quo and not acquire electronic navigation systems. The operator of the large recreational power boat (>60 ft) which has the range for Trans-Pacific operation probably has already acquired LORAN-C as well as other systems since system cost is generally secondary to those users. On the other hand, the large ocean sailing vessels often use more traditional means for navigation and will not acquire any electronic system.

- o The needs of the other users such as the precious coral industry or sea bed mining operations are oriented more toward positioning than navigation and hence those requirements may be more readily fulfilled by TRANSIT or NAVSTAR GPS than by LORAN-C. The current state of the Hawaiian deep sea precious coral industry is moribund; most of the current coral industry operations occur close inshore in relatively shallow water performed by scuba divers from small boats with no requirement for electronic positioning. On the other hand, deep sea foreign operations occur in the vicinity of Kure Island at the western extremity of the Archipelago. The current projected area for sea bed mining is outside the expected LORAN-C coverage area (Appendix C) although long term future operations may occur within this area.

Overall it would appear that the greatest potential purchaser of LORAN-C would be the commercial fishing user because of the direction of future growth of this industry. Further, most of these purchases would occur regardless of the expansion of LORAN-C since growth is expected westward into the current CENPAC coverage area.

# 8. SYSTEM BENEFITS

## 8.1 Introduction

The principal thrust of this study is to identify and quantify system benefits. While many benefit measures immediately come to mind which can be related to improved navigational accuracy, the determination of a numerical value for these measures was the subject of considerable investigation. This section addresses the benefit measures used in the analysis, their quantification, and results.

Improved navigation affects two principal areas: Productivity and Safety. Within the area of productivity are such benefits as reduction in trip time, closer adherence to desired or optimum track with resultant fuel savings and more efficient operations through improved arrival scheduling. Also in the productivity area are the benefits derived from the ability to accurately return to desired areas at sea, particularly those areas where fish or other exploitable natural resources are plentiful. In the area of safety there are benefits to be gained by a reduction of the potential for groundings, strandings, and rammings and a reduction in insurance premiums through lowered regional loss experience. Implicit in these safety benefits is a reduction in the probability of pollution.

## 8.2 Quantitative Benefit Measures

Based upon a review of the available literature, discussions with knowledgeable individuals in the marine community both on the mainland United States and in the Hawaiian Islands and on a review of the vessel data base which had been amassed in support of this study, five major quantifiable benefit measures were identified which could be attributable to improved navigation. These measures were: vessel fuel savings, reduction in operating expenses (at sea time), port scheduling savings, vessel casualty reductions, and enhanced fishing productivity. These measures are discussed below. Benefit measures for improved Coast Guard operations are discussed in Section 9.

### 8.2.1 Vessel Fuel Savings

Previous studies (References 22-25) have indicated that there is a potential fuel savings attributable to improved navigational accuracy. These savings can be derived through better shiphandling, more economical routing and better knowledge of the effect of set and drift upon vessel course and speed. In the above studies, the economic effect of improved navigational accuracy was determined as a function of shortened trip times, trip distances or fuel economics. These savings have ranged from a high of 2.0 percent to a low of 0.17 percent for various regions of the world and assumed navigational accuracies. For 0.25 nm navigational accuracy, the savings ranged from 0.5 percent to 1.0 percent for Trans-Pacific trade routes. For the derivation of the benefits accruing to Hawaiian LORAN-C, both CENPAC chain and the expansion alternatives, these latter values were used for a determination of fuel-related benefits for comparison purposes.

### 8.2.2 Vessel Operating Savings

Improved navigational accuracy can be translated into shortened trip times. The savings attributable to these reductions are a function of the operating expenses of the vessel. These operating expenses consist of wages and allowances, subsistence, stores and supplies, maintenance and repair, insurance, and other miscellaneous costs. Not included in these costs were at sea fuel charges. However, the percentage fuel savings derived from improved navigational accuracy are equally applicable to savings in operating expenses since the common element in both is a reduction in distance travelled (i.e., reduced at-sea times) and all savings are ultimately derived from savings in time. Thus, the percent savings used in the Vessel Fuel Savings measure discussed above were also used for this category as well.

### 8.2.3 Port Scheduling Savings

Based on discussions with shipping companies and port authorities (Appendix F), it appears that savings are possible through better scheduling of port services and more accurate determination of vessel arrival times. These productivity improvements can include reduced waiting times for pilotage and berths and more efficient scheduling of longshoremen services. However, the most costly element of a vessel's operating expenses is in port cargo handling. This element amounts to approximately 23 percent of the vessel's total operating expenses and is second only to crew wages. Further, payment for longshoremen services begins when the vessel is scheduled to arrive, not when the vessel actually arrives and hence, the delay of an hour in scheduled arrival can have a significant impact upon vessel operating expenses. Thus, savings in this area appeared to be most promising. By comparison, pilotage and berthing savings appeared to be minor.

Savings would accrue from the ability of a vessel to arrive at a certain place at a scheduled time with greater accuracy (e.g., arrival at a sea buoy or harbor entrance closer to a designated time). Two separate cases were examined to provide a range of values for savings due to improved navigational accuracy. It was assumed for those cases that navigational accuracies are either 4.0 nm or 2.0 nm and that all system expansion alternatives would provide an improvement of those accuracies to 0.25 nm or better. In each case, it was assumed that half of the vessels would arrive either early or on time and hence no benefits would accrue to them. In the first case, the remaining half of the vessels would miss their arrival point by 2.0 nm and in the second case by 1.0 nm. These results were based on the assumption that they will be late by one-half of the maximum error of the system (e.g., 2.0 nm for accuracies of 4.0 nm). When 0.25 nm accuracies were introduced, similar logic prevailed, however the numbers were too small to enter into the analysis and hence the final savings for all vessels were 1.0 nm and 0.5 nm per vessel, respectively. These figures were then converted into the times required for a vessel to cover these distances and the times used to determine savings based on the longshoremen's hourly rate.

8.2.4 Vessel Casualty Reduction

Savings attributable to the reduction in casualties due to faulty navigation are an obvious benefit from improved navigational accuracies. These savings include not only the reductions in vessel losses and damages, but also, the indirect and less obvious savings. This latter category includes the savings in the costs of refloating or salvaging the vessel, tug costs, deballasting and lighterage costs, divers inspection and drydocking costs. In addition, there are losses incurred while the vessel is aground and in a non-productive status.

In this analysis, a study of marine casualties in the Hawaiian Islands was conducted. The results of this study are given in Appendix B. These results include the probable impact of improved LORAN-C coverage and the expected savings both in casualty costs and in lost productivity.

8.2.5 Insurance Premium Savings

The effect of improved radionavigational capability also impacts upon the operating costs of the vessel, particularly in terms of the reduction of the premiums for hull and machinery insurance. Discussions with underwriters at the American Hull Insurance Syndicate (Appendix F) have indicated that as a rule, no insurance premium reduction is made for vessels or regions with improved navigation capability. Further, a certain minimum level of navigational capability is presumed. Vessels which do not meet these standards are assigned to a higher premium rate. On the other hand, if the loss history of the vessel is favorable, a proportionate reduction in premium can be gained. In the Hawaiian Islands however, the casualty rate is one the lowest in the world and hence the insurance premiums have already been reduced. Because of the favorable operating conditions and the already low insurance rate no additional savings were attributed to improved LORAN-C coverage. Only the reduction in casualties were considered as a benefit.

8.2.6 Fishing Benefits

In addition to the ability to navigate more accurately thereby reducing the at-sea time and affecting savings in operating expenses and fuel expenditures, there are also savings attributable to the ability to return accurately and expeditiously to a desired location at sea. These benefits are applicable particularly to the fishing user who perceives considerable increases in productivity through the ability to relocate prolific fishing spots, retrieve fish or lobster traps, or follow sea bed drop offs where fish tend to congregate due to availability of food carried from the bottom by the upwelling actions of undersea currents.

In this benefit category, it is difficult to quantify increased productivity attributable to expanded LORAN-C when increased productivity is defined by improvements on the quantity and quality of fish caught. Accordingly, a range of values was used which reflected both subjective and objective analysis. The upper limit represented the increase in productivity as perceived by knowledgeable professional fishermen who are at the forefront of the Hawaii fishing industry. It is axiomatic in benefit - cost projections that preceived benefits are often self-fulfilling due to an innate desire on the part of the system advocate to insure that predicted benefits are achieved. On the other hand, the lower value was derived from a characterization of the Hawaii fishing industry based upon the operating patterns of the vessels and the requirements for harvesting the predominant species. These latter benefits were based on navigability improvements as quantified by fuel savings and reduced operating (at-sea) times. These improvements were based upon the 1 percent reduction factor described previously. The derivation of these benefits are discussed subsequently.

## 8.3 Determination of User Benefits

### 8.3.1 Vessel Fuel Savings

Benefits due to improved navigational accuracy were determined as a function of vessel fuel savings. This determination included all the civil oceanic operators who were considered to be the principal quantifiable beneficiaries of LORAN-C. The users comprising this traffic consisted of both large and small commercial vessels including tanker and cargo vessels which either sail directly to or from Hawaii or transit the area. The traffic projections, traffic patterns and densities, trade route segments and LORAN-C alternative system coverages discussed in previous sections were used in this determination. The benefit measures of 0.5 and 1.0 percent savings were used. This resulted in annual savings in nautical miles as a function of vessel type and system configuration. These determinations were made each year from 1980-2000.

Two variables were introduced into these calculations: First, the price of oil was considered to be a separate, independent variable and was assumed to escalate 50 percent every 5 years. This approach was used since the escalating price of oil represents an unusual event which impacts directly only upon the benefits elements of this analisis. Assuming a price of $32.00 a barrel for Saudi crude in May 1981, this results in a price of $162.00 a barrel by 2001. No other inflation-based variables were used since overall inflation impacts equally upon the cost and benefits elements. Secondly, traffic projections for the region have indicated a fairly low rate of growth, based on the assumption that while the number of vessels remains reasonably constant, their size will increase. Hence, larger vessels of greater capacity were assumed to enter the Pacific fleet between 1985 and 1995.

Using MARAD-supplied estimates (Reference 26, 27) of average vessel speeds and fuel consumptions for the various categories and tonnages of vessels, together with the estimated fuel costs, fuel savings were determined on an annual basis for cargo and tank vessels, both large and small and tug/barge combinations for the three system configurations. These results are shown in Table 8-1, cumulated at five year intervals through the year 2000, in thousands of discounted dollars.

### 8.3.2 Vessel Operating Savings

The savings in vessel operating expenses were derived from the reduction in at-sea times and were based on more rapid and more efficient transit of the area through improved navigational capabilities. The approach and methods used were similar to that applied in the fuel savings determination. This benefit category was applicable to the same oceanic vessels using the trade routes, traffic patterns and LORAN-C coverages defined previously. Vessel operating costs were derived from MARAD estimates for various vessel sizes and classes both U.S. and foreign (Reference 26, 27). Further, these operating costs were varied to match the projected growth in vessel sizes and the changing mix of vessel classes as discussed previously.

The results of this determination are shown in Table 8-1 where the cumulative savings in operating expenses are shown at five year intervals through the year 2000. As compared to fuel savings, this category is significantly less since the fuel component is the most substantial part of the vessel's at-sea costs. In this case, the benefits due to fuel savings are approximately 10 times that of other at-sea costs. The savings in operations can, ultimately, be translated into an additional trip over a period of time.

### 8.3.3 Port Scheduling Savings

Port scheduling savings were determined based on inbound traffic scheduled to arrive at Hawaiian ports. All commercial vessels both ocean-going and inter-island were considered since expeditious unloading and rapid port turn around is a critical element in profitability of these vessels. Further, because of the limitation in available dockspace in Hawaii, optimum scheduling of facilities is necessary for efficient port clearance and maximum throughput.

The projections for commercial marine traffic arriving in Hawaii given in Section 5 were reduced by 50 percent to account for the fact that improved scheduling due to system expansion affects

TABLE 8-1
LORAN-C BENEFITS
(THOUSANDS OF DISCOUNTED DOLLARS)

| | CENPAC | | | | KAUAI | | | | MIDWAY | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1985 | 1990 | 1995 | 2000 | 1985 | 1990 | 1995 | 2000 | 1985 | 1990 | 1995 | 2000 |
| MAXIMUM BENEFIT | | | | | | | | | | | | |
| OCEAN TRAFFIC | | | | | | | | | | | | |
| Arrivals | 173 | 327 | 426 | 487 | 299 | 940 | 1,349 | 1,598 | 299 | 940 | 1,349 | 1,598 |
| Fuel | 1,256 | 2,800 | 4,291 | 5,806 | 1,441 | 3,936 | 6,355 | 8,830 | 1,414 | 3,847 | 6,241 | 8,649 |
| Operations | 364 | 685 | 895 | 1,028 | 429 | 1,011 | 1,385 | 1,613 | 438 | 1,056 | 1,485 | 1,747 |
| FISHING | 171 | 1,915 | 4,423 | 6,863 | 283 | 3,643 | 8,466 | 13,161 | 283 | 3,643 | 8,466 | 13,161 |
| GROUNDINGS | 1,293 | 2,427 | 3,152 | 3,595 | 1,386 | 2,895 | 3,863 | 4,458 | 1,386 | 2,895 | 3,863 | 4,458 |
| TOTAL | 3,257 | 8,154 | 13,187 | 17,779 | 3,838 | 12,425 | 21,418 | 29,660 | 3,820 | 12,381 | 21,404 | 29,613 |
| MINIMUM BENEFIT | | | | | | | | | | | | |
| OCEAN TRAFFIC | | | | | | | | | | | | |
| Arrivals | 87 | 163 | 213 | 243 | 150 | 470 | 674 | 799 | 150 | 470 | 674 | 799 |
| Fuel | 628 | 1,400 | 2,146 | 2,903 | 721 | 1,968 | 3,178 | 4,415 | 707 | 1,924 | 3,121 | 4,325 |
| Operations | 182 | 343 | 448 | 514 | 215 | 506 | 693 | 807 | 219 | 528 | 743 | 874 |
| FISHING | 69 | 182 | 314 | 459 | 165 | 734 | 1,328 | 1,919 | 165 | 734 | 1,328 | 1,919 |
| GROUNDINGS | 1,144 | 2,078 | 2,658 | 3,019 | 1,220 | 2,443 | 3,202 | 3,674 | 1,220 | 2,443 | 3,202 | 3,674 |
| TOTAL | 2,110 | 4,166 | 5,779 | 7,138 | 2,471 | 6,121 | 9,075 | 11,614 | 2,461 | 6,900 | 9,068 | 11,591 |

only inbound traffic. The expected values due to improved accuracy discussed in 8.2.3 were used (0.5-1.0 nm). In all cases vessel speed was assumed to be 15 knots which resulted in time savings of 2 and 4 minutes respectively. Based on discussions with ports authorities, cargo handling costs generally range between $3000-$4000 per hour per vessel and the charges begin at scheduled arrival time. Hence, small improvements in arrival scheduling can result in several hundred dollars' savings. In this case, the expected value savings are $167 and $233, respectively.

Using those planning factors and estimated vessel populations, savings were determined for the three configurations. These results are shown in Table 8-1. The Kauai and Midway results are identical since both alternatives provide coverage of the approaches to the Hawaiian Islands, thereby providing all oceanic users with the capabiltiy of accurately determining arrival times. On the other hand, CENPAC benefits are considerably less since only Western Pacific traffic is afforded coverage. This allocation of benefits is proportionately similar for both maximum and minimum cases.

8.3.4 Vessel Casualty Reduction

The results of the analysis of vessel casualties which occured in the Hawaiian Islands during the period 1977-1980 have indicated that there are few navigation-related incidents (Appendix B). Further, the incidents that could be caused by deficiencies in navigation are more realistically caused by human error. The reason for this low loss experience is in part accounted for by the favorable climate with few occurances of major storms, periods of low visibility or other phenomena which contribute negatively to vessel safety. However, in order to quantify benefits which may occur because of improved navigational capability attributable to expanded LORAN-C certain approaches and assumptions were used. These are discussed in the subsequent paragraphs.

The costs of each loss and damage incident were determined from the casualty reports, and were further augmented by estimates of the loss in productivity, refloating, salvage and inspection costs where appropriate. These values were based upon current dollars at the time the loss was sustained. These costs were then inflated at the rate of 10 percent per year to bring the values in line for the 1982 base year dollars. In order to quantify the loss and damage savings, it was assumed that improved radionavigation would reduce these losses by 50 percent. This factor was then applied to losses sustained in those areas where LORAN-C coverage does not now exist, but which would be covered if system expansion were to take place. For those incidents which occured in areas where coverage now exists, it was assumed that an equivalent incident had been averted. Hence, the dollar value of this loss represents a comparable dollar value of savings. Maximum and minimum values were determined for the three system alternatives. The minimum values were based on a straight line projection of the annual savings derived from the four year period under assessment. These values were then discounted over the life of the study period. The maximum values were based on the minimum values expanded by a factor which expressed the expected growth in traffic as discussed previously. In this estimate, a linear relationship was assumed to exist between vessel population growth and vessel casualties.

The results of this assessment are shown in Table 8-1. As can be seen, the maximum benefits attributable to the Kauai reconfiguration and Midway relocation alternatives are similar since the insular coverages provided by the two alternatives are identical and it is in these regions that groundings occur. The CENPAC benefits are approximately twenty percent less, yet are nevertheless, substantial. In the assumptions underlying this assessment it is assumed that the CENPAC coverage provides a savings equivalent to the amount of loss already sustained. In the CENPAC coverage area several major groundings have occured and it is those losses which impact on the results. Similar results are noted in the minimum benefits category.

8.3.5 Fishing Benefits

Fishing benefits constitute an often cited element in the package of benefits attributable to LORAN-C. However, the quantification of these benefits is subject to considerable speculation and conjecture. Because of the uncertainty associated with the determination of these values, a range of benefits were derived which represent the extremes of optimism as to the contribution of LORAN-C to the fishing industry in Hawaii. Two methods were used to determine those values. The first, or maximum benefit, is based upon the perceived value of LORAN-C to the fishing community; the second, or minimum value, is derived from an analysis of fishing operations. The assumptions and methodologies underlying these determinations are discussed below.

The perceived value of LORAN-C to the fishing community was derived in part from discussions with many fishermen and fisheries management experts on all of the principal islands. These individuals were representatives of the fishing community and most were members of the Western Pacific Fisheries Management Council. The focus of these discussions was to develop a quantitative measure for the increase in productivity attributable to LORAN-C. In this case productivity increase was defined as the dollar value increase in catch and comprised fuel savings, reduced operating costs, reduced at-sea time per trip, increased number of trips per year and increase in the amount of fish harvested. The consensus of these discussions indicated that a 25 percent increase in productivity could be achieved through expanded LORAN-C coverage. This factor was then used to determine the level of maximum benefits.

In the Hawaiian Fisheries Development Plan (Reference 11), projections are made in terms of poundages, species and ex-vessel dollar values of the current and possible future fishing yields. These projections are based upon implementation of the recommendations contained in the plan. These recommendations include improvements in infrastructure and organization, programmatic and financial assistance operations or improved techniques. It is these latter areas to which expanded LORAN-C would be applicable.

In the Plan, the projected increase in catch is estimated to reach 80 percent of the biologically sustainable yield by the year 2000. The sustainable yield is defined as the catch which can be harvested annually without an appreciable decline in population. Additional increases in yield can be achieved through improvements in efficiency or operating techniques. It is assumed that of the remaining 20 percent of the sustainable yield, a portion can be achieved through expanded LORAN-C. This portion is estimated to be 25 percent based on the perceived increase in productivity described above.

In Figure 8-1, the direction of the annual increase in fisheries productivity is shown. In this figure, the current dollar value of the annual projected yield is given as is the dollar value of the biologically sustainable yield. In the Fishery Development Plan it is estimated that the projected yield will reach 80 percent of the sustainable yield by the year 2000. Lesser values are also given for 1980 and 1990. The perceived increase in productivity due to expanded LORAN-C coverage is also shown as an incremental increase over the projected yield. It is assumed that this benefit will increase annually from 1985 (the year of improved operational capability of expanded LORAN-C) until it reaches the perceived 25 percent increase by 2000. The yearly values represent annual maximum benefits.

The yearly values derived above were then discounted over the life of the study and cumulated at five year intervals. The results are shown in Table 8-1 as maximum benefit values. For the Kauai and Midway alternatives, the fishing benefits are identical since it is assumed that both systems provide equivalent coverage of the fishing grounds. The CENPAC benefits are less based upon certain assumptions in the Fisheries Development Plan. The Plan assumes that the potential for future growth for bottomfish, lobster, shrimp, akule and opelu will be within the Northwest Hawaiian Islands - an area where coverage from the CENPAC chain already exists. Further, the plan also assumes that tunas will be caught in all ocean areas throughout the Hawaiian Islands. For purposes of attributing benefits to the CENPAC chain, it is assumed that benefits will be derived from all the former species, but only one-third of the ocean tunas will be so assigned. The one-third value was used to reflect the albacore harvest in the Midway Islands (Appendix D). Minimum benefits were derived from an analysis of current and projected fishing operations in Hawaii. Using the estimates for future growth of the industry as given in the Hawaii Fisheries

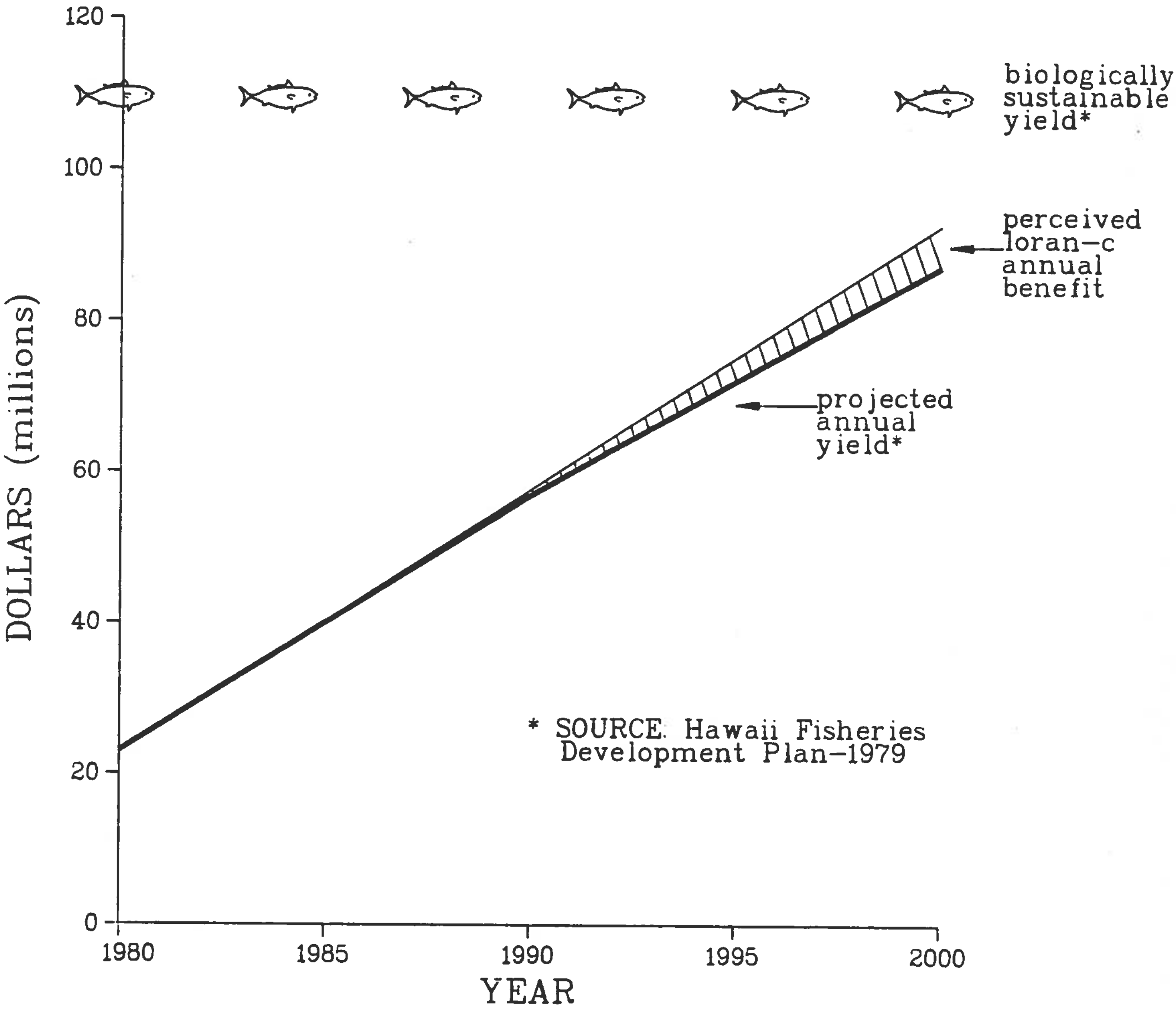



FIGURE 8-1
DEVELOPMENT OF MAXIMUM FISHING BENEFITS

Development Plan, together with the potential major species expected to be caught, vessel operating characteristics as determined by the harvesting requirements of the species and probable fishing ground locations, the annual number of trips and trip durations were estimated. Vessel operating costs, and fuel expenditure rates while in transit for current and future vessels were derived from data provided in the Plan. Maximum benefits were based on savings in fuel and operating costs and were attributable to an improved navigational capability. No fishery productivity values were assigned. These savings were assumed to amount to 1 precent of the at-sea time. This value was used to provide a lower limit to the fishing benefit category in order to bound these benefits and indicate the range of uncertainty.

The results of the minimum fishing benefits are shown in Table 8-1. The Kauai and Midway benefits are identical since, as indicated above, both provide similar fishing ground coverages. The CENPAC benefits are less since they represent only the navigation benefits for vessels operating in the Northwest Hawaiian islands.

## 8.4 Benefits Summary

### 8.4.1 Oceanic Benefits

The benefits to the ocean going commercial traffic are summarized in Figure 8-2 and are segregated between U.S. and foreign flag. These benefits are derived from the fuel, operations and arrival scheduling savings and include traffic both to and from the Hawaiian Islands as well as transient traffic which passes through the area. Also shown are maximum and minimum values for the base case (CENPAC) and the two alternatives. With respect to total oceanic benefits there is no apparent difference between the Kauai and Midway alternatives. The principal difference lies within the distribution of benefits to the U.S. and foreign flag vessels. In the Midway alternative maximum benefit case, approximately 33 percent of the total benefits accrue to U.S. oceanic traffic, while in the Kauai alternative only 25 percent accrue. In the minimum cases, similar ratios prevail. In the CENPAC configuration, only 15 percent of the U.S. flag traffic is covered since this chain provides coverage of the western approaches to the Hawaiian Islands wherein most of the traffic is foreign flag traffic.

This distribution of oceanic traffic and benefits for the three configurations is shown in Figures 8-3, 8-4, and 8-5. In these figures the original traffic patterns in terms of origin/destination for the direct Hawaii traffic is given as a function of the traffic values. Also shown are both the individual benefits for each region as well as the totals for each configuration. The benefits comprise fuel, operations, and arrival scheduling savings for the direct oceanic traffic. Not included are benefits for through or transient traffic. Figure 8-3 shows the CENPAC chain and illustrates the displacement of coverage away

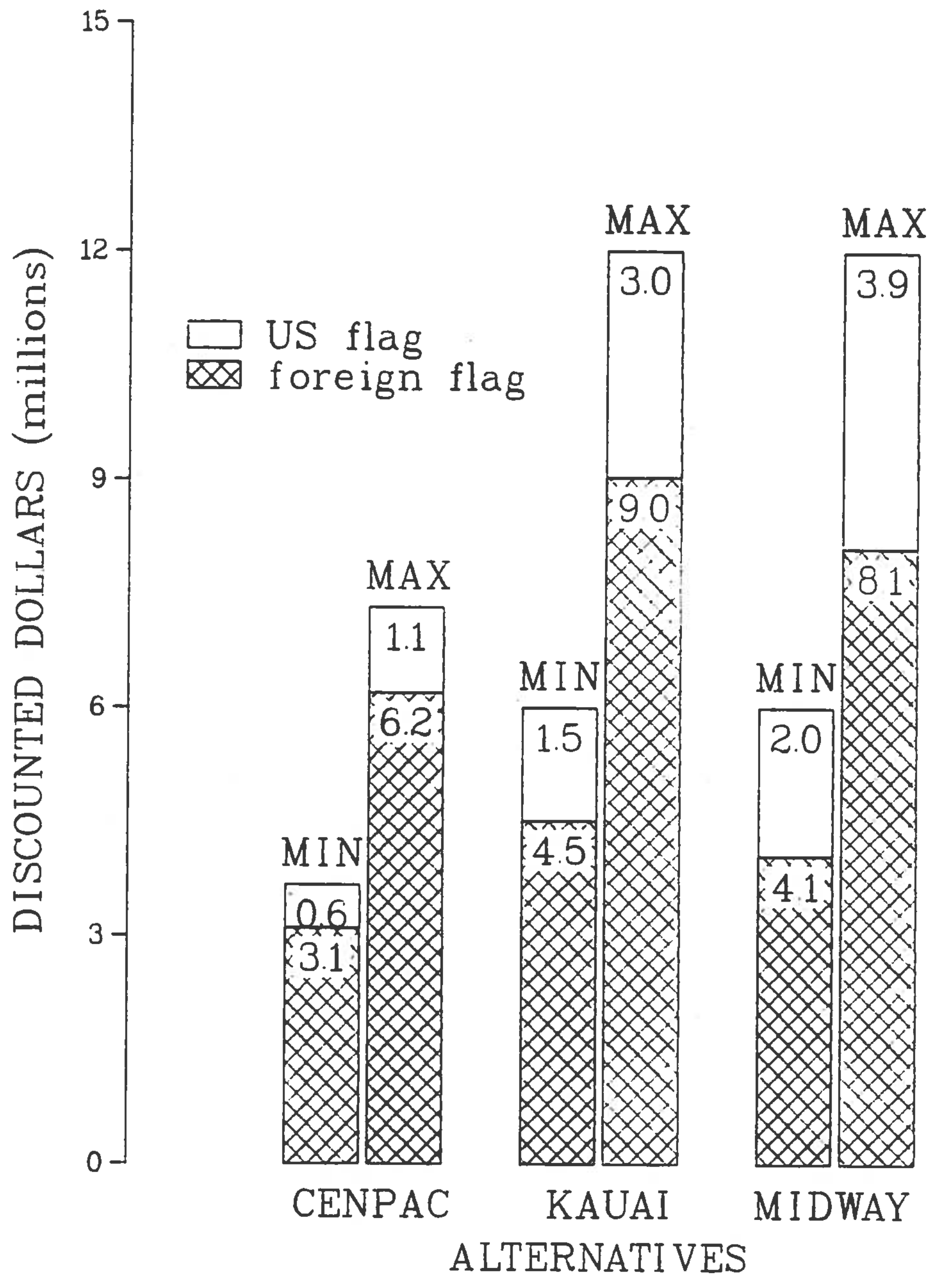



FIGURE 8-2
TOTAL OCEAN TRAFFIC BENEFITS
(Cumulative through Year 2000)

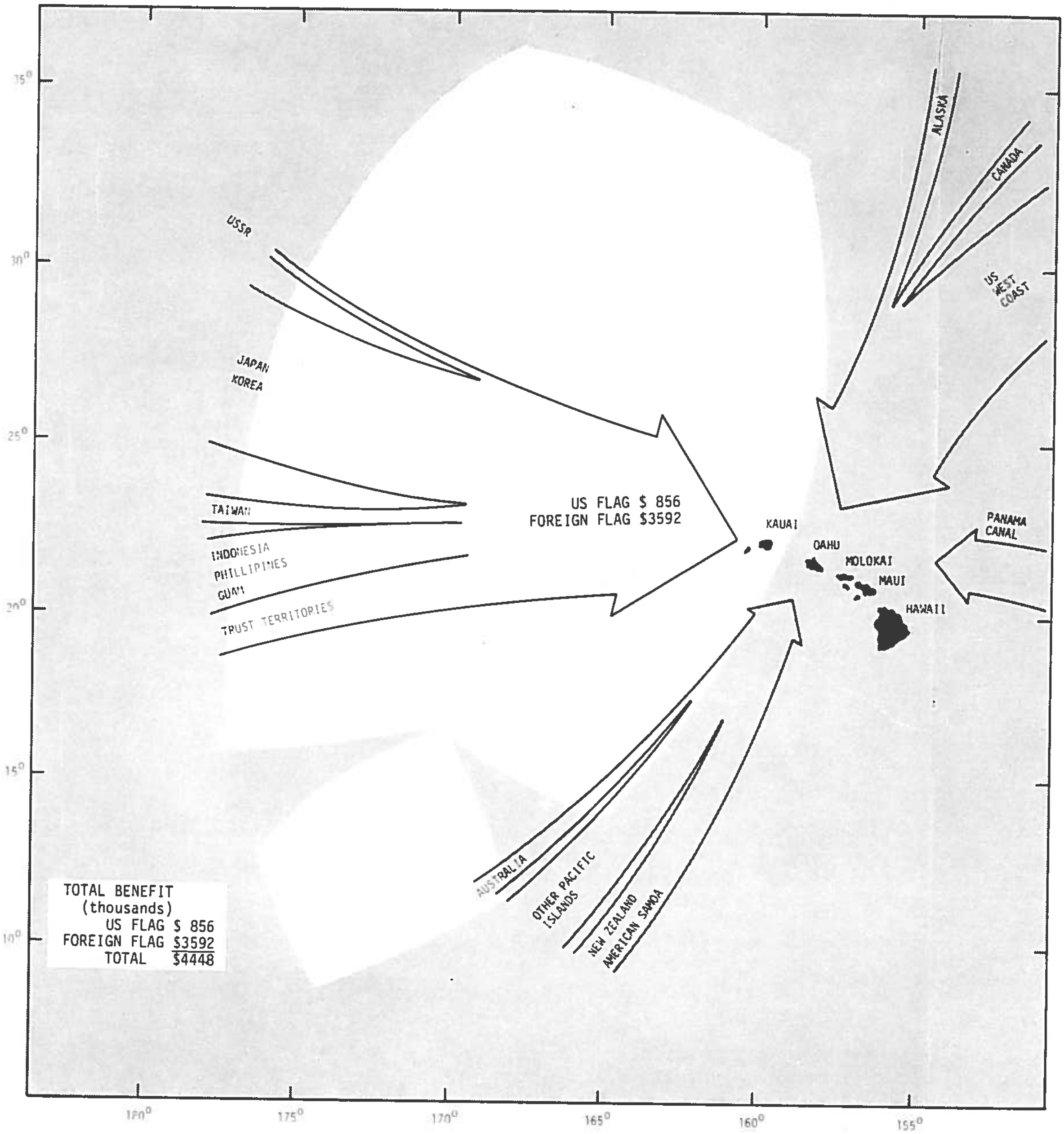



FIGURE 8-3
CENPAC CHAIN - OCEANIC BENEFITS
(Direct Traffic Only)

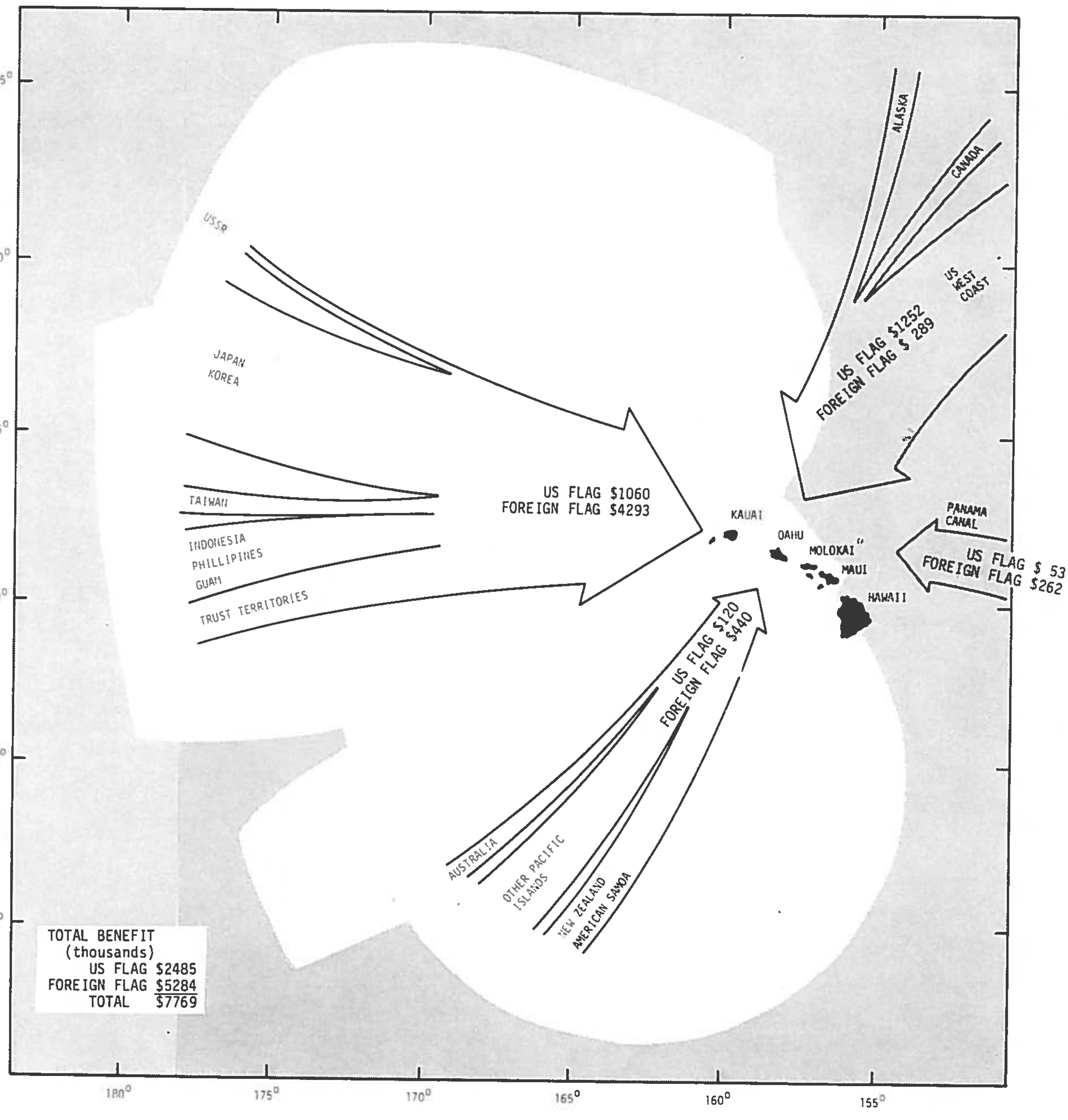



FIGURE 8-4
KAUAI RECONFIGURATION - OCEANIC BENEFITS
(Direct Traffic Only)

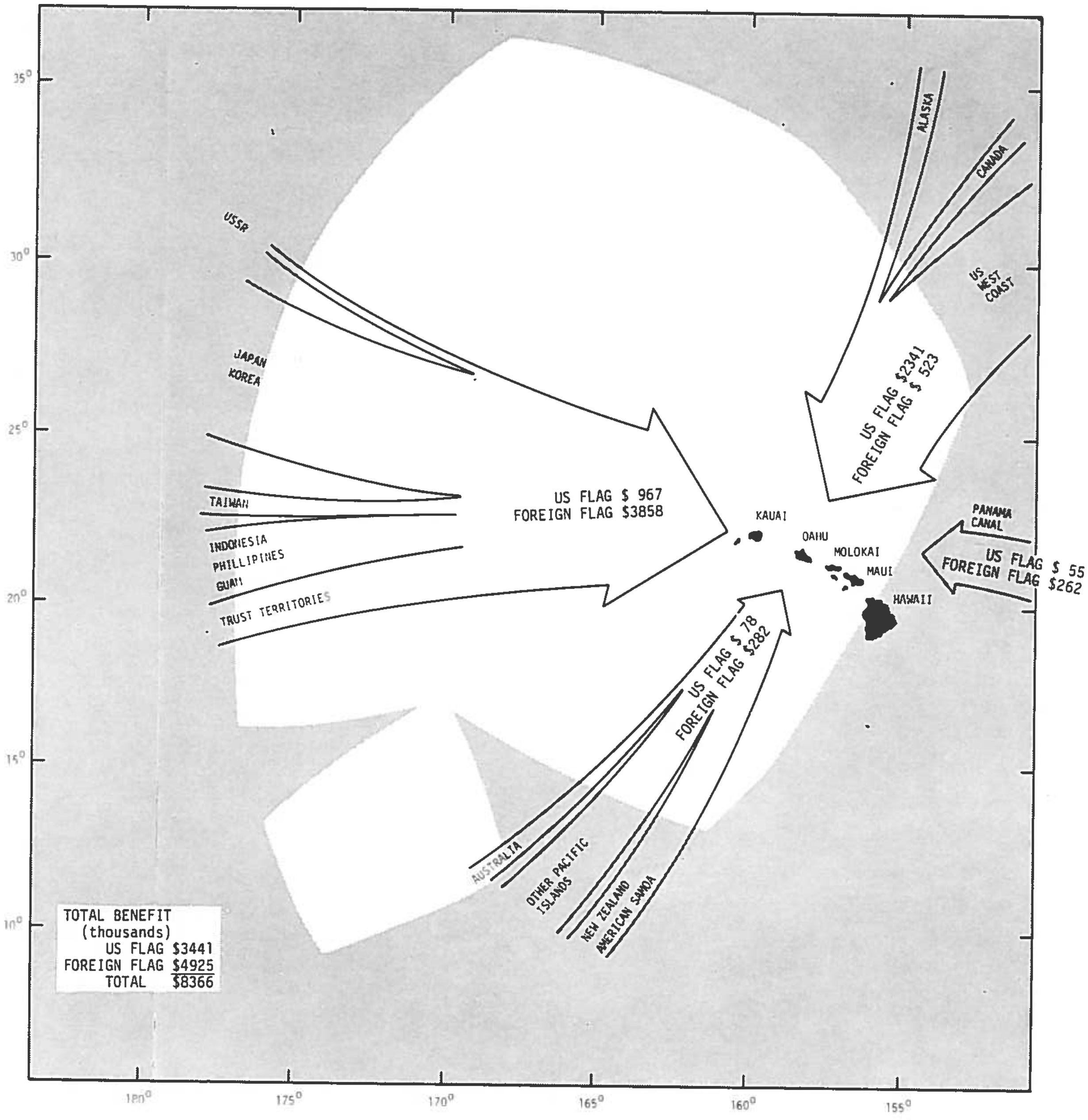



Figure 8-5

MIDWAY RELOCATION - OCEANIC BENEFITS
(Direct Traffic Only)

from the principal islands in favor of Western Pacific-FarEast traffic. As can be judged from the size of the arrow the Western Pacific compises over 50 percent of the Hawaii traffic. The benefits for this traffic amount to $3.6 million with less than 20 percent applicable to U.S. flag vessels. No benefits are ascribed to mainland U.S., Panama Canal, or South Pacific traffic.

Figure 8-4 shows the Kauai Reconfiguration coverage vis a vis the oceanic traffic as defined above. As can be seen, the principal additional regional coverage is for the South Pacific traffic, however, since this traffic is light, less than $1.0 million accrues to this area. The Western Pacific regional benefits also increase slightly since coverage from this configuration is extended 300 miles to the west. Further, there is a small amount of coverage of the North American and Panama Canal traffic. Even though this coverage is slight, the North American benefits are significant due to the relatively large traffic flows from and to this region. Approximately $1.6 million in benefits accrue to this traffic. Overall the total oceanic benefits are nearly $7.8 million with foreign flag vessels comprising the principal category of beneficiaries.

The impact of the Midway alternative upon direct oceanic traffic is shown in Figure 8-5. Due to the eastward movement of the coverage area, this configuration provides slightly greater coverage of and benefits to the Western Pacific traffic as compared to the CENPAC chain. As compared to the Kauai reconfiguration, these regional benefits are less. Further, the Midway alternative also provides coverage of the South Pacific and North American traffic. With respect to the South Pacific traffic, the benefits from this coverage are less than the Kauai alternative since this latter alternative provides substantial coverage in a southerly direction. On the other hand, the North American traffic is the principal additional beneficiary of the Midway expansion because this coverage is moved sufficiently far to the east to capture the major northeast-southwest trade flows. The benefits to the North American traffic amount to nearly $3.0 million of which over 80 percent accrues to U.S. flag traffic. Further, the total Midway benefits amount to over $8.3 million which makes it the more promising alternative in terms of absolute values.

Recalling that the results derived from Figures 8-3 through 8-5 refer to direct Hawaii oceanic traffic, the effect of transient or through traffic must be added to complete the total oceanic benefits. Incorporating these additional benefits increases the total to the results shown in Figure 8-2 such that the two alternatives then appear identical. This illustrates the fact that the alternatives must be examined in detail in order to derive conclusions as to their relative utility. What may appear at first to be a series of indifferent results will, upon disaggregated examination, reveal the preferred alternative.

### 8.4.2 Total Benefits

The distribution of the benefit elements among the three coverage configurations is given in Figure 8-6. This figure shows the similarity between the Kauai and Midway alternative and emphasizes the fact that little difference exists between the two, both in terms of the aggregate results and the main elements comprising these totals. The principal difference among the three alternatives is that the Kauai and Midway alternatives provide substantially greater benefits than does the CENPAC chain.

As discussed previously, it is only by detailed examination of each of these elements that the true differences between the alternatives be discerned. The results in Figure 8-6 also show the substantial role that fishing benefits play in the determination of maximum benefits. Further, the differences in the fishing benefits between the maximum and minimum cases serve to highlight the uncertainties that exist within these data. This is due to the two different approaches used in determining the benefits.

Another measure of system worth consists of the benefits per square mile of coverage. The results of this determination are given in Figure 8-7. In this figure, the Midway alternative appears as the most favorable as compared to the Kauai and CENPAC configurations. In terms of actual benefit values, both Kauai and Midway are similar. However, since the Kauai alternative has greater coverage, the benefits per square mile favor the Midway alternative.

A third approach to the analysis of total benefits is the benefits per vessel mile. This measure addresses the dynamic interaction between number of vessels in the coverage area and the distance they travel and may be a truer measure of relative system utility. The results of this approach are shown in Figure 8-8. In these results vessel miles consist of the sum of the distances travelled by all of the vessels in the coverage area through the year 2000. Included in the vessel miles are not only the oceanic traffic, but also the interisland traffic and fishing operations as well. This number is then divided into total benefits to give benefits per vessel mile. In Figure 8-8 the Midway alternative appears as the most promising configuration because of the greater amount of traffic covered. Further, the Midway alternative is more attractive because of greater diversity of traffic in the coverage area. Due to the geometry of this configuration, benefits are provided to a significant amount of North American traffic without a substantial loss of coverage to Western Pacific or Southern Pacific traffic. In both the Kauai and Midway alternatives, coverage of inter-island and fishing operations are similar and hence the potential benefits to these users are identical.

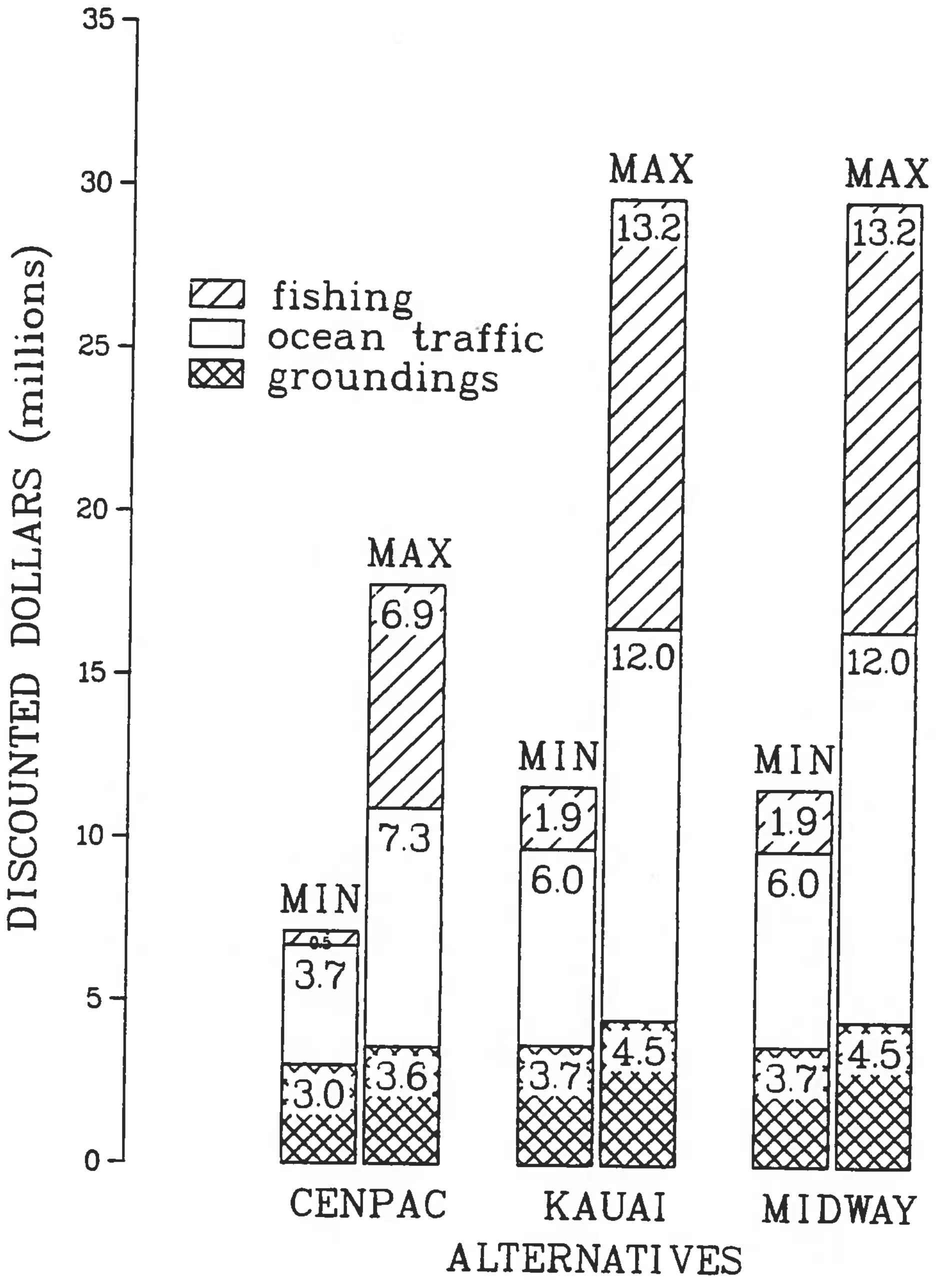



FIGURE 8-6
DISTRIBUTION OF BENEFITS
(Cumulative through Year 2000)

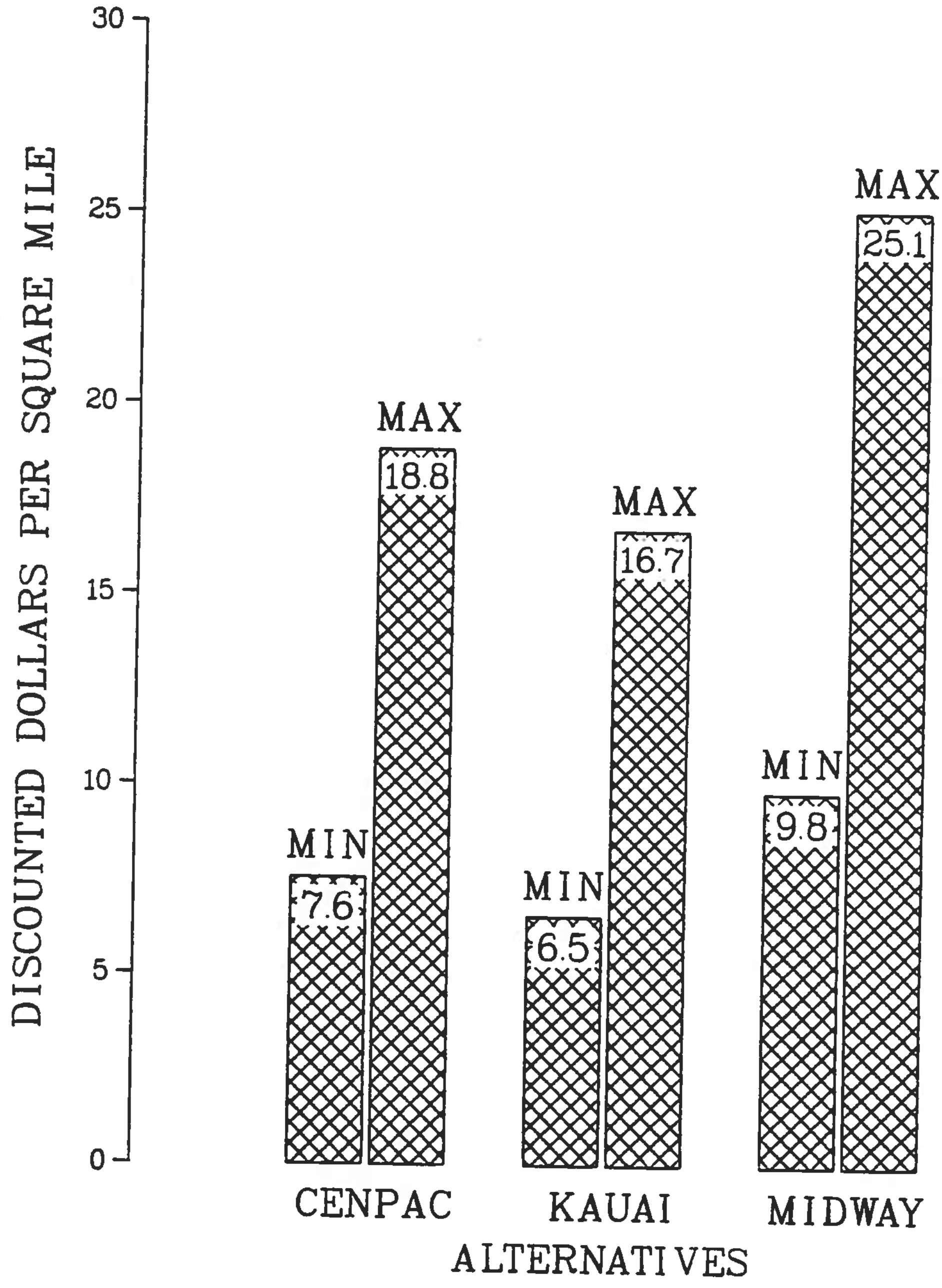



FIGURE 8-7
BENEFITS PER SQUARE MILE
(Cumulative through Year 2000)

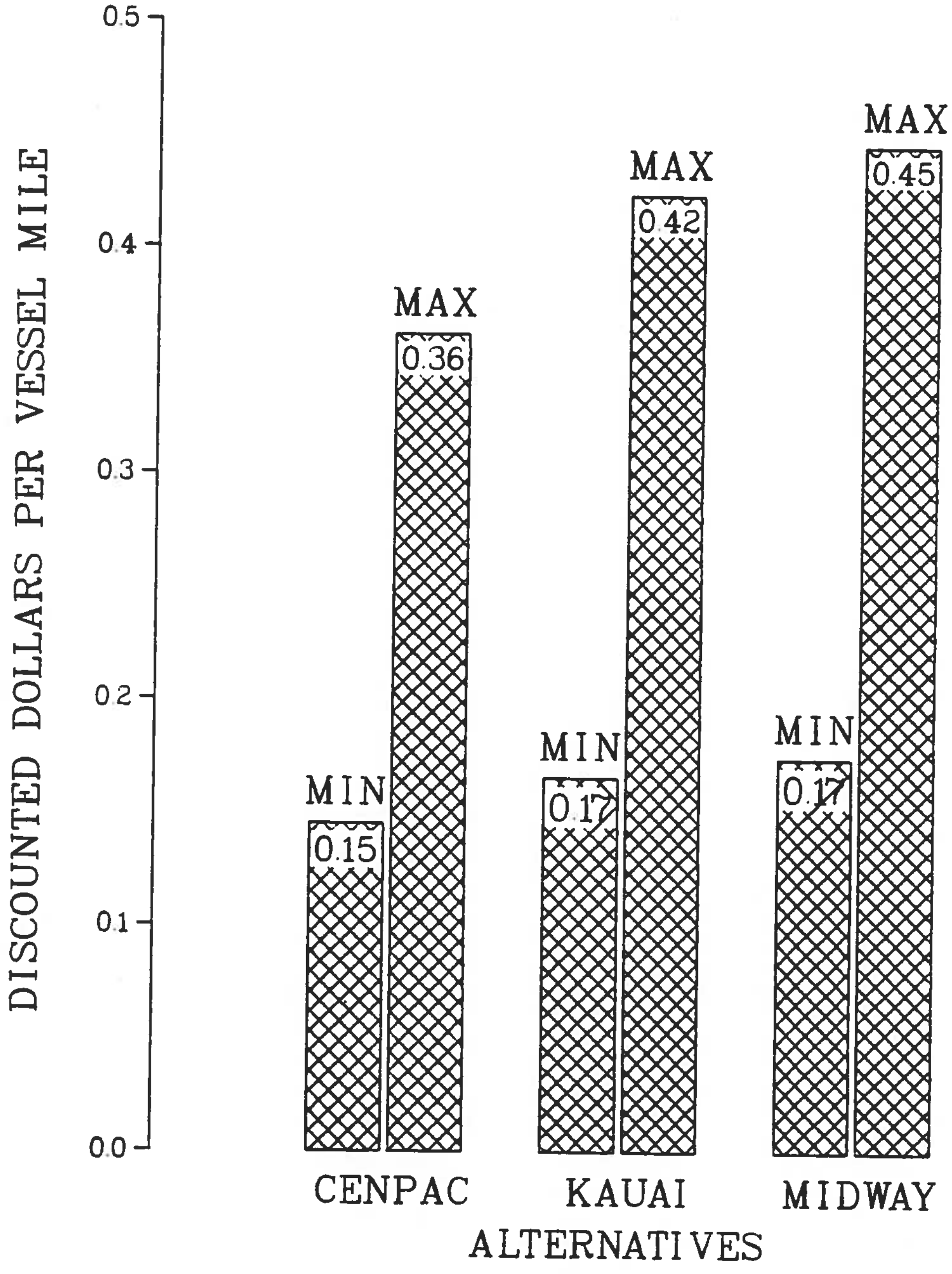



FIGURE 8-8
BENEFITS PER VESSEL MILE
(Cumulative through Year 2000)

With respect to the minimum benefits for all three alternatives, the results are approximately the same. This indicates that the coverage density as defined by dollars per vessel mile is similar. This similarity is due to the fact that although there is a large increase in benefits for the Kauai and Midway alternatives with respect to the CENPAC chain, there is a correspondingly large increase in vessel traffic covered. Similar conclusions can not be drawn with respect to the maximum benefits since fishing operations contribute disproportionately larger benefits to the results and increase the coverage density.

## 8.5 Qualitative Benefits

In addition to those quantified LORAN-C benefits and savings identified above, there are certain qualitative benefits which contribute to the overall well-being of the mariner on the open ocean, out of sight of land. Chief among these is the assurance that the vessel's location can be accurately and rapidly determined. Further, there is the assurance that in times of distress, the location provided by such a system (either in Latitude and Longitude or in time-difference coordinates) can be broadcast to search and rescue elements, and will provide a reference point for the initiation of the rescue mission. Such an attribute is of particular benefit to the recreational boater whose skills in navigation may not be as great as those of the seasoned mariner, particularly in times of stress and distress.

The political benefits associated with radionavigation cannot be measured, however, they can be significant. Generally, the availability of a radionavigation signal is not discriminatory, and can be used by any mariner with the proper equipment. As such, this signal reflects the presence of the originating country and provides a constant reminder of the country's contribution to international safety at sea. While the worth of such benefits can not be measured, the availability of a LORAN-C signal may provide a measure of international good will in the Central Pacific area and serve as tangible evidence to all users of the role of the United States in promoting maritime safety and commerce.

# 9. COAST GUARD OPERATIONS AND BENEFITS

## 9.1 Introduction

The requirements for and the effect of LORAN-C expansion on Coast Guard operations in the Hawaiian Islands are discussed in this section. Only those elements of the Coast Guard mission which will be affected by improved navigational accuracy are considered. Where those effects can be quantified in terms of benefits as measured by cost savings or personnel reductions, these missions are discussed in detail. Other effects which serve to improve the Coast Guard's mission are indirect benefits, not as readily quantifiable and require a detailed operations analysis of missions, effectiveness, and accuracy in greater depth than possible in this study. In addition, there are certain disbenefits which relate negatively to navigation improvements through constraints on operational effectiveness. These effects are also considered.

## 9.2 Central and Western Pacific Operations

The area of Coast Guard operations in the Central and Western Pacific extends from the Hawaiian Islands westward to Guam and the Northern Marianas Islands and southward to American Samoa. (Figure 9-1). While the Hawaiian Archipelago is the region of particular interest, the Coast Guard also has mission responsibilities in the various islands and atolls scattered through the region. Included in these latter areas are Howland and Baker Islands, Wake Island, Palmyra Island, Jarvis Island and Johnston Island. Altogether, this region encompasses 1.5 million square miles. Of these areas, currently the only regions with LORAN-C coverage are the Hawaiian Archipelago and Johnston Island. None of the above areas would be added if LORAN-C coverage were to be expanded, although Palmyra Island would be on the periphery of the coverage from the Kauai alternative.

Coast Guard Operations in this area are under the cognizance of the Commandant Fourteenth Coast Guard District, Honolulu, Hawaii. Coast Guard facilities are at the Coast Guard Base in Honolulu; Coast Guard Air Station, Barbers Point, Oahu; and Coast Guard stations at Kauai and Pago Pago. There are LORAN stations at Upolu Point, Hawaii, Johnston Island, and Kure Island as well as the stations comprising the Northwest Pacific chain. The resources available consist of 2 High Endurance Cutters at Honolulu; 3 Buoy Tenders, 2 at Honolulu, one at Guam; 3 - 95 ft Patrol Boats, one at Hilo, Hawaii, one at Maalaea, Maui, and one at Honolulu. In addition there are utility and patrol boats of various sizes and capabilities at Honolulu, Kauai, Pago Pago, and Guam. The aircraft in the area are based at Barbers Point and consist of 3 HC-130B long range patrol aircraft and 2 HH-52A Helicopters.

The principal areas of operation for those units include all of the above regions as well as Alaska Patrol deployment for the High Endurance Cutters. Further, extended search and rescue

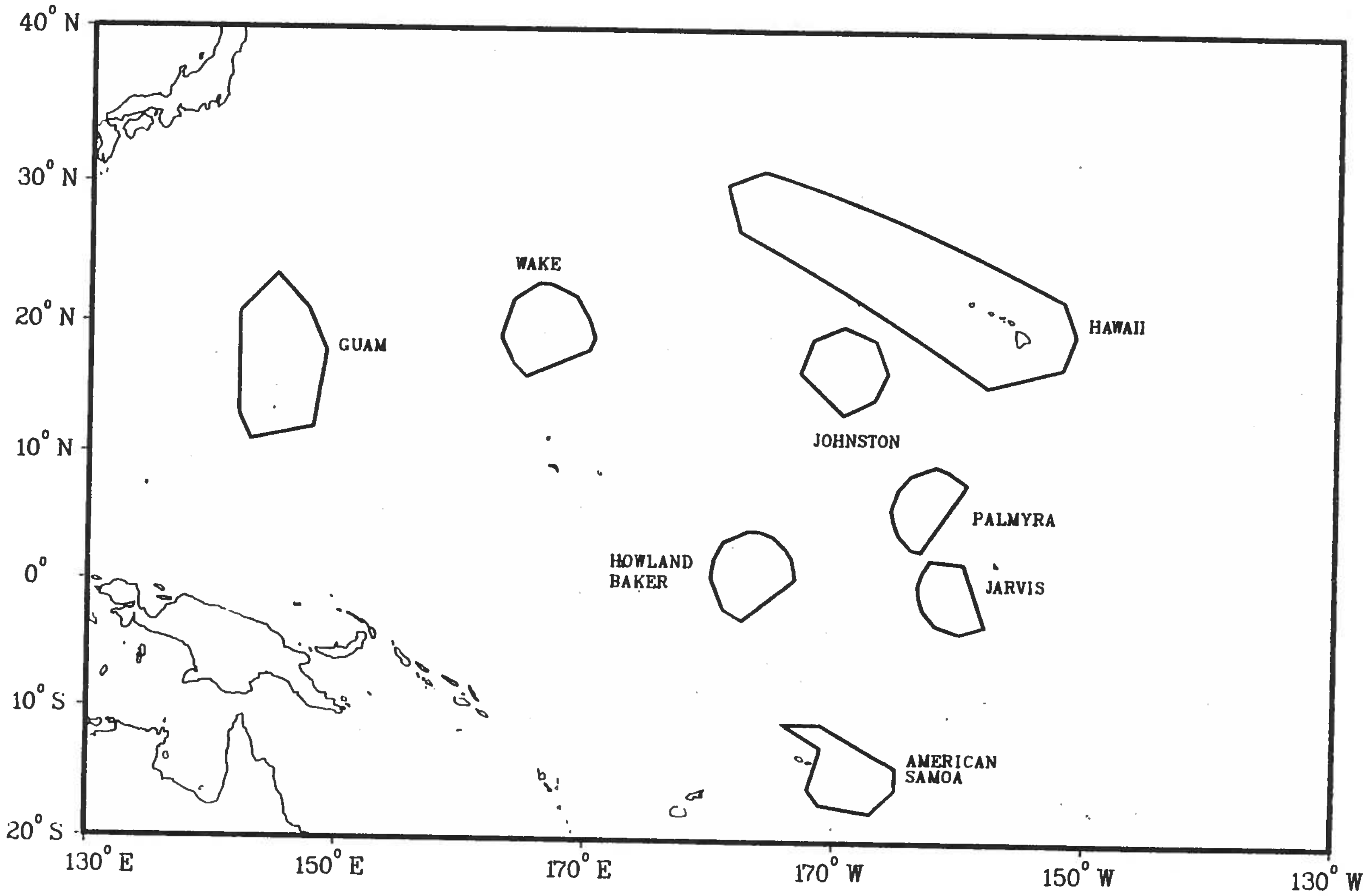



FIGURE 9-1
COAST GUARD FOURTEENTH DISTRICT
MAJOR FISHERY CONSERVATION ZONES

missions may encompass additional areas during these operations. With respect to resource allocation by mission, the principal aviation and small surface vessel effort is in support of search and rescue. The Enforcement of Laws and Treaties (ELT) mission mainly consists of fishery conservation responsibilities, particularly patrols of the northwest Hawaiian Islands and adjacent seamounts. Other elements of the enforcement mission such as drug interdiction and blocking operations in the major interisland passages similar to those in the Windward and Mona Island passages in the Caribbean are non-existent. Protection of the marine environment such as oil spill and ocean dumping surveillance constitute a limited allocation of effort and such missions as do exist are in combination with operations and training missions. There is a bi-weekly logistics/resupply mission to the LORAN Station at Kure which is conducted as part of the fishery conservation patrol of the northwest Hawaiian Islands.

Based on discussions with the commanding officers, executive officers, and operations officers (Appendix F) of Coast Guard surface operating units, it appears that the principal means of electronic navigation for Coast Guard vessels in the Hawaiian Islands is radar with LORAN-C as backup. Outstanding radar reception is reported when in the vicinity of the principal islands due to the steep and well defined topography of the islands which serves as an ideal radar reflector. Sometimes a single LORAN-C line of position is used in conjunction with a radar or visual bearing particularly to the east of Oahu. The High Endurance Cutters report utilization of the groundwave LORAN-C signal from the Central Pacific chain up to 1000 miles to the north of Honolulu and as far to the west as the Midway Islands. All units report using LORAN-C extensively to the west of Hawaii. Omega is used for open ocean navigation and in areas of limited LORAN-C coverage, however, atmospheric interference at sunset and sunrise tends to limit its utility during these periods. Although Omega receivers are installed aboard the 95 ft patrol vessels, they are rarely used except when operations extend beyond 50 miles from shore.

With respect to aircraft operations, the HC-130B aircraft have self-contained navigational systems aboard with LORAN-C used as backup. The principal mode of operation is to use the inertial system until LORAN-C fix has been acquired and then to reset the former system to the LORAN-C position. Thereafter, LORAN-C is used to monitor the performance of the inertial system. LORAN-C has been installed aboard the HH-52A helicopters but has subequently been removed from one of the aircraft due to its limited utility. Due to the limited range of these helicopters they tend to operate in the near offshore region, generally outside of the LORAN-C coverage area. They are scheduled for replacement in FY82 with H-65 helicopters, the latter units to be equipped with self-contained navigational packages.

## 9.3 Search and Rescue (SAR) Operations and Benefits

The magnitude of the Search and Rescue effort in the Hawaiian Islands is defined in absolute terms as the number of responses by the units of the Fourteenth Coast Guard District and in relative terms by the percent of service-wide workload. It is also defined by the ranking with respect to all Coast Guard Districts. These statistics (Reference 28) indicate that the level of search and rescue incidents as measured by the number of responses is last or next to last among all the districts. In terms of percent of the service-wide workload, similar results prevail. Slightly over one percent of the total Coast Guard search and rescue effort is centered in the Hawaiian Islands. While the reasons for these relatively few incidents are many and varied, undoubtedly the favorable weather conditions and the low level of recreational boating contribute significantly. While the SAR workload for this area is minimal and the operating conditions favorable as compared with service-wide experience, the large area of responsibility for the Fourteenth Coast Guard District can tax the ability of the responding unit to perform. This performance can be measured in terms of search plan adherence and on station endurance. Optimization of resources, while a critical element in any mission, is even more critical when large ocean areas are involved. Thus, any means of improving unit capability in terms of navigability or on station accuracy is desirable in enhancing overall operational effectiveness.

The role of improved LORAN-C coverage was examined for its effect on the SAR capability of Fourteenth District units. Because surface units have alternate means of navigation such as radar and Omega, and because the principal means of navigation of the HC-130B are self-contained inertial systems, only the HH-52A helicopter operations were considered for possible cost savings due to improved navigational capability. As this analysis progressed however, it was learned that the HH-52A helicopters were scheduled for replacement in FY82 with the longer range, longer endurance, and more modern H-65 helicopters. These latter platforms are equipped with self-contained navigation packages and thus the requirement for improved navigation capability in helicopter operations which may have existed with the HH-52A apparently has been met. Therefore no quantitative benefits have been ascribed to this area of Coast Guard operations.

Certain qualitative benefits due to increased LORAN-C coverage can be assigned to the SAR mission. These benefits include improved positional knowledge on the part of the distressed vessel, thereby providing a more reliable datum or initial search point with greater certainty and subsequent significant reduction in the search effort. Further, such improved navigational information may contribute to the prevention or attenuation of the severity of the incident altogether. Finally, system redundancy, while an incommensurable element in the navigation problem, provides a psychological and actual reassurance of location both to the searching as well as the distressed unit.

These qualitative benefits, while not measurable, nevertheless serve to improve overall mission effectiveness.

Because the analysis of HH-52A had been completed, these results are included as indications of the magnitude of the benefits which could be attributed to improved navigational capability. Further, these benefits also represent one element of cost savings due to platform replacement and upgrading. These results are not included as part of the overall benefits discussed in Section 8.

The HH-52A is the principal helicopter utilized in SAR operations in the Hawaiian Islands. This platform is of moderate range and capability, with maximum speed of 105 knots and an optimum endurance of 3.0 hours. Because of these operating characteristics, its most frequent utilization is for close inshore searching and for rescue and recovery operations in conjunction with other units. A typical SAR operation with the HH-52A would involve the assignment of the major search mission to an HC-130B or surface vessel. After contact had been made, the helicopter would be vectored in for recovery and evacuation. For purposes of this analysis it was assumed that improved navigability would permit the utilization of this helicopter for searching as well as recovery in near offshore areas so that the HC-130B might be released for other operations. In this analysis the near offshore region was defined as between 10 and 50 nm offshore such that the HH-52A could fly a search pattern or remain on station for an hour or more and still have adequate fuel for return.

A review of the SAR files was made at the Fourteenth Coast Guard District to develop a data base of incidents where an improved navigation capability and aircraft substitution might be applicable. As part of this review process, only incidents in which aircraft participated or could have participated were included. Missions such as medical evacuation were also eliminated. Further, the location of the remaining incidents were then examined to determine if they occurred within the current CENPAC LORAN-C coverage area, and further, if they would have occurred with the coverage to be provided by either the Midway or Kauai alternatives. The results of this analysis are shown in Figure 9-2 for the two years examined, 1977 and 1978.

From this figure, it can be seen that few incidents occur within the CENPAC coverage area (less than 50) and even fewer are between 10 and 50 nm offshore (less than 15). On the other hand, had LORAN-C been expanded, the number of incidents in the coverage area would have been approximately 450. Of these incidents, 20-25 percent occured beyond 10 miles offshore. These data were subsequently used for the determination of benefits through improved navigability.

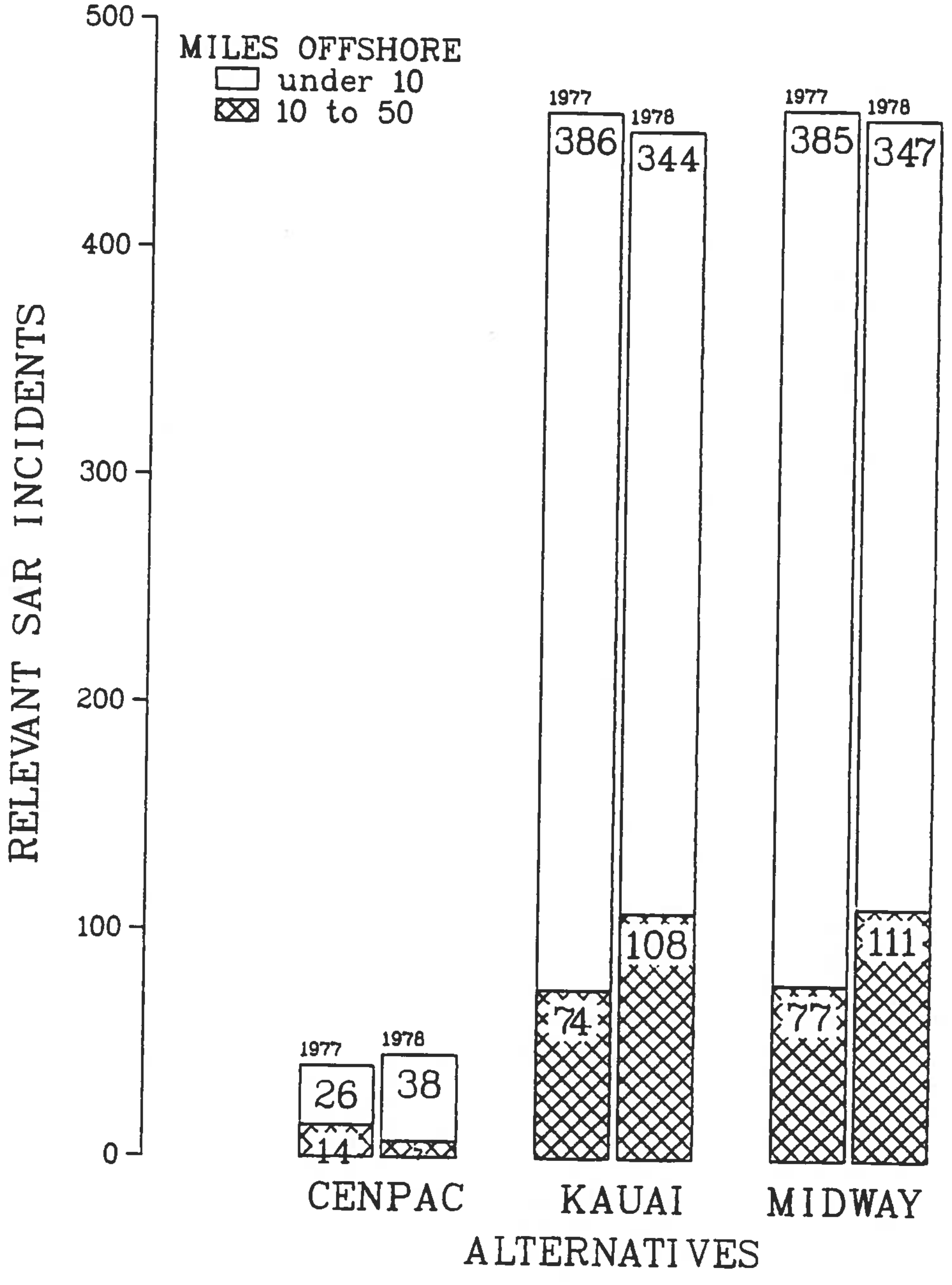



FIGURE 9-2
RELEVANT SAR INCIDENTS
1977 - 1978

Two benefit areas were considered in this analysis. The first involves the savings from the substitution of HH-52A for HC-130B aircraft in certain missions. The second benefit area includes savings from the reduction in the amount of effort required to obtain a given level of mission effectiveness due to improved helicopter navigational capability. The savings due to the substitution of HH-52A for HC-130B were derived from the following assumptions. Some SAR sorties use HC-130B aircraft for initial searching followed by vectoring of the HH-52A aircraft to datum after contact has been made. With improved navigational capability, some of the HH-52A's can be used for searching instead of the HC-130B's. The assumptions for the substitutions of aircraft were derived from an analysis of the allocation of aircraft to the various sorties. For the single sortie case, it was assumed that half the missions were flown by HC-130B's, half by HH-52A's and that no substitution could be made. For the two sortie case, it was assumed that the mission was equally divided between the two types of aircraft and that in half of the cases involving HC-130B's, the aircraft could be replaced with a HH-52A. From these assumptions a coefficient of substitutability was determined. This coefficient (0.31) was then applied to the number of relevant cases shown in Figure 9-2 for the LORAN-C alternatives. The result was the number of cases in which helicopters could be substituted for HC-130B aircraft.

Using the average number of sortie hours per year for fixed wing aircraft and helicopters, equivalent replacement hours for the two aircraft were determined. Since the operating costs both in fuel expenditures and O&M costs for the helicopters are considerably less than the HC-130B's, savings could be achieved though substitution of one aircraft type for another. These savings were determined on an annual basis. Number of incidents was inflated to reflect a projected increase in recreational boat population as indicated in Section 5. and Appendix E. Since over 80 percent of the SAR incidents involve recreational boats and there is direct relationship between increase in recreational boating and number of SAR cases, such a projection is a reasonable approximation of future realities. The results of this analysis are shown in Figure 9-3. These results are cumulated through the year 2000 under the assumption that these or equivalent aircraft types will be employed through the projected system life. The benefits attributable to aircraft substitution are approximately $1.2 million for the Kauai and Midway alternatives and are indicative of the magnitude of savings which may be achieved either through LORAN-C expansion or the employment of helicopters with self-contained navigation systems.

The other contributing element to SAR benefits is the effect of improved navigational capability. This benefit is measured by the savings in effort required to achieve a desired level of mission effectiveness. In this case, mission effectiveness is defined as the probability of detection (POD). While the relationship of navigational accuracy to the SAR mission is the subject of continuing studies and experiments, flight tests have shown that by utilizing LORAN-C, a 78 percent POD can be obtained with an increase in efficiency of approximately 31 percent as compared to navigation by dead reckoning (Reference 29). While these results are experimental, they are used in this analysis to obtain order-of-magnitude estimates which may be attributable to navigational improvements.

The numbers of incidents attributable to helicopter rescue expected within the LORAN-C expansion alternatives as well as those similar incidents which currently occur within the CENPAC coverage area were derived from the data in Figure 9-2. Using these data together with the average hours flown per SAR mission, the average annual helicopter utiliztion for relevant cases was determined.

These annual hours were then reduced by 31 percent to account for the savings in effort achievable with improved navigation capability. This reduction in effort was expressed in hours and the hours translated into fuel savings as well as savings in other time-related operating costs. Actual aircraft operating characteristics were used in this determination, which included burn rates as well as O&M costs. Fuel costs were assumed to inflate by 50 percent every five years using the rationale discussed in Section 7. The results of this analysis are shown in Figure 9-3 where the benefits due to an improved navigational capability are given as part of the total benefits package. From this figure, it can be seen that the major savings are derived from platform substitution rather than navigational capability and would indicate that a purchase strategy directed toward aircraft improvement rather than expanded navigation aids would be the preferred alternative. Therefore, these benefits were not included in this study.

## 9.4 Enforcement of Laws and Treaties (ELT)

The need for expanded LORAN-C coverage in the Enforcement of Laws and Treaties (ELT) mission area lies principally in the requirement for improved operational capability of the Coast Guard units involved. The quantification of these benefits is dependent upon a detailed analysis of this mission area and as such is properly the subject of a specific study oriented toward operational effectiveness and system performance. However, certain subjective conclusions can be made regarding the benefits from improved radionavigational accuracy.

The law enforcement activities of the Coast Guard include various responsibilities for the enforcement of laws concerning living resources as well as a range of acts covering controlled substances, smuggling, vessel theft and hijacking, and other activities affecting maritime law. In the Hawaiian Islands, however, the principal ELT mission is the enforcement of the Fishery Conservation and Management Act (FCMA). The enforcement of the FCMA involves frequent air and surface patrols of all active fishing areas within the Fishery Conservation Zone. The Fishery Conservation Zones (FCZ) shown in Figure 9-1 can be

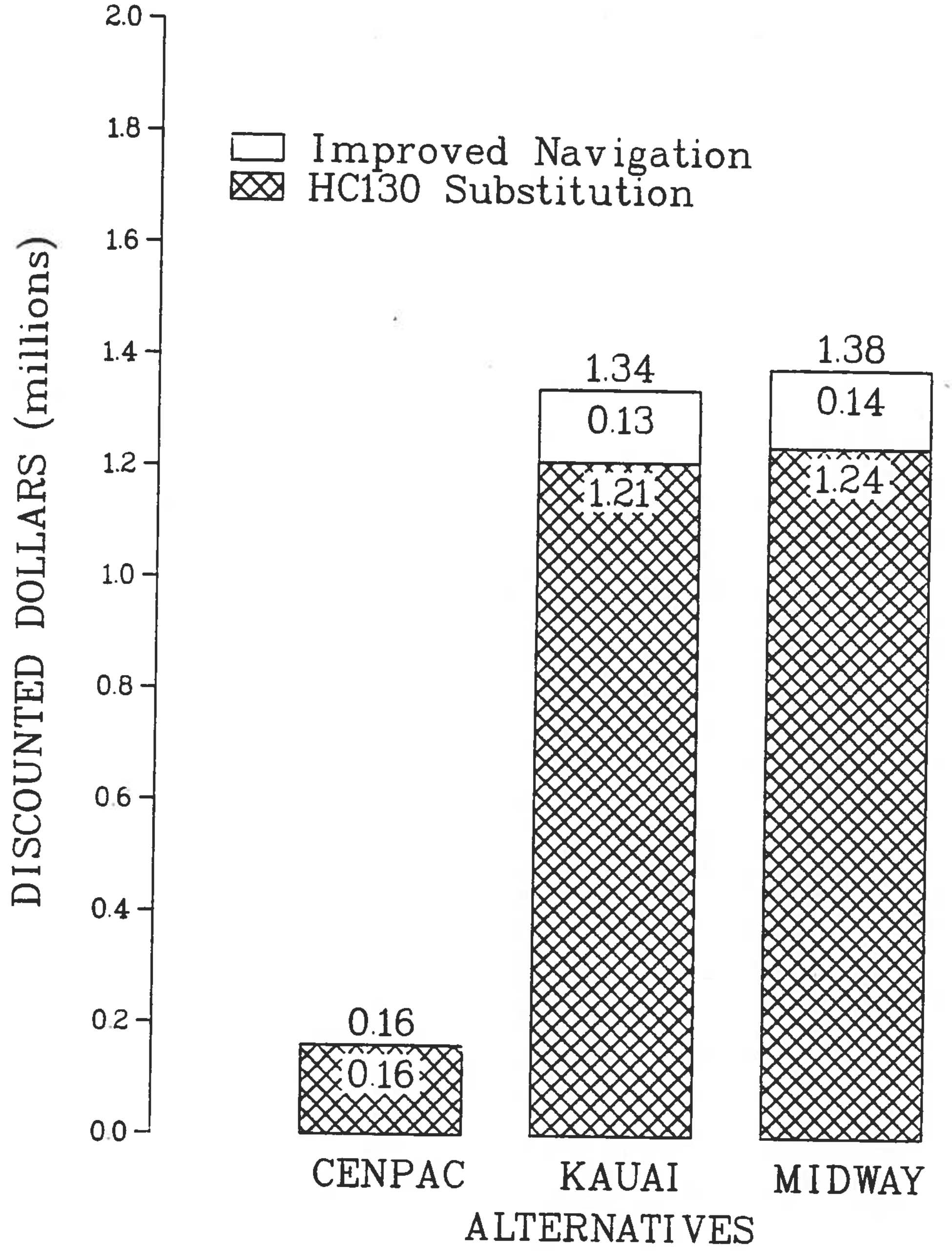



FIGURE 9-3
SAR BENEFITS

divided into two separate regions: Northwest Hawaiian Islands (NWHI), that region of the archipelago West of Necker Island; and major Hawaiian Islands (MHI), the region to the east encompassing the principal islands. Within these regions the Coast Guard has responsibility1 for enforcement of the regulations regarding the taking of Billfish and Sharks, Spiny Lobster, Seamount Ground Fishes and Precious Coral. The extent of the Coast Guard effort in these regions is shown in Table 9-1 where the resource allocation of aircraft and vessels is given as a function of region and regulated species. As can be seen, while there is a substantial enforcement effort in the Northwest Hawaiian Islands, there is also a lesser, but not inconsiderable, effort in the Major Islands.

Between 1977 and 1980 there have been five violations of the FCZ in the NWHI Region. All of these occured northwest of Kure Island at the outer extremity of the archipelago. Four of the incidents involved Japanese or Taiwanese coral draggers, one a Japanese stern trawler. Two of the incidents have been successfully prosecuted and fines levied, and one is pending. The remaining violation involved seven Japanese coral draggers who were sighted dredging for coral 194 nm northwest of Kure Island. The case was subsequently dropped since the positional accuracy of the reporting HC-130 aircraft was only good to within 10 nm.

The above discussion illustrates the requirement and benefits for improved positional accuracy in the ELT mission. Prosecution is dependent upon accurate and substantiated knowledge of the position of the violator with respect to the boundaries of the FCZ. Positional accuracy provided by LORAN-C fixes provides conclusive evidence of such flagrant violations. Thus the benefits accrue not only to enforcement vessel or aircraft through improved detection and prosecution of fishery violators but also to the fishing vessels through avoidance of inadvertent penetration and encroachment of the FCZ.

LORAN-C coverage of the NWHI portion of the FCZ is currently provided in part by the CENPAC chain. The Kauai expansion alternative would provide additional westward coverage of the NWHI out to the vicinity of Kure Island. This region is an area of considerable foreign fishing and coral dredging activity. The additional coverage would undoubtedly enhance the effectiveness of the Coast Guard's ELT mission, but as a disbenefit would improve the capability of foreign coral draggers to exploit the coral beds within the FCZ. The Kauai alternative would also provide coverage to the south of MHI. There are indications that this latter area is becoming the principal summertime foreign longline fishing region, and may cause additional enforcement problems for the Coast Guard. While the Midway alternative would not provide coverage to the west of the current CENPAC configuration it would provide coverage to the north and south of the MHI. This latter coverage area would also be supportive of the foreign longline activity. Hence, while improved LORAN-C

Table 9-1

FISHERY ENFORCEMENT EFFORT REQUIRED

| FISHERY | NORTHWEST HAWAIIAN ISLANDS | | MAIN HAWAIIAN ISLANDS | | TOTALS | |
|---|---|---|---|---|---|---|
| | AIRCRAFT HOURS/YEAR | VESSEL DAYS/YEAR | AIRCRAFT HOURS/YEAR | VESSEL DAYS/YEAR | AIRCRAFT HOURS/YEAR | VESSEL DAYS/YEAR |
| BILLFISH AND SHARK | 300 | 144 | 96 | 36 | 396 | 180 |
| SPINY LOBSTER | 150 | (144)* | 72 | - | 222 | (144)* |
| SEAMOUNT GROUNDFISH | 300 | 84 | - | - | 300 | 84 |
| PRECIOUS CORAL | 150 | (144)* | 160 | 20 | 310 | 20 (144)* |
| TOTALS | 900 | 228 | 328 | 56 | 1228 | 284 |

*Concurrent with Billfish and Shark

Source: Reference 30

coverage would not only assist the Coast Guard's enforcement activity, it may also improve foreign fishing capabilities within and outside of the FCZ.

Other activities in support of the ELT mission include at-sea enforcement of controlled substance laws, anti-smuggling laws, vessel theft and hijack, and other criminal laws involving vessels and waters subject to United States jurisdiction. Many of these laws require the boarding, search and seizure of the vessel by the Coast Guard. The authority for this activity lies in the Coast Guard's overall right to search vessels anywhere at sea in waters over which the United States has jurisdiction (14 U.S. 89). On the high seas, the Coast Guard's jurisdiction over foreign vessels is not so clear. With respect to controlled substances, the jurisdiction is derived from the Single Convention of Narcotic Drugs, 1961 and boarding requires authority from the country of registry, obtained by special request through the Department of State. Thus, the accurate establishment of the position of the enforcement vessel and the boarded vessel is critical with respect to the rapid and timely determination of the legalities of boarding and seizing. Expanded LORAN-C coverage which provides improved positional accuracy can enhance the effectiveness of the ELT mission and increase the probability of successful prosecution of offenders.

## 9.5 Marine Environment Protection (MEP)

The Marine Environment Protection Mission includes both oil spill surveillance, detection, and monitoring as well as monitoring of the ocean dumping waste. While the role of improved radionavigation could indirectly affect the oil spill detection activities through reduced groundings and diminished potential for pollution, the benefits directly accruing to the Coast Guard could not be quantified. (However, a sensitivity analysis showing the impact of a major marine disaster directly attributable to navigation deficiencies is discussed in Section 10.) Further, at present, there is no current activity in the Hawaiian Islands involving toxic waste disposal at sea. The ocean dumping program involves EPA-authorized offshore waste disposal in certain designated disposal sites. Monitoring of this activity is the responsibility of the Coast Guard. Monitoring is generally accomplished by labor-intensive methods such as aircraft surveillance, and shipriders. Under a notice of proposed rulemaking published on December 13, 1979, the Coast Guard has announced its intention to require the installation of an electronic surveillance device on vessels engaged in ocean dumping. This device, called the Ocean Dumping Surveillance System (ODSS), is based on automated LORAN-C inputs, dump station sensors and a digital recorder. The system is capable of recording the vessel movements and dump operations and can be used to electronically reconstruct a vessel's voyage thereby obviating the need for on-site monitoring. In addition, this system provides for full surveillance of dump operations.

Since there is no toxic waste disposal at sea and limited LORAN-C coverage, there is no current requirement for this system. However, if the industrial base of Hawaii expands in the future it is possible that toxic waste would be generated thereby requiring not only an ocean dumping program but also a monitoring mission for the Coast Guard. Automation of this latter activity through the ODSS would develop a requirement for increased LORAN-C coverage or restrictions to dumping in those areas where LORAN-C coverage already exists. Savings in shiprider and aircraft surveillance efforts projected for a similar system in the Eastern Caribbean (Reference 3) amounted to nearly one million dollars over a system life cycle of 15 years. It is reasonable to expect similar savings in Hawaii should such a requirement develop, however subsequent to this analysis, the ODSS Program has been cancelled.

## 9.6 Disbenefits

Heretofore the savings and improvements in mission capability due to LORAN-C coverage which have been ascribed to Coast Guard operations are the areas which benefit legitimate enterprises or government responsibilities. These benefits are positive contributions to marine safety or economic productivity. There are other areas which benefit a limited class of user and impact in a negative sense the maritime or governmental communities. These latter areas are disbenefits and serve to detract from the overall utility of the LORAN-C system. Some of these disbenefits include:

- The LORAN-C system has the characteristic of high repeatable accuracy which permits the fishing operator to return with great confidence to a known location. This characteristic can be used to its detriment to increase the exploitation of protected resources such as the more efficient and complete dredging of coral beds.

- The improved knowledge of the FCZ with respect to the vessels position permits the timing of the encroachment of the FCZ by foreign fishing vessels to be optimized to reduce the probability of detection and subsequent prosecution.

- The effectiveness of vessels engaged in contraband or smuggling activity can be increased through improved knowledge of the territorial limits vis a vis the vessel's position thereby enhancing the ability to avoid detection, search, and arrest. Further, the ability of such vessels to rendevous accurately, in darkness or in remote or isolated locales will be improved, thereby increasing the difficulty of enforcement by the Coast Guard.

# 10. BENEFIT/COST RESULTS

## 10.1 Introduction

The results of the synthesis of the benefits and costs determined in the preceeding sections are presented in this section. These results are given in two levels of detail. First, the summary results which define, in an aggregated manner, the overall merits of the three system alternatives. Second, the detailed results which provide the relative cost and benefit data of the three systems.

## 10.2 Summary Results

The overall results of the benefit/cost analysis are shown in Figure 10-1. In this figure the results of the two expansion alternatives, Kauai and Midway, are compared against the current LORAN-C configuration (CENPAC Chain). In the data given in this figure, as in all others presented in this section, the benefits relate to improved civil maritime productivity and vessel safety. The costs in both of the expansion alternatives include acquisition, construction, and installation (AC&I) as well as annual Operating Expenses (OE). In the CENPAC costs, only operating expenses are included. Since this chain is already in operation the AC&I costs are considered sunk and do not enter into the determination.

In these results, ranges of values are given to reflect the uncertainties associated with the determination of the benefits. The CENPAC chain results are shown as the shaded areas while the bounds of the expansion alternatives, including the maximum and minimum benefit values, are defined by the unshaded region. The benefit/cost ratios are cumulated over the life of the system and are shown as time streams through the year 2000.

In Figure 10-1 the benefit/cost streams for the expansion alternatives show a steep dip followed by subsequent growth. The reason for this dip is that investment costs are obligated early in the system life cycle (1983-1984) yet no additional benefits are assumed to accrue until the system expansion becomes operational in 1985. Further, during the expansion implementation the system benefits for the alternatives are identical to the CENPAC benefits, yet the costs consist of CENPAC costs plus expansion obligations.

The results shown in Figure 10-1 do not appear promising either for the CENPAC configuration or for system expansion. The CENPAC configuration even under the most optimistic assumptions provides only marginal benefits such that the payback period for system costs occurs late in the benefit/cost time stream. This is equivalent to a break-even point by the year 2000 (i.e., benefit/cost ratio of 1.0). Further, using a less optimistic and more conservative set of assumptions the CENPAC chain will not provide sufficient total benefits to equal total operating expenses (benefit cost ratio less than 1.0) during the system life cycle considered.

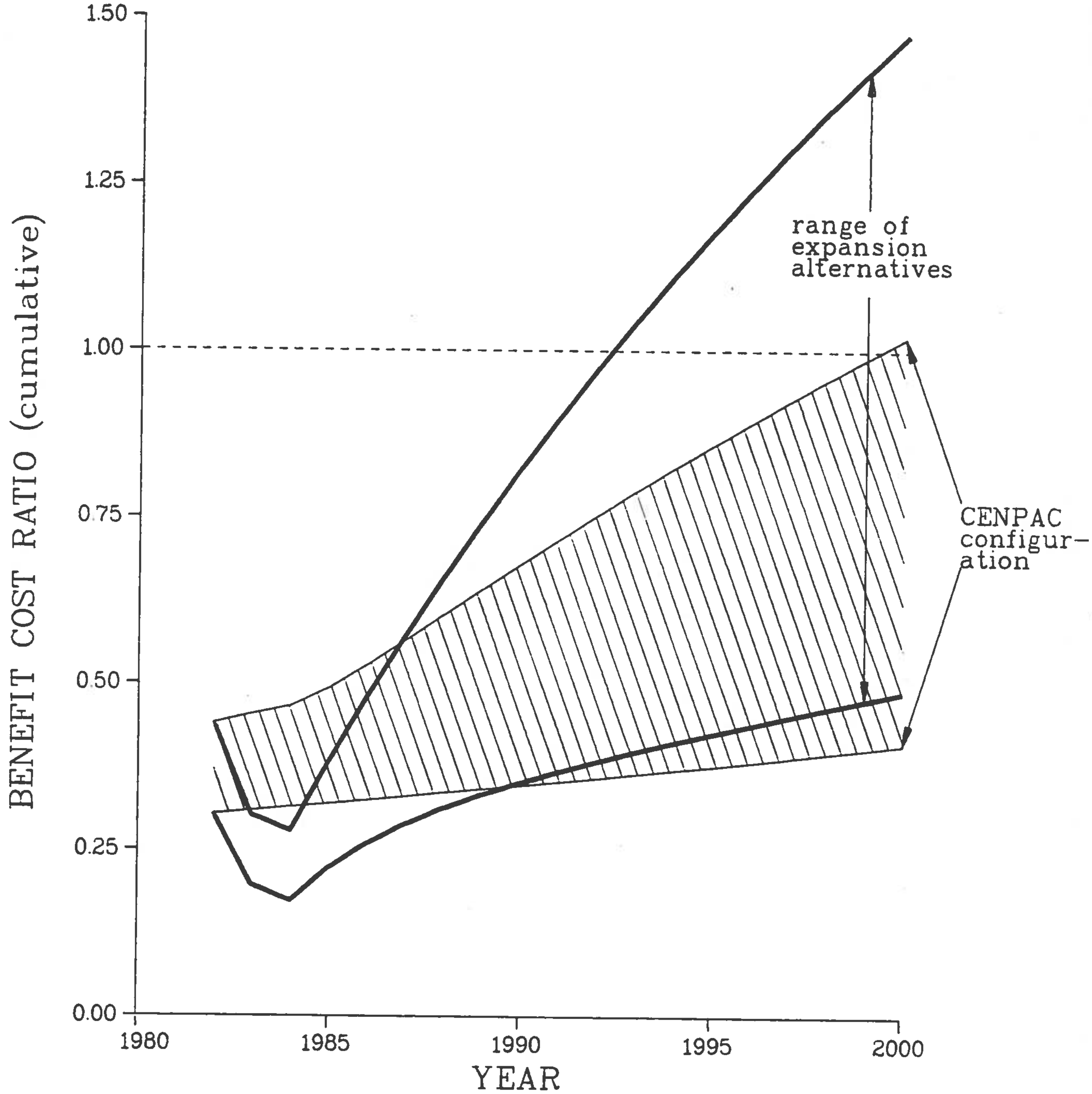



FIGURE 10-1
CUMULATIVE BENEFIT/COST RATIOS
ALL ALTERNATIVES - DISCOUNTED DOLLARS

The expansion alternatives provide an even greater range of results with benefit/cost ratios from 0.5 to 1.5. While the most optimistic expansion alternatives provide a system payback by the year 1992 the benefit/cost ratio is only marginally promising to warrant consideration for future system investment. The maximum benefit/cost ratio which was derived was 1.5 which would indicate that the total level of benefits are only 50 percent greater than cumulated investment and operating costs. The minimum values for the alternatives are even less attractive such that no payback is attained and the end result is only slightly greater than the minimum CENPAC values (0.5 vs 0.4). If benefit/cost ratios are the sole criteria used for investment decisions, none of the alternatives should be regarded as candidates for LORAN-C expansion.

Other measures of system value can be used. Figure 10-2 shows the cumulative benefits and costs as a function of vessel traffic density. In this case, vessel traffic density is expressed as dollars per vessel mile and is a measure of system value generated by vessel traffic, vessel populations and the distance that each vessel travels. In this figure, histograms of the three LORAN-C systems are shown. The shaded areas reflect ranges of values to show the uncertainties in the level of benefits. From this figure greater insights can be gained into the relative attributes of the three configurations. The Midway alternative appears as the most promising based on the total benefits per vessel mile. This would indicate that there is either greater vessel coverage or that more vessels are covered or both, than either the Kauai or CENPAC alternatives. Further, on the basis of costs per vessel mile, the Midway alternative is also the most attractive. This configuration has the least cost per vessel mile of coverage which would indicate that this system tends to cover more traffic and more or longer segments of the trade routes. The greater benefit measures and the lower cost measures associated with the Midway alternative suggest that this configuration provides greater system utility than the other configurations.

In terms of relative system coverage the comparative costs and benefits of the three alternatives are shown in Figure 10-3. In this figure the costs and benefits per square mile of system coverage are used as measures of system value. Using these criteria, the Midway alternative again is the most promising on the basis of benefits per square mile of coverage. This would indicate that the marine traffic and other users of LORAN-C would benefit most from the Midway alternative. On the other hand, in absolute terms, the Kauai alternative has the greatest square miles of coverage, while in comparative terms it has the lowest benefit per square mile. This latter benefit measure implies that the traffic density in this alternative is least. This results in a less attractive overall alternative. Further, the cost per square mile for the Kauai alternative is least and although larger areas are covered at an attractive cost per

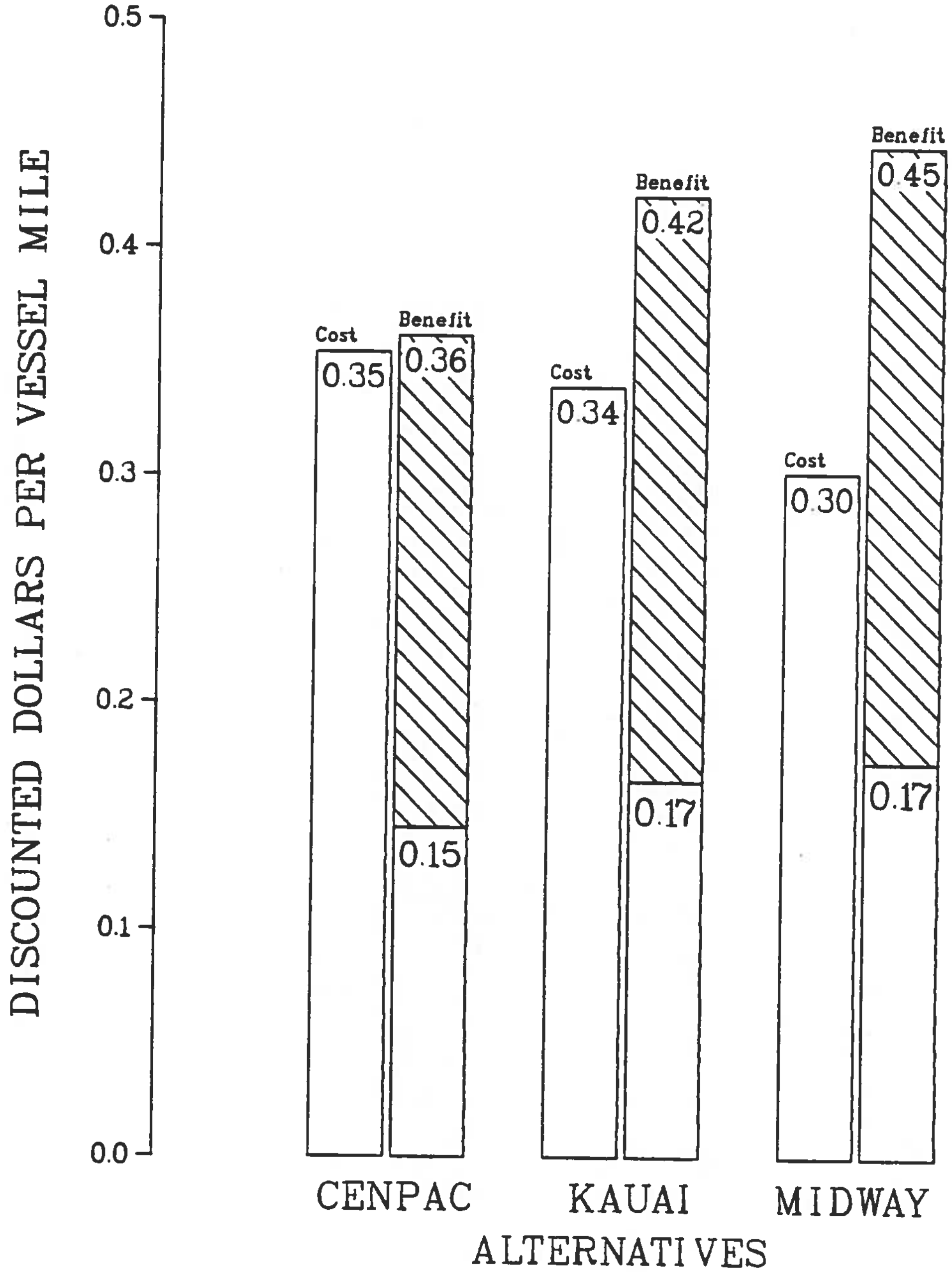



FIGURE 10-2
COSTS AND BENEFITS PER VESSEL MILE
(Cumulative through Year 2000)

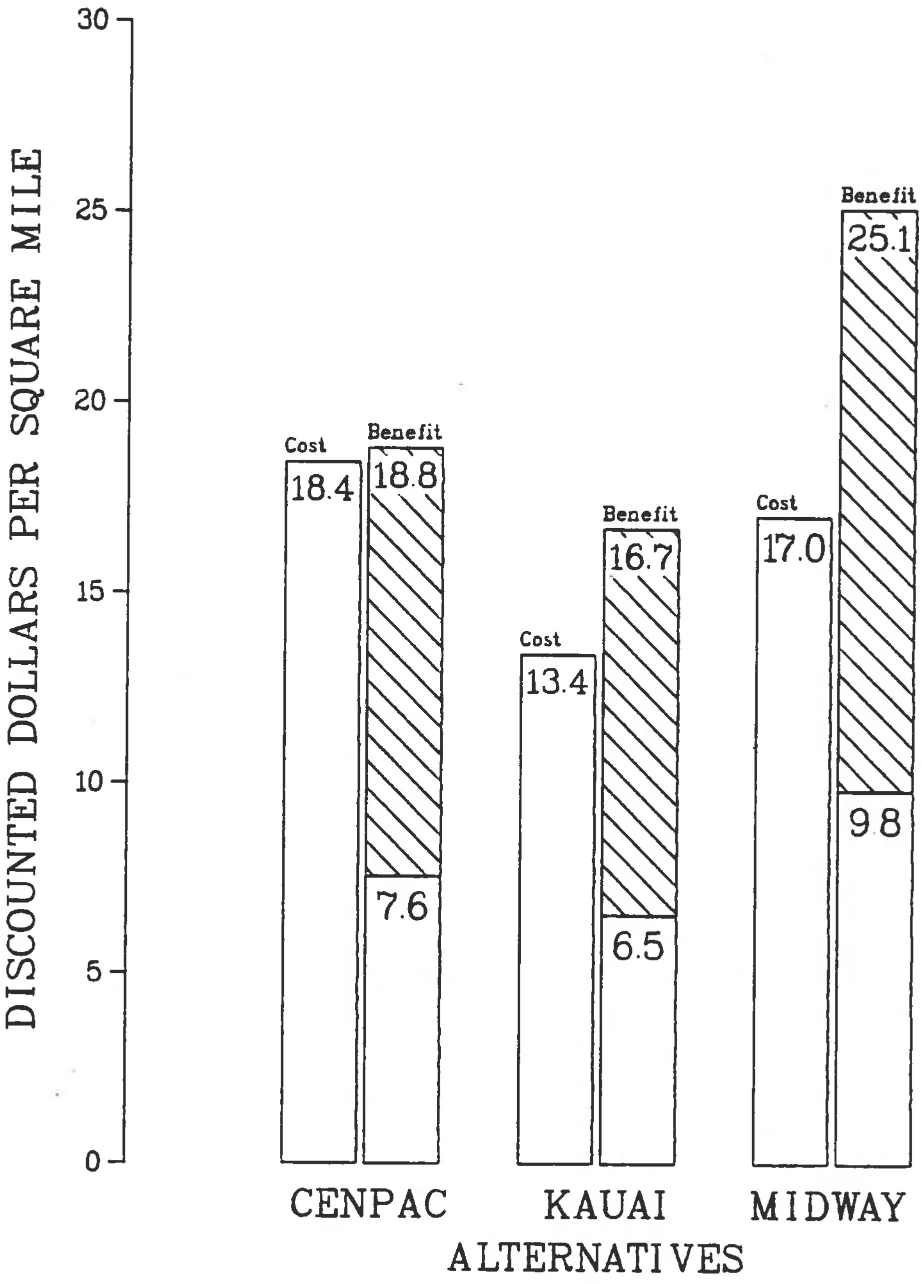



FIGURE 10-3
COSTS AND BENEFITS PER SQUARE MILE
(Cumlmulative through Year 2000)

square mile basis, the relative benefits that this coverage provides are less than the other configurations.

## 10.3 Detailed Results

### 10.3.1 CENPAC Configuration

The cumulated system benefits and cost for the CENPAC configuration are given in Figure 10-4. Shown in this figure are the maximum and minimum benefits attributable to to this alternative, the range of fishing benefits and the maximum benefit with the minimum fishing benefits. The range of fishing benefits are shown as the shaded area to indicate the uncertainties associated with this benefit category. The costs shown reflect only operating expenses (OE) since this configuration is already operational. The original investment costs are sunk costs and not considered in the determination.

Under the most optimistic benefit assumptions, the total benefits barely equal the total costs by the year 2000. Other benefit options are even less attractive with the minimum benefit being the worst case; in this option the total benefits are less than 50 percent of the total cost. The impact of the fishing benefits can be judged from the lower edge of the shaded portion of the curves; in this case the total maximum benefits with minimum fishing benefits equals approximately two-thirds of the total cost. When maximum fishing benefits are included, the total benefits equal the total cost. The range of uncertainty associated with fishing benefits is sufficient to alter the results from a fractional to a break-even benefit/cost ratio which results in ultimate system payback, although one of long duration. Using the criteria of benefits and costs, the CENPAC configuration does not provide sufficient quantitive benefits to exceed overall system costs. However, qualitative benefits or other unstated reasons such as national security may provide a compelling rationale to warrant its retention.

If LORAN-C coverage in the Hawaiian Islands is to be improved, it must be based upon not only retention of the current system but also enhancement of that system so as to substantially increase the benefit/cost relationships. The subsequent sections address the role of the expansion alternatives in meeting this goal.

### 10.3.2 Kauai Reconfiguration

The benefits and cost streams for the reconfiguration of the CENPAC chain involving incorporation of an additional station on Kauai is shown in Figure 10-5. In this figure the range of benefits are shown as is the effect of and uncertainties associated with the fishing benefits. The cost curve reflects the investment costs (AC&I) as well as operating costs (OE). Since investment costs are obligated early in the system life cycle they are shown as an initial steep rise in the cost curve followed by a more gradual rise as operating costs are

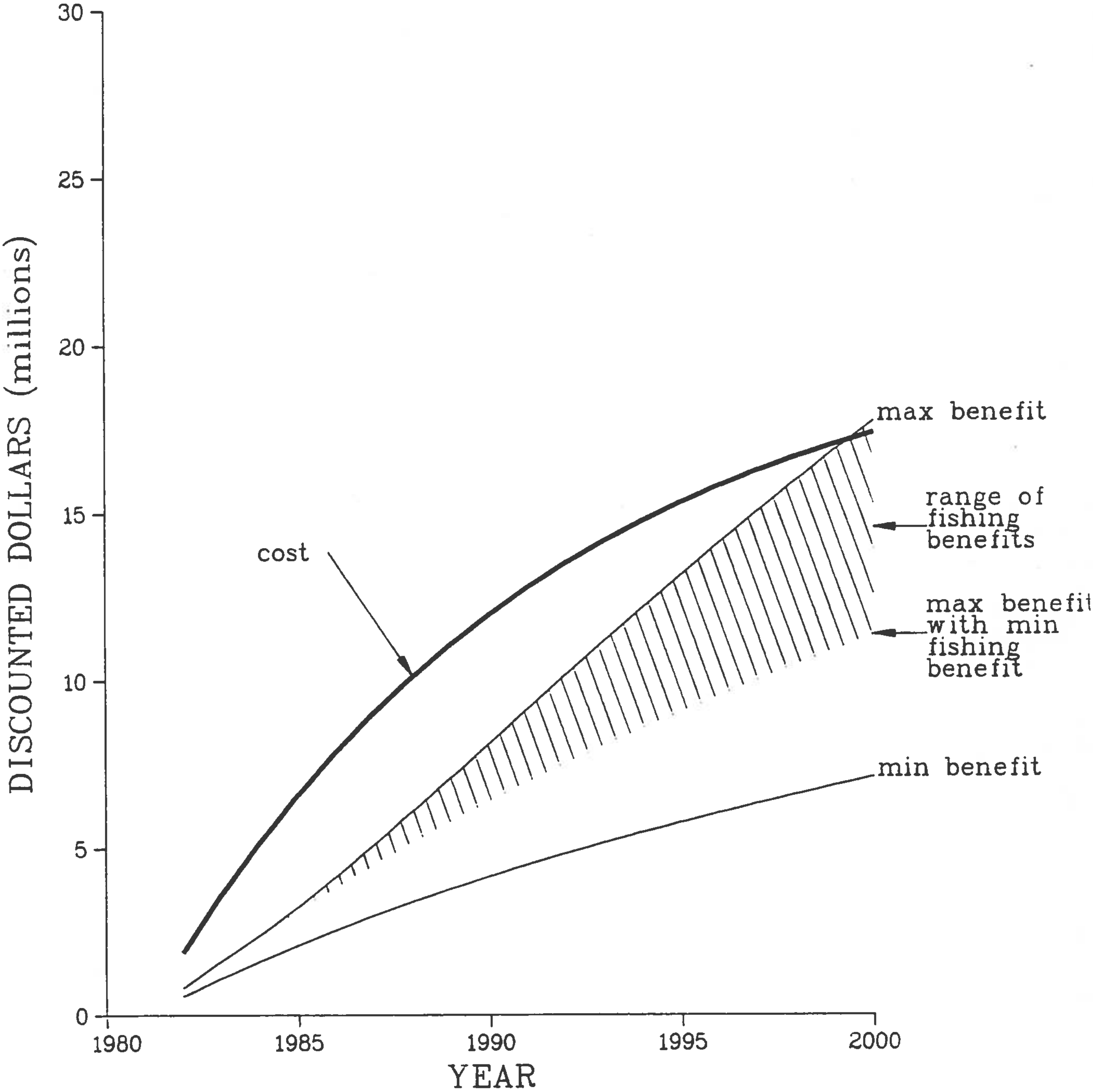



FIGURE 10-4
CENPAC CONFIGURATION
SYSTEM BENEFITS AND COST

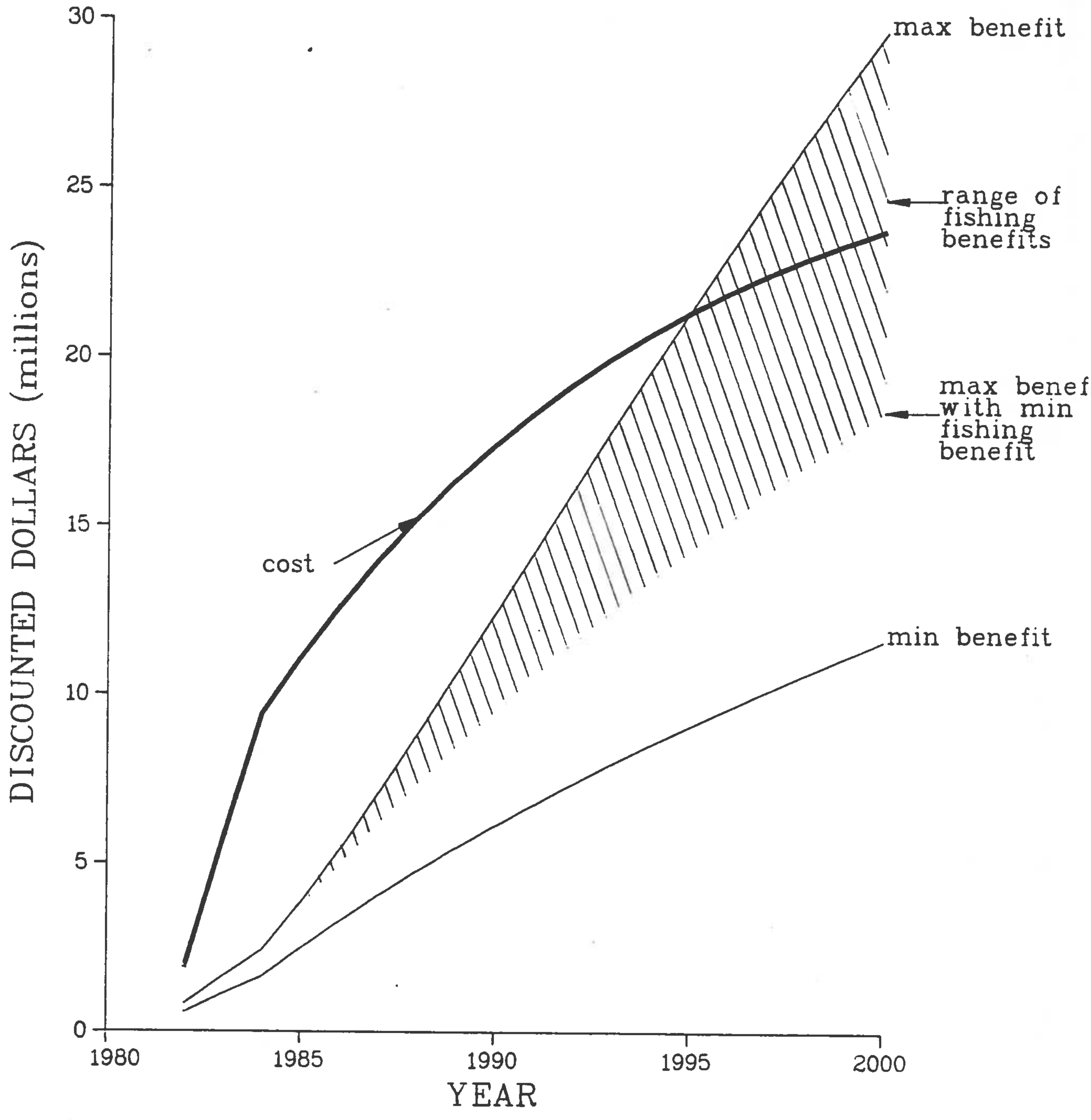



FIGURE 10-5
KAUAI RECONFIGURATION
SYSTEM BENEFITS AND COSTS

accumulated. On the other hand, benefits are accrued at a low rate between 1982 and 1985 since no reconfiguration benefits accrue during that period and the only benefits then are those attributable to the basic CENPAC chain.

Under the most optimistic assumptions for the Kauai reconfiguration, the total benefits exceed the total costs by approximately 25 percent (benefit/cost ratio of 1.25). Further, these benefits will reach a payback period with respect to total costs by 1995. However, the wide range of fishing benefits can significantly influence the final results. This effect can be seen by the case of the maximum marine user benefits with minimum fishing benefits (the lower portion of the shaded area under the maximum benefits curve). In this case there is a less than favorable level of benefits such that the benefit/cost ratio is 0.75. In the least optimistic benefit case which involves both minimum marine user benefits and minimum fishing benefits the benefit/cost ratio is 0.50.

Overall it appears that the uncertainties associated with the fishing benefits affect the final results such that the conclusions can range from a positive, but not overriding case for system expansion to a negative case wherein system expansion is obviously not warranted. However, even under the most optimistic set of assumptions the benefit/cost ratio is not significantly promising to justify system expansion solely on this measure. Should there be compelling reasons to expand LORAN-C criteria other than benefits and costs must be used.

### 10.3.3 Midway Relocation

The second expansion alternative considered involves the relocation of the Kure station to Midway Island and increasing its power. The results for this alternative are shown in Figure 10-6. As with the case of the Kauai alternative, system costs include both investment and operating costs while system benefits include both maximum and minimum benefits as well as the range of uncertainties associated with fishing benefits. A comparison of these benefit envelopes with those of the Kauai reconfiguration would reveal that they are identical and hence at this level of aggregation, similar conclusions as to the benefits may be drawn. However, a detailed evaluation of the benefits as discussed in Section 8 indicates that Midway would be the preferred alternative.

With respect to the costs however, the Midway alternative is less. Although the investment costs are nearly identical, it is the lower operating costs for the Midway station as well as the elimination of one additional station which influence these results.

The lower cost structure associated with the Midway alternative provides a slightly more favorable benefit/cost ratio. Under the most optimistic set of assumptions, this benefit/cost ratio is

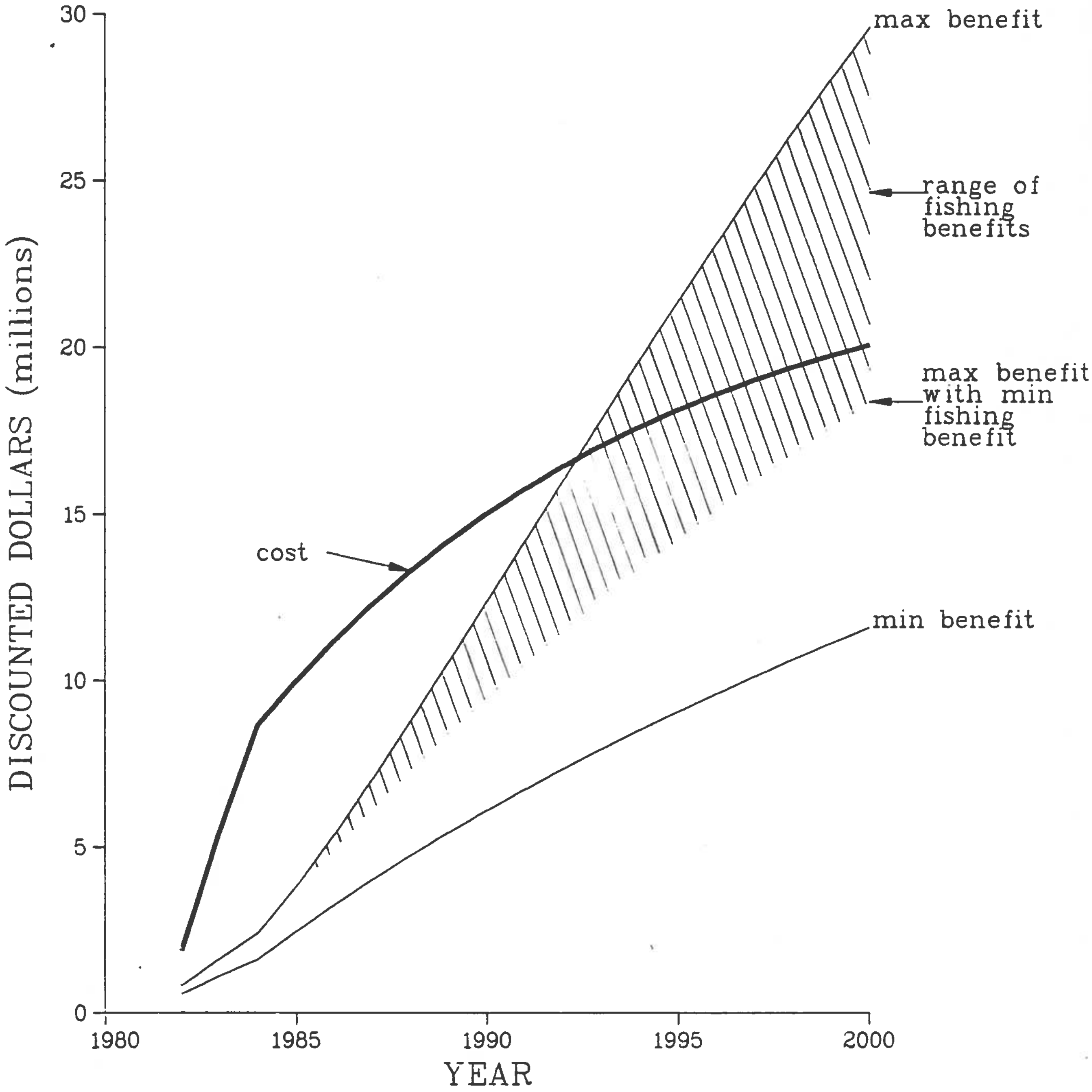



FIGURE 10-6
MIDWAY RELOCATION
SYSTEM BENEFITS AND COSTS

1.47. Further, the system payback associated with this ratio occurs earlier in the life cycle (1992 vs 1995). The effect of fishing benefits upon the overall results is to raise most of the benefit options to a break-even benefit/cost ratio. For example, minimum marine benefits with maximum fishing benefits attain a benefit/cost ratio of approximately 1.2. Under the worst fishing case conditions however, none of the total benefit/cost ratios reach a level greater than 0.9.

While the Midway alternative appears slightly more promising than the Kauai alternative, the magnitude of the benefit/cost ratios for both of these alternatives are not sufficiently great as to substantiate a system expansion solely on this basis. Further, the uncertainties associated with fishing can, under a worst case condition provide the grounds for rejection of an expansion decision.

## 10.4 Sensitivity Analysis

### 10.4.1 Major Marine Disaster

A major investment decision is frequently justified on the basis of, among other things, a favorable benefit/cost ratio. In all of the LORAN-C alternatives assessed in this study the life cycle benefit/cost ratios rarely exceeded the break-even point and hence such systems did not appear promising. However, the argument is sometimes made that the investment in a navigation system could be rationalized on the grounds that if it could prevent one major marine disaster its costs could be justified. Accordingly the benefit/cost results of the LORAN-C expansion assessment were examined to determine the impact of a major navigation-related marine disaster.

It is assumed that a major tank vessel grounding occurs within the Hawaiian Archipelago and that this disaster could have been prevented by improved radionavigation aids. It is further assumed that the losses incurred in such a disaster are $25 million. The probability of such an event not occuring was considered to be a function of the area coverage provided by the expansion alternatives. The area coverage was considered in those regions wherein such a navigation-related marine disaster could occur, i.e., reefs, shoals, and close inshore areas. An analysis was performed to determine the extent of these areas and the relative amount of coverage provided by the three configurations. These relative coverages were converted into percentages and the expected value of the disaster determined for each of the LORAN-C alternatives. These values were $13.3, $22.5, and $19.5 million for the CENPAC, Kauai, and Midway configurations respectively. Further, the disaster was assumed to occur in 1985, 1990, 1995, and 2000. Discounted values were determined for each time period and the effect upon the total benefit/cost ratios ascertained for the most optimistic benfit assumptions. These results are shown in Figure 10-7.

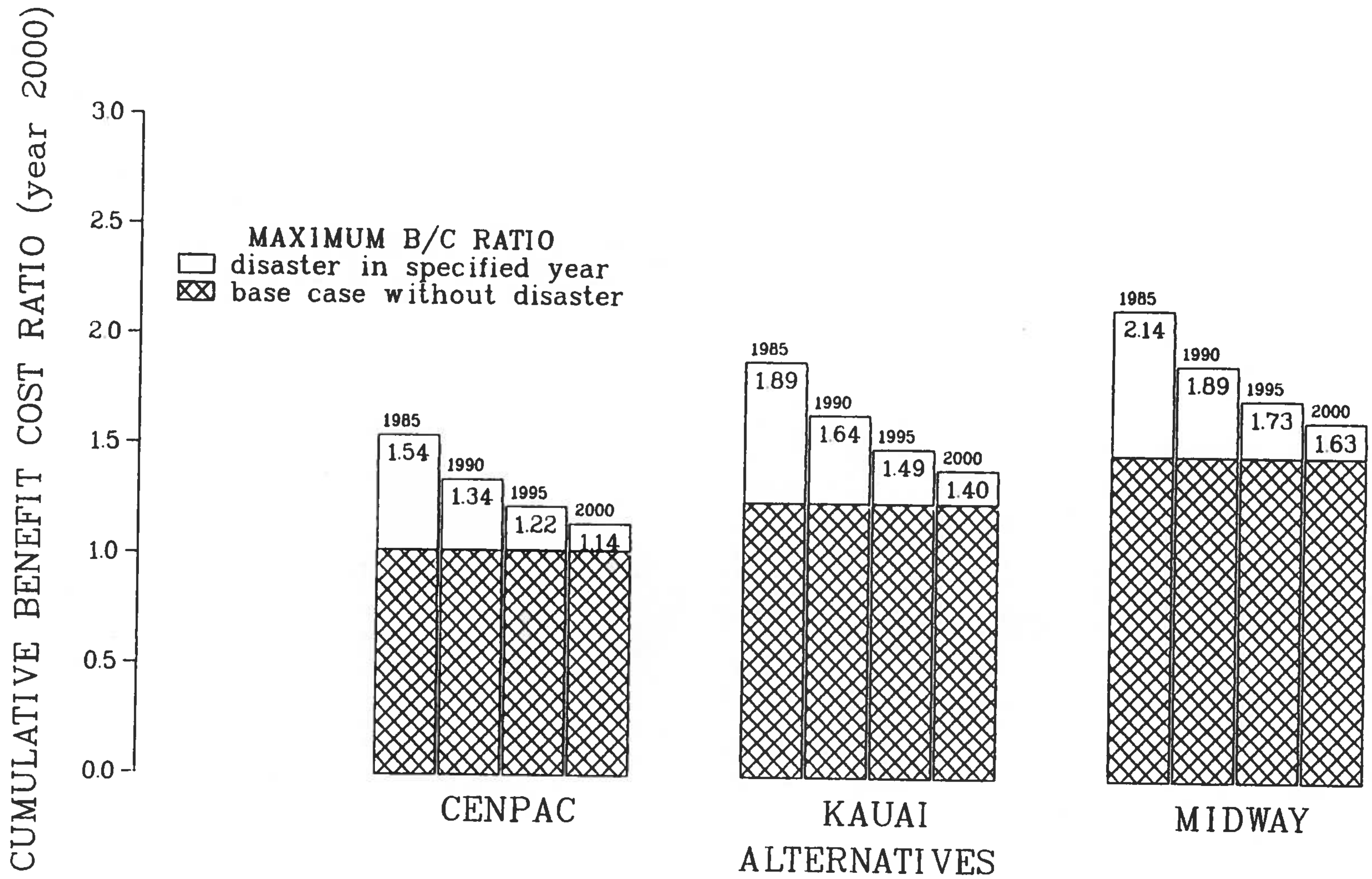



Figure 10-7

SENSITIVITY ANALYSIS
MAJOR MARINE DISASTER
(by year of occurrence)

As would be expected, the highest benefit/cost ratios occur when the marine disaster happens early in the system life. However, the ratio for the most promising alternative (Midway relocation, disaster in 1985) does not exceed 2.1 and the values for the other alternatives are correspondingly less both in 1985 and later in the time stream. Accordingly, on the basis of benefit/cost ratios, the impact of the prevention of a major marine disaster does not significantly affect any of the alternatives such that that they warrant closer analysis for possible implementation.

10.4.2 Effects of Additional Benefits

Alternatively, an analysis was performed to determine the amount of benefits which would be necessary to drive the benefit/cost ratio to a level at which the expansion of the current LORAN-C coverage would become attractive. In this analysis, the most favorable alternative, Midway relocation, was selected. Similar to the major marine disaster analysis, various amounts of benefits were added to the most optimistic benefit for the alternative. These amounts ranged from 0 to $200 million and were applied as single benefits at various points in time throughout the range of the study (from 1985 through 2000). These amounts were adjusted to account for the relative coverage of traffic attributable to the Midway alternative. The results of this analysis are displayed in Figure 10-8. This figure shows benefit/cost ratios for any combination of additional dollars and year applied. Further, as can be seen, the greatest benefit/cost ratio is achieved when benefits are applied in 1985. This is because the results of discounting are minimized early in the time stream.

A benefit/cost ratio of 5 was arbitrarily selected as a minimum desirable level to justify investment. In order to attain this benefit/cost ratio, an additional benefit of approximately $130 million would have to be applied in 1985. By 1990 a benefit of $200 million would be required to achieve this benefit/cost level. These levels of $130 and $200 million compare with Midway's overall cumulative benefit of less than $30 million which was determined to be the most optimistic level attainable.

The sensitivity analysis results in two conclusions. First, the effects of an averted single marine disaster are not enough to significantly alter the study results. Second, the conclusions are insensitive to possible errors in benefit estimation.

To significantly alter the findings, additional benefits of about an order of magnitude are needed. It is therefore concluded that the study results are not sufficiently sensitive so as to reflect the omission or the under estimation of system benefits.

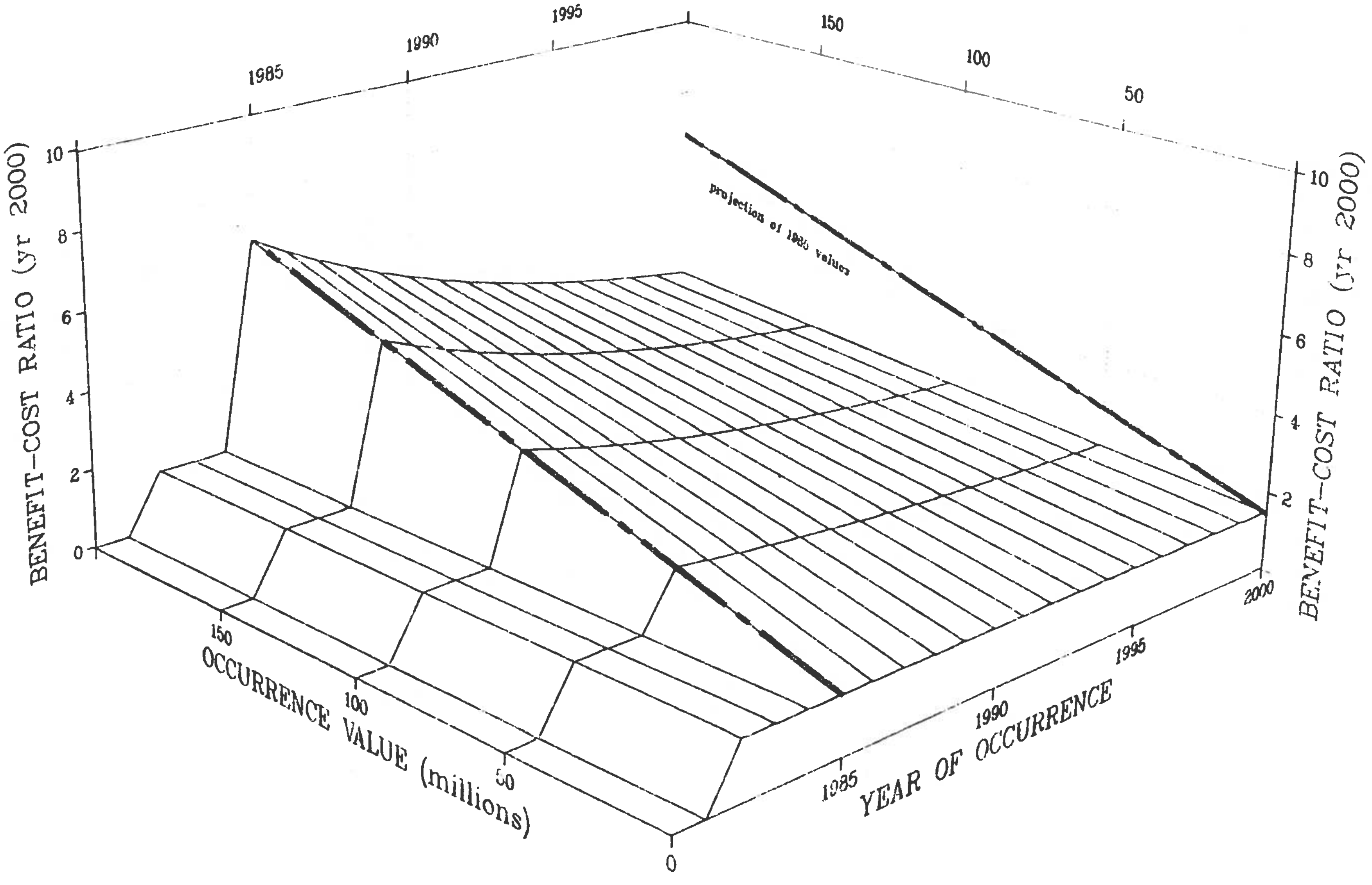



FIGURE 10-8
EFFECTS OF ADDITIONAL BENEFITS
ON THE MIDWAY ALTERNATIVE

## 11. CONCLUSIONS AND FINDINGS

### 11.1 Cost and Benefit Conclusions

The following conclusions and findings can be made with respect to the costs and benefits of LORAN-C expansion and retention in the Hawaiian Islands.

- o Under the most optimistic set of assumptions the Central Pacific chain which currently provides LORAN-C coverage of the Hawaiian Islands is marginally justifiable on the basis of costs and benefits to the civil marine users. This chain was designed to meet the requirements of the Defense community and does not provide benefits to that area of the Hawaiian Islands where the greatest civil maritime activities lie.

- o The benefit/cost relationships of the configurations designed to extend LORAN-C coverage narrowly favor system expansion since those alternatives show slight improvement over the Central Pacific chain. However, these relationships do not reach a level considered sufficient to warrant either an investment decision or futher study. The benefit/cost ratio for the reconfigured chain with a master station on Kauai is 1.25 while the ratio for the chain with a repowered station located on Midway Island is 1.47.

- o Benefits to U.S. fishing vessels drive the results. However, the uncertainties associated with these benefits are such that under the worst case assumptions for the Central Pacific chain the accrued benefits do not reach a level to pay back operating expenses. Similar conclusions can be drawn with respect to the minimum benefit/cost relationships for the expansion alternatives.

- o Because of the limited civil utility of the Central Pacific chain and the less than favorable benefit/cost relationships for the expanded chains, no overriding case for either system expansion or retention can be made. Although, if the Central Pacific system is retained for reasons other than benefit/cost considerations its worth will be enhanced through expanded coverage.

- o The benefits for the expansion alternatives are similar and, in the aggregate, present little discernable difference. However, using other criteria such as costs and benefits per vessel mile and per square mile of coverage it is apparent that the Midway relocation alternative provides greater benefits to a greater number of users at slightly lower costs. On this basis it is the preferred alternative.

- The principal beneficiaries of coverage from the Central Pacific chain are foreign flag fishing and foreign flag cargo vessels. The Kauai reconfiguration will provide additional benefits to these groups of users. The Midway relocation alternative will benefit the U.S. flag users the most by providing coverage to the North America - Hawaii traffic.

- The benefit/cost ratios for all alternatives including the Central Pacific chain tend to be insensitive to major events which cause changes in benefits. For example, the prevention of a major navigation-related marine disaster through expanded LORAN-C coverage will not raise the benefit/cost relationships to a level sufficient to justify a positive investment decision.

- Vessel groundings occur throughout the entire Hawaiian Archipelago. However, the frequencies and severities are low and the greatest numbers occur within the main Hawaiian Islands. In the shoal areas of the archipelago to the west of the main Hawaiian Islands fewer groundings occur but they are of greater severity. LORAN-C coverage from the Central Pacific chain is available in the latter area but not in the former. Based on historic data some quantitative benefits can be attributed to expanded coverage.

- Although most Coast Guard benefits from expanded LORAN-C coverage cannot be quantified, substantial qualitative benefits can result. These benefits are in improved capability in the Enforcement of Laws and Treaties, particularly the enforcement of the Fishery Conservation Management Act, in the Marine Environment Protection mission and in Search and Rescue operations. With respect to search and rescue some quantitative benefits can also be derived from LORAN-C expansion through improved navigability. These benefits can result in savings in helicopter/fixed wing operations. However, helicopter upgrading with self-contained navigational capability can yield similar benefits without LORAN-C expansion. Since this upgrading is already planned for FY82-83 no LORAN-C benefits have been assigned.

- The advent of NAVSTAR GPS in 1985-87 could significantly affect the number of ships that equip with LORAN-C. This, in turn, would lower all projected benefit/cost ratios thereby making all system alternatives investigated even less promising. Some large marine operators have already indicated their intent to defer the acquisition of any additional radionavigation receivers until the availability of NAVSTAR GPS.

## 11.2 User Conclusions

The following findings and conclusions have been derived with respect to the impact of expanded LORAN-C upon the marine community.

- If coverage should be expanded into the main Hawaiian Islands, the principal purchasers of LORAN-C receivers will be drawn from the fishing and recreational community. If LORAN-C is not expanded and the Central Pacific chain is retained, there will be some growth in the utilization of LORAN-C by fishing operators as these users move out into the Northwest Hawaiian Islands into the area of current coverage.

- Under conditions of no LORAN-C expansion, the number of fishing users will probably increase from less than 10 to over 100 as fishing operations extend westward. Should LORAN-C be expanded however, this number should triple to over 300. With respect to recreational boating and recreational fishing, virtually none of these users have acquired LORAN-C. This buying pattern is not expected to change under the no expansion scenario. The expansion of LORAN-C should alter this recreational boater buying pattern however. The large recreational boat owners who traditionally cruise between islands as well as the serious recreational fishing community will be the more likely purchasers of LORAN-C receivers. These purchases are projected to reach 800 units. This population is based on similar experiences and buying habits in the Miami-Ft. Lauderdale area.

- Most large commercial vessels operating in the Hawaiian trade have LORAN-C installed particularly those vessels entering the U.S. Coastal Confluence Zone where Federal Regulations require the installation of LORAN-C or other authorized electronic navigation systems. This user installation and utilization strategy will be unaffected if LORAN-C should be expanded, but may be altered if and when NAVSTAR GPS becomes available.

- The oceangoing small commercial vessels, mostly tugs, engaged in U.S. mainland - Hawaii traffic have already acquired LORAN-C. Many of these vessels also engage in inter-island operations. Further, of the tugs dedicated to inter-island operations, many have LORAN-C installed although it is infrequently used. Hence, these categories of users constitute a limited market for LORAN-C should the system be expanded.

## 11.3 Vessel Traffic and Population Conclusions

The current status and future trends for marine traffic and populations in the Hawaiian Islands can be characterized as follows:

- Total oceanic inbound-outbound traffic for Hawaii in 1979 amounted to 3544 moves while the inter-island traffic constituted an additional 4794 moves. Approximately 40 percent of the oceanic traffic was between Hawaii and the U.S. west coast. Of the total oceanic traffic 42 percent was carried in U.S. flag vessels, mostly in the West Coast - Hawaii trade. There are an estimated 240 large tank and cargo vessels which customarily call in Hawaii as well as 27 tugs which operate between the west coast and Hawaii and in inter-island trade. By the year 2000 the Hawaii oceanic traffic was projected to increase by about 25 percent to 4390 moves. The vessel populations contributing to these moves are expected to remain reasonably constant. Although the tonnage anticipated to be carried will rise, the projected world-wide shipbuilding trends are toward larger and more efficient vessels resulting in a vessel population which will increase only slightly.

- The fishing industry in Hawaii is currently embarked on a program of growth and revitalization. Should this program mature as planned, fishing areas will expand westward into the Northwest Hawaiian Islands. The product of this growth will be an expansion of the numbers and types of fishing vessels. In 1979, there were 342 major fishing vessels, 100 of which were engaged full time in the commercial sport fishing trade, 56 were large full time commercial vessels and 186 were smaller semi-commercial vessels. By the year 2000 if the projections of the Hawaiian fisheries program hold true, this mix of vessels will nearly double with the principal growth occuring in the large commercial fishing vessel category.

- Despite the seafaring tradition of the residents of Hawaii and despite the fact that Hawaii is an insular state and ranks eighteenth in the number of miles of tidal coastal shoreline, in terms of registed recreational boats, Hawaii ranks fifty-first among all the states and territories. The lack of sheltered harbors, marinas and dock space constrain the growth of recreational boating and cause most of the boats to be stored on trailers and towed to launching ramps. This limits not only the size of the boats but also the number. In 1979 there were 12,326 recreational boats, 85 percent of which were under 26 feet. By the year 2000 this population is expected to grow modestly to over 15,000 but retain the distribution favoring the smaller boats.

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# APPENDIX A

## RADIONAVIGATION SYSTEM CHARACTERISTICS AND REQUIREMENTS

## 1. INTRODUCTION

This Appendix addresses the characteristics, capabilities, coverages, and limitations of those radionavigation systems currently in use or under development by the United States. Also included are the current range of prices for system receiver costs. Against these system characteristics are presented the requirements of the various system users in terms of vessel activity and certain performance parameters. The data in this appendix are derived principally from the "Federal Radionavigation Plan" and "Radionavigation Systems" (References 1 and 16).

## 2. RADIONAVIGATION SYSTEMS

Only those systems which have application for marine users in the Hawaiian Islands are considered in this Appendix. These systems are:

- o LORAN-C
- o Omega
- o Transit
- o NAVSTAR GPS

Most of the systems are expected to be available through the year 2000 (Reference 1). Hawaiian Island coverage from those systems vary from partial to full coverage including worldwide availability. Finally, one of these systems (NAVSTAR GPS) is still under development with full marine coverage and operational capability (2-dimensional) not expected until late 1985 and (3-dimensional) coverage is not expected until 1987 or later. In this study, LORAN-C is assumed to be available at least through the year 2000. (Reference 1) Radiobeacons are not considered since there are none installed in the main Hawaiian Islands.

The above systems are defined in the following sections in terms of certain performance parameters as specified in "Federal Radionavigation Plan" (Reference 1). These data have been modified in some instances to reflect the constraints of the Hawaiian Island region.

### 2.1 System Characteristics - LORAN-C

#### 2.1.1 General

LORAN-C was developed to provide the DOD with a radionavigation capability having longer range and much greater accuracy than its predecessor system, LORAN-A. It was subsequently selected as the U.S. Government-provided radionavigation system for civil marine use in the U.S. coastal areas.

LORAN-C is a pulsed, hyperbolic system, operating in the 90-110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of RF energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The measurements of time-difference (TD) are made by a receiver which achieves improved accuracy by comparing a zero crossing of a specified RF cycle within the pulses transmitted by master and secondary stations within a chain. Making this comparison early in the pulse assures that the m-easurement is made before the arrival of the corresponding skywaves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To prevent sky waves from affecting TD measurements, the phase of the 100 kHz carrier of each pulse is changed in a predetermined pattern.

Navigation is based primarily on the use of the LORAN-C groundwave. Within the groundwave range, LORAN-C will provide the user, who employs an adequate receiver, with predictable accuracy of 0.25 NM (2 drms) or better. The repeatable and relative accuracy of LORAN-C is usually between 18 to 90 meters. Skywave navigation is also feasible but with some loss in accuracy and signal availability. Both groundwaves and skywaves may be used for measuring time and time interval. Although it is designed for use, and normally operated in the hyperbolic mode, LORAN-C can be used to obtain accurate fixes by determining the range to individual stations. This is accomplished by a comparison of the received signal phase to a known time reference to determine propagation time and, therefore, range from the stations. This is referred to as the range-range (rho-rho) mode. It can be used in situations where the user is within reception range of individual stations, but beyond the hyperbolic coverage area. The rho-rho method of using LORAN-C requires that the user have a very precise and stable time reference. The high cost of equipment of this type limits the use of this mode.

Other characteristics of LORAN-C are given in Table A-1.

2.1.2 Coverage

On the Pacific Coast, LORAN-C coverage extends from the U.S./Mexican border northward throughout the Gulf of Alaska and Aleutians into the Bering Sea. East Coast and Gulf of Mexico coverage is provided by expanding and reconfiguring the existing East Coast Chain and constructing additional stations to form three new chains. This reconfigured system provides coverage of the entire Eastern United States including the Great Lakes as well as the coastal waters of Gulf and Eastern littoral States.

In the Pacific, partial coverage of the Hawaiian Islands is provided by the Central Pacific Chain. This coverage extends from Kauai westward to nearly the Midway Islands, as well as to the North and South of the Archipelago. Figure A-1 shows the LORAN-C coverage for the U.S.

TABLE A-1: SELECTED SYSTEM CHARACTERISTICS - LORAN-C, OMEGA

| System | Accuracy (95%) | | | Fix Rate | Coverage | Availability | Reliability | Ambiguity Resolution |
|---|---|---|---|---|---|---|---|---|
| | Predictable | Repeatable | Relative | | | | | |
| LORAN-C | 0.25NM (worst case) for 1:3 SNR (460 m) | 60-300 ft. (18-90 m) | 60-300 ft. (18-90 m) | 25 Fixes/ Second | U.S. Coastal Areas, Continental U.S., Selected Overseas Areas | 99+% | (1) | Yes, Easily Resolved |
| OMEGA | 2-4NM (goal) (3.7-7.4km) | 2-4NM (3.7-7.4km) | 1-2NM (1.85-3.7km) | 1 Fix/ 10 Seconds | Near Global (over 90%) | 99% | (1) | Requires Knowledge of Approx. Position |

(1) depends on mission time

NOTE: Each system has unlimited capacity in terms of potential user populations, and all provide two-dimensional fixes.

SOURCE: REFERENCE 1

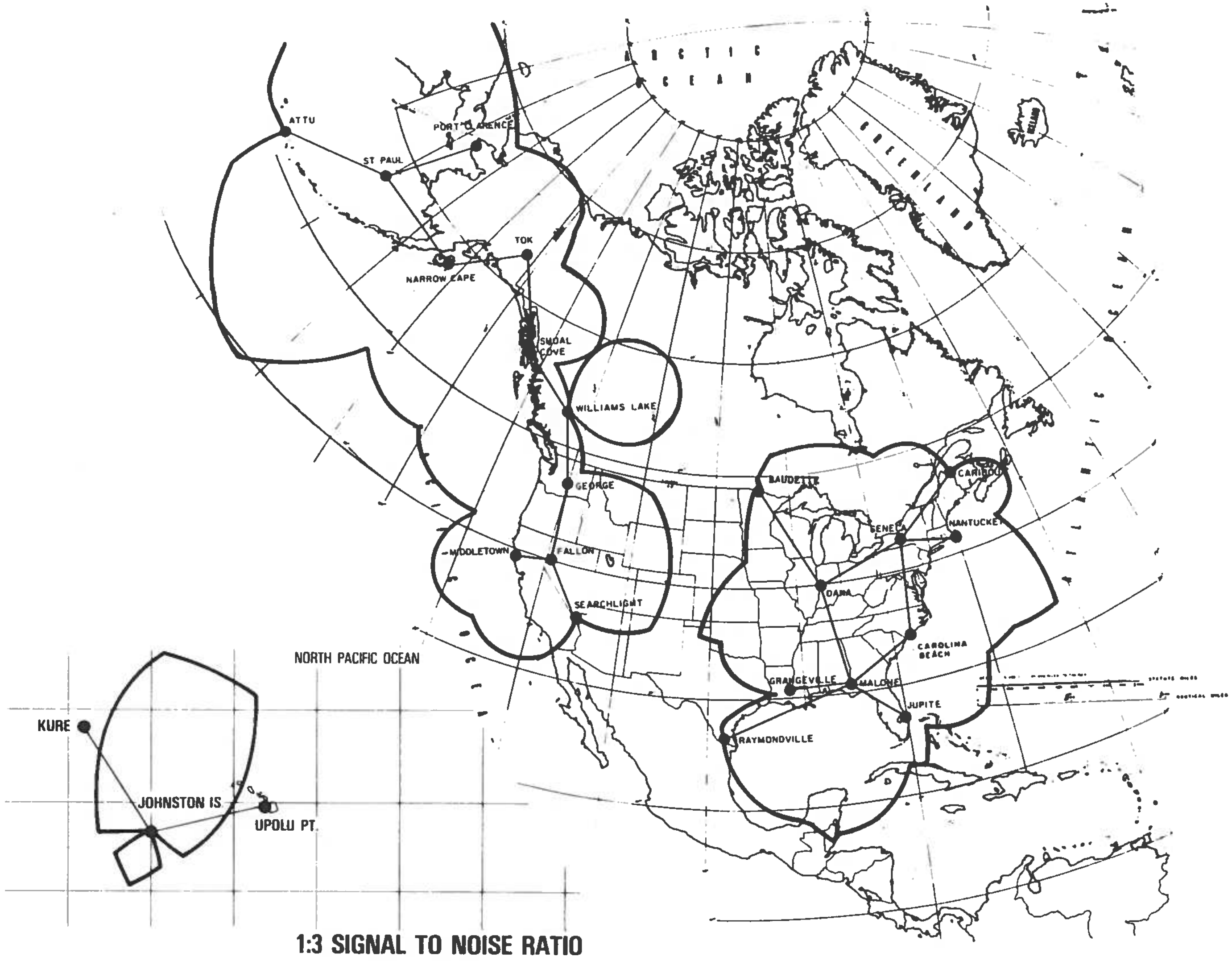



FIGURE A-1
US LORAN-C COVERAGE

2.1.3 Receiver Costs

Receiver costs for the individual user categories vary as a function of the sophistication of the vessel and the various requirements of the user. These costs were derived from previous studies in this area, current trade pricings and discussions with industry representatives (Reference 31, 32). These prices are subject to downward pressure as the economics of scale and the effects of competition are felt. The following prices were assumed for marine LORAN-C receivers based upon the requirements and operations of the individual user categories.

Large Commercial Vessels - $2000-$5000
Small Commercial Vessels - $1000-$2000
Fishing & Sport Fishing Vessels - $2000-$3000
Recreational Boats - Under $1000

2.2 System Characteristics - OMEGA

2.2.1 General

The Omega system was developed by the DOD to meet the need for worldwide enroute general navigation. Omega utilizes CW phase comparison of skywaves from pairs of stations. The stations transmit time shared signals in four frequencies: 10.2kHz, 11 1/3 kHz, 13.6 kHz and 11.05 kHz. In addition to these common frequencies, each station transmits a unique frequency to aid station identification and to enhance performance. The system is comprised of seven transmitting stations situated throughout the world. Worldwide position coverage will be attained when an eighth station in Australia becomes operational in 1982. Additional characteristics of the Omega system are given in Table A-1.

The inherent accuracy of the Omega System is limited by the accuracy of the propagation corrections that must be applied to the individual receiver readings. The corrections may be obtained in the form of predictions from tables or automatically in computerized receivers. The system has a design goal of 2 to 4 nm (2 drms). This depends on location, station pairs used, time of day, and validity of the propagation corrections. Area validations conducted to date indicate this goal will be met.

Propagation correction tables are based on theory and modified to fit monitor data taken over long periods for localized areas. An extensive monitoring program is in use to verify the propagation model used to predict the corrections. A number of permanent monitors will be maintained to update the model on a long-term basis. The system is currently usable and provides coverage over more than 90 percent of the earth and nearly all of the Northern Hemisphere. However, a continuing program of monitoring and validating Omega signals must be completed before the system can be considered fully operational. This validation program which will help define system capabilities and limitations, is being carried out on a regional basis. As each region is validated, it will be declared operational. Worldwide oceanic validation depends on the Australia Station becoming operational and its signals evaluated. At this time about 60 percent of the Omega oceanic coverage area has been validated, with the remainder to be completed between 1982-1986.

Ambiguity on lines of position sometimes occur since points of constant phase difference recur periodically throughout the coverage area. The area between lines of zero phase difference are termed "lanes." Single-frequency receivers use the 10.2 kHz signals whose lane width is about eight nautical miles on the baseline between stations. Multiple-frequency receivers extend the lane width, but these are more expensive than single-frequency receivers. Because of the lane ambiguity, receivers must be preset to a known location. Once set to a known location, the Omega receiver counts the number of lanes it crosses in the course of a voyage. This lane count is subject to errors which may be introduced by an interruption of power to the receiver, changes in propagation conditions near local sunset and sunrise, and other factors. To use Omega effectively for navigation, it is essential that a DR plot be maintained carefully, and that the DR and Omega positions be compared periodically so that "jumps" in the Omega lane count can be detected and corrected. The accuracy of an Omega phase difference measurement is independent of the elapsed time or distance since the last update. Unless the Omega position is verified occasionally by comparison to a fix obtained with another navigation system or by periodic comparison to a carefully maintained DR plot, the chance of an error in the Omega lane count increases with time and distance.

### 2.2.2 Coverage

When the Omega System is fully implemented it will provide air and maritime users with a worldwide navigation system. The most commonly used stations in the Hawaiian area are Norway (A), North Dakota (D), LaReunion (E), and Japan (H). When the Australia Station (G) becomes operational it is expected to provide a strong, reliable signal in the Hawaii region. Coverage from these stations varies from day to night. Coverage contours for these stations are shown in Figures A-2 through A-11.*

### 2.2.3 Receiver Costs

The degree of sophistication of the Omega receivers is directly proportional to the level of receiver pricing. The manually operated receiver is the least expensive unit but requires a high degree of knowledge and skill on the part of the operator in order to employ it effectively. Because of the need for lane identification, automatic tracking is particularly desirable in Omega receivers, but this feature raises the level of sophistication and price of the unit for receivers not equipped with lane

*The Australian station has recently become operational. However, the coverage diagrams do not reflect this.

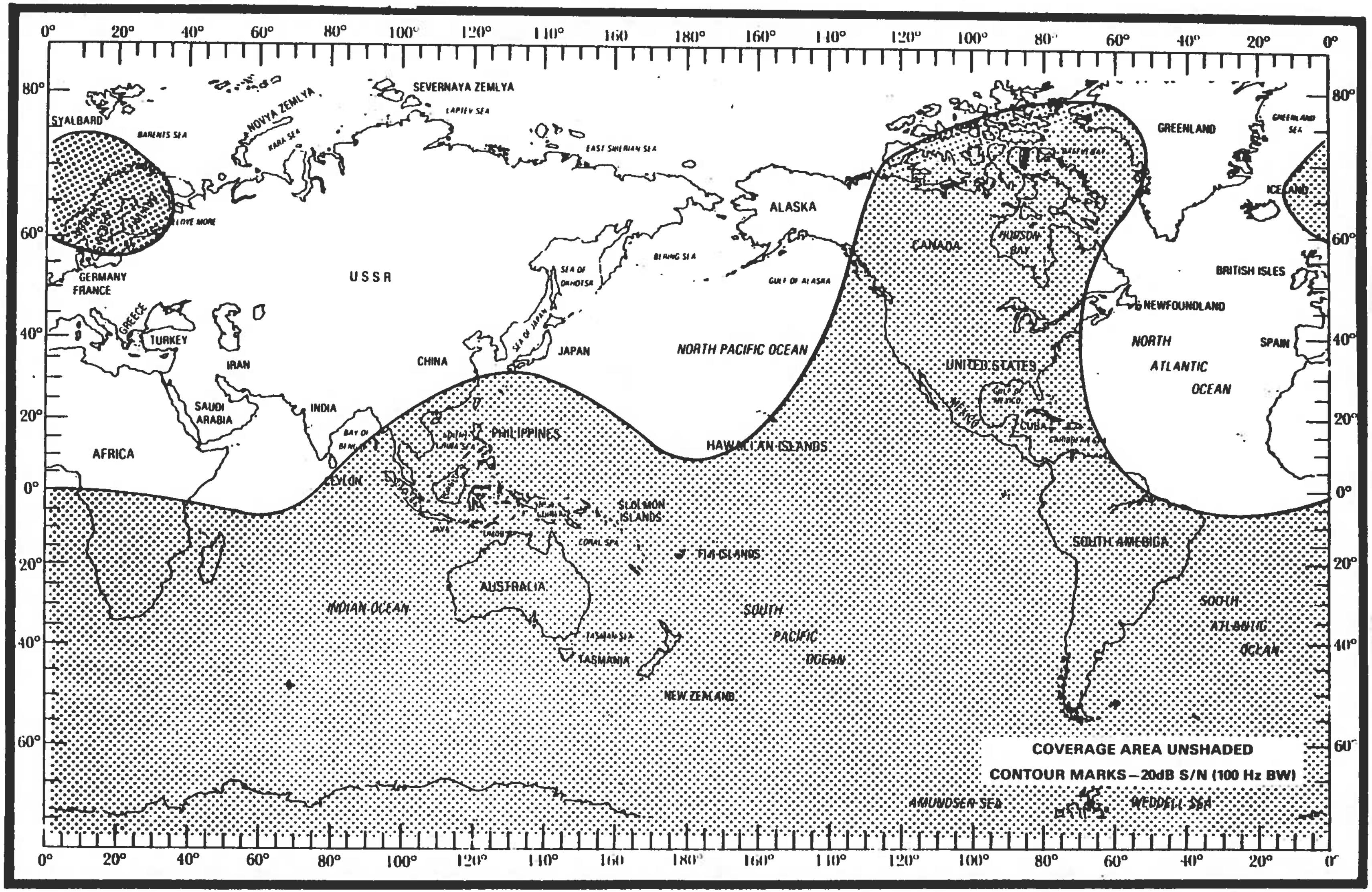



FIGURE A-2. OMEGA COVERAGE, NORWAY STATION (DAYTIME)

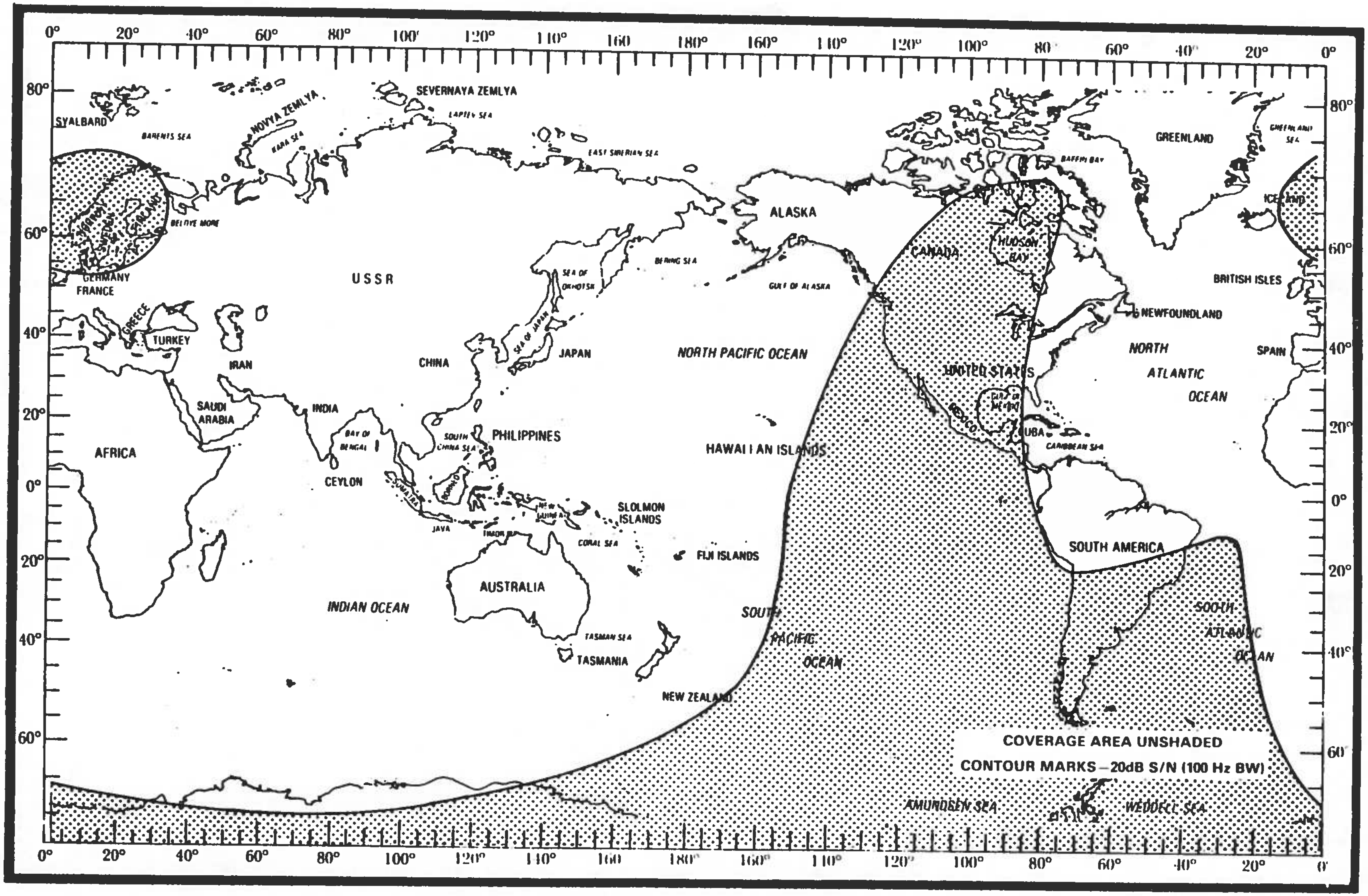



FIGURE A-3. OMEGA COVERAGE, NORWAY STATION (NIGHTTIME)

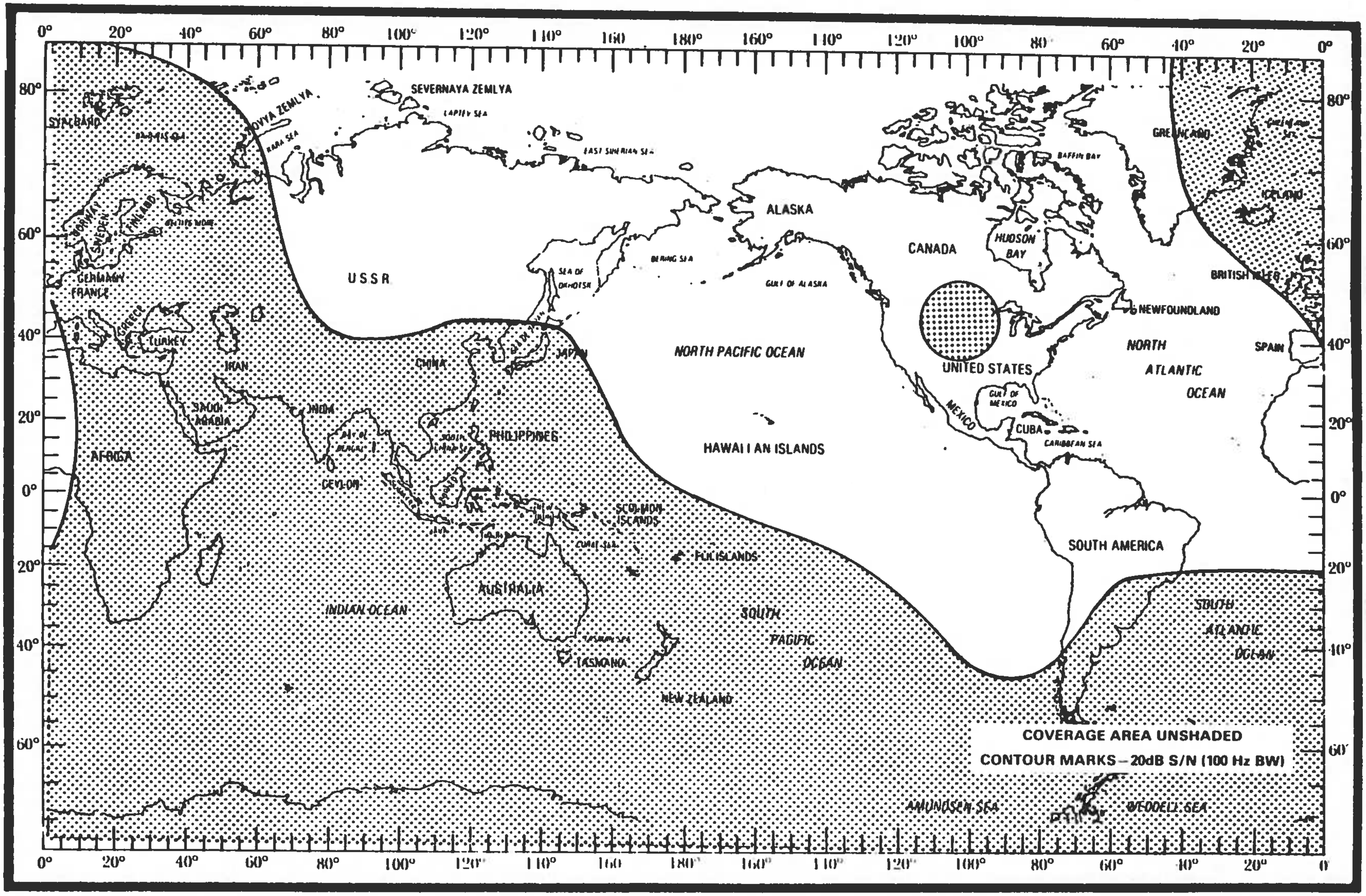



FIGURE A-4. OMEGA COVERAGE, NORTH DAKOTA STATION (DAYTIME)

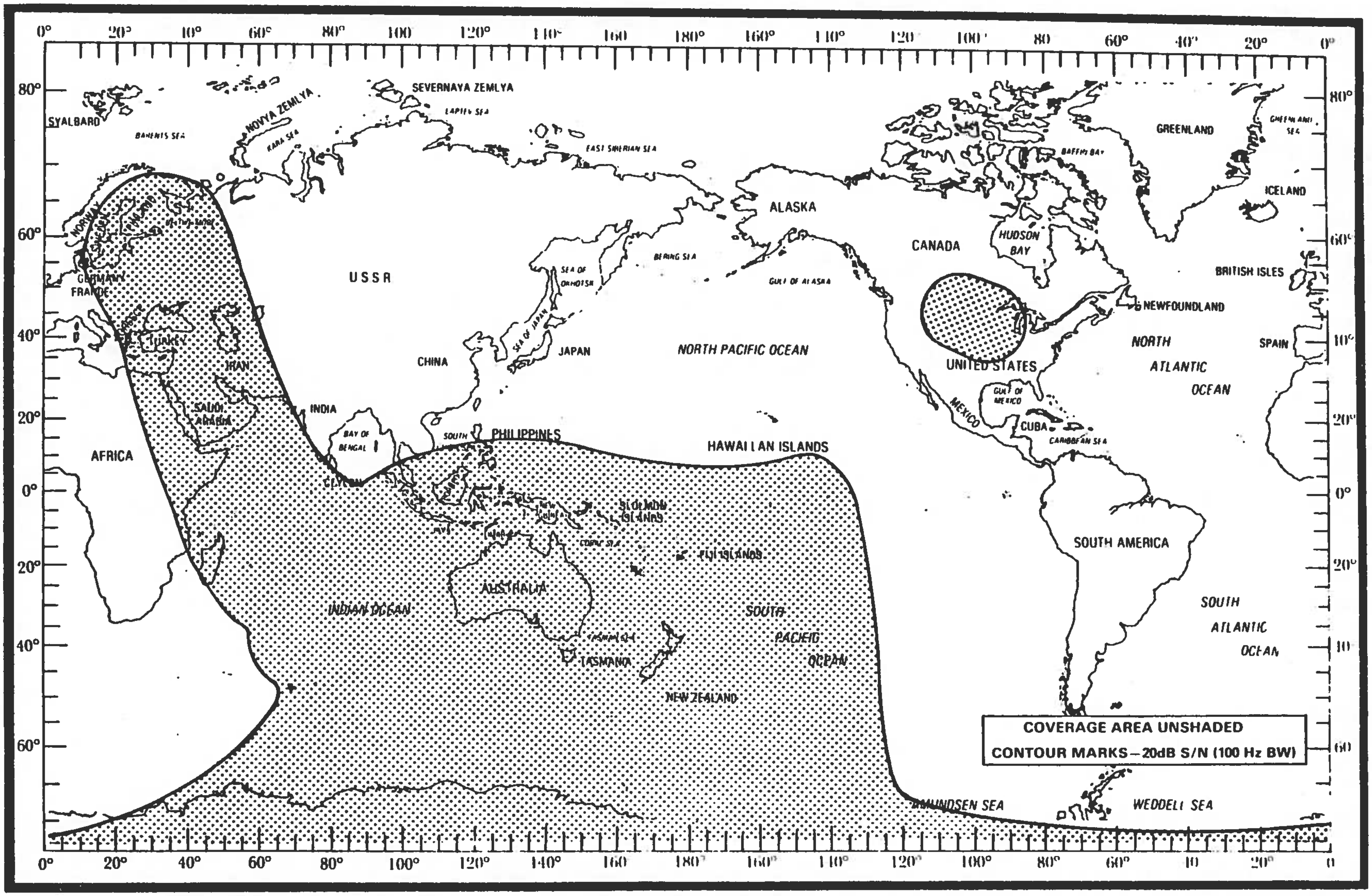



FIGURE A-5. OMEGA COVERAGE, NORTH DAKOTA STATION (NIGHTTIME)

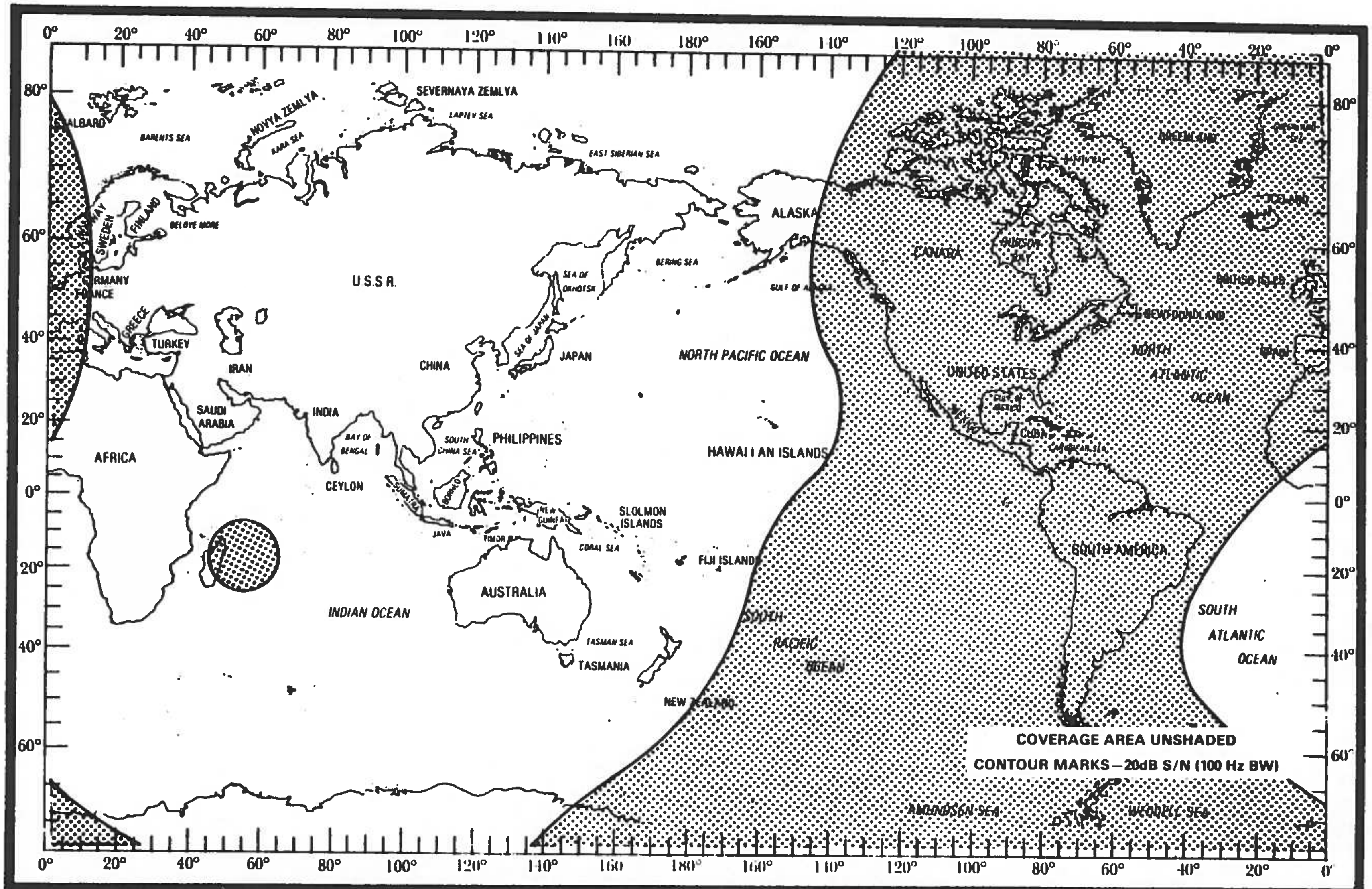



FIGURE A-6. OMEGA COVERAGE, LA REUNION STATION (DAYTIME)

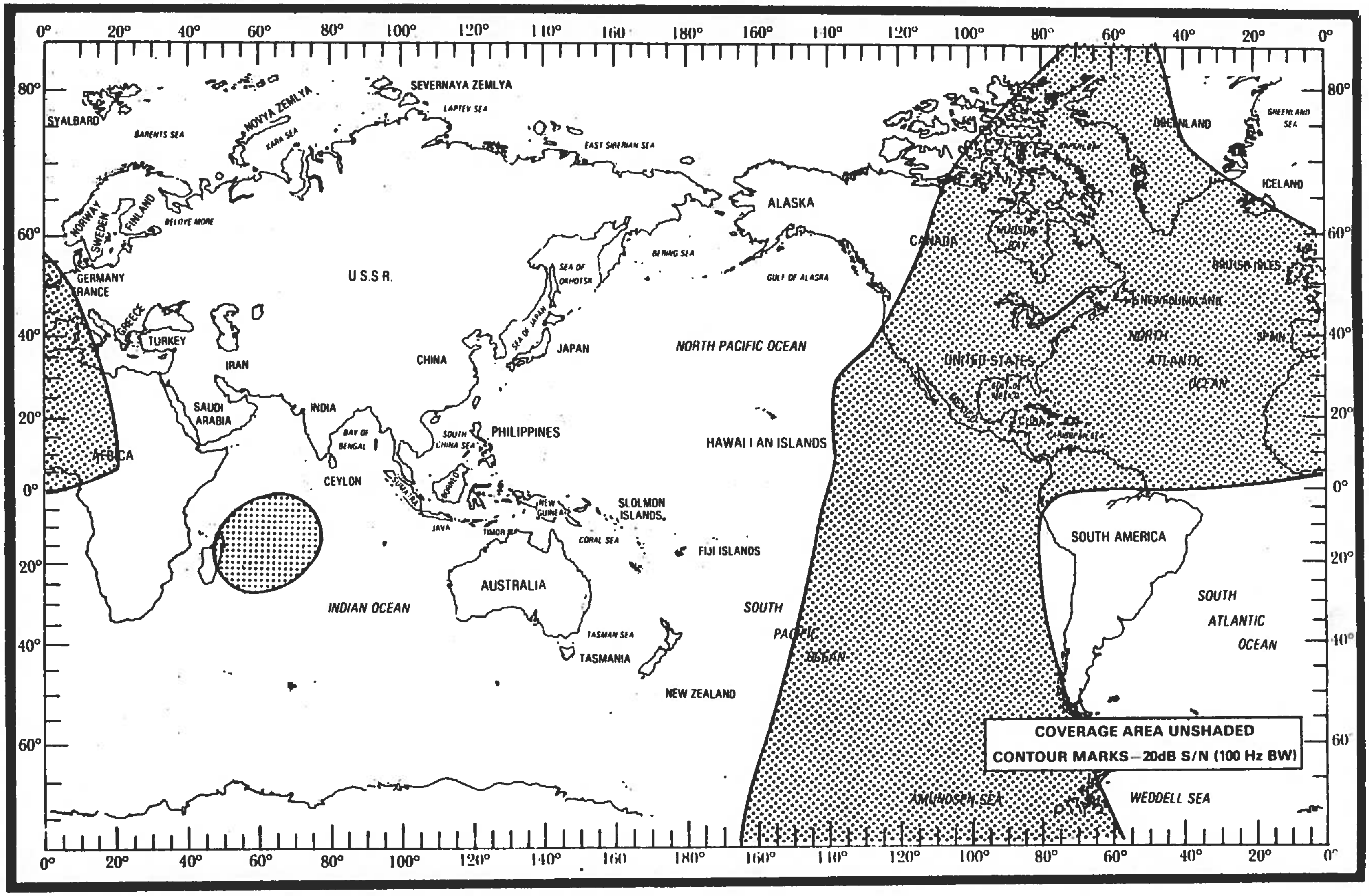



FIGURE A-7. OMEGA COVERAGE, LA REUNION STATION (NIGHTTIME)

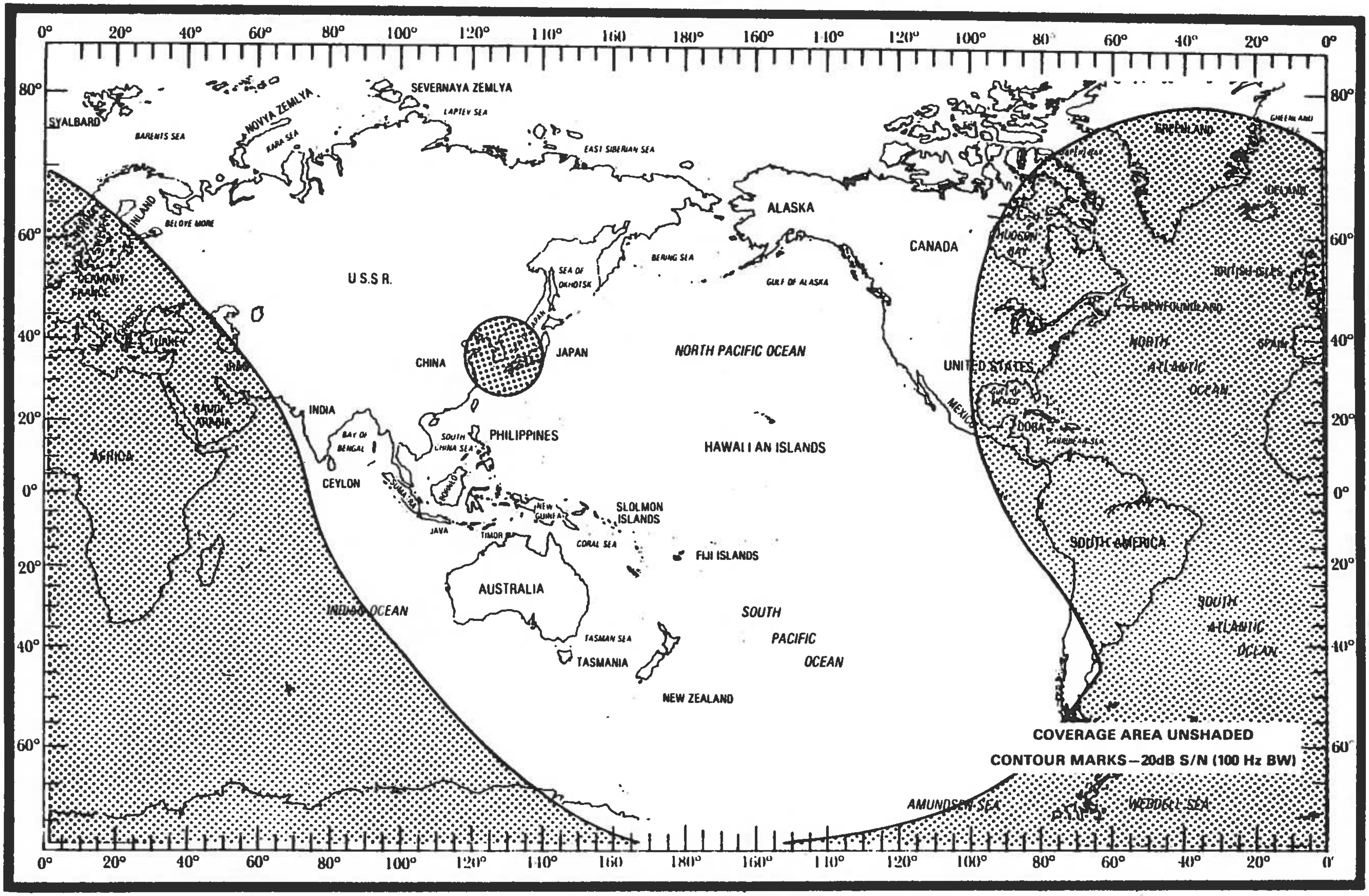



FIGURE A-8. OMEGA COVERAGE, JAPAN STATION (DAYTIME)

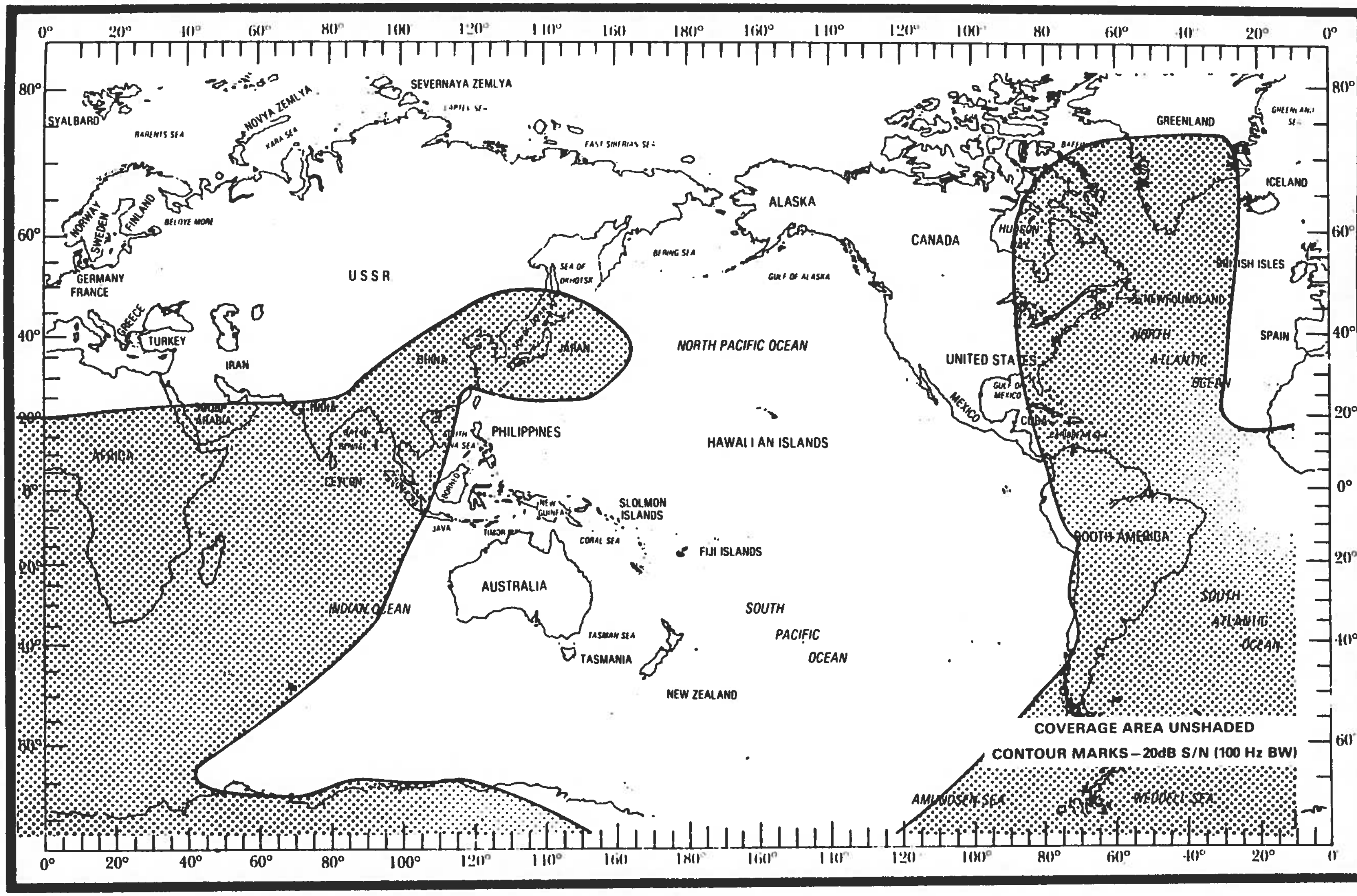



FIGURE A-9. OMEGA COVERAGE, JAPAN STATION (NIGHTTIME)

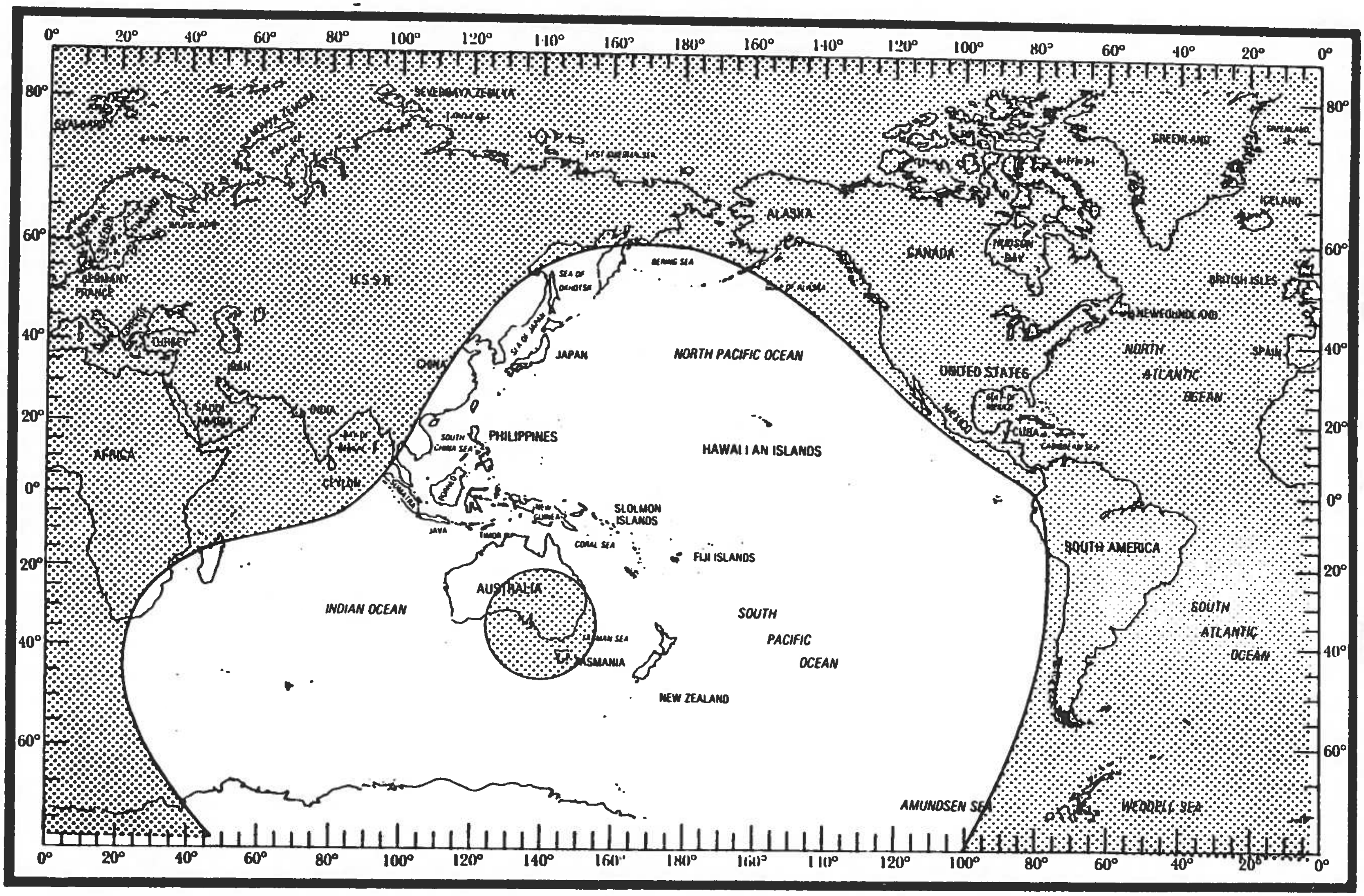



FIGURE A-1Ø. OMEGA COVERAGE, AUSTRALIA STATION (DAYTIME)

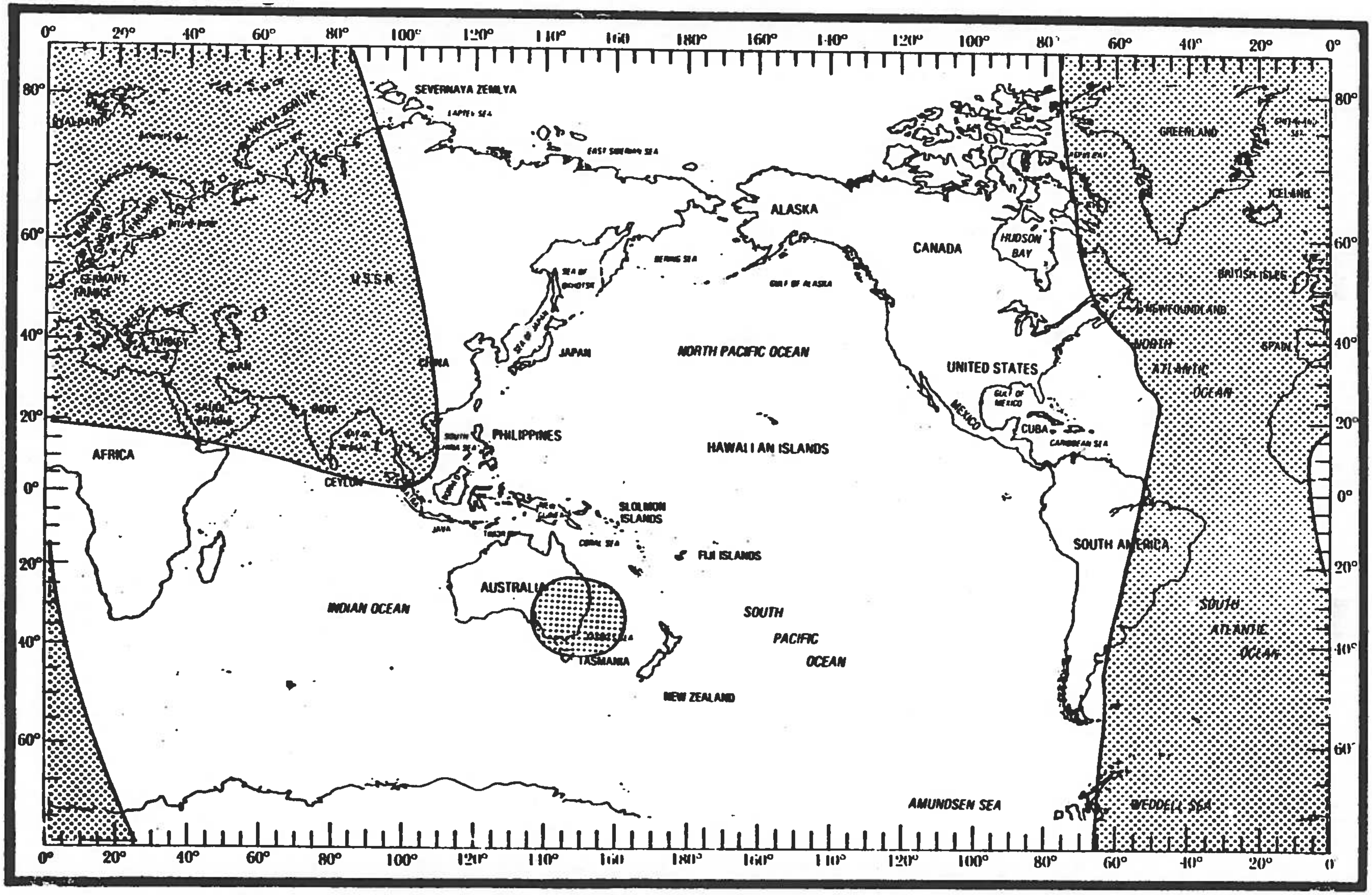



FIGURE A-11. OMEGA COVERAGE, AUSTRALIA STATION (NIGHTTIME) counters. Strip chart recorders are necessary for lane identification and result in a concomitantly higher level of pricing.

Omega receiver prices for the various user categories are given below and are based on the data contained in References and from discussion with industry representatives.

- Large Commercial Vessels - $5000
- Small Commercial Vessels - $3100
- Fishing & Sport Fishing Vessels - $3400
- Recreational Boats - $2000

## 2.3 Systems Characteristics - TRANSIT

### 2.3.1 General

TRANSIT is a space-based navigational system consisting of five satellites in 600 NM polar orbits. The phasing of the satellites is staggered to minimize time-between-fixes for users. In addition, the Transit system consists of four groundbased monitors. The monitor stations track each satellite while in view and provide the tracking information necessary to update satellite orbital parameters every 12 hours.

The satellites broadcast ephemeris information continuously on approximately 150 MHz and 400 MHz signals. One frequency is required to determine a position. However, by using the two frequencies, higher accuracy can be attained. A receiver measures successive doppler, or apparent frequency shifts of the signal, as the satellite approaches or passes the user. The receiver then calculates the geographic position of the user based on knowledge of the satellite position that is transmitted from the satellite every two minutes, and a knowledge of the doppler shift of the satellite signal. Also, vessel course, speed, and time must be known in order to determine position accurately. TRANSIT system characteristics are in Table A-2.

Predictable accuracy for a single frequency receiver is 500 meters, for a dual frequency receiver 25 meters. Repeatable accuracy is 50 meters for a single frequency and 15 meters for a dual frequency receiver.

### 2.3.2 Coverage

Coverage is worldwide but not continuous. While there is coverage in the Hawaiian area, the mean time between TRANSIT fixes is approximately 1.5 hours. This translates into a cumulative cross-track error of less than 1.5 miles at least half the time (95 percent confidence limit). In 10 percent of the time, there is at least a five hour duration between fixes and may be as great as eight hours in a limited number of cases. For these extended periods, cross-track error ranges between 2.5 and 7 miles and 2.5 to 4 miles error along-track (95 percent

TABLE A-2
SELECTED SYSTEM CHARACTERISTICS
TRANSIT, NAVSTAR GPS

| System | Description | Accuracy 1/ | | | Avail. | Coverage | Rel. | Fix Rate | Fix Dim. | Capacity | Ambiguity Potential |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pred. | Repeat. | Relative | | | | | | | |
| TRANSIT | Satellite Doppler | 500m | 50m | 38m | 99+% when Satellite is in View | Worldwide Non-Continuous | – | 30 Min. at 80° lat. to 110 min. at Equator (Average) | 2D | Unlimited | – |
| NAVSTAR GPS | Satellite, UHF Spread Spectrum Structured Navigation Signal | Horiz. 25m<br>Vert. 30m | 25m<br>30m | 10m<br>8m | 95% | Global Continuous | 99+% | Essentially Continuous | 3D+ Time and 3D Velocity | Unlimited | – |

NOTE: Horizontal (2 drms) and vertical (2 sigma) accuracies are available to military and selected civil users. Accuracy available to other users is estimated at: 500m (2 drms) horizontal and 430m (2 sigma) vertical.

Source: Reference 1

Source: Reference 1:confidence limits). These latter errors are dependent upon vessel course, speed and quality of dead reckoned position.

### 2.3.3 Receiver Costs

The number of TRANSIT receivers presently exceeds 20,000 sets in use worldwide. This number is growing annually as more ocean going vessels acquire and install this system. As a result of this growing market, the impact of price competition has been felt. The following prices were derived from industry discussions and reflect the current downward pressure

Large Commercial Vessels - $10,500
Small Commercial Vessels - $4850
Fishing and Sport Fishing Vessels - $6950
Recreational Boats - $4000

## 2.4 System Characteristics - NAVSTAR GPS

### 2.4.1 General

NAVSTAR GPS is a space-based radionavigation system being developed by the Department of Defense under Air Force management. The concept is predicated upon accurate and continuous knowledge of the spatial position of each satellite in the system with respect to time and distance from the transmitting satellite to the user. Each satellite transmits its ephemeris data. This is periodically updated by the master control station based upon data obtained from the monitors. The fully deployed operational system is intended to provide highly accurate positional information in three dimensions and precise time and velocity information on a global basis continuously, to an unlimited number of properly-equipped users. It will be unaffected by weather and will provide a worldwide coverage with a common grid reference system. While the system was initially conceived to meet the requirements of a wide spectrum of military missions, current policy calls for civil availability with a degradation in system accuracy required to protect national security interests.

The user system automatically selects appropriate signals from each of four satellites (selected from those in view with respect to optimum satellite-to-user geometry). It then solves the three time-of-arrival difference quantities to obtain distance between user and satellites. This information establishes the user position with respect to the satellite system. A time correction factor then relates the satellite system to earth coordinates. Each satellite will continuously transmit a composite signal at 1227.6 and 1575.42 MHz consisting of a precise navigational signal, a coarse acquisition navigational signal, data such as satellite ephemeris, atmospheric propagation correction data and clock bias information. User equipment measures four independent pseudoranges and range-rates and translates these to three-dimensional position, velocity and system time. Worldwide full operational capability is expected by 1987. The characteristics of NAVSTAR GPS are summarized in Table A-2.

### 2.4.2 Receiver Costs

Receiver costs for the civil user have been estimated in several previous studies (References 31, 32, 33, 34,). These costs are estimates and dependent upon the assumptions made with respect to the level of technology employed, the degree of technical sophistication incorporated into the receiver, production quantities, market split and user demand, to name a few. Further, some of these studies addressed only the civil aviation user. References 31 and 32 translated aviation equipment costs into marine equipment costs. These results indicated that GPS marine receiver prices would lie between $4200 and $10,800 depending upon signal availability, needs of the user, and degree of receiver sophistication. These prices were based upon 1980 dollars and production base of 20,000 units. Specifically, for the various user categories, these prices were:

Large Commercial Vessels - $7300 - $10,800
Small Commercial Vessels - $5200 - $7700
Fishing and Sport Fishing Vessels - $5200 - $7700
Recreational Boats - $4200 - $6200

## 3. USER REQUIREMENTS

### 3.1 General

The radionavigation requirements for vessels operating in the Hawaiian Islands are based on the generalized requirements detailed in the Federal Radionavigation Plan (Reference 1). Because of the lack of hazards to navigation and due to the relatively benign weather conditions, there are few Hawaii-specific requirements which exceed those of the general requirements. Those that do exist are related to the specific function of the user, e.g., fishing. The fishing requirements as a function of species are discussed in detail in Appendix D.

The navigational requirements of a vessel depend upon its type and size, the activity in which the ship is engaged, e.g., point-to-point transit, fishing; the geographic region in which it operates, e.g., ocean, coastal; and other factors. Safety requirements for navigation performance are dictated by the physical constraints imposed by the environment and the vessel, and the need to avoid the hazards of collision, ramming and grounding.

In this study, system performance parameters are identified based on the need to satisfy current maritime user requirements or to achieve special benefits on the high seas (ocean phase) and in the coastal waters. These parameters are divided into two categories. There are unique requirements needed to provide special benefits to the various classes of navigation users, and there are those related to safety of navigation. The requirements are categorized in terms of performance characteristics which represent the minimum performance considered necessary to satisfy the requirements or achieve special benefits.

### 3.2 Ocean Navigation Requirements

The requirements for safety of navigation on the high seas are given in Table A-3. For safe general navigation under normal circumstances, the requirements for the accuracy and frequency of position-fixing on the high seas are not very strict. All position accuracy requirements are 2 drms. As a minimum, these requirements include a predictable accuracy of 2-4 nm coupled with a maximum fix interval of two hours or less. These minimum requirements would permit reasonable safe oceanic navigation, provided that the navigator understands and makes allowances for the probable error in navigation, and provided that more accurate navigational service is available as land is approached. While these minimum requirements would permit all vessels to navigate with relative safety on the high seas, more desirable requirements would be predictable accuracy for 1-2 nm and a fix interval of 15 minutes or less. The navigation signal should be available 95 percent of the time. Further, in any 12-hour period, the probability of obtaining a fix from the system should be at least 0.99.

Larger recreational craft and smaller commercial fishing vessels which sail beyond the range of coastal navigation systems require, for a reasonable level of safety, some means of establishing their position reliably at intervals of a few hours at most. Even more so than with larger ships, this capability is particularly important in time of emergency or distress. Many (perhaps most) of these craft, however, will accept the risk of ocean sailing without reliable radionavigation unless that capability is available at relatively low cost. In addition, many of the recreational ocean sailers for whom sailing is a serious avocation shun the more precise electronic systems and choose to rely on celestial navigation because this method is more in keeping with the traditions of the sea.

Economic efficiency in transoceanic transportation, special maritime activities and safety in emergency situations require or benefit from navigational accuracy higher than that need for safety in routine point-to-point ocean voyages. These requirements are summarized in Table A-3. The predictable accuracy requirements may be as stringent as 0.1 nm for special maritime activities and large, economically efficient vessels; and may range to 0.25 nm for all of the above categories, including search operations. Search operations must also have a repeatable accuracy of at least 0.25 nm. As indicated in Table A-3, the required fix rate may range from as low as once per five minutes to as high as once per minute. Signal availability must be at least 95 percent and approach 99 percent for search and

## TABLE A-3
## CURRENT MARITIME USER REQUIREMENT
## OCEAN PHASE

| REQUIREMENTS | VALUES OF MINIMUM PERFORMANCE MEASURES TO MEET REQUIREMENTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ACCURACY (2 drms) | | | | | | | | | |
| | PREDICTABLE | REPEATABLE | RELATIVE | COVERAGE | AVAILABILITY | RELIABILITY | MINIMUM FOR INTERVAL | FIX DIMENSION | CAPACITY | AMBIGUITY |
| Safety of Navigation - All Craft | 2-4NM(3.7-7.4km) Minimum 1-2NM(1.8-3.7km) DESIRABLE | - | - | Worldwide | 95% full cap. 99% Fix at least every 12 hours | (2) | 15 Mins. or Less Desired; 2 hrs. Maximum | Two | Unlimited | Resolvable with 99% Confidence |

| BENEFITS | VALUES OF MINIMUM PERFORMANCE MEASURES TO ACHIEVE BENEFITS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Large Ships Maximum Efficiency | 0.1-0.25NM (185-460M) | - | - | Worldwide except Polar Regions | 99% | (2) | 5 Min. | Two | Unlimited | Resolvable with 99% Confidence |
| Hydrography Science, Resource Exploitation | 10-100 M (1) | 10-100 M (1) | - | Worldwide | 95% | (2) | 1 Sec | - | Unlimited | Resolvable with 99% Confidence |
| Search Operations | 0.25NM (460 M) | 0.25 MN | 185 M | National Maritime SAR Region (NPAC, NWLAN) | 99% | (2) | 1 Min. | Two | Unlimited | Resolvable with 99% Confidence |

(1) Based on Stated User's Need
(2) Dependent Upon Mission Time

rescue operations and large, high-efficiency ships. These requirements are based on current estimates and are to be used for the purposes of system planning. There has not been sufficient analysis to establish definitive, quantitative relationships between navigational accuracy and economic efficiency, however, estimates have been made for purposes of this study in order to derive ranges of benefits (see Sections 8. and 9.).

The expensive, satellite-based navigation systems used by ships engaged in science and resource exploration, and the increasing use of relatively expensive satellite navigation by merchant ships and larger, oceangoing fishing vessels is evidence of the perceived value attached to highly accurate ocean navigation by the vessel owners.

### 3.3 Coastal Navigation Requirements

Requirements for position fixing accuracy for coastal navigation are based upon the need for larger vessels to navigate at safe distances from shallow water, on the need to remain in the designated traffic separation lane at the approaches to many ports and in fairways established through offshore oil fields. Only the first requirement is applicable to the Hawaiian Islands. Further, there is a need for accurate definition for enforcement purposes of the boundaries of the Fishery Conservation Zone, the U.S. Customs Zone and the territorial waters of the U.S.

In Reference 1 it has been stated that a navigation system providing a capability to fix position to an accuracy of 0.25 nm will satisfy the minimum safety requirements if a fix can be obtained at least every fifteen minutes. As indicated in Table A-4, these requirements may be relaxed slightly for the recreational boat and other small vessels.

In such activities as marine scientific research, hydrographic surveying, commercial fishing, and petroleum or mineral exploration, as well as naval operations, there may be a need to establish position in the coastal area with much higher accuracy than that needed for safety of general navigation. As shown in Table A-4, the most rigid requirement of any of this general group of special operations is for position measurement with a repeatable accuracy on the order of 1.0-100 meters (2 drms), a signal availability of at least 99 percent, and a fix rate of once per second for most applications.

### 3.4 Specific Hawaii Requirements

Based on discussions with marine interests in the Hawaiian Islands (Appendix F) no user requirements could be identified which exceeded or differed from those already discussed above.

TABLE A-4
CURRENT MARITIME USER REQUIREMENTS
COASTAL PHASE

| REQUIREMENTS | VALUES OF MINIMUM PERFORMANCE MEASURES TO MEET REQUIREMENTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ACCURACY (2 drms) | | | | | | | | | |
| | PREDICTABLE | REPEATABLE | RELATIVE | COVERAGE | AVAILABILITY | RELIABILITY | FIX INTERVAL | FIX DIMENSION | CAPACITY | AMBIGUITY |
| Safety of Navigation - All Ships | 0.25 NM (460 M) | - | - | U.S. Coastal Waters | 99.7% Minimum | (1) | 2 Min. | Two | Unlimited | Resolvable with 99.9% Confidence |
| Safety of Navigation - Recreational Boats & Other Smaller Vessels | 0.25NM-2NM (460-3700 M) | - | - | U.S. Coastal Waters | 99% Minimum | (1) | 5 Min. | Two | Unlimited | Resolvable with 99.9% Confidence |

| BENEFITS | VALUES OF MINIMUM PERFORMANCE MEASURES TO ACHIEVE BENEFITS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Commercial Fishing (including Commercial Sport Fishing) | 0.25 NM (460 M) | 50-600 ft. (15-180M) | | U.S. Coastal/ Fisheries Areas | 99% Minimum | (1) | 1 Min. | Two | Unlimited | Resolvable with 99.9% Confidence |
| Hydrography Science, Resource Exploitation | 1.0-100 M (2) | 1.0-100 M (2) | - | U.S. Coastal Area | 99% Minimum | (1) | 1 Sec. | Two | Unlimited | Resolvable with 99.9% Confidence |
| Search Operations, Law Enforcement | 0.25 NM (460 M) | 300-600 ft. (90-180M) | 300 ft. (90M) | U.S. Coastal/ Fisheries Areas | 99% Minimum | (1) | 1 Min. | Two | Unlimited | Resolvable with 99.9% Confidence |
| Recreational Sports Fishing | 0.25 NM (460 M) | 100-600 ft. (30-180M) | - | U.S. Coastal Areas | 99% Minimum | (1) | 5 Min. | Two | Unlimited | Resolvable with 99.9% Confidence |

(1) Dependent on Mission Time
(2) Based on Stated User's Need

## APPENDIX B

## VESSEL CASUALTY ANALYSIS

### 1. INTRODUCTION

This appendix represents the results of a review and analysis of vessel casualties in the Hawaiian Islands. The particular focus of this activity was upon groundings and other incidents which may bear upon deficiencies in navigation and reflect the need for improved aids to navigation in the region. The area which was the subject of this review was the entire Hawaiian Archipelago including not only the principal islands of Oahu, Kauai, Maui, and Hawaii, but also the Northwest Hawaiian Islands (NHWI) including Laysan, French Frigate Shoals and Midway Islands. This area is particularly unique in a radionavigation sense since there is only partial LORAN-C coverage in the region and hence an empirical model exists for a comparative analysis between vessel groundings which occur inside and outside ground wave signal coverage areas (1:3 signal-to-noise ratio). The vessel casualty data were derived principally from the files of the U.S. Coast Guard Marine Safety Office in Honolulu and represent four years worth of incidents and subsequent investigations. Thus the framework for the assessment of the possible role for improved LORAN-C coverage is based upon historical data.

The principal data element used was the U.S. Coast Guard Merchant Vessel Casualty Reports (MVCR). These reports are prepared by the investigating officer and contain the causal factors, a narrative description of the incident, vessel(s) and personnel data, location, time and environmental conditions, deaths, injuries and dollar value of loss and damage. These reports are required to be filed for each stranding or grounding, physical damage to property in excess to $1,500, material damage affecting the vessels seaworthiness or loss of life or severe injury. These reports are required to be filed by all U.S. and foreign flag vessels for casualties which occur within the navigable waters of the U.S. (3-mile limit). Further, U.S. vessels are required to report on each casualty, regardless of location. Hence, this data base is deficient in data on casualties involving foreign flag vessels in international or foreign waters. For example, because of these limitations and constraints, this data base would not contain a report on the grounding of the Liberian Tanker Argo Merchant on December 15, 1976 on Nantucket Shoals. This vessel was of foreign registry and the incident occurred 29 miles from shore.

As well as providing the Merchant Vessel Casualty Reports, the files of the Marine Safety Office were used to develop background information and insights into the causes of the casualties and direct and indirect loss and damage costs. Further, these files were used to provide information on recent incidents about which the investigation was pending and no Merchant Vessel Casualty Report had been prepared.

To supplement this data base, other sources were consulted. These included the National Transportation Safety Board Reports and the Casualty Returns from Lloyd's Registry of Shipping. The former provided additional information about major marine casualties as well as all marine accidents in which a public and non-public vessel were involved. The latter source contained data on foreign flag casualties, particularly those which occured in international waters. However, this source was limited with respect to both causal factors and loss and damage factors. Both of the sources contained few entries with respect to vessel casualties in the Hawaiian Islands region. Hence, the principal basis for this analysis were the files of the Coast Guard Marine Safety Office in Honolulu.

## 2. CASUALTY CHARACTERIZATION

In order to provide a comprehensive assessment of the impact of improved LORAN-C coverage on the navigational capability of a vessel in Hawaiian waters, all entries for the four year period, 1977-1980 were initially reviewed. The purpose of this initial screening was two fold: first, to exclude from further analysis those incidents wherein personal injury or death was involved and there was no accompanying vessel damage. These were incidents which occured on the high seas and included assaults, accidental injuries, murder or death from natural causes. The second purpose was to identify maritime incidents which did not meet the following criteria:

- Occurence withing either the territorial waters of the United States or the State of Hawaii.

- Occurence in international waters but within the Central Pacific LORAN-C coverage area.

- Occurence in international waters outside the Central Pacific LORAN-C coverage area but inside the proposed expanded LORAN-C coverage area.

This initial screening would provide a base of vessel casualties and would identify those which occured outside of Hawaiian or contiguous waters but about which a Merchant Vessel Casualty Report had been filed.

The results of this initial process indicated that there were 282 entries in this data base for the four year period, 1977-1980. Of these entries, 179 were vessel related; the balance 103, pertained to personal injury or death.

A second series of reviews were made to classify the vessel incidents based on type of casualty or by principal causes. If more than one cause was involved, the major contributing cause was used. Five incident-causing factors were identified:

- Collisions
- Fire and explosions
- Weather
- Groundings
- Engineering Failure and Other

Groundings were considered to be the principal navigation-related factor, however the other factors were examined as well for navigation deficiencies. For example, collision incidents were reviewed for evidence of faulty navigation either as the primary or contributing cause of the incident. Also included in the grounding category were strandings, that is, those incidents where the vessel was grounded or beached through tidal or current actions. Included in the collision category were rammings wherein the vessel struck a fixed or submerged object. This type of incident frequently occurs in regions of offshore petroleum activity with the vessel either striking a submerged structure such as the wellhead or the offshore rig itself. In none of the incidents examined other than groundings were navigation deficiencies found to be a supplemental or contributing cause.

The results of this review are shown in Figure B-1. This figure gives the distribution of the total vessel incidents for the period 1977-1980. Further, the incidents are identified by causal factor both in terms of absolute numbers and as a percentage. As can be seen, approximately 21 percent of the incidents are vessel groundings. This amounted to 39 incidents during this period.

The vessel grounding incidents were then further analyzed to eliminate those which did not have a direct bearing on deficiencies in navigation. This analysis initially discriminated between those incidents that occured in-port and those that occurred while underway. The in-port category included groundings which occurred while the vessel was maneuvering to tie up or moor as well as those incidents which occured while the vessel was already anchored or moored but subsequently grounded through wind, current or tidal conditions. The breakdown of vessel incidents and vessel groundings are shown in Table B-1. Out of 39 vessel groundings, twenty-four occured while the vessel was underway. This amounted to an average of six incidents per year.

The underway categories were then examined to determine which ones were attributable wholly or in a major part to navigation errors, which ones were principally caused by other conditions such as material failure and which ones would be excluded for other reasons such as occurence outside of the territorial waters or outside of the proposed LORAN-C expanded coverage area. The results of this analysis are also shown in Figure B-1. Of the 25 groundings which occurred while the vessel was underway, thirteen were navigation-related, either as a primary or contributing

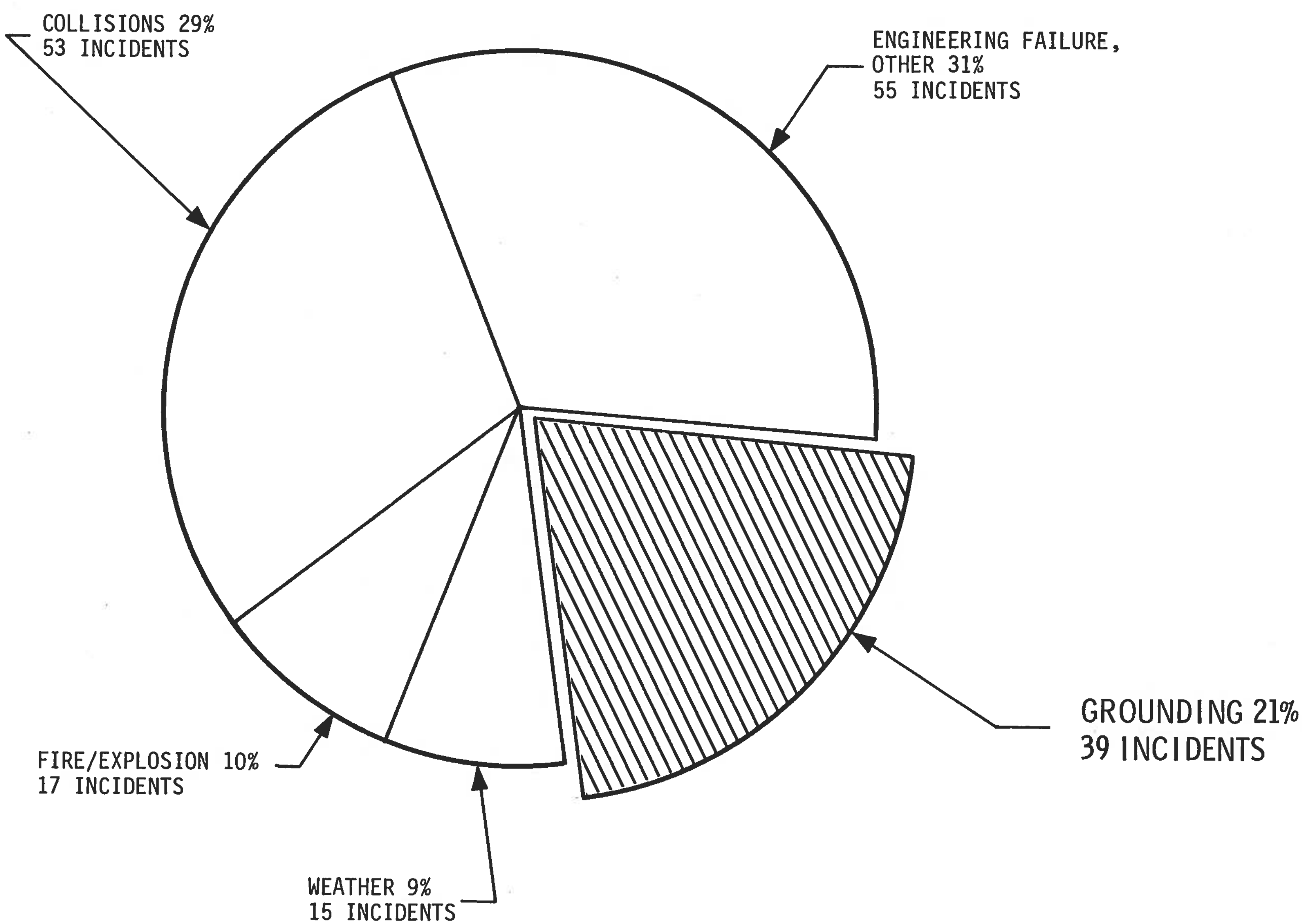



Figure B-1

CAUSAL FACTORS - VESSEL INCIDENTS

1977-1989

Table B-1

VESSEL GROUNDINGS - HAWAII 1977-1980

| | | YEAR | | | | TOTALS | 4-YEAR AVERAGE |
|---|---|---|---|---|---|---|---|
| | | 1980 | 1979 | 1978 | 1977 | | |
| TOTAL VESSEL INCIDENTS | GROUNDINGS | 13 | 9 | 7 | 10 | 39 | 10 |
| | OTHER INCIDENTS | 50 | 22 | 20 | 48 | 140 | 35 |
| | TOTAL | 63 | 31 | 27 | 58 | 179 | 45 |
| TOTAL VESSEL GROUNDINGS | INPORT | 7 | 3 | 3 | 1 | 14 | 4 |
| | UNDERWAY | 6 | 6 | 4 | 9 | 25 | 6 |
| | TOTAL | 13 | 9 | 7 | 10 | 39 | 10 |
| TOTAL UNDERWAY GROUNDINGS | MATERIAL FAILURE | 1 | 1 | 1 | 5 | 8 | 2 |
| | OUTSIDE HAWAII | 1 | 1 | 1 | 1 | 4 | 1 |
| | NAVIGATION RELATED | 4 | 4 | 2 | 3 | 13 | 3 |
| | TOTAL | 6 | 6 | 4 | 9 | 25 | 6 |

factor. Eight of the remaining groundings had as their primary cause a material failure affecting the navigability or control of the vessel. For example, the motor vessel Jag Jiwan grounded in the entrance to Honolulu Harbor due to an undetected increase in vessel draft. This increase in draft was due to poorly maintained cargo hatches which permitted the seas to enter the cargo holds and to increase the draft of the vessel. Other material failures which were contributing factors to these groundings included loss of steering control, loss of power or parting of tow lines. None were navigation-related.

On the other hand, there were four groundings which occured outside of the Hawaiian waters or outside of the proposed expanded LORAN-C coverage area. All of this latter category of groundings were navigation-related, but since LORAN-C (either current or projected) would not have been available for the prevention or attenuation of the incident, these groundings were not considered. One incident in this category occured on the edge of the coverage estimated to be provided by the addition of a LORAN station on Kauai. This incident involved the grounding of the Japanese Fishing Vessel Myojin Maru on Kingman Reef located to the northwest of Palmyra Atoll. The vessel grounded due to a navigational error by the master and subsequently broke up with a total loss to the vessel and cargo. This loss amounted to $650,000. Had LORAN-C been available, if a high quality receiver were aboard, and had the master been skilled in its use in marginal signal coverage areas it is possible that this incident could have been averted. However, since this incident occured in a peripheral area it is questionable if LORAN-C could have contributed to its prevention, hence it was not considered.

The remaining incidents were navigation-related and occurred within current or projected LORAN-C coverage areas. For the four year period in question, there were a total 13 of these incidents with an annual ocurrence of between two and four per year (See Table B-1). These incidents provided the base for the casualty analysis and each one was subsequently examined in detail for navigational deficiencies, LORAN-C applications and benefits.

3. DETAILED CASUALTY ANALYSIS

The thirteen vessel incidents involving navigation-related groundings were analyzed to establish the cost of the incident including loss, damage, recovery and salvage costs. Also included in this analysis was an investigation of the causes and events leading up to the grounding in order to develop insights into the navigational deficiencies and to determine the possible role for LORAN-C in its prevention. The results of this analysis were used to determine benefit factors in the prevention or reduction of navigation-related incidents. These factors were based on this historic data as well as future traffic projections and were expressed as dollar savings.

Table B-2 summarizes the results of this analysis. This table shows the name and nationality of the vessel, the date of the grounding, the location of the incident, a brief description, and cause of the incident, whether radar and/or LORAN-C was installed, if it was working and in use and the costs of the incident. Most of these data were derived from the Merchant Vessel Casualty Reports and other supporting data from the Marine Safety Office in Honolulu. The cost data which were obtained from these files were modified to include the costs associated with the salvage or recovery of the vessel. These latter data included tug and divers time, inspection costs and loss of vessel productivity and were based on estimates derived from the narrative description of the incident.

Thirteen vessel incidents are shown in Table B-2. These incidents range in severity from relatively minor occurrences such as the grounding of the Unicorn I in Pailolo Channel off Molokai at a cost of $1500 to major vessel groundings and/or subsequent sinkings (Anagel Liberty and Santa Ines at French Frigate Shoals for a total loss and damage of $1,170,000). While these vessel incidents occurred throughout the archipelago, most occured within the major islands, with six incidents occuring in the Barber's Point - Honolulu area in Oahu. Figure B-2 shows the location of the incidents and the total loss and damage costs at each locale. In terms of dollar losses the region of greatest loss is French Frigate Shoals with two groundings occurring during the period under analysis.

The principal cause of the grounding in four of the incidents was the inattention of the master to the position of the vessel. This inattention took the form of leaving the bridge to get a cup of coffee, or permitting the vessel to drift while awaiting the arrival of a pilot. While it is conjectural that the availability of LORAN-C would have prevented the incident or if the master would used it if it were available, nevertheless if the master had been able to avail himself of better vessel positional knowledge, he might have paid attention to the operation of his vessel while approaching hazardous waters.

Nine of the groundings occurred through lack of accurate positional information. In two of these groundings the effects of wind or current were misjudged causing the vessels to be set on reefs. Four of the groundings occured at night, with the operator or master unfamiliar with the waters such that lights or other aids to navigation were mistakingly identified. In two more of the incidents, the effects of wind and sea were contributing factors. In all of the nine incidents, it appears that had LORAN-C been available and that if a receiver was aboard the vessel and in use it is possible that the incident might have been averted or the effects attenuated.

However, the availability of LORAN-C or any electronic aid to navigation does not relieve the master or operator from the exercise of prudence or good seamanship. This is borne out by the fact that three of the above nine incidents occured within

## Table B-2

# GROUNDING INCIDENT SUMMARY
# HAWAIIAN ISLANDS - 1977-1980

| GROUNDING INCIDENT | DATE | LOCATION OF INCIDENT | DESCRIPTION CAUSE | RADAR | LORAN-C | COSTS- LOSS, DAMAGE, SALVAGE |
|---|---|---|---|---|---|---|
| MYOJIN MARU (JAPAN) | 2/19/80 | MAMALA BAY, OAHU | INATTENTION OF MASTER TO VESSEL POSITION EARLY MORNING, CALMSEA VISIBILITY 8 MILES | OPERATING | UNKNOWN | $44,500 |
| UNICORN I (US) | 9/13/80 | PAILOLO CHANNEL, MOLOKAI | MASTER MISJUDGED AFFECTS OF WIND/SEA WHILE OPERATING CLOSE TO REEF | NO | NO | $1500 |
| SANTA INNES (US) | 9/11/80 | FRENCH FRIGATE SHOALS | FAILED TO SEE REEF, GROUNDING, SUNK WHILE BEING TOWED | OPERATING | PROBABLY | $385,000 |
| ANANGEL LIBERTY (GREEK) | 4/27/80 | FRENCH FRIGATE SHOALS | FAILURE OF CHIEF MATE TO DETERMINE VESSEL POSITION. GROUNDED, CARGO JETTISONED, REFLOATED | OPERATING | NOT OPERATING | $785,000 |
| SEIWA MARU #8 (JAPAN) | 12/4/78 | 1000 YDS OFF WAIKIKI BEACH, OAHU | FAILURE TO MAINTAIN PROPER WATCH-LEFT BRIDGE TO GET COFFEE | NOT OPERATING | UNKNOWN | $46,000 |
| TARUS (US) | 1/3/79 | KIKIAOLA HARBOR, KAUAI | MISTOOK LIGHT HEADED FOR PT. ALLEN-NIGHT, RAIN, 20K + WINDS, 6FT. SEAS, GROUNDED, TOTAL LOSS | NOT OPERATING | PROBABLY | $129,000 |
| CAROL LEE (US) | 9/22/78 | MANELE BAY, LANAI | OPERATION DURING DARKNESS IN HAZARDOUS WATERS. FAILED TO ACCOUNT FOR SET/DRIFT | NO | NO | $19,000 |
| SEIYO MARU #2 (JAPAN) | 7/26/79 | MAMALA BAY, OAHU | NAVIGATED OUTISDE HONOLULU CHANNEL- INATTENTION TO DUTY BY MASTER | OPERATING | OPERATING | $17,000 |
| IRENE KAY (US) | 2/28/78 | PENGUIN BANK, MOLOKAI | MISJUDGED POSITION OF VESSEL-NIGHT | UNKNOWN | UNKNOWN | $165,000 |
| HELEN W. (US) | 6/13/78 | BARBER'S POINT, OAHU | NAVIGATION ERROR | NO | NO | $34,000 |
| BARGE 225 (US) | 12/10/76 | BARBER'S POINT OAHU | TOUCHED UNCHARTED BOTTOM OBSTRUCTION | NO | NO | $26,000 |
| KATSUEI MARU (JAPAN) | '77 | MAMALA BAY, OAHU | VESSEL DRIFTED ASHORE WHILE AWAITING PILOT | PROBABLY | UNKNOWN | $4200 |
| SHAMAN (US) | 6/7/77 | KAHULUI BAY, MAUI | LACK OF FAMILIARITY WITH AREA. NIGHT | OPERATING | (LORAN-A) | $146,000 |

WITHIN LORAN C COVERAGE AREA [shaded box]

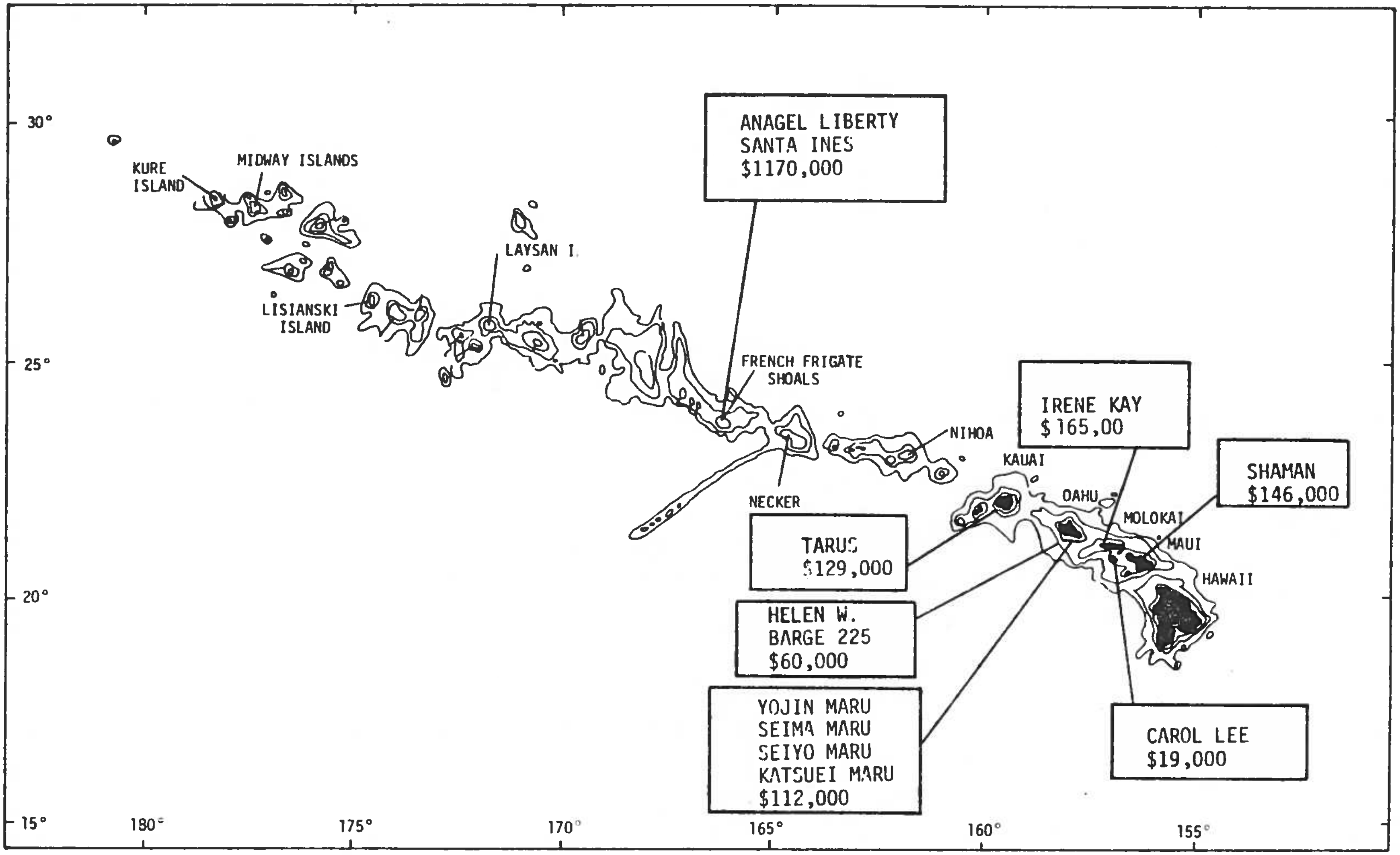



Figure B-2

MAJOR GROUNDINGS 1977-1980

the current CENPAC LORAN-C coverage area. The cargo vessel Anagel Liberty grounded on French Frigate Shoals on April 27, 1980. The vessel grounded due to the failure of the chief mate to ascertain the vessel's position. The vessel was subsequently refloated, but only after the cargo of kaolin was jettisoned. The vessel was on its maiden voyage and it had LORAN-C aboard, but it was not in operation. The U.S. fishing vessel Santa Innes also grounded on French Frigate Shoals on March 11, 1980. The master failed to see the reef, the vessel grounded and subsequently sunk while being towed due to the damage sustained in the grounding. The Santa Innes was homeported in Westport, Washington and although the record is unclear, it undoubtedly had LORAN-C aboard since most Pacific Coast fishing vessels are so equipped. The third incident involved the U.S. fishing vessel Tarus. This West Coast mackerel boat grounded on January 3, 1979 at Kikiaola small boat harbor on Kauai. The vessel master was unfamilar with the area and mistook the Kikiaola Light for the Port Allen light and subsequently grounded. Again, the record does not state if the vessel had LORAN-C aboard, but since the vessel originated from the U.S. West Coast it was highly likely that it was equipped.

These three incidents emphasize the fact that LORAN-C in and of itself will not prevent accidents. The system must be used by diligent and competent mariners and it must be used in conjunction with all navigational aids which are available.

From the review of the above data it would appear that approximately half of the above incidents could have been avoided or reduced had LORAN-C been available and used properly. Accordingly, for analytical purposes and in order to ascribe a quantitative value to the role of LORAN-C in the prevention of marine navigation-related incidents, it was assumed that the total dollar value of these losses could be reduced by 50 percent. From the data in Table B-2 and from the discussion above it can be seen that three of the losses occured within the area of coverage of the current CENPAC Chain. Therefore, it is assumed that for these three incidents, an equal dollar value of loss has already been averted. This averted loss amounts to a savings of $1.4 million. This savings plus 50 percent of the dollar value of the remaining grounding losses comprised the benefits attributable to LORAN-C in the prevention of navigation-related incidents. Using the above approach and assumptions, the average annual savings would be $470 thousand. This figure was then used as the basis for projections of future benefits as indicated in Section 8.

APPENDIX C

# COMMERCIAL VESSEL TRAFFIC AND POPULATIONS

## 1. INTRODUCTION

The purpose of this appendix is to develop a profile of large and small commercial vessels, engaged in trade between the U.S. mainland and Hawaii, Hawaii and foreign ports, and between the main Hawaiian islands. Current traffic, vessel populations and LORAN-C users were estimated and projections were made for the years from 1980 to 2000.

This appendix is primarily concerned with vessels which make a trade transaction, that is, load or discharge cargo. However, separate statistics are shown for commercial vessels calling at the Hawaiian ports either to buy supplies, conduct repairs, or to obtain medical services for the crew (non-revenue transactions). Further, the traffic volume generated by commercial vessels sailing through the Hawaiian islands between U.S. west coast and the Far East is presented.

For this appendix, the following vessel categories were used:

- Large Cargo - a vessel greater than 1600 gross tons. Included are: containerships, break bulks, dry cargoes, auto-carriers, RoRos, and freighters.
- Large Tanker - a tank vessel greater than 1600 gross tons.
- Small Cargo - a vessel less than 1600 gross tons.
- Small Tanker - a tank vessel less than 1600 gross tons.
- Tug Boat - a vessel utilized to tow or push barges.
- Barge - a vessel that is not self-powered.
- Other - e.g., yacht, sailing vessel, or research vessel.

## 2. DATA SOURCES AND METHODS USED

### 2.1 Data Sources

An extensive literature search was performed to identify data for this study. The most comprehensive and reliable data were the marine traffic statistics compiled by: a) the Department of Commerce, Foreign Trade Division of the Bureau of the Census, b) the State of Hawaii, Department of Transportation, Harbors Division, and c) statistics maintained by the U.S. Customs, Hawaii District. These statistics were supplemented with information provided by many shipping companies operating vessels in the study area. A list of contacts is shown in Appendix F.

### 2.2 Methods Used

In order to facilitate the presentation of data, and the benefit-cost calculations, the traffic within the LORAN-C coverage area was classified in four categories as follows:

- o Direct Oceanic Traffic - consisting of two components: a) traffic between U.S. mainland Alaska* and Hawaii, and b) Hawaii to from foreign ports.
- o Inter-Island Traffic - the traffic generated within the islands of Hawaii.
- o Non-Revenue Traffic - the traffic created by vessels which are not involved in trade (load or discharge cargo), but call in Hawaii while en-route to other ports to obtain supplies, conduct repairs or obtain medical care for the crew.
- o Through Traffic - vessels transiting in the vicinity of the Hawaiian islands between the U.S. west coast ports and the Far East.

The Foreign Trade Division of the Bureau of the Census provided the principal data source to estimate the following traffic and population components:

- o Foreign flag vessels sailing between U.S. mainland ports and Hawaii.
- o Foreign flag vessels sailing between foreign ports and Hawaii.
- o U.S. flag vessels sailing between foreign ports and Hawaii.
- o U.S. flag vessels sailing between foreign ports and U.S. mainland via Hawaii.
- o U.S. and foreign flag vessels sailing between U.S. west coast and Far East ports.

The Foreign Trade Division of the Bureau of the Census compiles its statistics from U.S. Customs documents which contain vessel, movement, and cargo information on all U.S. vessels engaged in foreign trade and foreign vessels engaged in U.S. trade (Reference 13). This information is obtained from manifest documents supplied to the U.S. Customs by vessel masters and shipping agents. The Bureau of the Census utilizes this information to compile monthly traffic statistics by U.S. port. The information is presented in two forms: vessel clearances Form (AE 750) and vessel entrances Form (AE 350). Figure C-1 represents parts of these forms.

The statistics compiled by the Hawaii Department of Transportation, Harbors Division were utilized to estimate the following traffic components:

- o U.S. flag vessels operating between U.S. mainland and Hawaii.
- o U.S. flag vessels operating within the Hawaiian Islands.

*Hereafter referred to as U.S. mainland.

Date: Month
Year
Day

Passengers
Army engineer channel
Customs district and port
Vessel manifest
Vessel name
Flag
Type service
Rig
Net registered tonnage
Ballast or cargo
Country and subdivision of U.S. port
Type vessel
Type cargo
Trip
Draft (feet)
0-Entrance code
Census use only
Month and serial number (census use only)

Figure C-1
AE 350 PART 2, MONTHLY VESSEL ENTRANCE IN DISIRICT, PORT, AND MANIFEST ARRANGEMENT
(Page 1 of 3)

EXPLANATION OF CODES

Type of Service
1. Liner or berth
4. Tanker
5. Irregular or tramp

Rig
1. Motor dry cargo, steam dry cargo
2. Motor tanker, steam tanker
3. Tug
4. Barge (other than tanker), scow
5. Tanker barge
6. Other, including yacht, gas, sloop, schooner, sailboat, houseboat, rowboat, research vessel

Ballast or Cargo
1. Vessel cleared direct to foreign ports in ballast
2. Vessel cleared direct to foreign ports with bulk cargo
3. Vessel cleared direct to foreign ports with general cargo
4. Vessel cleared via other domestic ports in ballast
5. Vessel cleared via other domestic ports with bulk cargo
6. Vessel cleared via other domestic ports with general cargo

Country and Subdivision or U.S. Port
Indicates first foreign country clearing direct to (destination of outbound voyage) in terms of Schedule C code. Where "country to" has marked coastal differences a further distinguishing sub-country code is added - otherwise sub-country code is always "0". If clearing via domestic ports, indicates first U.S. port vessel entered in terms of Schedule D code.

FIGURE C-1. AE 350 PART 2, MONTHLY VESSEL ENTRANCE IN DISTRICT, PORT, AND MANIFEST ARRANGEMENT
(Page 2 of 3)

EXPLANATION OF CODES (Cont.)

Type Vessel
0. Vessels to other domestic ports, Navy operated vessels, vessels in for repairs or crew changes, and all other types excluded by reason of FT 975 coverage.
1. All vessels except tanker cleared direct to foreign ports
2. Tankers cleared direct to foreign ports

Type Cargo
0. All vessels coded "0" under type vessel
1. Bulk or general cargo
3. Ballast

Trip
0. No U.S. or in-transit cargo laden at this port
1. U.S. or in-transit export cargo laden at this port
9. Vessels under 26 net registered tons

*US Vessels not engaged in foreign trade or carrying foreign cargo

FIGURE C-1. AE 350 PART 2, MONTHLY VESSEL ENTRANCE DISTRICT, PORT, AND MANIFEST ARRANGEMENT (Page 3 of 3)

These statistics, however, do not contain origin, destination, type, and gross tonnage of vessels. Shipping companies and vessel operators in the U.S. mainland and Hawaii were contacted to determine this information (Appendix F).

Numbers of vessels not making trade transactions (load or discharge cargo), but calling in Hawaii, were obtained from the "Bunker Log Book" from the U.S. Customs, Hawaii District.

## 3. TOTAL DIRECT OCEANIC TRAFFIC

Total direct oceanic traffic is estimated by adding together two separate components, U.S. mainland to/from Hawaii and Hawaii to/from foreign ports. Table C-1 shows the total estimated 1979 traffic by country and vessel type. As Table C-1 indicates, this traffic accounts for 2727 moves. A vessel move is defined as a transit with either origin or destination in Hawaii. Of these, 1154 moves, or 42 percent, were made by U.S. flag vessels. Nearly 75 percent of the traffic is accomplished with large and small cargo vessels.

Tables C-2 through C-5 show traffic for the ports of Honolulu, Hilo, Kahului and Nawiliwili-Port Allen (Nawiliwili), respectively. Honolulu is the busiest, handling 96 percent of the direct oceanic traffic. Vessels unload cargo in Honolulu which is then transshipped to the other Hawaiian ports, principally via tugs/barges.

### 3.1 U.S. Mainland to Hawaii Traffic

U.S. flag vessels sailing between U.S. ports are not required to clear with Customs, unless they carry foreign cargo. Statistics provided by the Hawaii Department of Transportation, Harbors Division (References 35, 36) were utilized to estimate U.S. flag traffic between the U.S. mainland and Hawaii. In addition, shipping companies and vessel operators engaged in this trade were contacted to obtain information on their operations (Appendix F).

Hawaiian ports handled 1059 moves from to U.S. mainland. Honolulu accounts for 96 percent of this traffic. The principal U.S. mainland ports accommodating the trade are Oakland, Los Angeles, San Francisco, Seattle and Portland. Discussions with vessel operators revealed that very little, if any, traffic exists between Hawaii and other U.S. mainland ports with the exception of Alaska which supplies crude oil to the two refineries located in Oahu.

#### 3.1.1 Large Vessel Cargo Traffic

General cargo traffic represented 693 moves, or about 65 percent of the total U.S. mainland to Hawaii traffic. Table C-1 indicates that this traffic is handled principally by west coast ports. U.S. flag vessels accounted for 562 moves, nearly all of

## TABLE C-1. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 1979

(Page 1 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska | 0 | 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 34 |
| U.S. Gulf | 1 | 0 | 0 | 0 | 0 | 6 | 6 | 0 | 0 | 1 | 14 |
| U.S. West Coast | 561 | 51 | 2 | 0 | 220 tug barge 7 | 124 | 5 | 10 | 1 | 29 | 220 tug barge 790 |
| Caribbean | 0 | 0 | 0 | 0 | 1 | 5 | 7 | 1 | 0 | 0 | 14 |
| South America | 0 | 2 | 0 | 0 | 0 | 8 | 5 | 17 | 2 | 5 | 39 |
| Panama Canal[1] | 21 | 2 | 0 | 0 | 1 | 22 | 10 | 29 | 6 | 1 tug barge 3 | 1 tug barge 94 |
| Japan | 31 | 5 | 0 | 0 | 0 | 88 | 8 | 711 | 2 | 6 | 851 |
| Africa | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 11 |
| Australia | 0 | 0 | 0 | 0 | 0 | 35 | 3 | 1 | 0 | 0 | 39 |
| New Zealand | 0 | 0 | 0 | 0 | 2 | 11 | 0 | 0 | 0 | 8 | 21 |
| Brunei | 2 | 0 | 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 19 |
| Malaysia | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 0 | 16 |
| Taiwan | 45 | 0 | 1 | 0 | 0 | 18 | 1 | 2 | 0 | 1 tug barge 0 | 1 tug barge 67 |
| Trust Territory[2] | 1 | 2 | 4 | 0 | 25 tug barge 2 | 0 | 14 | 1 | 0 | 2 | 25 tug barge 26 |
| Korea | 2 | 0 | 0 | 0 | 0 | 7 | 0 | 16 | 0 | 0 | 25 |
| Other Pacific Islands[3] | 1 | 0 | 8 | 0 | 9 tug barge 9 | 13 | 13 | 18 | 0 | 50 | 9 tug barge 112 |
| Canada | 4 | 0 | 3 | 0 | 9 tug barge 1 | 4 | 1 | 10 | 0 | 11 | 9 tug barge 34 |
| Singapore | 2 | 2 | 0 | 0 | 0 | 1 | 28 | 5 | 0 | 0 | 38 |

## TABLE C-1. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 1979

(Page 2 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Phillipines | 15 | 2 | 0 | 0 | 0 | 6 | 0 | 4 | 0 | 1 tug barge<br>0 | 1 tug barge<br>27 |
| Guam | 7 | 2 | 0 | 0 | 1 tug barge<br>0 | 0 | 2 | 0 | 0 | 0 | 1 tug barge<br>11 |
| American Samoa | 0 | 3 | 4 | 0 | 2 tug barge<br>3 | 1 | 2 | 4 | 0 | 2 | 2 tug barge<br>19 |
| Indonesia | 1 | 0 | 0 | 0 | 0 | 2 | 27 | 0 | 0 | 0 | 30 |
| U.S.S.R. | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 4 | 0 | 1 | 9 |
| Other | 22 | 13 | 4 | 0 | 1 | 6 | 0 | 66 | 0 | 6 | 118 |
| TOTAL | 717 | 118 | 26 | 0 | 266 tug barge<br>27 | 359 | 177 | 899 | 11 | 3 tug barge<br>124 | 269 tug barge<br>2458 |

[1]Panama Canal is not really an origin or destination of vessels, however, vessels which sail through it, declare it as the last port of departure or first port of arrival. The actual origin or destination of the vessel may be different.

[2]Includes the Caroline, Marshall, and Mariana Islands (except Guam) under U.S. administration.

[3]Includes the French and British Pacific Islands. Included in the French Pacific Islands are: New Caledonia, including the Loyalty Islands, Isle of Pines, and Walpole Island; Wallis and Futuna; and French Polynesia, including the Society Islands, Tuamotu and Gambier, Marquesas Islands, the Iles Australes, and Clipperton Island. Included in the British Pacific Islands are: Gilbert and Ellice Islands, including the Phoenix Islands, (except Canton and Enderbury Islands), Ocean Island, and the Line Islands (Washington, Fanning, and Christmas Islands, and the Central and Southern Line Islands); Solomon Islands, including southern Solomon Islands, primarily Guadalcanal, Malaita, San Cristobal, Santa Isabel, and Choiseul; New Hebrides; and Pitcairn Island.

[4]Includes Mexico (2 moves), Europe (3 moves), New York (1 move) and Unknown Origin, Destination (112 moves).

## TABLE C-2. HONOLULU TOTAL DIRECT OCEANIC TRAFFIC - 1979

(Page 1 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska | 0 | 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 34 |
| U.S. Gulf | 1 | 0 | 0 | 0 | 0 | 6 | 6 | 0 | 0 | 1 | 14 |
| U.S. West Coast | 560 | 51 | 2 | 0 | 220 tug barge<br>7 | 120 | 4 | 10 | 1 | 22 | 220 tug barge<br>777 |
| Caribbean | 0 | 0 | 0 | 0 | 1 | 5 | 7 | 1 | 0 | 0 | 14 |
| South America | 0 | 2 | 0 | 0 | 0 | 8 | 5 | 14 | 2 | 3 | 34 |
| Panama Canal | 21 | 2 | 0 | 0 | 1 | 13 | 4 | 25 | 6 | 1 tug barge<br>2 | 1 tug barge<br>74 |
| Japan | 31 | 5 | 0 | 0 | 0 | 70 | 7 | 689 | 2 | 6 | 810 |
| Africa | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 11 |
| Australia | 0 | 0 | 0 | 0 | 0 | 35 | 0 | 1 | 0 | 0 | 36 |
| New Zealand | 0 | 0 | 0 | 0 | 2 | 11 | 0 | 0 | 0 | 6 | 19 |
| Brunei | 2 | 0 | 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 19 |
| Malaysia | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 0 | 16 |
| Taiwan | 45 | 0 | 1 | 0 | 0 | 18 | 0 | 2 | 0 | 1 tug barge<br>0 | 1 tug barge<br>66 |
| Trust Territory | 1 | 2 | 4 | 0 | 25 tug barge<br>2 | 0 | 14 | 1 | 0 | 2 | 25 tug barge<br>26 |
| Korea | 2 | 0 | 0 | 0 | 0 | 6 | 0 | 16 | 0 | 0 | 24 |
| Other Pacific Islands | 1 | 0 | 8 | 0 | 9 tug barge<br>8 | 11 | 13 | 18 | 0 | 35 | 9 tug barge<br>94 |
| Canada | 3 | 0 | 2 | 0 | 7 tug barge<br>1 | 4 | 1 | 10 | 0 | 8 | 7 tug barge<br>29 |
| Singapore | 2 | 2 | 0 | 0 | 0 | 1 | 28 | 5 | 0 | 0 | 38 |

## TABLE C-2. HONOLULU TOTAL DIRECT OCEANIC TRAFFIC - 1979

(Page 2 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Phillipines | 15 | 2 | 0 | 0 | 0 | 6 | 0 | 4 | 0 | 1 tug barge<br>0 | 1 tug barge<br>27 |
| Guam | 7 | 2 | 0 | 0 | 1 tug barge<br>0 | 0 | 2 | 0 | 0 | 0 | 1 tug barge<br>11 |
| American Samoa | 0 | 3 | 3 | 0 | 2 tug barge<br>1 | 1 | 2 | 4 | 0 | 2 | 2 tug barge<br>16 |
| Indonesia | 1 | 0 | 0 | 0 | 0 | 2 | 26 | 0 | 0 | 0 | 29 |
| U.S.S.R. | 1 | 0 | 0 | 0 | 0 | 2 | 11 | 4 | 0 | 1 | 9 |
| Other | 22 | 13 | 4 | 0 | 1 | 6 | 0 | 66 | 0 | 6 | 118 |
| TOTAL | 715 | 118 | 24 | 0 | 264 tug barge<br>24 | 325 | 164 | 870 | 11 | 3 tug barge<br>94 | 267 tug barge<br>2345 |

TABLE C-3. HILO TOTAL DIRECT OCEANIC TRAFFIC - 1979

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. SMALL CARGO | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN OTHERS | TOTAL |
|---|---|---|---|---|---|---|---|
| West Coast | 0 | 0 | 0 | 1 | 0 | 7 | 8 |
| South America | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| Panama Canal | 0 | 0 | 2 | 4 | 0 | 1 | 7 |
| Japan | 0 | 0 | 6 | 1 | 2 | 0 | 9 |
| Australia | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| New Zealand | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| Korea | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Other Pacific Islands | 0 | 1 | 0 | 0 | 0 | 14 | 15 |
| Canada | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| American Samoa | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| TOTAL | 1 | 2 | 9 | 8 | 2 | 28 | 50 |

TABLE C-4. KAHULUI TOTAL DIRECT OCEANIC TRAFFIC - 1979

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN OTHERS | TOTAL |
|---|---|---|---|---|---|---|---|
| West Coast | 1 | 0 | 4 | 0 | 0 | 0 | 5 |
| South America | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| Panama Canal | 0 | 0 | 7 | 2 | 4 | 0 | 13 |
| Japan | 0 | 0 | 12 | 0 | 20 | 0 | 32 |
| Other Pacific Islands | 0 | 0 | 2 | 0 | 0 | 1 | 3 |
| Canada | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| American Samoa | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| TOTAL | 1 | 1 | 25 | 2 | 27 | 2 | 58 |

TABLE C-5. NAWILIWILI TOTAL DIRECT OCEANIC TRAFFIC - 1979

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. SMALL CARGO | U.S. OTHER | FOREIGN LARGE TANKER | TOTAL |
|---|---|---|---|---|---|
| Australia | 0 | 0 | 0 | 1 | 1 |
| Taiwan | 0 | 0 | 0 | 1 | 1 |
| Canada | 1 | 1 | 2 tug barge<br>0 | 0 | 2 tug barge<br>2 |
| Indonesia | 0 | 0 | 0 | 1 | 1 |
| TOTAL | 1 | 1 | 2 tug barge<br>0 | 3 | 2 tug barge<br>5 |

which originated or terminated in west coast ports.

Discussions with U.S. operators indicated that U.S. vessels departing from west coast ports bound to Hawaii usually call first in Honolulu and then may sail to the other Hawaiian ports. A second move, e.g., Honolulu to Hilo, does not represent a direct U.S. mainland to Hawaii movement. Rather this secondary move is defined as inter-island traffic. The general cargo traffic is principally handled by containerships and break bulk vessels.

### 3.1.2 Large Tanker Traffic

The total tanker traffic between the U.S. mainland and Hawaii consisted of 96 moves. U.S. flag tankers handled the majority of this traffic, 85 moves. Crude oil, representing approximately 34 moves, was shipped from Alaska to the two refineries, Hawaiian Independent Refinery, Inc. and Chevron U.S.A., Inc., located at the Barber's Point, Oahu. The refined product is either consumed locally or shipped to west coast ports (San Francisco, Oakland, and others), Trust Territories and other Pacific Islands.

### 3.1.3 Small Vessel Traffic

In general, most goods are shipped from the U.S. mainland to Hawaii via large cargo vessels and tugs/barges. The traffic handled by small cargo vessels accounted for only 12 moves, of which 10 were handled by foreign flag vessels.

Small tanker traffic consisted of a single foreign flag move.

### 3.1.4 Tug/Barge and "Other" Traffic

Tug/barge traffic accounted for 220 moves, all U.S. flag. The tug/barge traffic, consisting principally of sugar, pineapple and construction materials was handled exclusively through west coast ports and Honolulu.

The "other" vessel traffic consisted of 37 moves, most of which, were handled by foreign flag.

## 3.2 Foreign Direct Oceanic Traffic

Foreign oceanic traffic was defined as foreign flag vessels and U.S. flag vessels sailing from non-U.S. mainland ports to Hawaii. Table C-1 shows that the total foreign oceanic traffic was composed of 1668 moves, half of which was represented by traffic between Hawaii and Japan. Again, Honolulu handled nearly all of the foreign oceanic traffic. The Japan to Hawaii trade was carried principally by small cargo vessels. Some remaining traffic was distributed among the "Other Pacific Islands" (British and French Pacific Islands), the Panama Canal, and Taiwan.

### 3.2.1 Large Vessel Cargo Traffic

Table C-1 indicates that the large vessel cargo traffic consisted of 383 moves, representing 14 percent of the total traffic. U.S. flag vessels accounted for 155 moves, while foreign flag vessels handled the remaining 228 moves. The traffic volume between Japan and Hawaii was the highest, 119 moves, while Taiwan and Australia ranked second and third accounting for 63 and 35 moves, respectively. The port of Honolulu accommodated 92 percent of this traffic.

### 3.2.2 Large Tanker Traffic

The large tanker traffic between foreign ports and Hawaii comprised nearly 67 percent of the total tanker traffic. The major countries which shipped crude oil to the two refineries were Singapore, Indonesia, Brunei and Malaysia. These countries combined, made 90 shipments, out of a total of 199 large tanker moves. More than 80 percent of the moves were made by foreign tankers.

### 3.2.3 Small Vessel Traffic

In contrast to the U.S. mainland and Hawaii traffic which was handled by large cargo vessels and tugs/barges, direct foreign oceanic traffic was handled principally by small cargo vessels. Small cargo vessels accounted for 913 moves, or 55 percent of the total direct foreign oceanic traffic. Nearly all of the small cargo vessel moves were conducted with foreign flag vessels. Three-quarters of this traffic is between Japan and Hawaii. Small tanker traffic accounted for only 10 moves, all of which were handled by foreign flag tankers.

### 3.2.4 Tug/Barge and "Other" Vessel Traffic

Tug/barge traffic consisted of 49 moves, the great majority of which, were handled by U.S. flag vessels. Approximately 43 moves were made between Hawaii and Trust Territories, Other Pacific Islands and Canada.

"Other" vessel types accounted for 114 moves. The majority of this traffic was handled by foreign flag vessels.

## 3.3 Inter-Island Traffic

Since inter-island traffic in Hawaii is handled almost exclusively by U.S. flag vessels, it does not appear in Census data. This traffic was estimated from statistics compiled by the Hawaii, Department of Transportation, Harbors Division and contacts with local operators (Appendix F).

Table C-6 shows the inter-island traffic, and indicates that Honolulu is the center of traffic activity. Most goods from foreign or mainland ports are shipped to Honolulu and then

TABLE C-6. TOTAL INTER-ISLAND TRAFFIC - 1979

| ORIGIN, DESTINATION | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|
| Honolulu | 262 | 1 | 1908 tug barge | 3 | 4 | 1 | 8 | 1908 tug barge<br>279 |
| Hilo | 162 | 2 | 360 tug barge | 1 | 7 | 0 | 6 | 360 tug barge<br>178 |
| Kahului | 98 | 1 | 480 tug barge | 8 | 9 | 0 | 3 | 480 tug barge<br>119 |
| Nawiliwili | 74 | 0 | 200 tug barge | 0 | 9 | 1 | 0 | 200 tug barge<br>84 |
| Konokakai | 0 | 0 | 270 tug barge | 0 | 0 | 0 | 0 | 270 tug barge |
| Lanai | 0 | 0 | 380 tug barge | 0 | 0 | 0 | 0 | 380 tug barge |
| Port Allen | 90 | 0 | 100 tug barge | 4 | 2 | 0 | 0 | 100 tug barge<br>96 |
| Kawaihae | 100 | 0 | 240 tug barge | 0 | 0 | 0 | 0 | 240 tug barge<br>100 |
| TOTAL | 786 | 4 | 3938 tug barge | 16 | 31 | 2 | 17 | 3938 tug barge<br>856 |

transshipped to other Hawaiian islands via tugs/barges. U.S. vessels accounted for 3938 tug/barge and 786 large cargo moves. Foreign oil tankers generated 31 moves, transporting refined product to Hilo, Kahului and Nawiliwili. "Other" foreign vessel types accounted for 17 moves, representing a very small percentage of the total inter-island traffic.

Kerosene and gasoline is shipped by U.S. flag oil barges from Honolulu to the other islands. These barges accounted for 552 moves.

3.4 Non-Revenue Traffic

Honolulu has the advantage of being situated in a commercially strategic location and vessels make occasional stops to obtain fresh supplies, conduct unexpected repairs, replace and or obtain medical treatment for the crew.

Since this traffic is not engaged in trade, it is not recorded in the Census data. This traffic was obtained from the "Bunker Log-Book" maintained by the U.S. Customs, Hawaii District.

Table C-7 shows that small vessels comprise the majority of this traffic, 80 percent, or 653 moves out of a total of 817. Discussions with personnel from the U.S. Customs, Hawaii District and Hawaii Department of Transportation, Harbors Division revealed that these small cargo vessels are, principally comprised of Japanese fishing vessels (Appendix F). These vessels fish on the high seas for extended time periods and call in Honolulu to replenish their fresh food and fuel.

Most of the large commercial vessels were of foreign flag, the largest single portion of which were Japanese.

3.5 Through Traffic

Through traffic was defined to be generated by vessels which do not call at Hawaii, but sail between U.S. west coast ports (Los Angeles, San Francisco and Seattle) and Guam, Singapore, Malaysia, Brunei, Indonesia, Philippines and Australia.
The Census Forms AE350 and 750 were used to estimate this traffic. Table C-8 shows that this traffic accounted for a total 391 moves. The majority, 48 percent represented tanker traffic handled by foreign flag tankers. Foreign flag large cargo vessels accounted for 37 percent or 143 moves. U.S. flag vessels accounted for 15 percent of the traffic.

3.6 Vessel Populations

Since most U.S. mainland to Hawaii traffic is not recorded in Census data, vessel operators were identified and contacted to obtain information on the number of U.S. vessels involved in the U.S. to Hawaii trade (Appendix F). The Census data, however, were utilized to estimate the number of large and small foreign

## TABLE C-7. NON REVENUE TRAFFIC

| ORIGIN, DESTINATION IN LAST CUS- TOMS CLEARANCE | U.S. LARGE CARGO | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|
| U.S. Gulf | 1 | 2 | | | | 3 tug barge | 3 tug barge<br>3 |
| U.S. West Coast | 5 | 12 | 1 | 3 | | | 21 |
| South America | | 12 | 3 | 12 | | | 27 |
| Panama Canal | 3 | 23 | 1 | 14 | | | 41 |
| Japan | 1 | 55 | 4 | 620 | | 1 tug barge | 1 tug barge<br>680 |
| Africa | | 1 | | 1 | | | 2 |
| Australia | | 2 | | | | | 2 |
| Malaysia | | 1 | | | | | 1 |
| Taiwan | 1 | 12 | 1 | | | 1 tug barge | 1 tug barge<br>14 |
| Trust Territory | | 1 | | | | | 1 |
| Korea | | 1 | | | | | 1 |
| Other Pacific Islands | | | | 1 | | | 1 |
| Canada | | 2 | | | | | 2 |
| Singapore | | | | 1 | | 1 tug barge | 1 tug barge<br>1 |
| Philippines | | 2 | 2 | 1 | | | 5 |
| Guam | 1 | | | | | | 1 |
| Indonesia | | 1 | 1 | | | | 2 |
| U.S.S.R | | 3 | | | | | 3 |
| Mexico | | 2 | 1 | | | | 3 |
| TOTAL | 12 | 132 | 14 | 653 | | 6 tug barge | 6 tug barge<br>811 |

TABLE C-8. THROUGH TRAFFIC - 1979

| LOS ANGELES, SAN FRANCISCO, SEATTLE TO FROM | U.S. LARGE CARGO | U.S. LARGE TANKER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | TOTAL |
|---|---|---|---|---|---|
| Australia | 12 | - | 64 | 4 | 80 |
| Indonesia | 20 | 12 | 31 | 156 | 219 |
| Philippines & Others[1] | 16 | | 48 | 28 | 92 |
| TOTAL | 48 | 12 | 143 | 188 | 391 |

[1]Include Brunei, Malaysia, Singapore and Guam.

flag vessels involved in the U.S. mainland to Hawaii traffic.

3.6.1 Large Commercial Vessels

Table C-9 shows the U.S. and foreign flag vessel populations serving in the Hawaiian trade. Approximately 77 large U.S. flag vessels are engaged in this trade, of which 61 represent cargo vessels and the balance tankers. Of the 61 U.S. flag cargo vessels, 10 vessels are exclusively engaged in the trade between the west coast and Hawaii. In addition, 15 more vessels perform regularly scheduled trips from the west coast to the Far East via Honolulu. The balance of 36 vessels are tramp vessels which provide non-scheduled services. Sixteen U.S. flag tankers transport North Slope crude from Alaska to the two refineries in Leeward Oahu. These same tankers carry the refined product to the ports of San Francisco and Los Angeles.

Approximately 163 large foreign flag vessels operated in Hawaiian trade. Of these, 116 vessels, consisted of cargo vessels and the balance were tankers. Foreign flag tankers and large cargo vessels operate on a strict demand basis rather than on a schedule. This is evidenced by the observation that two-thirds of these vessels do not cause more than two moves each.

3.6.2 Small Commercial Vessels

Eight shipping companies operating tugs were identified and contacted to estimate the number of those vessels operating between Hawaii and U.S. mainland, as well as those accommodating inter-island trade (Appendix F). This effort revealed that approximately 27 tugs operate between the west coast and Hawaii and within the Hawaiian islands.

The 899 moves between Hawaii and foreign ports were handled by 310 foreign flag small cargo vessels. The majority of those were Japanese fishing vessels, which first call at Honolulu to discharge their cargo (fish) and then sail on the high seas to fish.

3.7 LORAN-C Users

All U.S. flag commercial vessels or foreign flag vessels calling at U.S. ports which are over 1600 gross tons are required to carry LORAN-C or its equivalent (Reference 15).

All major companies operating tugs were contacted to determine number of tugs carrying LORAN-C. Twenty tugs engaged in the U.S. mainland to Hawaii and inter-island trade are equipped with LORAN-C.

## TABLE C-9. VESSEL POPULATION

| VESSEL TYPE | NUMBER OF VESSELS U.S. FLAG | NUMBER OF VESSELS FOREIGN FLAG | PERCENT OF U.S. FLAG VESSELS CARRYING LORAN-C |
|---|---|---|---|
| Large Cargo | 61 | 116 | 100 |
| Large Tanker | 16 | 47 | 100 |
| Tug | 27 | 3 | 80 |
| Small Cargo | 7 | 306 | N.A.* |
| Small Tanker | - | 4 | N.A. |
| Other | 10 | 46 | N.A. |
| TOTAL | 121 | 522 | |

*Not Available

# 4. VESSEL TRAFFIC, POPULATION AND LORAN-C USERS PROJECTIONS: 1980 - 2000

## 4.1 Vessel Traffic

The Ordinary Least Squares (OLS) estimation method was used to project traffic from 1980 through 2000. The overall approach to estimating the traffic consisted of the following steps:

1. Estimating growth rate of the tourist industry.

2. Estimating growth rate of the resident population.

3. Estimating defacto population (number of individuals in the state at any given day).

4. Utilizing the OLS to estimate the relationship between defacto population and cargo tonnage.

5. Estimating cargo tonnage from 1980 through 2000.

6. Estimating traffic.

The cargo tonnage shipped from to Hawaii was projected to increase; however, the traffic volume in 2000 was projected to be lower than in 1990 and 1995, due to the following shipbuilding trends:

1. The number of general cargo vessels is expected to decrease from 1980 to 2000 by 60 percent (Reference 14).

2. From 1980 to 2000, the average increase in deadweight per vessel for the world fleet is expected to be 71 percent (Reference 14).

### 4.1.1 Total Direct Oceanic Traffic

Tables C-10 through C-13 show traffic projections from 1985 to 2000. Table C-10 shows that in 1985, total oceanic traffic is projected to be 3248 moves; an increase of 521 moves, or 19 percent from 1979. Large and small cargo vessels account for most of this traffic.

U.S. flag vessels account for 45 percent of the moves. The port of Honolulu is projected to handle the majority of the traffic, approximately 95 percent.

Table C-11 shows that the projected 1990 traffic consists of 3428 moves, an increase of 26 percent from 1979. Table C-12 indicates that the projected 1995 traffic consists of 3483 moves, an increase of 27.7 percent from 1979. Table C-13 shows that the projected 2000 traffic consists of 3380 moves, an increase of 24 percent from 1979.

The port of Honolulu was projected to handle the majority of the additional traffic, approximately 80-90 percent. Cargo will

# TABLE C-10. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 1985

(Page 1 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska | 0 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45 |
| U.S. Gulf | 1 | 0 | 0 | 0 | 0 | 8 | 8 | 0 | 0 | 1 | 18 |
| U.S. West Coast | 750 | 65 | 2 | 0 | 295 tug barge 8 | 166 | 8 | 14 | 1 | 39 | 295 tug barge 1,053 |
| Caribbean | 0 | 0 | 0 | 0 | 1 | 6 | 8 | 1 | 0 | 0 | 16 |
| South America | 0 | 2 | 0 | 0 | 0 | 9 | 5 | 19 | 2 | 6 | 43 |
| Panama Canal | 22 | 2 | 0 | 0 | 1 | 26 | 11 | 30 | 7 | 1 tug barge 3 | 1 tug barge 102 |
| Japan | 35 | 5 | 0 | 0 | 0 | 98 | 9 | 780 | 2 | 7 | 936 |
| Africa | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 12 |
| Australia | 0 | 0 | 0 | 0 | 0 | 39 | 3 | 1 | 0 | 0 | 43 |
| New Zealand | 0 | 0 | 0 | 0 | 2 | 12 | 0 | 0 | 0 | 9 | 23 |
| Brunei | 2 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 0 | 0 | 21 |
| Malaysia | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 0 | 0 | 18 |
| Taiwan | 51 | 0 | 1 | 0 | 0 | 20 | 1 | 2 | 0 | 1 tug barge 0 | 1 tug barge 75 |
| Trust Territory | 1 | 2 | 4 | 0 | 28 tug barge 2 | 0 | 16 | 1 | 0 | 2 | 28 tug barge 28 |
| Korea | 2 | 0 | 0 | 0 | 0 | 8 | 0 | 16 | 0 | 0 | 26 |
| Other Pacific Islands | 1 | 0 | 9 | 0 | 10 tug barge 9 | 15 | 15 | 18 | 0 | 56 | 10 tug barge 123 |
| Canada | 5 | 0 | 3 | 0 | 10 tug barge 1 | 6 | 1 | 11 | 0 | 11 | 10 tug barge 38 |
| Singapore | 2 | 2 | 0 | 0 | 1 | 1 | 31 | 6 | 0 | 0 | 43 |

## TABLE C-10. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 1985

(Page 2 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Phillipines | 16 | 2 | 0 | 0 | 0 | 7 | 0 | 4 | 0 | 1 tug barge 0 | 1 tug barge 29 |
| Guam | 8 | 2 | 0 | 0 | 1 tug barge 0 | 0 | 2 | 0 | 0 | 0 | 1 tug barge 12 |
| American Samoa | 0 | 4 | 4 | 0 | 3 tug barge 3 | 1 | 2 | 4 | 0 | 2 | 3 tug barge 20 |
| Indonesia | 1 | 0 | 0 | 0 | 0 | 2 | 30 | 0 | 0 | 0 | 33 |
| U.S.S.R. | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 5 | 0 | 1 | 10 |
| Other | 25 | 14 | 4 | 0 | 1 | 7 | 0 | 74 | 0 | 6 | 131 |
| TOTAL | 923 | 145 | 27 | 0 | 347 tug barge 29 | 433 | 200 | 986 | 12 | 3 tug barge 143 | 350 tug barge 2898 |

## TABLE C-11. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 199Ø
(Page 1 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska | 0 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 49 |
| U.S. Gulf | 1 | 0 | 0 | 0 | 0 | 9 | 10 | 0 | 0 | 1 | 21 |
| U.S. West Coast | 814 | 73 | 2 | 0 | 319 tug barge 9 | 180 | 8 | 14 | 1 | 42 | 319 tug barge 1143 |
| Caribbean | 0 | 0 | 0 | 0 | 1 | 6 | 8 | 1 | 0 | 0 | 16 |
| South America | 0 | 2 | 0 | 0 | 0 | 10 | 6 | 19 | 2 | 6 | 45 |
| Panama Canal | 25 | 2 | 0 | 0 | 1 | 26 | 13 | 29 | 7 | 1 tug barge 3 | 1 tug barge 106 |
| Japan | 40 | 5 | 0 | 0 | 0 | 100 | 10 | 792 | 2 | 7 | 956 |
| Africa | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 14 |
| Australia | 0 | 0 | 0 | 0 | 0 | 42 | 3 | 1 | 0 | 0 | 46 |
| New Zealand | 0 | 0 | 0 | 0 | 2 | 14 | 0 | 0 | 0 | 9 | 25 |
| Brunei | 2 | 0 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 24 |
| Malaysia | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 20 |
| Taiwan | 55 | 0 | 1 | 0 | 0 | 22 | 1 | 2 | 0 | 1 tug barge 0 | 1 tug barge 81 |
| Trust Territory | 1 | 2 | 4 | 0 | 29 tug barge 2 | 0 | 17 | 1 | 0 | 2 | 29 tug barge 29 |
| Korea | 3 | 0 | 0 | 0 | 0 | 9 | 0 | 16 | 0 | 0 | 28 |
| Other Pacific Islands | 1 | 0 | 9 | 0 | 11 tug barge 9 | 16 | 15 | 19 | 0 | 58 | 11 tug barge 127 |
| Canada | 5 | 0 | 3 | 0 | 11 tug barge 1 | 6 | 1 | 12 | 0 | 11 | 11 tug barge 39 |
| Singapore | 2 | 2 | 0 | 0 | 1 | 1 | 33 | 6 | 0 | 0 | 45 |

## TABLE C-11. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 1990

(Page 2 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Phillipines | 16 | 2 | 0 | 0 | 0 | 8 | 0 | 3 | 0 | 1 tug barge<br>0 | 1 tug barge<br>29 |
| Guam | 8 | 2 | 0 | 0 | 1 tug barge<br>0 | 0 | 2 | 0 | 0 | 0 | 1 tug barge<br>12 |
| American Samoa | 0 | 4 | 4 | 0 | 3 tug barge<br>3 | 1 | 2 | 4 | 0 | 2 | 3 tug barge<br>20 |
| Indonesia | 1 | 0 | 0 | 0 | 0 | 2 | 31 | 0 | 0 | 0 | 34 |
| U.S.S.R. | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 5 | 0 | 1 | 10 |
| Other | 25 | 14 | 4 | 0 | 1 | 8 | 0 | 74 | 0 | 6 | 132 |
| TOTAL | 1000 | 157 | 27 | 0 | 374 tug barge<br>30 | 462 | 217 | 998 | 12 | 3 tug barge<br>148 | 377 tug barge<br>3051 |

## TABLE C-12. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 1995

(Page 1 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 |
| U.S. Gulf | 1 | 0 | 0 | 0 | 0 | 11 | 10 | 0 | 0 | 1 | 23 |
| U.S. West Coast | 825 | 75 | 2 | 0 | 327 tug barge<br>9 | 186 | 10 | 14 | 1 | 45 | 327 tug barge<br>1,167 |
| Caribbean | 0 | 0 | 0 | 0 | 1 | 6 | 8 | 1 | 0 | 0 | 16 |
| South America | 0 | 2 | 0 | 0 | 0 | 10 | 6 | 19 | 2 | 6 | 45 |
| Panama Canal | 27 | 2 | 0 | 0 | 1 | 28 | 15 | 29 | 7 | 1 tug barge<br>3 | 1 tug barge<br>112 |
| Japan | 43 | 5 | 0 | 0 | 0 | 102 | 11 | 792 | 2 | 7 | 962 |
| Africa | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 14 |
| Australia | 0 | 0 | 0 | 0 | 0 | 43 | 3 | 1 | 0 | 0 | 47 |
| New Zealand | 0 | 0 | 0 | 0 | 2 | 14 | 0 | 0 | 0 | 9 | 25 |
| Brunei | 2 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | 0 | 0 | 25 |
| Malaysia | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 20 |
| Taiwan | 57 | 0 | 1 | 0 | 0 | 22 | 1 | 2 | 0 | 1 tug barge<br>0 | 1 tug barge<br>83 |
| Trust Territory | 1 | 2 | 4 | 0 | 32 tug barge<br>2 | 0 | 17 | 1 | 0 | 2 | 32 tug barge<br>29 |
| Korea | 4 | 0 | 0 | 0 | 0 | 9 | 0 | 16 | 0 | 0 | 29 |
| Other Pacific Islands | 1 | 0 | 9 | 0 | 11 tug barge<br>9 | 16 | 15 | 19 | 0 | 58 | 11 tug barge<br>127 |
| Canada | 5 | 0 | 3 | 0 | 11 tug barge<br>1 | 6 | 1 | 12 | 0 | 11 | 11 tug barge<br>39 |
| Singapore | 2 | 2 | 0 | 0 | 1 | 1 | 33 | 6 | 0 | 0 | 45 |

## TABLE C-12. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 1995

(Page 2 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Phillipines | 16 | 2 | 0 | 0 | 0 | 8 | 0 | 3 | 0 | 1 tug barge 0 | 1 tug barge 29 |
| Guam | 8 | 2 | 0 | 0 | 1 tug barge 0 | 0 | 2 | 0 | 0 | 0 | 1 tug barge 12 |
| American Samoa | 0 | 4 | 4 | 0 | 3 tug barge 3 | 1 | 2 | 4 | 0 | 2 | 3 tug barge 20 |
| Indonesia | 1 | 0 | 0 | 0 | 0 | 2 | 31 | 0 | 0 | 0 | 34 |
| U.S.S.R. | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 5 | 0 | 1 | 10 |
| Other | 25 | 14 | 4 | 0 | 1 | 8 | 0 | 74 | 0 | 6 | 132 |
| TOTAL | 1,019 | 160 | 27 | 0 | 385 tug barge 30 | 475 | 223 | 998 | 12 | 3 tug barge 151 | 388 tug barge 3095 |

## TABLE C-13. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 2000
(Page 1 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska | 0 | 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 47 |
| U.S. Gulf | 1 | 0 | 0 | 0 | 0 | 8 | 9 | 0 | 0 | 1 | 19 |
| U.S. West Coast | 800 | 67 | 2 | 0 | 318 tug barge<br>9 | 173 | 8 | 14 | 1 | 42 | 318 tug barge<br>1,116 |
| Caribbean | 0 | 0 | 0 | 0 | 1 | 6 | 8 | 1 | 0 | 0 | 16 |
| South America | 0 | 2 | 0 | 0 | 0 | 10 | 6 | 19 | 2 | 6 | 45 |
| Panama Canal | 25 | 2 | 0 | 0 | 1 | 26 | 13 | 29 | 7 | 1 tug barge<br>3 | 1 tug barge<br>106 |
| Japan | 40 | 5 | 0 | 0 | 0 | 100 | 10 | 782 | 2 | 7 | 946 |
| Africa | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 14 |
| Australia | 0 | 0 | 0 | 0 | 0 | 42 | 3 | 1 | 0 | 0 | 46 |
| New Zealand | 0 | 0 | 0 | 0 | 2 | 14 | 0 | 0 | 0 | 9 | 25 |
| Brunei | 2 | 0 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 24 |
| Malaysia | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 20 |
| Taiwan | 55 | 0 | 1 | 0 | 0 | 22 | 1 | 2 | 0 | 1 tug barge<br>0 | 1 tug barge<br>81 |
| Trust Territory | 1 | 2 | 4 | 0 | 30 tug barge<br>2 | 0 | 17 | 1 | 0 | 2 | 30 tug barge<br>29 |
| Korea | 3 | 0 | 0 | 0 | 0 | 9 | 0 | 14 | 0 | 0 | 26 |
| Other Pacific Islands | 1 | 0 | 9 | 0 | 11 tug barge<br>9 | 16 | 15 | 14 | 0 | 58 | 11 tug barge<br>122 |
| Canada | 5 | 0 | 3 | 0 | 11 tug barge<br>1 | 6 | 1 | 12 | 0 | 11 | 11 tug barge<br>39 |
| Singapore | 2 | 2 | 0 | 0 | 1 | 1 | 33 | 6 | 0 | 0 | 45 |

TABLE C-13. HAWAII TOTAL DIRECT OCEANIC TRAFFIC - 2000

(Page 2 of 2)

| ORIGIN, DESTINATION IN LAST CUSTOMS CLEARANCE | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. SMALL CARGO | U.S. SMALL TANKER | U.S. OTHER | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN SMALL TANKER | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Phillipines | 16 | 2 | 0 | 0 | 0 | 8 | 0 | 3 | 0 | 1 tug barge 0 | 1 tug barge 29 |
| Guam | 8 | 2 | 0 | 0 | 1 tug barge 0 | 0 | 2 | 0 | 0 | 0 | 1 tug barge 12 |
| American Samoa | 0 | 4 | 4 | 0 | 3 tug barge 3 | 1 | 2 | 4 | 0 | 2 | 3 tug barge 20 |
| Indonesia | 1 | 0 | 0 | 0 | 0 | 2 | 31 | 0 | 0 | 0 | 34 |
| U.S.S.R. | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 5 | 0 | 1 | 10 |
| Other | 25 | 14 | 4 | 0 | 1 | 8 | 0 | 74 | 0 | 6 | 132 |
| TOTAL | 986 | 149 | 27 | 0 | 374 tug barge 30 | 454 | 216 | 981 | 12 | 3 tug barge 148 | 377 tug barge 3003 |

continue to be shipped to Honolulu and thereafter transshipped to the other major islands.

The oceanic traffic handled by the Hilo port was projected to account for 10-15 percent of the additional traffic, because the growth of the tourist industry will generate additional demand for construction materials and other goods.

It was projected that the ports of Nawiliwili and Kahului will handle three and five percent, respectively of the additional traffic generated.

4.1.2 U.S. Mainland to Hawaii Traffic

The U.S. mainland to Hawaii traffic was estimated to account for approximately two-thirds of all the additional trade generated. In 1979, the U.S. to Hawaii traffic consisted of 1059 moves. It was projected that this traffic will increase to 1500 by the year 2000.

U.S. flag vessels were projected to handle about 65 percent of the additional U.S. mainland to Hawaii traffic. In 1979, U.S. flag vessels accounted for 876 moves out of a total 1059. By the year 2000, this number will grow to 1244.

In 1979, U.S. flag large cargo vessels accounted for 552 moves. This was projected to 801 annual moves by the year 2000.

In 1979, U.S. flag tankers, accommodating the U.S. to Hawaii trade, made 85 moves. It was projected that they will account for 114 moves in year 2000.

The traffic made by small tanker and cargo vessels was projected to remain unchanged from its 1979 level because of the more efficient and larger vessels to accommodate the trade between the U.S. mainland and Hawaii.

The tug/barge traffic was projected to range from 295 moves in 1985 to 318 moves in 2000. "Other" traffic between U.S. mainland and Hawaii was projected to increase from 48 in 1985, to 52 in 2000.

4.1.3 Foreign Direct Oceanic Traffic

Tables C-10 through C-13 show the foreign direct oceanic traffic projections from 1985 to 2000. In 1985, the foreign ports to Hawaii traffic was projected to consist of 1837 moves. This will grow slightly to 1880 moves by the year 2000.
The share of foreign and U.S. flag large cargo vessels generating this traffic was projected as follows:

| Year | Foreign Flag | U.S. Flag |
|---|---|---|
| 1985 | 259 | 172 |
| 1990 | 273 | 185 |
| 1995 | 278 | 193 |
| 2000 | 273 | 185 |

The most active trade partners of Hawaii were assumed to remain Japan and Taiwan due to their advantageous locations and advanced industries. Japan and Taiwan combined will account for approximately 47 percent of the total large cargo vessel traffic.

The distribution of foreign versus U.S. flag tanker traffic was projected to be:

| Year | Foreign Flag | U.S. Flag |
|---|---|---|
| 1985 | 184 | 35 |
| 1990 | 199 | 35 |
| 1995 | 203 | 35 |
| 2000 | 199 | 35 |

It was projected that Hawaii will obtain crude oil from the same countries as currently. Thus, Brunei, Malaysia, Singapore and Indonesia will account for approximately 55 percent of the tanker traffic between foreign ports and Hawaii.

Small cargo traffic will not change substantially over the twenty-year period. In 1979, small cargo vessels made 913 moves. It was projected that by 2000 this number will be 992.

As in 1979, approximately 80 percent of the small cargo vessels traffic will accommodate trade between Japan and Hawaii.

Small tanker traffic was projected to remain unchanged because the trend is toward the utilization of larger and more efficient vessels.

The tug/barge traffic in 1979 was 49 moves. By 2000, there will be 59 moves. "Other" traffic was projected to remain constant at 126 moves.

4.2 Inter-Island Traffic Projections: 1980-2000

Inter-island traffic projections were based on the following assumptions:

- o Visitor arrivals on the major islands will grow at a rate of three to five percent per year.
- o Hotel construction will procede at the rate 3500 rooms per year.
- o Resident population will grow at a rate of two percent per year.

Tables C-14 through C-17 show the projected traffic from 1985 to 2000. It was projected that approximately 84.5 percent of the traffic, 7264 moves by year 2000, will be handled by U.S. flag tugs barges. Approximately 90 percent of the non-tug/barge traffic will be accommodated by U.S. large cargo vessels. The balance will be handled by foreign flag vessels, mostly large cargo and tankers.

Personnel from Hawaii Department of Transportation, Harbors Division, indicated that Honolulu will remain the transshipment point. Cargo from the U.S. mainland and foreign ports will continue to be shipped to Honolulu and then transshipped to the other islands mainly via tugs/barges.

### 4.3 Non-Revenue Traffic Projections: 1980 - 2000

Table C-18 shows the non-revenue traffic projections from 1985 to 2000. By 2000, the moves will have grown to 1010 from 817 in 1979. The mix of the non-revenue traffic from 1980 to 2000 was assumed to remain the same as in 1979. Thus, approximately 84 percent of the traffic will be represented by fishing vessels.

### 4.4 Through Traffic Projections: 1980 - 2000

The through traffic generated between the U.S. west coast ports (Los Angeles, San Francisco, and Seattle) and Australia, Indonesia, Philippines and others (the others include: Singapore, Brunei, Guam and Malaysia) was projected to grow from 703 moves in 1985, to 907 moves in 2000. Table C-19 shows the through traffic projections.

The majority of the estimated 232 percent increase in traffic volume from 1979 to 2000, will occur in tanker traffic. The additional traffic volume will be handled primarily by foreign flag vessels.

### 4.5 Vessel Populations And LORAN-C Users Projections: 1980-2000

#### 4.5.1 U.S. Flag Vessels

Currently, 10 U.S. large cargo vessels are exclusively engaged in the trade between U.S. and Hawaii. In addition, 51 U.S. large cargo vessels call occasionally in Honolulu. The latter vessels are principally engaged in trade between U.S. and Far East via Honolulu.

The increased traffic will be accommodated by 23 additional vessels, of which three or four will exclusively serve the U.S. to Hawaii trade. The balance will serve the U.S. to Far East trade via Honolulu. Thus, by 2000, the population of U.S. large cargo vessels was projected to be 84.

U.S. flag tanker traffic will increase only modestly by 29 moves. This small increase can be easily handled by the 16 tankers currently accommodating the tanker traffic.

TABLE C-14. TOTAL INTER-ISLAND TRAFFIC - 1985

| | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. TUG BARGE | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|
| Honolulu | 298 | 2 | 2278 | 3 | 1 | 1 | 8 | 2278 tug barge<br>313 |
| Hilo | 186 | 4 | 404 | 3 | 9 | 0 | 6 | 404 tug barge<br>208 |
| Kahului | 112 | 2 | 540 | 11 | 10 | 0 | 3 | 540 tug barge<br>138 |
| Nawiliwili | 85 | 0 | 224 | 1 | 10 | 1 | 0 | 224 tug barge<br>97 |
| Konokakai | 0 | 0 | 304 | 0 | 0 | 0 | 0 | 304 tug barge<br>0 |
| Lanai | 0 | 0 | 426 | 0 | 0 | 0 | 0 | 426 tug barge<br>0 |
| Port Allen | 100 | 0 | 112 | 0 | 0 | 0 | 0 | 112 tug barge<br>100 |
| Kawaihae | 115 | 1 | 268 | 1 | 1 | 0 | 0 | 268 tug barge<br>118 |
| TOTAL | 896 | 9 | 4556 | 19 | 31 | 2 | 17 | 4556 tug barge<br>974 |

## TABLE C-15. TOTAL INTER-ISLAND TRAFFIC - 1990

| | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. TUG BARGE | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|
| Honolulu | 326 | 3 | 2550 | 4 | 1 | 1 | 8 | 2550 tug barge<br>343 |
| Hilo | 204 | 5 | 452 | 4 | 10 | 0 | 6 | 452 tug barge<br>229 |
| Kahului | 122 | 3 | 604 | 12 | 11 | 0 | 3 | 604 tug barge<br>151 |
| Nawiliwili | 92 | 0 | 250 | 2 | 12 | 1 | 0 | 250 tug barge<br>107 |
| Konokakai | 0 | 0 | 340 | 0 | 0 | 0 | 0 | 340 tug barge<br>0 |
| Lanai | 0 | 0 | 478 | 0 | 0 | 0 | 0 | 478 tug barge<br>0 |
| Port Allen | 108 | 0 | 126 | 0 | 0 | 0 | 0 | 126 tug barge<br>108 |
| Kawaihae | 126 | 1 | 300 | 2 | 2 | 0 | 0 | 300 tug barge<br>131 |
| TOTAL | 978 | 12 | 5100 | 24 | 36 | 2 | 17 | 5100 tug barge<br>1069 |

TABLE C-16. TOTAL INTER-ISLAND TRAFFIC - 1995

| | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. TUG BARGE | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|
| Honolulu | 350 | 4 | 2854 | 5 | 1 | 1 | 8 | 2854 tug barge<br>369 |
| Hilo | 218 | 6 | 506 | 5 | 11 | 0 | 6 | 506 tug barge<br>246 |
| Kahului | 130 | 4 | 676 | 13 | 12 | 0 | 3 | 676 tug barge<br>162 |
| Nawiliwili | 100 | 0 | 280 | 3 | 13 | 1 | 0 | 280 tug barge<br>117 |
| Konokakai | 0 | 0 | 380 | 0 | 0 | 0 | 0 | 380 tug barge<br>0 |
| Lanai | 0 | 0 | 536 | 0 | 0 | 0 | 0 | 536 tug barge<br>0 |
| Port Allen | 118 | 0 | 140 | 0 | 0 | 0 | 0 | 140 tug barge<br>118 |
| Kawaihae | 136 | 1 | 336 | 3 | 3 | 0 | 0 | 336 tug barge<br>143 |
| TOTAL | 1052 | 15 | 5708 | 29 | 40 | 2 | 17 | 5708 tug barge<br>1155 |

## TABLE C-17. TOTAL INTER-ISLAND TRAFFIC - 2000

| | U.S. LARGE CARGO | U.S. LARGE TANKER | U.S. TUG BARGE | FOREIGN LARGE CARGO | FOREIGN LARGE TANKER | FOREIGN SMALL CARGO | FOREIGN OTHER | TOTAL |
|---|---|---|---|---|---|---|---|---|
| Honolulu | 368 | 5 | 3022 | 6 | 1 | 1 | 8 | 3022 tug barge 389 |
| Hilo | 230 | 7 | 536 | 7 | 12 | 0 | 6 | 536 tug barge 262 |
| Kahului | 136 | 5 | 716 | 14 | 13 | 0 | 3 | 716 tug barge 171 |
| Nawiliwili | 104 | 0 | 296 | 4 | 14 | 1 | 0 | 296 tug barge 123 |
| Konokakai | 0 | 0 | 402 | 0 | 0 | 0 | 0 | 402 tug barge 0 |
| Lanai | 0 | 0 | 568 | 0 | 0 | 0 | 0 | 568 tug barge 0 |
| Port Allen | 124 | 0 | 148 | 0 | 0 | 0 | 0 | 148 tug barge 124 |
| Kawaihae | 142 | 1 | 356 | 4 | 4 | 0 | 0 | 356 tug barge 151 |
| TOTAL | 1104 | 18 | 6044 | 35 | 44 | 2 | 17 | 6044 tug barge 1220 |

TABLE C-18. NON REVENUE TRAFFIC PROJECTIONS: 1985 - 2000

| ORIGIN DESTINATION IN LAST CUSTOMS CLEARANCE | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| U.S. Gulf | 8 | 8 | 8 | 7 |
| U.S. West Coast | 24 | 26 | 27 | 26 |
| South America | 32 | 34 | 34 | 33 |
| Panama Canal | 49 | 51 | 52 | 51 |
| Japan | 809 | 856 | 868 | 844 |
| Africa | 2 | 2 | 2 | 2 |
| Australia | 2 | 2 | 2 | 2 |
| Malaysia | 1 | 1 | 1 | 1 |
| Taiwan | 17 | 17 | 18 | 19 |
| Trust Territory | 1 | 1 | 1 | 1 |
| Korea | 1 | 1 | 1 | 1 |
| Other Pacific Islands | 1 | 1 | 1 | 1 |
| Canada | 2 | 2 | 3 | 3 |
| Singapore | 2 | 2 | 2 | 2 |
| Philippines | 6 | 6 | 7 | 6 |
| Guam | 1 | 1 | 1 | 1 |
| Indonesia | 2 | 2 | 2 | 2 |
| U.S.S.R. | 3 | 4 | 4 | 4 |
| Mexico | 4 | 4 | 4 | 4 |
| TOTAL | 967 | 1021 | 1038 | 1010 |

TABLE C-19. THROUGH TRAFFIC PROJECTIONS: 1985 - 2000

FROM TO LOS ANGELES, SAN FRANCISCO, SEATTLE

| | AUSTRALIA | | | | INDONESIA | | | | PHILIPPINES AND OTHERS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VESSEL TYPE AND FLAG | 1985 | 1990 | 1995 | 2000 | 1985 | 1990 | 1995 | 2000 | 1985 | 1990 | 1995 | 2000 |
| U.S. Large Cargo | 13 | 13 | 14 | 15 | 21 | 22 | 23 | 24 | 17 | 17 | 19 | 20 |
| U.S. Large Tanker | 0 | 0 | 0 | 0 | 14 | 16 | 19 | 20 | 0 | 0 | 0 | 0 |
| Foreign Large Cargo | 148 | 155 | 162 | 170 | 102 | 105 | 111 | 118 | 50 | 53 | 55 | 58 |
| Foreign Large Tanker | 5 | 6 | 7 | 7 | 300 | 348 | 390 | 428 | 33 | 38 | 43 | 47 |
| TOTALS | 166 | 174 | 183 | 192 | 437 | 491 | 543 | 590 | 100 | 108 | 117 | 125 |

Tug/barge traffic was projected to increase by 98 moves. This increase will require approximately five to six tugs.

The small cargo vessel traffic and vessels accommodating this traffic were projected to remain fairly constant.

Table C-20 shows the vessel population from 1985 through 2000.

### 4.5.2 Foreign Flag Vessel

Table C-20 shows that the population of the foreign flag large cargo vessels will not change. In 1979, 116 large cargo vessels called in Honolulu, accounting for 359 moves. The additional 95 moves (from 1979 to 2000) could easily be handled by the same number of cargo vessels.

Similarly, the tanker, small cargo, small tanker, tug/barge and "other" vessel populations will not change in any substantial manner.

### 4.5.3 LORAN-C Users

All U.S. flag commercial vessels greater than 1600 gross tons are required to carry LORAN-C or its equivalent (Reference 15). Likewise, all foreign flag vessels over 1600 gross tons involved in U.S. trade are required to carry LORAN-C or its equivalent. Table C-20 shows that 90 percent of the U.S. flag tugs will be equipped with LORAN-C. This estimate was based on discussions with tug/barge operators which indicated that ocean-going tugs carry all available navigation equipment (Appendix F).

TABLE C-2Ø. VESSEL POPULATION AND LORAN-C USERS: 1985 - 2ØØØ

| | NUMBER OF VESSELS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | U.S. FLAG | | | | FOREIGN FLAG | | | | |
| VESSEL TYPE | 1985 | 1990 | 1995 | 2000 | 1985 | 1990 | 1995 | 2000 | PERCENT OF U.S. FLAG VESSELS CARRYING LORAN-C |
| Large Cargo | 67 | 72 | 78 | 84 | 116 | 116 | 116 | 116 | 100 |
| Large Tanker | 16 | 16 | 16 | 16 | 47 | 47 | 47 | 47 | 100 |
| Tug | 29 | 30 | 31 | 32 | 4 | 4 | 4 | 4 | 90 |
| Small Cargo | 7 | 7 | 7 | 7 | 306 | 306 | 306 | 306 | N.A* |
| Small Tanker | - | - | - | - | 4 | 4 | 4 | 4 | N.A |
| Other | 10 | 10 | 10 | 10 | 46 | 46 | 46 | 46 | N.A |
| Total | 129 | 135 | 142 | 149 | 523 | 523 | 523 | 523 | |

*Not Available.

# APPENDIX D
# THE FISHING INDUSTRY IN HAWAII

## 1. INTRODUCTION

The purpose of this appendix is to present the current status of the fishing industry in Hawaii and to indicate its probable future direction. Current and projected vessel populations, landings, value of landings, fishing locations and other similar data presented in this appendix were taken from the state planning document "Hawaii Fisheries Development Plan" (Reference 11). In some cases, this information was amplified with data from other planning documents and more up-to-date information furnished by officials within state, regional and private fishing organizations (References 37, 38, 39, 40, Appendix F).

In this appendix, an overview of the commercial fishermen, fishing fleet, and species landed is presented in Section 2. Section 3 presents the current fishing operations by major species group. Section 4 provides an assessment of future fishing operations.

## 2. CURRENT STATUS

In 1978, the fishing industry in Hawaii accounted for 0.8 percent of the Gross State Product. The tax revenue created from commercial fishing processing and distribution was estimated at three million dollars. Figure D-1 shows the number of individuals possessing commercial fishing licenses, and the number of commercial fishing boats from 1928 through 1978. As Figure D-1 shows, commercial fishing licenses have substantially increased. In 1965, only 800 individuals possessed commercial fishing licenses; but in 1979, the number increased to 2447. However, in 1979 the number of full-time commercial fishermen was estimated at about 800. The remaining 1600 represented recreational, commercial sport and part-time commercial fishermen. Figure D-1 also depicts the trend in commercial fishing boats. It indicates that, in 1968, the fishing fleet reached its lowest population since World war II, 300 boats, but since then has experienced a constant growth. In 1977, the population was 1250 boats.

Figure D-2 shows landings and value of catch from 1949 through 1977. The wide fluctuations in catch are attributed to the availability of tuna species, especially skipjack and yellowfin tunas, and to the decline of both boats and fishermen from 1952 through 1969. However, in the last several years, the catch has increased from 9.5 million pounds in 1974 to 13.5 million pounds in 1977.

Table D-1 shows the most commercially important species landed in 1978, the additional landings potential and, the total landings potential. The landings potential are estimates based on the Potential Sustainable Yields (PSY) in the Hawaiian region. In

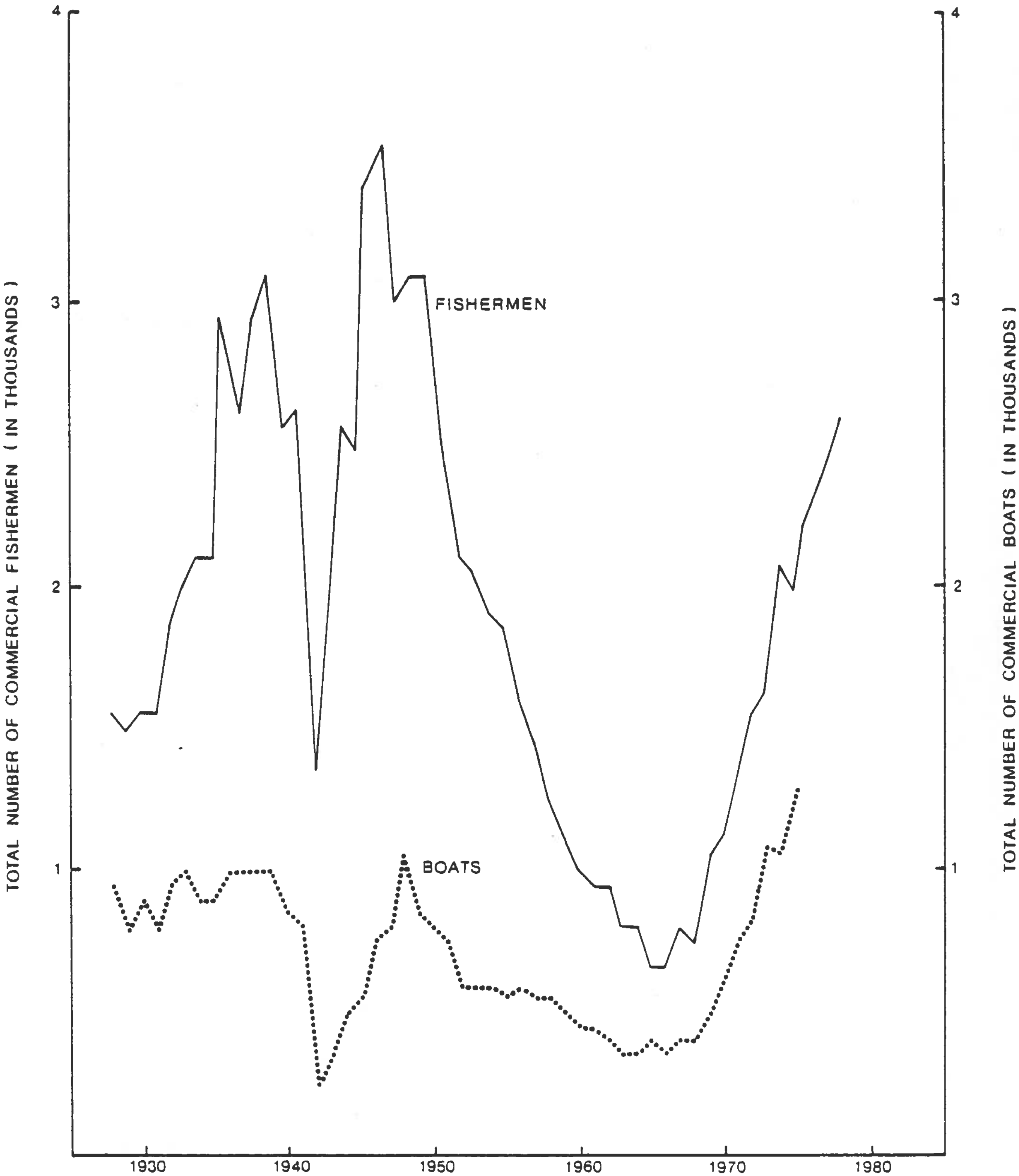



FIGURE D-1. COMMERCIAL FISHERMEN AND BOATS IN HAWAII

SOURCE: REFERENCE 11

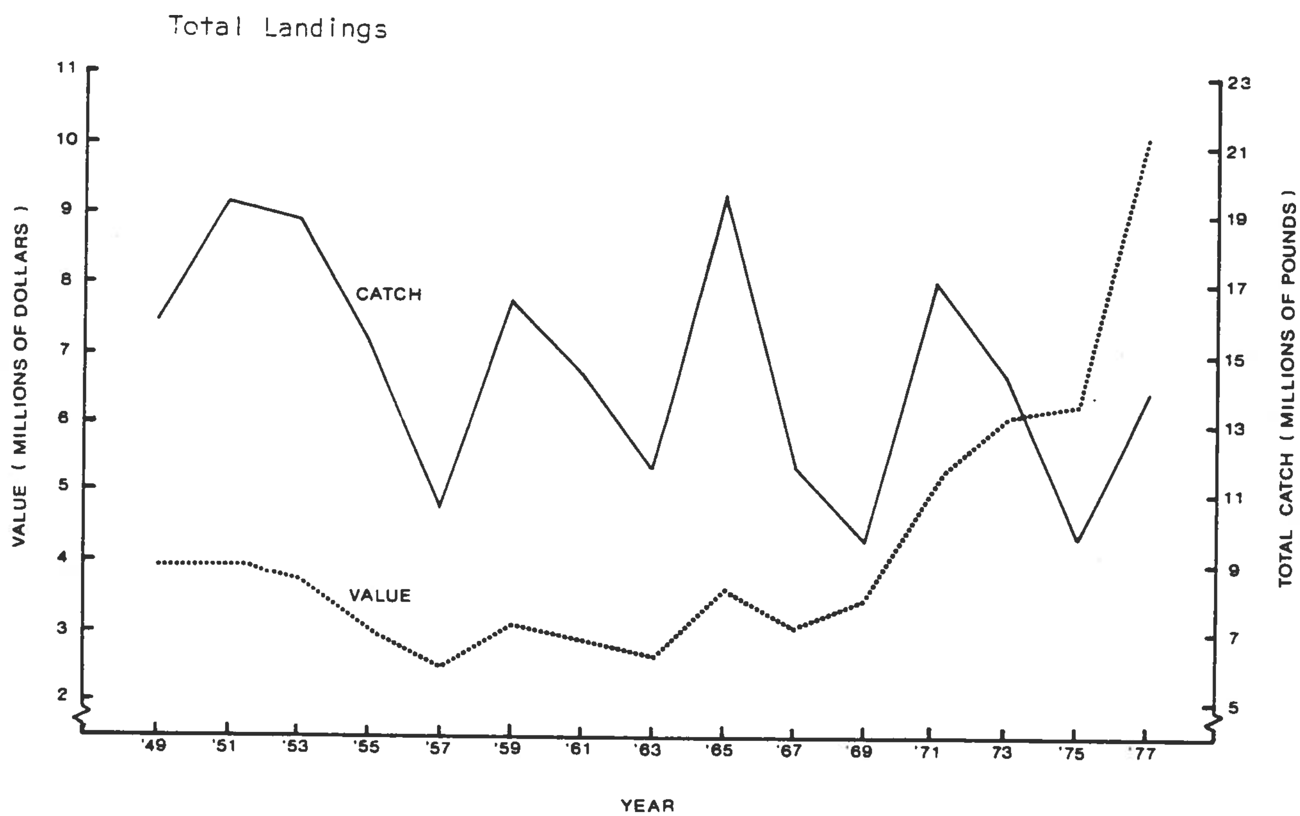



FIGURE D-2. REPORTED MARINE FISH LANDINGS IN HAWAII

SOURCE: REFERENCE 11

TABLE D-1. PRESENT LANDINGS (1978) AND POTENTIAL SUSTAINABLE YIELDS IN THE HAWAIIAN REGION (WEIGHT IN POUNDS)

| SPECIES OR GROUP | 1978 LANDINGS | ADDITIONAL POTENTIAL | TOTAL POTENTIAL IN MILLIONS |
|---|---|---|---|
| Skipjack Tuna - Aku | 6,794,000 | 20,000,000 | 26.8 |
| Albacore Tuna (surface) | 569,000 | 10-20,000,000 | 10.6-20.6 |
| Albacore (subsurface) | 125,000 | 6,000,000 | 6.1 |
| Bigeye Tuna | 460,000 | 10-20,000,000 | 10.5-20.5 |
| Yellowfin Tuna | 2,122,000 | 1- 5,000,000 | 3.1- 6.1 |
| Bottomfish (deepsea) | 770,000 | 1- 2,600,000 | 1.7- 3.3 |
| Bottomfish (inshore) | 1,044,000 | 900,000- 1,300,000 | 1.9- 3.3 |
| Seamount Grounfish | -0- | 4-10,000,000 | 4.0-10.0 |
| Bigeye Scad - Akule | 415,000 | 450,000- 1,400,000 | .8- 1.8 |
| Round Scad - Opelu | 299,000 | 1- 1,400,000 | 1.3- 1.7 |
| Sharks | 21,000 | 600,000- 2,400,000 | .6- 2.4 |
| Billfish | 741,000 | 1- 2,500,000 | 1.7- 3.2 |
| Spiny Lobster | 34,000 | 700,000- 1,400,000 | .7- 1.4 |
| Shrimp | 2,000 | 4-10,000,000 | 4.0-10.0 |
| Kona Crab | 28,000 | 50-75,000 | .08-.1 |
| Total | 13,423,000 | 60,700,000-104,075,000 | 74-117.4 |

Source: Reference 11

1978, total landings amounted to 13,423,000 pounds. Five tuna species accounted for 75 percent of the total landings indicating the importance of the tuna resource to the fishing industry. Skipjack tuna alone, comprised nearly 50 percent of the total landings and yellowfin tuna accounted for 16 percent. Bottomfish (deepsea) and bottomfish (inshore) combined represented 13.5 percent of the total landings.

When the fishing industry reaches its projected full harvesting potential, an estimated 74.0 to 117 million pounds of fish could be harvested. This poundage represents 80 percent of the biologically sustainable yield. According to the same source, tuna species would account for 68 percent of the total landings while landings for other currently under-exploited species (shrimp, spiny lobster, seamount groundfish and others) will increase dramatically (Reference 11).

## 2.2 Characterization of Fishing Operations

Hawaii is surrounded by the sea and it is natural that many individuals fish commercially or recreationally. In general, any individual who sells his catch must obtain a commercial fishing license from the Department of Land and Natural Resources. The fisheries are divided into four categories as follows:

- o Commercial Fishing - is pursued by individuals who derive their primary source of income from the fish they sell.
- o Commercial Sport Fishing - is done by individuals chartering their boats to customers seeking large pelagic species. Some owners fish commercially when charter business is slow.
- o Subsistence Fishing - close to shore small operations lasting half to a full day.
- o Recreational Fishing - operations by any individual fishing a half to a full day per week. An unspecified number of recreational fishermen possess commercial fishing licenses. Some recreational fishermen sell part or all of their catch.

Fishermen in the first two categories are the most likely users of LORAN-C since fishing is their primary source of income and they will adopt innovative methods to increase their catch. Hence, commercial fishermen are the focus of this appendix.

# 3. CURRENT FISHING OPERATIONS

The harvesting efforts of the fishing industry in Hawaii are concentrated on three major species groups: tunas including dolphinfish and ono, bottomfish and billfishes. A fourth group of species currently under-exploited that consists of lobster, shrimp and Kona crab is also discussed. Table D-2 shows the principal characteristics of vessel operations by major species group.

# TABLE D-2. FISHERY/VESSEL OPERATIONS

| SPECIES & PORT OF OPERATION | FISHERY CHARACTERISTICS: FISHING PATTERNS | OPERATING RANGE | PRINCIPAL AREAS | LOCATING METHODS | GEAR USED | VESSEL CHARACTERISTICS: NUMBER | LENGTH (FT) | LORAN-C |
|---|---|---|---|---|---|---|---|---|
| Skipjack Tuna<br>o Honolulu | One Day Catching Live Bait; One Day Fishing | Within 60nm | Open Sea | Floating Objects, Bird Concentrations | Pole and Lines | 13 | 50-80 | No |
| o Maalaea | As Above | As Above | As Above | As Above | As Above | 2 | 50-80 | No |
| Yellowfin Tuna<br>o Hilo | Night Time Fishing, Daily Trips | Within 60nm | Deepwater Banks, Submarine Ledges | Compass Bearings, Landmarks, Fathometer | Longlines<br>Handlines | 30<br>2 | 16-28<br>40-42 | No<br>No |
| o Kona | As Above | As Above | As Above | As Above | As Above | 10<br>2 | 16-28<br>40-42 | No<br>No |
| o Honolulu | Six Boats, Daily Trips; Nine Boats, Three Day Trips | As Above | As Above | As Above | As Above | 6<br>9 | 60-80<br>24-40 | No<br>No |
| Bigeye and Bluefin Tuna<br>o Hilo, Kona, Honolulu | Included With Yellowfin Fishery By Same Vessels | As Above | As Above | As Above | As Above | As Above | | |
| Albacore Tuna<br>o Honolulu | Five to Six Months On The Seas | Unlimited. Vessels Resupplied By Mothership | Seamounts (Midway Island Fishery) | LORAN-C | Pole and Lines | 26<br>1 | 65-75<br>175 | Yes<br>Yes |
| Bottomfishing<br>o Honolulu | 20 Vessels, One to Three Day Trips, 4 Vessels, Three to Five Months | 20 Vessels Within 120nm, 4 Vessels 1000-1400nm (Northwest Hawaiian Islands) | Rocky Grounds, Dropoffs, Pinacles, Holes | Compass Bearings, Landmarks, LORAN-C, Fathometer | Handlines, Traps | 20<br>4 | 35-45<br>75-150 | No<br>Yes |
| o Lahaina and Maalea | Mostly Daily Trips | Up to 50nm | As Above | Compass Bearings, Landmarks, Fathometer | Handlines | 10 | 30-40 | No |
| o Nawiliwili | One to Four Day Trips | 120-150nm | As Above | As Above | Handlines | 2 | 50-60 | No |
| Ono, Dolphinfish and Tuna Trolling<br>o Hilo, Kona, Honolulu | Daily Trips | 30-40nm | Dropoffs | As Above | Handlines | 80 | 18-30 | No |
| Billfish Trolling<br>o Kona, Honolulu, Nawiliwili, Port Allen, Lahaina and Maalaea | Half to a Full Day, Commercial Sport Fishing | 1-30nm | Dropoffs | As Above | Handlines | 100 | 35-55 | No |

### 3.1 Tuna Species

The tuna resource is currently the most important fishery accounting for 75 percent of the landings and catch value. Fifteen full-time vessels are engaged in skipjack tuna fishing; however, incidental catches are also taken by vessels engaged in commercial sport fishing and yellowfin tuna fishing. None of the vessels are equipped with LORAN-C receivers. Skipjack tuna is a highly migratory species and, hence, it is difficult to determine the extent to which LORAN-C would be utilized by skipjack tuna vessels to relocate fishing areas.

Yellowfin tuna is the second most important tuna species. The island of Hawaii accounts for 70 percent of the total landings and Oahu for 26 percent. Yellowfin tuna is sought principally by 10 large longline vessels and 49 smaller boats. However, during either high demand periods or abundance of stock, a large number of boats seek this high priced species. Bigeye and bluefin tunas are sought together with yellowfin tuna by the same vessels. Oahu vessels landed 87 percent of the bigeye and bluefin tunas catch. When charter business is slow and during high demand periods, charter boats may engage in yellowfin, bigeye, and bluefin tuna fishing. The albacore fishery started in 1978 on an experimental basis to determine its economic viability. The operation was carried out in the Midway Islands by 21 contract vessels (one mothership), while six additional vessels participated at their own expense. The vessels stayed on the seas for six months and were resupplied by the mothership. Albacore operations were conducted within an area having LORAN-C coverage and the vessels utilized LORAN-C receivers to help locate seamounts which are the usual feeding areas of albacore.

### 3.2 Bottomfish and Billfish Species

In 1978, bottomfish accounted for 13.5 percent of the total landings. Bottomfishing is done by small vessels (30-50 feet) and four multi-purpose vessels (75-150 feet). The small vessels fish in North Molokai, Penguin Bank, Maui, Kahoolawe, Northwest of Niihau, while the multi-purpose vessels, in addition to these areas, fish in the Nero Bank, Gambia Shoal, Salmon Bank and other distant areas.

Billfish fishing is done by commercial sport fishing boats. While these boats seek mostly trophy fishes, such as Pacific blue marlin and stripped marlin, incidental catches of dolphinfish, yellowfin, bigeye and other species is not rare. As mentioned earlier, these boats may also engage in commercial fishing.

### 3.3 Lobster, Shrimp and Kona Crab

Total lobster, shrimp and Kona crab landings (not shown in Table D-2) accounted for 63,821 pounds of the total catch in 1978. Lobster is sought by multi-purpose vessels in Necker Island, Maro

Reef, Gardner Pinnacles and other distant areas. Most of the lobster producing areas are within areas having LORAN-C coverage and vessels use LORAN-C to set traps at desirable locations as well as to recover them. The current shrimp catches are incidental but it has been estimated that a potential shrimp fishery exists in Pailolo Channel, Penguin Bank and possibly Leeward Islands. The Kona crab fishery produced 27,700 pounds in 1978. Most of the resource is taken by small vessels in Penguin Bank, southwest of western Molokai and the Northwest coast of Niihau.

## 4. FUTURE DIRECTION

By U.S. mainland standards, the fishing industry in Hawaii is small in both landings and number of commercially operating vessels. In spite of the fishing fleet's size and composition (i.e. size of boats), the Hawaiian waters have the potential for development of several promising fisheries. Prior to analyzing the nature of future operations, it is necessary to address the current limitations and constraints which must be overcome before the available resources can be harvested.

### 4.1 Constraints and Limitations

The growth of the fishing industry is not constrained so much by the availability of fish resources as it is hindered by harbors, infrastructure, marketing and product promotion, financing, and fuel costs (Reference 11). A brief description of each major constraint is presented below.

#### 4.1.1 Harbors

Availability of dock space for fishing vessels is the most serious constraint which may limit the growth of the fishing fleet. Currently 800 boats (16-30 feet in length), which supply the market with their catches, are accommodated on trailers due to unavailability of dock space. Furthermore, it is projected that by the year 2000, 185 large fishing vessels (65-185 feet in length) will be added to the fishing fleet. These 185 vessels will require 6004 linear feet of additional dock space. Consequently, if the projected additional dock space required is not provided, the number of vessels to join the fleet could be reduced accordingly.

#### 4.1.2 Other Infrastructure

The current fisheries infrastructure does not adequately support the existing fishing fleet. The infrastructure related problems primarily consist of inadequate fuel facilities, cold storage, ice plants, and ship repair facilities. Thus, a further expansion of the fleet might be restricted if these constraints are not removed.

### 4.1.3 Marketing and Product Promotion

At the present time, the harvesting capability of the fishing fleet is limited. Thus, only a small fraction of the catch is exported. However, if the projections (104 million pounds of fish by 2000) are attained, most of the non-tunas species will have to be exported since the local demand will absorb only a fraction of the additional catch. Consequently, it will be essential that new markets be established in the U.S. mainland and abroad.

### 4.1.4 Financing

"It is projected that the total large vessel financing requirements for the next twenty years will approach 100 million dollars" (Reference 11). Potential sources for providing loan guarantees could be state and federal entities. Availability of credit from private lending institutions should also be considered.

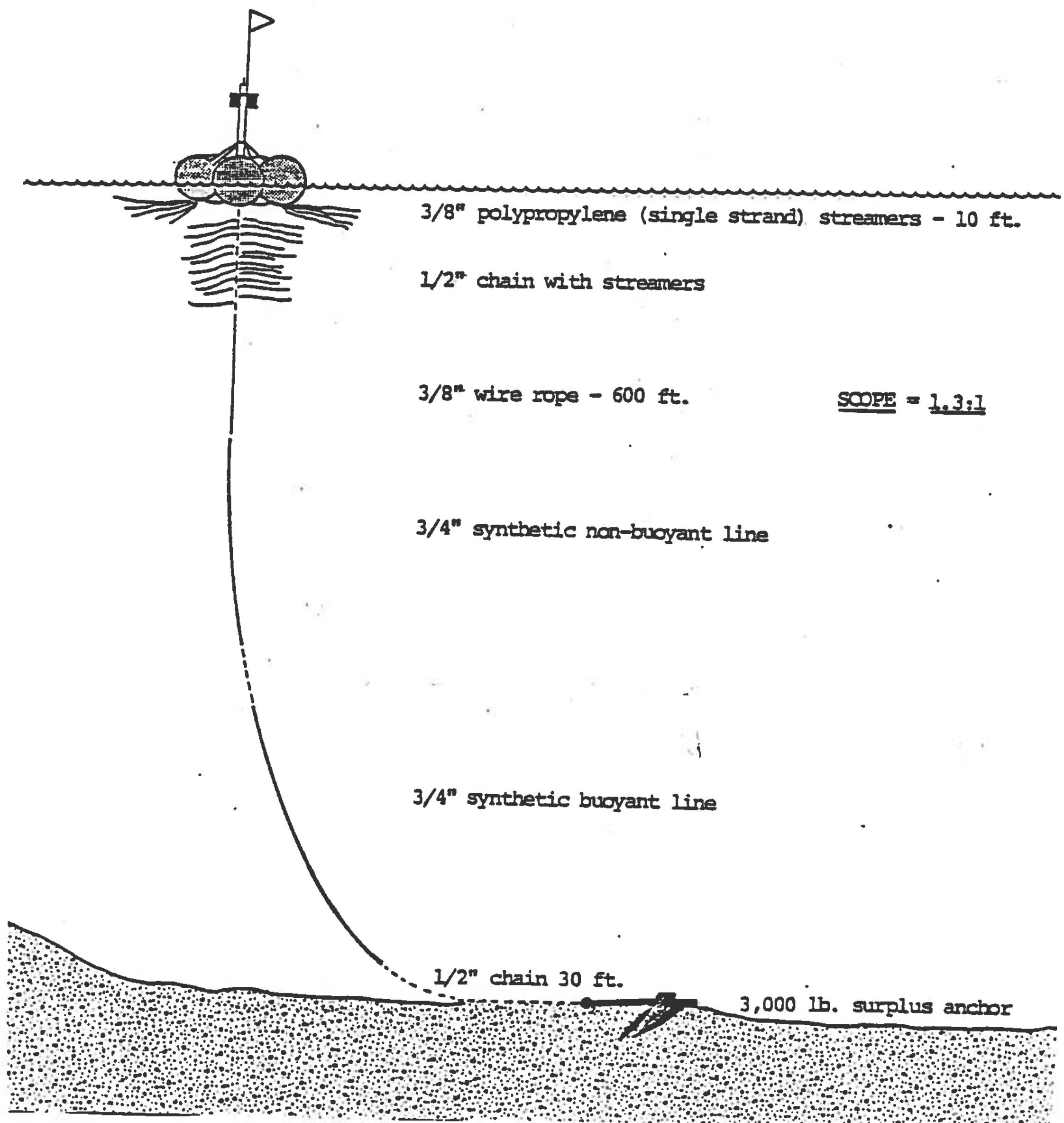
### 4.1.5 Fuel Costs

Rising fuel costs may discourage individuals from buying fishing vessels or force marginal operators to either leave the industry or reduce their operations.

## 4.2 Future Operations

One experimental program, aggregation devices (buoys), should be addressed because of its possible future implications. Figure D-3 shows an aggregation device deployed in Hawaii. It is known that tunas and other pelagic species are attracted to and congregate around floating objects. In 1977, the National Marine Fisheries Service (NMFS) and Hawaii Department of Land and Natural Resources (DLNR) installed 26 buoys around the major islands in order to assess their effectiveness. The results of the skipjack tuna vessel activities were indicative of the following trends. (Reference 41)

- Fish schools attracted to the buoys appeared to remain in the vicinity for up to several days.
- Catches of 10,000-20,000 pounds occured frequently and the largest catch was well over 30,000 pounds.
- The average catch-per-boat-per-day near the buoys was considerably higher than the 15-year long-term average catch of the commercial skipjack tuna fleet from a comparable area and time.
- The buoys reduced the time lost due to scouting for fish schools.
- Far less bait than would normally be used for fishing schools was required to fish around the buoys.
- Because of the need for less bait, the vessels made more fishing trips per week. Several boats fished on 5 to 6 successive days during 1 week, while another fished for 8 days over a 9 day period.




COURTESY HAWAII DIVISION OF FISH AND GAME

FIGURE D-3. AGGREGATION DEVICE (BUOY)

Deployment of additional buoys would interfere with navigation. If more buoys are to be deployed, they will be installed approximately 200 feet below sea level. These new buoys will also be deployed further off shore where locating them by landmarks would not be feasible. Thus, LORAN-C would greatly assist vessels to locate the buoys. At the present time, however, there are no plans calling for deployment of aggregation devices.

The balance of this section provides an analysis of the future fishing operations by major species group.

## 4.3 Vessel Projections

The primary source of information for the vessel projections presented in Table D-3 was the "Hawaii Fisheries Development Plan". Vessel projections in this planning document were derived assuming that 185 vessels would be required to harvest 80 percent of the potential sustainable yield of the species. The totals were obtained by summing up the current and projected fleet. Due to lack of sufficient data concerning the age of the current fleet boat retirements were not estimated. Table D-3 shows commercial fishing vessel projections from 1980 to 2000. As Table D-3 indicates, by the year 2000, 185 large vessels will be added to the current commercial fishing fleet.* These vessels will be modern and 65 to 185 feet in length (Reference 11). In addition, it was projected that 105 smaller vessels will also be added to the fleet (Appendix F). Table D-3 also shows the total vessel population from 1980 to 2000. As Table D-3 indicates, in 1980, the fishing fleet consisted of 342 vessels. By the year 2000, this number will grow to 641.

### Skipjack Tuna

By 2000, 40 skipjack tuna vessels will harvest this resource. Table D-4 shows various data associated with the skipjack tuna fishery. As Table D-4 indicates, approximately 6.8 million pounds of skipjack tuna were landed in 1978. In 1990, 24.8 million pounds will be landed, representing an ex-vessel price of 12.5 million dollars. By 2000, landings are projected to consist of 36.8 million pounds valued at 17.8 million dollars.

Skipjack tuna operations are projected to change substantially (Reference 11). In 1990, it is projected that 4-10 million pounds of skipjack tuna will be caught near the aggregation devices. No similar estimate is available for 2000. New skipjack tuna fisheries will also be developed in the Midway islands, but projections with respect to number of vessels which will fish in these areas and fish caught are not available.

### 4.3.2 Yellowfin, Bluefin and Bigeye Tuna

Table D-5 shows data pertinent to yellowfin, bluefin and bigeye tuna fishery. Table D-5 indicates that by 2000, 28

TABLE D-3. FISHING VESSEL POPULATION PROJECTIONS BY FISHERY: 1980-2000

| NUMBER OF VESSELS | VESSEL POPULATION | | | | |
|---|---|---|---|---|---|
| | 1980 | 1985 | 1990 | 1995 | 2000 |
| Skipjack Tuna | 15 | 30 | 30 | 35 | 40 |
| Yellowfin, Bluefin, Bigeye Tuna (Longline Vessels) | 10 | 14 | 18 | 24 | 28 |
| Multi-purpose (Lobster, Shrimp and Other Species) | 4 | 15 | 22 | 32 | 42 |
| Albacore Vessels (Resident) | 4 | 5 | 20 | 20 | 20 |
| Albacore Vessels (from U.S. Mainland) | 23 | 30 | 50 | 60 | 80 |
| Total Full-Time Large Commercial Fishing Vessels | 56 | 94 | 140 | 171 | 210 |
| Other Smaller Fishing Vessels (Semi-commcercial Recreational) | 186 | 212 | 239 | 265 | 291 |
| Commercial Sport Fishing Vessels (Charter) | 100 | 110 | 120 | 130 | 140 |
| Grand Total | 342 | 416 | 499 | 566 | 641 |

## TABLE D-4. SKIPJACK TUNA FISHERY

| FISHERY DATA | 1978 | 1990 | 2000 |
|---|---|---|---|
| Number of Vessels | 15 | 30 | 40 |
| Pounds/Year | 6,794,086 | 24,794,086 | 36,794,086 |
| Ex-vessel | $4,358,429 | $12,458,429 | $17,858,429 |
| Percentage of catch by location: | | | |
| o Aggregation devices | 17 | 16-40 | N.A. |
| o 0-50 nm from the shore | 83 | N.A. | N.A. |
| o 50-100 nm from the shore | 0 | N.A. | N.A. |
| o Leeward Islands | 0 | N.A. | N.A. |

N.A. - Not available

TABLE D-5. YELLOWFIN, BLUEFIN AND BIGEYE TUNA

| FISHERY DATA | 1978 | 1990 | 2000 |
|---|---|---|---|
| Number of vessels | 10 | 18 | 28 |
| Pounds/Year | 6,929,000 | 9,510,596 | 18,173,596 |
| Ex-vessel | $3,745,362 | $9,045,362 | $15,674,362 |
| Percentage of catch by location: | | | |
| o 0-50nm from the islands of Hawaii, Oahu, Maui and Kauai | 100 | 27 | 27 |
| o lat. $30^oN$ - $35^oN$ long $150^oW$ - $165^oW$ | N.A. | N.A. | N.A. |
| o South of Hawaii | N.A. | N.A. | N.A. |

N. A. - Not Available

longline vessels will fish for yellowfin, bluefin and bigeye tunas. These vessels will land approximately 18.2 million pounds of fish valued at 15.7 million dollars. Fishing operations will be expanded south of the Hawaii Island and also to the north (lat. 30°N - 35°N, long 150°W - 165°W). No specific estimates are available concerning number of vessels to fish these areas and pounds of fish caught in these locations.

In addition to those large longline vessels, smaller trolling vessels will also seek these tuna species together with other species. The extent to which the effort of those smaller vessels will be devoted on any one specific species will depend on such considerations as market conditions, season, stock availability and prices. However, the operation of the small trolling vessels is not anticipated to change substantially, though their number is projected to grow from 185 in 1980 to 291 in 2000.

4.3.3 Albacore Fishery

Table D-6 shows that, by the year 2000, 100 albacore vessels will harvest the albacore. Approximately 24.0 million pounds of albacore are projected to be harvested each year, valued at 14.8 million dollars. All of this resource will be harvested in the Midway Islands.

4.3.4 Shrimp and Lobster Fishery

Table D-7 shows the projected landings and value of catch for lobster and shrimp in 1978, 1990 and 2000. It is projected that, by the year 2000, approximately 11.2 million pounds of shrimp and lobster worth 9.3 million dollars will be harvested.

Shrimp will be harvested in Pailolo Channel, Penguin Bank, northwest coast of Molokai and north coast of Maui. However, projections with respect to how many pounds of shrimp will be caught in each location are not available. Lobster will be taken from the areas near the Midway Islands.

4.3.5 Other Species

Included in the other species category were such examples as bottomfish, billfish, Kona crab, scads and others. Table D-8 shows the projected landings and value of catch for those species. As Table D-8 indicates it is projected that by the year 2000, 431 vessels (20-44 feet in length) will pursue these species. In 2000, landings are projected to consist of 8.7 million pounds valued at 9.5 million dollars.

The locations where the fishing boats will seek these species are not available. However, the vessels will be small in size (except the charterboats) and therefore have a limited operating range. Thus, it could be reasonably assumed that they will operate close to the shore (0-100nm) of the major islands as they do currently.

# TABLE D-6. ALBACORE FISHERY

| FISHERY DATA | 1978 | 1990 | 2000 |
|---|---|---|---|
| Number of vessels | 27 | 60 | 100 |
| Pounds Year | 694,406 | 17,074,406 | 24,094,406 |
| Ex-vessel | $493,312 | $10,485,312 | $14,767,312 |
| Percentage of catch by location: | | | |
| o Midway Islands | 100 | 100 | 100 |

## TABLE D-7. SHRIMP AND LOBSTER FISHERY

| FISHERY DATA | 1978 | 1990 | 2000 |
|---|---|---|---|
| Number of vessels (Multi-purpose) | 4 | 22 | 42 |
| Pounds Year | 36,051 | 5,869,593 | 11,172,813 |
| Ex-vessel | $105,376 | $4,933,474 | $9,253,329 |
| Percentage of catch by location: | | | |
| • Shrimp | | | |
| • Pailolo channel | N.A. | N.A. | N.A. |
| • Penguin Bank | N.A. | N.A. | N.A. |
| • Northwest coast of Molokai | N.A. | N.A. | N.A. |
| • North coast of Maui | N.A. | N.A. | N.A. |
| • Lobster | | | |
| • Midway Islands | 100 | 100 | 100 |

N. A. - Not Available

## TABLE D-8. OTHER FISHERIES

| FISHERY DATA | 1978 | 1990 | 2000 |
|---|---|---|---|
| Number of vessels | 286 | 359 | 431 |
| Pounds Year | 3,173,868 | 6,088,326 | 8,737,106 |
| Ex-vessel | $3,512,074 | $5,815,976 | $9,509,796 |
| Percentage of catch by location: | N.A. | N.A. | N.A. |

N. A. - Not Available

## 4.4 LORAN-C Users

The purpose of this section is to provide estimates concerning current and potential LORAN-C users. LORAN-C user estimates were developed according to two scenarios. Scenario One assumes that LORAN-C coverage is not expanded. Under Scenario Two, LORAN-C user projections were based on the assumption that LORAN-C coverage is expanded.

### 4.4.1 Scenario One

Table D-9 shows the current and projected LORAN-C users from 1980 to 2000. These estimates were based on the following assumptions:

- o LORAN-C coverage is not expanded.
- o The 185 new, large (65-185 feet in length), modern vessels that will be added to the current fishing fleet would be equipped with LORAN-C.
- o None of the additional 105 smaller vessels which were projected to join the fleet, will be equipped with LORAN-C. This assumption was based on the fact that none of the small vessels are currently equipped with LORAN-C.

Table D-9 shows that in 1980, 31 vessels were equipped with LORAN-C. The number of vessels will rise to 185 in the year 2000.

Of these, 80 vessels represent albacore vessels from the U.S. mainland. The 185 vessels projected to carry LORAN-C will fish mostly in the Midway Islands where LORAN-C coverage currently exists.

### 4.4.2 Scenario Two

Table D-10 shows the current and projected LORAN-C users from 1980 to 2000. These estimates were based on the following assumptions:

- o LORAN-C coverage is expanded as shown in Figures 6-2 and 6-3.
- o The 185 new large modern vessels that will be added to the fleet from 1980 to 2000 will be equipped with LORAN-C.
- o By 2000, 134 smaller vessels will acquire LORAN-C. This estimate was based on boat size, operation patterns, gear used, fishing locations and other similar considerations.
- o From the 140 commercial sport fishing boats projected to operate by 2000, 80 boats will carry LORAN-C. This estimate was based on such considerations as boat size, fishing operations, and perception of skippers in Hawaii about the usefullness of LORAN-C to their operations (Appendix F).

TABLE D-9. SCENARIO ONE - LORAN-C USER PROJECTIONS: 1980-2000

| | VESSELS CARRYING LORAN-C | | | | |
|---|---|---|---|---|---|
| NUMBER OF VESSELS | 1980* | 1985 | 1990 | 1995 | 2000 |
| Skipjack Tuna | 0 | 8 | 15 | 20 | 25 |
| Yellowfin, Bluefin, Bigeye Tuna (Longline Vessels) | 0 | 4 | 8 | 14 | 18 |
| Multi-purpose (Lobster, Shrimp and Other Species) | 4 | 15 | 22 | 32 | 42 |
| Albacore Vessels (Resident) | 4 | 5 | 20 | 20 | 20 |
| Albacore Vessels (from U.S. Mainland) | 23 | 30 | 50 | 60 | 80 |
| Total Full-Time Large Commercial Fishing Vessels | 31 | 62 | 115 | 146 | 185 |
| Other Smaller Fishing Vessels (Semi-commcercial Recreational) | 0 | 0 | 0 | 0 | 0 |
| Commercial Sport Fishing Vessels (Charter) | 0 | 0 | 0 | 0 | 0 |
| Grand Total | 31 | 62 | 115 | 146 | 185 |

*Actual

TABLE D-1Ø. SCENARIO TWO - LORAN-C USER PROJECTIONS: 198Ø-2ØØØ

| NUMBER OF VESSELS BY FISHERY | VESSELS CARRYING LORAN-C 1980* | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|
| Skipjack Tuna | 0 | 30 | 30 | 35 | 40 |
| Yellowfin, Bluefin, Bigeye Tuna (Longline Vessels) | 0 | 14 | 18 | 24 | 28 |
| Multi-purpose (Lobster, Shrimp and Other Species) | 4 | 15 | 22 | 32 | 42 |
| Albacore Vessels (Resident) | 4 | 5 | 20 | 20 | 20 |
| Albacore Vessels (from U.S. Mainland) | 23 | 30 | 50 | 60 | 80 |
| Total Full-Time Large Commercial Fishing Vessels | 31 | 94 | 140 | 171 | 210 |
| Other Smaller Fishing Vessels (Semi-commcercial Recreational) | 0 | 47 | 75 | 106 | 134 |
| Commercial Sport Fishing Vessles (Charter) | 0 | 30 | 40 | 60 | 80 |
| Grand Total | 31 | 171 | 255 | 337 | 424 |

*Actual

Table D-10 shows that by the year 2000, 424 vessels will carry LORAN-C receivers.

APPENDIX E
RECREATIONAL BOATING IN HAWAII

1. INTRODUCTION

The purpose of this appendix is to estimate the population of pleasure vessels in Hawaii, determine the traffic between the U.S. mainland and Hawaii, and project the number of pleasure vessels and potential LORAN-C users from 1980 to 2000.

2. POPULATION OF PLEASURE CRAFT IN HAWAII

A pleasure boat is defined as any power or sailboat that is registered or documented* in Hawaii. Estimates for the population of pleasure craft were derived from three sources:

- U. S. Coast Guard, "Boating Statistics" (Reference 42);
- National Association of Engine and Boat Manufacturers, "Boating Registration Statistics" (Reference 43);
- Interviews with personnel from Hawaii Department of Transportation, Harbors Division Boating Office, and marina dockmasters (Appendix F).

2.1 Current Population

Table E-1 shows the population of pleasure craft in 1979. As this table indicates, the boat population consisted of 12,326 craft. The majority of the boats, 6208 or 50.3 percent, represented craft in the 16 to less than 26 foot category; the under 16 foot category accounted for 4365 boats or 35.4 percent of the population. Approximately 14.2 percent or 1753 boats represented craft over 26 feet; only 367 boats were over 40 feet.

The type of navigation equipment carried by the vessels registered and/or documented, in Hawaii was determined by visiting the major state and private marinas in Honolulu, Kona, Hilo, Kauai, and Maui. Dockmasters and port captains indicated that most recreational boats do not carry electronic navigation equipment due to the following reasons:

- The majority of the boats navigate in the daytime and always stay within sight of land
- Only a few boats take trips to the neighboring islands
- Those that sail in the open ocean use celestial means to navigate
- Except for experienced blue water sailors, all others take trips usually lasting half day
- Good weather conditions prevail year round.

It was estimated that only five or six locally owned and operated boats carry LORAN-C receivers. However, mainland-owned boats which cruise to Hawaii comprise a more substantial number of users. (See Section 4 of this Appendix).

*A documented vessel is not registered and has at least a five net ton capacity.

## TABLE E-1. PLEASURE BOAT POPULATION IN 1979

| BOAT CATEGORY* | INBOARD | OUTBOARD | TOTAL |
|---|---|---|---|
| Under 16 feet | 131 | 4234 | 4365 |
| 16 to less than 26 feet | 2232 | 3976 | 6208 |
| 26 to less than 40 feet | 1108 | 278 | 1386 |
| 40 to 65 feet | 340 | 14 | 354 |
| Over 65 feet | 13 | 0 | 13 |
| TOTAL | 3824 | 8502 | 12,326 |

*Includes all motorboats and sailboats over 8 feet in length. In addition to 12,326 boats, 1100 are classified as undocumented commercial fishing and 277 as documented fishing and charter passenger vessels.

## 3. PROJECTED POPULATION AND LORAN-C USERS: 1980-2000

### 3.1 Projected Population

The following assumptions were used to estimate the pleasure craft population through the year 2000:

- Examination of historical trends - historical boat population data were examined to extrapolate future trends. This examination revealed that from 1973 to 1979 the boat population increased by 10 percent. The highest increase was experienced in the categories of under 16 feet and 16 to less than 26 feet.
- Dock space availability - currently all harbors are fully occupied. Furthermore, due to a lack of berthing facilities, the majority of the boats which are less than 26 feet are stored and transported on trailers. Thus, potential buyers of boats over 26 feet may be deterred if dock space is not available.
- Cost and availability of credit - tight credit conditions tend to drive marginal buyers out of the market and thereby, affect the growth rate of the pleasure craft population, particularly the larger size vessels.

Based on this evidence, a growth rate of 140 boats per year was applied to calculate the boat population from 1980 through 2000.

Table E-2 shows the estimated pleasure boat population from 1980 to 2000. This table also shows the distribution of growth among the various boat categories. As can be seen, the major growth is projected to occur in the less than 26 foot categories and reflect the assumptions discussed above. In the 21 year period the recreational boat population was projected to increase by 2940 boats to a total of over 15,200 boats.

### 3.2 Projected LORAN-C Users: 1980-2000

Discussions with dockmasters, port captains and owners of electronic component retail stores revealed that in the Hawaiian Islands only five or six pleasure boats carry LORAN-C receivers (Appendix F). In order to project the number of boats which may use LORAN-C from 1980 through 2000, the following factors were considered:

- Boat size - in general boats which are less than 35 feet in length do not use LORAN-C. This trend was based on an examination of boats operating in a similar marine environment (Miami and Fort Lauderdale, Florida) (Reference 3).
- Operational characteristics - the majority of the boats operate for half day, stay within sight of land and travel to the neighboring islands very rarely. Thus, navigation is mostly done by visual means and dead reckoning.

TABLE E-2. PROJECTED POPULATION OF PLEASURE CRAFT: 1980-2000

| BOAT CATEGORY | YEAR | | | | | |
|---|---|---|---|---|---|---|
| | 1979 | 1980 | 1985 | 1990 | 1995 | 2000 |
| 1 - Under 16 feet | 4365 | 4433 | 4772 | 5111 | 5450 | 5789 |
| 2 - 16 to less than 26 feet | 6208 | 6264 | 6544 | 6824 | 7104 | 7384 |
| 3 - 26 to less than 40 feet | 1386 | 1400 | 1470 | 1540 | 1610 | 1680 |
| 4 - 40 to 65 feet | 354 | 355 | 362 | 369 | 376 | 383 |
| 5 - Over 65 feet | 13 | 14 | 18 | 22 | 26 | 30 |
| TOTAL | 12,326 | 12,466 | 13,166 | 13,866 | 14,566 | 15,266 |

The following percentages were applied to estimate the increase of each boat category.

1 - 48.5 percent
2 - 40.0 percent
3 - 10.0 percent
4 - 1.0 percent
5 - .50 percent

- o Weather conditions - in general, the weather conditions prevailing in Hawaii are favorable to navigators.
- o Fishing activities - the majority of the recreational boaters fish extensively (half to a full day per week) for pleasure or to supplement their income. It is likely that some recreational fishermen may acquire LORAN-C receivers to improve their fishing operations should LORAN-C be expanded to cover the major islands.
- o Expert opinions - experts on recreational fishing activities in Hawaii estimated that if LORAN-C coverage was expanded, 10 to 12 percent of the recreational fishermen would buy LORAN-C by the year 2000.

Assuming that LORAN-C coverage were expanded to include the main Hawaiian islands, the projected number of recreational boat users are estimated to grow from essentially zero in 1980 to 776 by 2000. This growth and distribution is shown in Table E-3.

By 2000, approximately eight percent of the pleasure boats greater than 16 feet are expected to be equipped with LORAN-C receivers.

## 4. POPULATION AND TRAFFIC OF U.S. MAINLAND PLEASURE CRAFT CRUISING TO HAWAII

U.S. registered recreational vessels that cruise from the U.S. mainland to Hawaii do not appear in the Census data base nor do U.S. recreational vessels entering Hawaii from foreign ports. Information on the latter vessels is recorded in the "Recreational Boats Log Book," maintained by the U.S. Customs, Hawaii District. This document was one of the principal sources used for recreational vessel data. Information pertinent to the number and operational characteristics of the U.S. recreational vessels sailing directly from the U.S. mainland to Hawaii was obtained from the following sources:

- o Hawaii Department of Transportation, Harbors Division/ Boating Office (Appendix F)
- o State Marinas (Appendix F)
- o Private Marinas and Yacht Clubs (Appendix F)

### 4.1 Vessel Population and LORAN-C Users

In 1980 approximately 1100-1200 U.S. pleasure vessels cruised to Hawaii. Approximately 80 to 90 percent of these vessels were sailboats and ranged in length from 35 to 80 feet.

The number of vessels carrying LORAN-C receivers was estimated according to the following assumptions:

- o Approximately 80 percent of the large powerboats are equipped with all available electronic navigation equipment such as radio direction finders, radar, depth finders, LORAN-C, Omega and Transit (Reference 3)

TABLE E-3. LORAN-C USER PROJECTIONS: 1980-2000

| BOAT CATEGORY | ESTIMATED LORAN-C USERS | | | |
|---|---|---|---|---|
| | 1985 | 1990 | 1995 | 2000 |
| Under 16 feet | / | / | / | / |
| 16 to less than 26 feet | 68 | 146 | 234 | 333 |
| 26 to less than 40 feet | 32 | 53 | 78 | 107 |
| 40 to 65 feet | 151 | 199 | 250 | 306 |
| Over 65 feet | 10 | 15 | 22 | 30 |
| TOTAL | 261 | 413 | 584 | 776 |

- Nearly 40 percent of sailboats which are over 50 feet carry LORAN-C receivers (Reference 3).

Applying these assumptions to the number of powerboats and sailboats over 50 feet, the number of these vessels carrying LORAN-C receivers could be estimated. Of the 100-200 large powerboats cruising to Hawaii from the U.S. mainland, approximately 90-180 are equipped with LORAN-C receivers.

Based on information obtained in Hawaii regarding oceanic sailboats sailing to Hawaii, it was estimated that approximately 40 to 50 percent of these are over 50 feet. Thus, it can be assumed that between 140 and 220 sailboats carry LORAN-C receivers.

The number of U.S. pleasure boats cruising to Hawaii carrying LORAN-C receivers was estimated to be between 230 and 400.

## 4.2 Traffic

In 1980, the recreational traffic between the U.S. mainland and Hawaii was estimated at approximately 2400 trips. Further, U.S. boats which sailed to Hawaii from foreign ports accounted for an additional 78 trips. Most of this traffic occurred between April and September, principally because of the favorable weather conditions prevailing in the Central Pacific at this time.

Vessels sailing from the U.S. mainland to Hawaii usually sail to all of the main Hawaiian islands thereby, generating inter-island as well as trans-Pacific traffic. This inter-island traffic is estimated at 4800 trips under the assumption that these vessels visit all the main islands before returning to the mainland.

With respect to foreign traffic in 1980, 105 foreign recreational vessels visited the four major islands. These vessels generated 210 transoceanic trips to Hawaii and 420 inter-island moves.

## 4.3 Projected Population and LORAN-C Users: 1981-2000

Projections with respect to the U.S. mainland boats which may sail to Hawaii from 1981 to 2000 were based on discussions with marina dockmasters and an examination of past trends. The number of the U.S. boats sailing to Hawaii has remained fairly constant in the last several years. Since Hawaii is situated 2100 nm from the U.S. West Coast, only a limited number of powerboats has the capability to cruise to Hawaii. The traffic generated by large powerboats is not expected to change in any substantial manner and indeed, rising fuel costs may exert downward pressure on this number.

The majority of sailboats cruising to Hawaii participate in two world famous races, the Transpac and Clipper Cup. The number of participant boats in these two races has remained fairly constant over the last several years.

Thus, the number of boats, traffic generated and LORAN-C users were not projected to change significantly from the 1979-1980 level.

APPENDIX F

LIST OF CONTACTS

1. U.S. GOVERNMENT

o U.S. Coast Guard Headquarters, Washington, D.C.
  - CAPT Jon C. Uithol, Chief, Radionavigation Division
  - CDR N.A. Pealer, Chief, LORAN Branch
  - LT T.M. Drown, LORAN Branch
  - CDR W.K. May, Omega Navigation System Operations Detail
  - LCDR K.C. Hollemon, Office of Operations, Aviation Branch

o U.S. Coast Guard, Commander Pacific Area, San Francisco, CA
  - CAPT Ralph Winn, Aids to Navigation
  - CDR Harold T. Sherman, Aids to Navigation LORAN-C

o U.S. Coast Guard, Fourteenth District, Honolulu, Hawaii
  - CAPT Victor R. Robillard, Chief, Aids to Navigation Branch
  - LTJG Scott D. Bair, COCO, CENPAC LORAN Chain
  - LTJG Michael L. Vanhouten, Hydrographer
  - LCDR Keith King, SAR
  - LCDR Michael J. Mierzwa, Chief, Law Enforcement Branch
  - CDR Gill R. Goodman, Chief, Electronics Engineering Branch
  - LT John G. Witherspoon, Chief, Recreational Boating Safety Branch
  - LT David B. Pascoe, XO, Marine Safety Office
  - Michael B. Bee, YN1, Marine Safety Office
  - LT Randall W. Freitas, XO, USCGC MALLOW
  - LT David M. Giraitis, Operations Officer, USCGC MUNRO

o U.S. Coast Guard Air Station, Barber's Point, Hawaii
  - CDR Robert W. Cathey, Operations
  - LCDR Gerald R. Murphy, Operations

o U.S. Coast Guard, Hilo, Hawaii
  - LTJG Stephen P. Carpenter, CO, USCGC CAPE SMALL

o U.S. Coast Guard, Upolu Pt., Hawaii
  - CWO2 Robert A. Vanderzyl, OINC, LORAN Station

o U.S. Coast Guard, Maalaea, Hawaii
  - LTJG Beverly G. Kelly, CO, USCGC CAPE NEWAGEN

o Department of Commerce, Bureau of the Census Foreign Trade Division
  - Mr. Charles Alexander, Washington, D.C.
  - Ms. Mary Green, Washington, D.C.

o National Oceanic and Atmospheric Administration
  - Mr. Jack Johns, Director of Statistics, Alexandria, VA

o Maritime Administration
  - Office of Ship Operations, Mr. F. Larson, Mr. D. Murray, Washington, D.C.

- o U.S. Army, Corps of Engineers
  - Navigation Analysis Center, Mr. Max Swartch, New Orleans, Louisiana

- o National Marine Fishery Service
  - Resource Statistics Division, Mr. Leslie Robinson, Washington, D.C.

- o U.S. Customs, Hawaii District
  - Mr. John Robert, District Director, Honolulu, Hawaii
  - Mr. Noah Koon, Supervisory Customs Inspector, Honolulu, Hawaii
  - Mr. George Uchida, District Inspector, Honolulu, Hawaii
  - Mr. Leong Ken, Inspector, Honolulu, Hawaii
  - Ms. Betty Shodhal, Customs Marine Officer, Honolulu, Hawaii

- o National Marine Fisheries Service, Honolulu Laboratory
  - Dr. Tamio Otsu, Marine Biologist, Honolulu, Hawaii
  - Dr. Reginold Gooding, Marine Biologist, Honolulu, Hawaii
  - Dr. Paul Struhsaker, Marine Biologist, Honolulu, Hawaii

2. STATE OF HAWAII

- o Department of Land and Natural Resources, Fish and Game Division, Dr. Stanley Swerdloff, Honolulu, Hawaii
- o Department of Transportation, Harbors Division
  - Finance and Statistics Department, Mr. George Uchida, Finance and Statistics Manager, Honolulu, Hawaii
  - Harbors Planning Division, Mr. Joseph Amaki, Planning Officer, Honolulu, Hawaii
  - Boat Registration Office, Mr. John McDonald, Safety Officer, Honolulu, Hawaii
  - Ala Wai Marina, Mr. Barton Jackson, Marina Captain, Honolulu, Hawaii
  - Keehi Lagoon, Ms. Susan Keliikuli, Clerk, Honolulu, Hawaii
  - Hilo Port, Ms. Alice Moses, Acting Port Manager, Hilo, Hawaii
  - Kailua Harbor, Mr. Henry Paso, Harbor Captain, Kailua-Kona, Hawaii

- o Department of Planning and Economic Development
  - Ms. Linda Komeshur, Administrative Assistant, Honolulu, Hawaii

3. MARITIME ORGANIZATIONS

- o Maritime Transportation Research Board, Mr. Dave Mellor, Washington, D.C.
- o National Marine Manufacturing Association, Mr. John Lamont, New York, New York
- o Maritime Association of the Port of New York, Mr. Nick Cretan, New York, New York

4. SHIPPING COMPANIES

- Matson Navigation Company: Captain Watson, Director of Marine Operations; Mr. Don Smith, Sales Manager, San Francisco, California
- U.S. Lines: Mr. Mark Jenson, Operations Manager, Oakland, California
- Lykes Bros. S.S. Lines: Del Osborne, Traffic Operations, San Francisco, California
- Hawaiian Marine Lines: Mr. Jim Vander Veen, Traffic Supervisor, Seattle, Washington
- Keystone Shipping: Mr. Allen Putnam, Chief of Operations, Philadelphia, Pennsylvania
- Marine Transport Lines: Mr. John Cross, Traffic Operations, New York, New York
- Dillingham Brothers Corporation: Mr. Ray Johnson, Traffic Operations, Honolulu, Hawaii
- Young Brothers, Ltd.: Mr. Calvin Yamashito, Operations Manager, Honolulu, Hawaii

5. TUG/BARGE OPERATORS

- Sause Brothers Lines: Ms. Jackie Sissero, Clerk, Honolulu, Hawaii
- Hilo Terminal and Transportation: Mr. Bill Hibbito, Operations Manager, Hilo, Hawaii
- Isleway Tug Company: Mr. Ace Clark, Traffic Manager, Honolulu, Hawaii
- P.A.R. Tug and Tow, Ltd.: Captain Al Kohlua, Operations Manager, Honolulu, Hawaii

6. OIL REFINERIES

- Chevron, Inc.: Mr. Guy Gilmen, Planning Department, Honolulu, Hawaii
- Pacific Resources, Inc.: Mr. Bill Alderman, Director of Transportation, Honolulu, Hawaii

7. VENDORS OF NAVIGATION EQUIPMENT

- KEMS, Inc., Mr. Roy Yee, Vice President, Mr. Wes Thorsson, Consultant, Honolulu, Hawaii
- Dillingnam Maritime Electric, Mr. Jim O'Hara, Operations Manager, Honolulu, Hawaii
- West Hawaii Electronics, Mr. Jim Black, Proprietor, Kailua-Kona, Hawaii

8. UNIVERSITY OF HAWAII SEA GRANT PROGRAMS

- Mr. Peter Hendricks, Marine Advisory Agent, Kailua-Kona, Hawaii

9. PRIVATE MARINAS

- o Waikiki Yacht Club, Mr. Mike Welsh, Port Captain, Honolulu, Hawaii
- o Hawaii Yacht Club, Mr. Barry Russel, Port Captain, Mr. Les Albright, Honolulu, Hawaii

10. FISHING ORGANIZATIONS

- o Western Pacific Fishery Management Council, Mr. Svein Fougner, Executive Director, Honolulu, Hawaii
- o Pacific Basin Development Council, Mr. Jerry Norris, Executive Director, Honolulu, Hawaii
- o Pacific Tuna Development Foundation, Mr. David Nada, Administrative Coordinator, Honolulu, Hawaii
- o Pacific Bill Fish Association, Mr. Jim Sutherland, President, Honolulu, Hawaii
- o Tuna Boat Owners Co-op, Inc., Mr. Robert Hee, President, Mr. John Robey, Manager, Honolulu, Hawaii

11. OTHER ORGANIZATIONS/INDIVIDUALS

- o American Hull Insurance Syndicate, Mr. William Patterson, New York, New York
- o World Bank, Ms. Morko, Washington, D.C.
- o Hawaii Fishing News, Mr. Chuck Johnston, Editor and Publisher, Honolulu, Hawaii
- o "Wicked Wahine" Research Vessel, Mr. Charles Yamamoto, Captain, Honolulu, Hawaii
- o AMFAC, Mr. Don Wiest, Sales Manager, Honolulu, Hawaii
- o United Fishing Agency, Mr. Brooks Takenaka, Manager, Honolulu, Hawaii
- o Alika Cooper and Sons, Inc., Mr. Alika Cooper, Proprietor, Hilo, Hawaii
- o Suissan Company, Mr. Toshio Haeda, Vice President, Mr. Nishimura, Auctioner, Hilo, Hawaii
- o Western Pacific Fishery Management Council, Mr. George Parker, Member, Kailua-Kona, Hawaii
- o Volcano Isle Fish, Inc., Mr. Jerry Kinney, Proprietor, Kailua-Kona, Hawaii
- o Stan's Fishery, Inc., Mr. Stan Shimizu, Proprietor, Honaunau, Hawaii
- o Fishing Boatowner, Mr. Ralph Young, Nawiliwili, Hawaii
- o Bruce Johnson, Fresh Island Fishery, Maalaea, Hawaii
- o Maui Divers Inc., Kaanapali, Hawaii