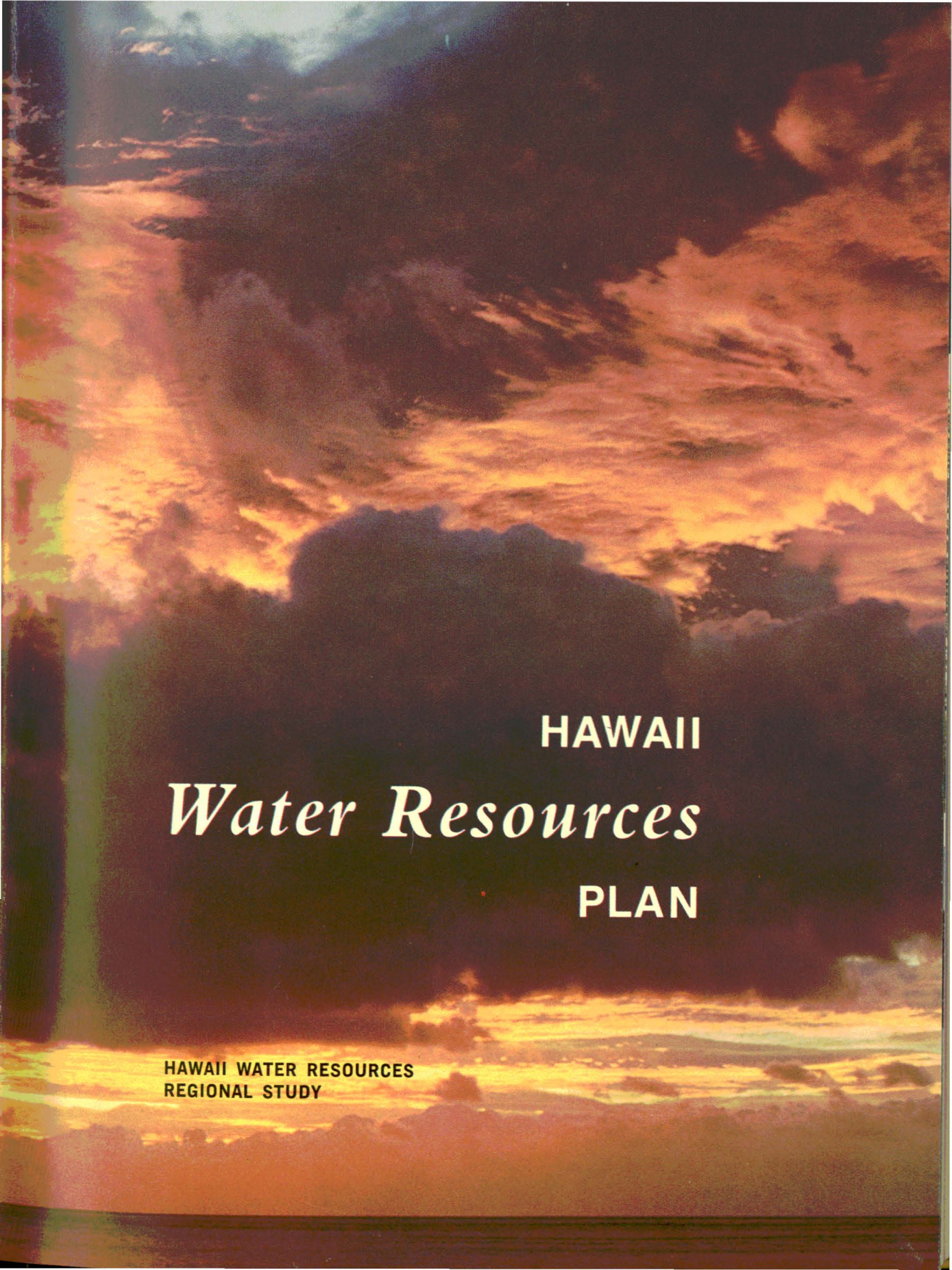
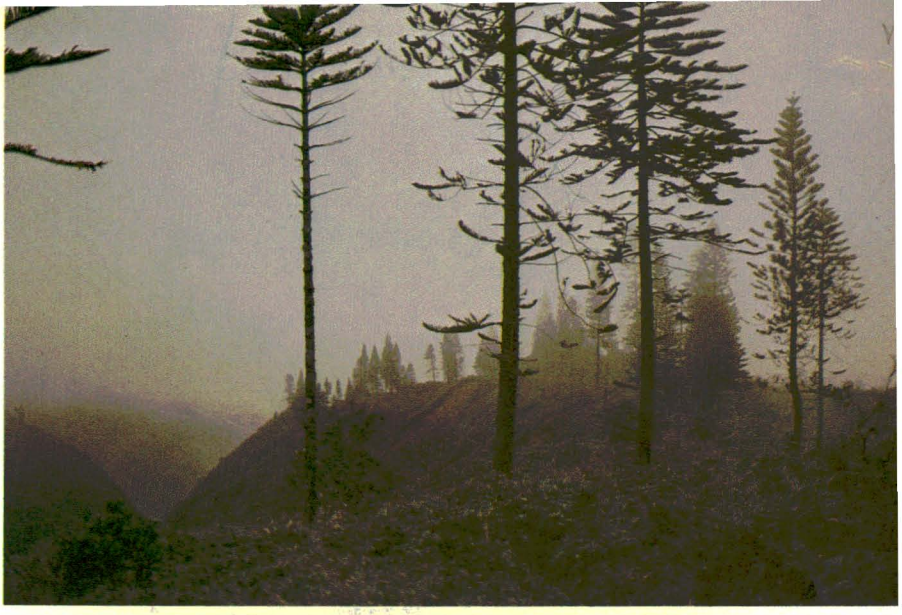


HAWAII *Water Resources* PLAN

HAWAII WATER RESOURCES
REGIONAL STUDY

Norfolk pines, Lanai.
Ocean shore, Oahu.
Kanaha Pond, Maui.



HAWAII
Water Resources
PLAN

Hawaii Water Resources Regional Study

HONOLULU, HAWAII
January 1979

COVER: Sunrise at Lanikai, Oahu.

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PREFACE

This publication summarizes the results of a statewide study aimed at balancing conservation, development, and use of Hawaii's water and related land resources through the next 15 to 25 years to the year 2000. Emphasis of the study has been on an appropriate balance of economic and environmental considerations in water and related land resource planning.

The plan presented here has been prepared by the Hawaii Water Resources Regional Study, an intergovernmental team representing nearly 50 agencies. The plan was published in a 1977 review draft considered by agencies concerned at all levels of government, by private industry, and by the general public. Although revised and restructured in response to review comments, this final report presents the substance of the review draft without updating.

This report is respectfully submitted to the U.S. Water Resources Council for forwarding to the Persident and his transmittal to Congress. It is also respectfully submitted to the Governor, the Legislature, the Mayor of each of Hawaii's four counties, and those federal, state, and county agencies concerned with Hawaii's water and related land resources.

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Team leaders, alternates and plan formulation team members.

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Ron Walker, p. 86.

EXECUTIVE SUMMARY

The Hawaii Water Resources Regional Study has formulated — with the participation of the public, all levels of government, and private interests — this comprehensive plan of action to achieve the balanced conservation, development, and use of Hawaii's water resources and related land resources. The planning period of primary concern is the decade 1990-2000. The planning area is the Hawaii Region, as shown in Figure 4.

The U.S. Water Resources Council has coordinated the study. Participants have been an advisory planning board comprised of agency heads, a full-time planning staff, and personnel assigned part-time to study element teams by those agencies with major water resource responsibilities in Hawaii. Public participation has been achievd through citizens advisory committees and public meetings.

THE PLANNING PROCESS

Elements of the Study

The study was organized to cover 15 subjects, or elements. A study element team was assigned to each of these subjects and to plan formulation.

The three teams assigned to general planning considerations were concerned with the people, economy, and environment of Hawaii — past, present, and future. The future is derived from projections which cover a range of probabilities; that is, alternative futures keyed to various population and employment levels viewed from federal, state, and local perspectives. The projected future provides the general planning base for this water resources plan.

The four study element teams covering water and related land resources were concerned primarily with the quantity, quality, and distribution of those resources. These teams provided resource data for the use of other study element teams. Similarly, the laws and institutions team analyzed government and private programs relating to all other study elements.

The remaining seven teams were concerned with the management of water and related land resources. Using the planning base projections, these teams estimated future demands. Demands were matched with available resources in order to identify water related needs, problems, and opportunities.

The details of this process, and the background data are presented in 19 study element reports and supplements, prepared for the use of the plan formulation team, participating agencies, and the public.

Plan Formulation

Study element reports were used to formulate preliminary drafts of this plan, which were reviewed by study participants and the public. Major planning concerns identified in the review process were then analyzed to formulate specific water resource planning objectives.

Possible management alternatives to achieve the planning objectives were then determined and assembled into three plans. An *economic development plan* emphasized those actions that would contribute primarily to economic objectives; an *environmental quality plan* emphasized environmental objectives. Those compatible actions that contribute significantly to either or both objectives comprised the *balanced plan*. Throughout the plan formulation process, beneficial and adverse effects of each action were evaluated, in order to select those actions that best achieve both economic and environmental objectives.

The relative social, economic, environmental, and regional development impacts of the three plans were also evaluated. Conflicts and issues were resolved to the extent practicable to arrive at a comprehensive list of recommendations and specific actions, presented in Chapters 7 to 27 of this report with pertinent background information. A suggested institutional arrangement for implementing, revising, and updating the plan is detailed in Chapter 28.

All recommendations and actions are

assembled in a plan implementation schedule presented in Chapter 30. The schedule includes suggested lead and participating agencies, estimated costs, and time frame. Priority recommendations extracted from the full schedule are highlighted in Chapter 29. Cost sharing is covered briefly in Chapter 30.

Planning Considerations

The planning base used to formulate this plan includes the following major assumptions concerning Hawaii's future.

The population of Hawaii will continue to increase, with approximately 1.4 million people living in the Islands by the year 2000 and 1.9 million by the year 2020. About 77 percent, or 1.04 million people, will live on Oahu in the year 2000. Employment in all industries will need to expand to provide jobs for the population. No major wars or economic depressions will occur.

Per capita use of municipal water will increase. The sugar industry will remain viable, using slightly more water than at present. Diversified agriculture will expand, using somewhat more water than at present. Industrial water use will decline as a result of pollution control requirements and increased efficiency in industrial processes.

Technology for recovery and treatment of water will be basically the same as at present.

There will be a continuing emphasis on environmental protection. The program for eliminating point source waste discharges (NPDES) will accomplish its goals by 1985.

RECOMMENDATIONS

Recommendations presented in Chapters 7 through 27 are highlighted here. See Chapter 30 for a full statement of recommendations and specific actions.

7. Surface and Ground Water

Decisive public policy on rights to surface water use should be expressed by legislative codification, as well as rights to reasonable use of ground water resources. Also, laws and regulations should be improved to reflect the inter-relation between ground water and surface water sources.

Legislation should be considered to grant administrative authority for comprehensive and coordinated management of all water resources on each island and the allocation of water resources among competing uses.

8. Coastal Water

The "archipelago doctrine" should be applied to the Hawaiian Islands, giving the United States the right to control the waters around the Islands and delegating administrative authority to the state.

9. Water Related Land

Research should be undertaken to determine water consumption by plants in forested areas, soil characteristics and resource values in watersheds, and wildlife values in watersheds.

10. Domestic Water

Overall, Hawaii is blessed with an abundance of high quality water. On the Neighbor Islands, some additional development of sources and construction of transfer and storage facilities will be necessary in order to assure adequate supplies.

Only on Oahu will the demand begin to tax the total supply of fresh water. With present trends, this will likely occur between the years 2000 and 2020. During dry years, the effects will be noticed before that time. This eventuality can be prevented by conserving water, restoring high level storage, exchanging municipal wastewater, increasing ground water recharge, and optimizing the location and pumping schedules of ground water sources.

Integrating management of water supply and wastewater treatment facilities would maximize opportunities for the reuse of water.

11. Domestic Wastewater

By 1985, more than $350 million will have been spent on sanitary sewer systems in the state. The combined systems will treat and discharge an aggregate of about 300 mgd. Effluent from the larger systems will be of sufficient quantity to constitute a major water resource for beneficial reuse.

12. Flood Protection

Flood damage and loss of life must be averted by construction of flood control projects in areas where development is already in the flood hazard zone. Urban development should be on flood-free lands, where available, in preference to flood plains. Zoning should be updated and enforced to accomplish the wisest development. Flood hazard maps should be refined for use in flood control projects and clearly define the areas eligible for flood insurance.

Although the numerous small dams in Hawaii have been catalogued in a preliminary federal survey, a comprehensive program of safety inspection should be funded and pursued immediately.

13. Water Related Recreation

As the population increases, so will the demand for outdoor recreation; much of this demand will be directed toward water and water related land. Although development of additional sites is needed, the greatest problem is access to public lands both at the shore and in watersheds. A continuing program of access acquisition should be carried out, with adequate provisions for maintenance and policing, in order to minimize litter and the abuse of adjacent owners' property rights.

Early action is indicated to assure that the state and local governments acquire desirable recreation properties, and that such unique natural features as surf sites, waterfalls, scenic reaches of rivers offshore islands, and natural lakes be preserved for future generations.

14. Agricultural and Industrial Water

Coordination of programs can ensure the preservation of prime agricultural lands. Irrigation water supplies can be enhanced by a combination of federal, state, and private effort. Such systems will provide increased storage, more efficient diversion and field application, and the maximum reuse of water, including wastewater.

In-plant recycling and use of lower quality water to replace potable water used for industrial cooling should be encouraged.

15. Land Productivity

Forest production is an underdeveloped industry with potentially great local and overseas markets. However, the industry requires a long-term commitment of resources. The state can assure a financial and political climate conducive to the growth of this industry.

A continuing program of erosion and siltation abatement must be pursued on all susceptible lands, with emphasis on the control of erosion from new construction and agricultural operations. A remedial program for critically eroded areas and for road cuts should be implemented.

16. Fisheries

Like forest production, aquaculture is another underdeveloped industry which merits government assistance.

The surrounding ocean has always provided a livelihood for a segment of Hawaii's population. Prospects for increasing this contribution to the economy appear bright, if appropriate commitments are made now. The recently passed federal law extending the fishery management zone to 200 miles should provide the impetus for both the state and federal governments to increase grants and loans for local fisherman, and to allow the Hawaii-based fleet to expand the catch of underfished resources, such as skipjack tuna.

17. Marine Industries

The wealth of metallic ores discovered on the Pacific Ocean floor could be the basis of a substantial new industry in Hawaii. The state should pursue an active role in this enterprise.

The state should also take appropriate measures to protect the precious coral industry and promote the mining of offshore sand deposits.

18. Marine Transportation

The state's program for improvement of ports and harbor facilities appears to be adequate at this time. However, the opportunities for a multimodal inter-island "marine highway" system should be further considered, especially the use of high-speed watercraft both in a coastal commuter system and for inter-island travel.

19. Energy Production

Completion of a geothermal test well in 1976 at Pahoa in the Puna District of Hawaii has indicated a potentially significant geothermal energy field. The Puna area is blessed with abundance of water, adequate land, and a nearby deep water port. It would appear to be an ideal location for such operations as the metallic ore processing industry mentioned above.

Exploration for geothermal energy should be expanded to likely locations on Oahu and Maui. Meanwhile, the maximum use should be made of the hydroelectric power potential, especially on Kauai. A pilot plant should be constructed for ocean thermal energy conversion at Ke'ahole Point on Hawaii.

20. Water Quality

The greatest hazard to the water supplies of the state lies in the degradation of water quality due to unwise water development or waste disposal. Basal ground water is susceptible to the intrusion of salt water as a result of over pumpage from a concentration of wells. Ground water laws and water supply management should provide a means of protecting the rights of all users, at the same time insuring the long-term integrity of the ground water body.

Prevention of ground water pollution will require close control of underground injection of wastes, disposal by seepage pits and cesspools, and the location of sanitary land fills. Such controls are part of the Area Wide Waste Treatment Management Plan administered by the Department of Health.

Improvements are already discernible in the quality of coastal waters as a result of controlling point source discharges. Certain segments of the shoreline, however, will still not meet the water quality standards even after elimination of all known discharges.

These "water quality" segments are areas where such measures as additional treatment of watershed areas, street sweeping, cleaning of stream channels, and even treatment of storm runoff may be necessary. In some cases, the problem may be unrealistically high standards for coastal segments, which could be solved by redefining the standards.

In a similar vein, the treatment standards for domestic wastewaters presently applied to Hawaii are those designed for release of treated wastes to Mainland streams or shallow bays and estuaries. In Hawaii, where extremely deep water is very near the shore, and where open ocean currents can carry wastes to areas of largely sterile water, lower levels of treatment are indicated. If exceptions can be granted, millions of dollars can be saved.

Actions taken to eliminate point sources and to improve coastal water quality will also greatly reduce surface water pollution. Remaining pollution will be in the form of sediment loads from eroding areas, pollutants from urban areas and cesspol seepage. Programs to be initiated under Section 208 of PL 92-500 should further resolve these problems.

21. Land Quality

Protection of land quality will require enhanced programs to protect forests against fires, disease and insects, and erosion control on all severely affected areas, including cropland, urbanizing land, and transportation corridors. Coastal bays, wetlands, and estuaries also need protection from sedimentation.

Programs that can be used to lessen these problems include county erosion control ordinances, anti-pollution laws, and the aid available through local Soil and Water Conservation Districts and the Hawaii and U.S. Departments of Agriculture.

22. Biological Resources

Hawaii has a larger number of unique native plants and animals than any other comparable area on earth. During the course of settlement, man has caused the extinction of many species, and many more are rare or endangered.

Although lists of these rare and endangered animals and plants are now published, a major effort will be necessary between now and the end of the century to save as many as possible. An effort should be made to preserve ecosystems supporting native species, both on land and in coastal and marine environments.

The successful accomplishment of the program will require a system of sanctuaries, natural area reserves, multiple use areas, and

artificially enhanced environments in which Hawaiian wildlife can thrive, at the same time allowing enough development to serve the future population.

23. Cultural Resources

Certain water and land developments of the past represent cultural bench marks and as such should be preserved. These include the fishponds and shoreline structures of the ancient Hawaiians, as well as remnants of their irrigation systems.

Later contributions, such as the extensive high level tunnels and ditches and the various types of wells and shafts developed for sugarcane irrigation all merit preservation as part of Hawaii's cultural heritage.

24. Aesthetic Values

Perhaps in no other place is the consideration of aesthetics more important than in Hawaii. The remarkable beauty of the Islands, famous worldwide, is a most fragile attribute. Development must be planned to protect ocean and mountain vistas, while at the same time assuring appropriate access for passive and active enjoyment.

25. Data Collection and Analysis

A central water resources data referral center should be established to publish a catalog of water related data sources, identify gaps in the present water data base, identify long-term basic data requirements to support water resources planning and management, and participate in national data exchange programs.

26. Research Needs

Priority should be given to research into means of more efficient and extensive use of existing water supplies, as well as new and developing water technology. Also, guidelines should be developed to reflect the impact of technological advances upon water resources planning.

27. Coordinated Water Planning

This plan should be used to guide authorization and appropriation of federal funds for water related agency programs and projects undertaken in the Hawaii Region.

The plan should be implemented and updated by a permanent water planning committee with membership from government agencies at all levels and private entities having substantial water resources programs in Hawaii. The committee should also recommend Hawaii's priorities for national planning and appraisal programs.

PRIORITY IMPLEMENTATION

Recommendations have been selected for priority implementation on the basis of U.S. Water Resources Council *Principles and Standards,* legislative expression of public policy, state and county administrative goals, agency missions, and citizen response.

Due consideration has also been given to representative coverage of the broad spectrum of water related needs, problems, and opportunities both from a functional viewpoint and a balanced economic/environmental perspective.

No attempt has been made to rank the following priority recommendations, which are presented in numerical sequence. See Chapter 29 for specific actions to implement these priority recommendations.

7-1 Express decisive public policy on rights to surface water use by legislative codification.

7-4 Enact legislation to codify rights to reasonable use of ground water resources.

7-5 Establish rules and regulations for implementing the Ground Water Use Act (H.R.S., Chapter 177).

7-6 Improve laws and regulations to reflect the substantial inter-relation between ground water and surface water sources.

7-7 Consider legislation to grant appropriate administrative authority for comprehensive and coordinated management of all surface and ground water resources on each island.

7-8 Consider legislation to grant express administrative authority to allocate water resources among competing uses.

10-2 Develop alternative water sources to supply Oahu in addition to planned development from conventional ground water sources.

10-3 Intensify water conservation programs to improve efficiency of domestic water use.

10-5 Improve domestic water systems to insure that water quality meets minimum standards of the Safe Drinking Water Act of 1975.

10-6 Improve rural domestic water systems to deliver a dependable supply in adequate quantities and at sufficient pressures for droughts and firefighting.

11-1 Reuse treated sewage effluent water for beneficial purposes.

11-2 Consider integration of domestic water supply and wastewater management functions at both state and county levels.

12-1 Reduce the loss of life and property damage caused by storm flooding.

12-2 Reduce the loss of life and property damage caused by tsunami and high surf.

13-1 Improve access to public shoreline and inland recreation areas.

14-1 Use more efficient irrigation methods.

14-2 Provide additional irrigation water.

15-2 Increase commercial forest production from selected watersheds, at the same time preventing threat to native forests.

15-3 Reduce erosion of inland areas.

16-3 Encourage aquaculture as an industry of potential major importance to Hawaii.

16-4 Safeguard the commercial fishing potential of the Northwestern Hawaiian Islands.

16-5 Identify and develop opportunities for Hawaii's fishing industry within the 100-mile fishery conservation zone established under PL 94-265.

17-3 Establish an appropriate continuing role for Hawaii in the mining and processing of manganese deposits.

18-2 Improve inter-island marine transportation services.

19-2 Develop geothermal energy as a major power source on Hawaii and investigate potential as a supplemental source on Maui and Oahu.

20-1 Control salt water intrusion into basal fresh water aquifers.

20-2 Regulate subsurface injection of wastewater to prevent contamination of basal fresh water aquifers and wetlands.

20-5 Reduce non-point source pollution of streams and coastal waters.

21-4 Preserve and enhance wetlands, shorelines, and submerged lands.

22-1 Preserve rare and endangered animals and plants.

22-2 Preserve unique coastal and terrestrial ecosystems.

24-3 Protect the beauty of waterfalls and other scenic water resources.

25-4 Establish a central water resources data referral center.

27-1 Accelerate implementation of the National Water Assessment and Appraisal Program to establish priorities for federal funding of water and related land resources programs and projects.

27-2 Use this plan to guide federal funding of water related agency programs and projects in the Hawaii Region.

27-3 Apply U.S. Water Resources Council's *Principles and Standards* to all federal agencies having substantial water and related land resources programs.

27-5 Establish a permanent water planning committee with membership from federal, state, county and private agencies having substantial water resources programs in Hawaii.

27-8 Coordinate public meetings and establish continuing community citizen groups on all islands for orderly public participation in all government programs.

INTRODUCTION

Increasing Public Awareness

Events of the last decade have brought a realization that Hawaii's resources, although plentiful, are not unlimited. Even renewable resources such as water require more sophisticated and enlightened management in order to assure an adequate supply for future generations.

In Hawaii, abundant rainfall in the windward and mountain areas of the major islands was collected and channeled by the early Hawaiians for taro cultivation and for fish culture. Caucasian settlers added to the ditch systems and developed wells and tunnels to tap ground water for sugarcane irrigation.

A realtively sparse population, largely dependent on agriculture, had little concern for water supply or quality problems, and the deep ocean nearby offered a convenient and seemingly infinite disposal site for agricultural, industrial, and domestic wastes.

As population grew, waste production reached levels beyond the absorption capacity of streams, bays, and estuaries. Sediment, floating debris, and decomposing organic matter become obvious. At the same time, the number of visitors increased substantially, and the promise of an unspoiled tropical paradise was not always fulfilled. Residents as well as visitors became increasingly aware of environmental degradation, particularly its effect upon the aesthetic qualities of water.

The increasing demand for domestic water supplies in many areas has begun to conflict with agricultural and industrial water requirements.

The availability of water for irrigation is a major factor in the future of Hawaiian agriculture. Decisions on land use frequently have not taken into account water availability, particularly as it affects the utilization of prime agricultural lands.

Urban centers have encroached upon the shoreline and wetlands, and Oahu suburbs have expanded into mountain watersheds. Flood damages have increased as a result of urban encroachment on flood plains and increased runoff from paved and roofed areas.

Soil disturbed by crop cultivation, overgrazing of pasture land, uncontrolled feral game animals, and urban construction activities has found its way into streams and has accelerated the filling of bays and choking of reefs.

Recreation demand continues to grow because of increased population and the greater amount of leisure time available. At the same time, more and more of the shoreline has ben developed for private use. Access to beaches and to publicly owned inland areas is often restricted by the ownership of surrounding lands. Even where such areas are accessible, funds are not always sufficient to assure adequate facilities and necessary services such as patrolling, maintenance, and litter control.

Recreational boating has grown faster than have facilities for mooring, docking, and launching.

The increasing seriousness and complexity of resource management has resulted in a multiplicity of plans and planning agencies, each concerned with one or more aspects of the problem. Also, a growing number of agencies are concerned with water. The need to coordinate water planning, management, protection, and use at all levels of government has become increasingly apparent.

History of the Regional Study

The Water Resources Planning Act of 1965 created a coordinating agency, the U.S. Water Resources Council, and established the mechanism for a series of comprehensive studies to serve as background for regional water resources planning. The Act also declared a national policy to encourage the conservation, development, and utilization of water and related land resources of the United States by all levels of government and private interests.

Three planning study levels have been defined by the Water Resources Council. At Level A are framework studies and assessments of major regions designed to: (1) determine the extent of water and land needs and problems; (2) indicate the general approaches for problem solution; and (3) identify regions or river besins where Level B or Level C studies are needed. At Level B are reconnaissance studies of selected areas, designed to coordinate water planning and to suggest broad actions to solve the emerging water problems of the next 15 to 25 years. At Level C are program or project feasibility studies generally undertaken by a single federal, state, or local entity to implement the findings, conclusions, and recommendations of Level A or Level B studies.

In February 1968, the council designated the Department of Land and Natural Resources, State of Hawaii, to chair an *ad hoc* committee of government agencies for the purpose of preparing a preliminary plan of study and budget estimates for a Hawaii water resources regional plan.

In June 1968, the *ad hoc* Hawaii Water Resources Coordinating Committee submitted to the council a preliminary plan of study for an Hawaii Region Comprehensive Framework Study (Level A). A supplement to the 1968 plan of study was submitted to the council in April 1970. The proposed framework study for the Hawaii Region was not funded. The *ad hoc* committee then developed a proposal for a Level B study.

Upon acceptance of a draft plan of study in April 1973, the Hawaii Water Resources Regional Study commenced with the appointment of a study manager and staff to prepare a final plan of study, published in July 1973. The Hawaii Legislature appropriated $580,000 for the proposed study in fiscal year 1972, and Congress authorized $200,000 in fiscal year 1973. Manpower and scheduling were provided to produce a Hawaii water resources regional plan over a period of three and one-half years with a total budget of $1.78 million.

Purpose and Scope of the Study

The purpose of the Hawaii Water Resources Regional Study has been to formulate — with the participation of the public, all levels of government, and private interests — a comprehensive plan of action to achieve the balanced conservation, development, and use of Hawaii's water resources and related land resources. The planning period of primary concern is the decade 1990-2000.

The Hawaii Water Resources Regional Study has been a reconnaissance evaluation of water and related land resources in the State of Hawaii, comprised of 132 islands, shoals, and atolls of the Hawaiian Archipelago stretching more than 1,600 miles across the Pacific Ocean from the Island of Hawaii in the south to Kure Atoll in the north. Primary focus of the study, however, has centered on the eight principal islands of Hawaii, Maui, Molokai, Lanai, Kahoolawe, Oahu, Kauai, and Niihau.

The study was designed to suggest solutions to complex, long-range problems and needs on a coordinated basis by federal, state and county governments and the private sector.

The study's overall goal has been to promote and enhance the quality of life in 6,450 square miles of land area with a projected population of more than 1.3 million people in the year 2000. The study has attempted to achieve this goal by: (1) identifying the water and related land resource problems and needs, (2) reflecting public attitudes and preferences in the measures or alternatives proposed to satisfy those problems and needs, and (3) suggesting a schedule to implement recommended actions.

The study has been based largely on judgmental planning with little or no original data collection. Continuous and iterative plan formulation, along with significant participation by state and local government agencies and the public at large, have added to the study base.

During the course of the study, draft reports were distributed for review by interested agencies and by the public at meetings held on all of the major islands. Agency and public response was accommodated in revised drafts to the fullest extent practicable.

The study's main concerns have been:

1. To coordinate and integrate existing plans and planning.
2. To identify significant needs, problems, and opportunities.
3. To emphasize solutions to problems emerging in the next 15 to 25 years.

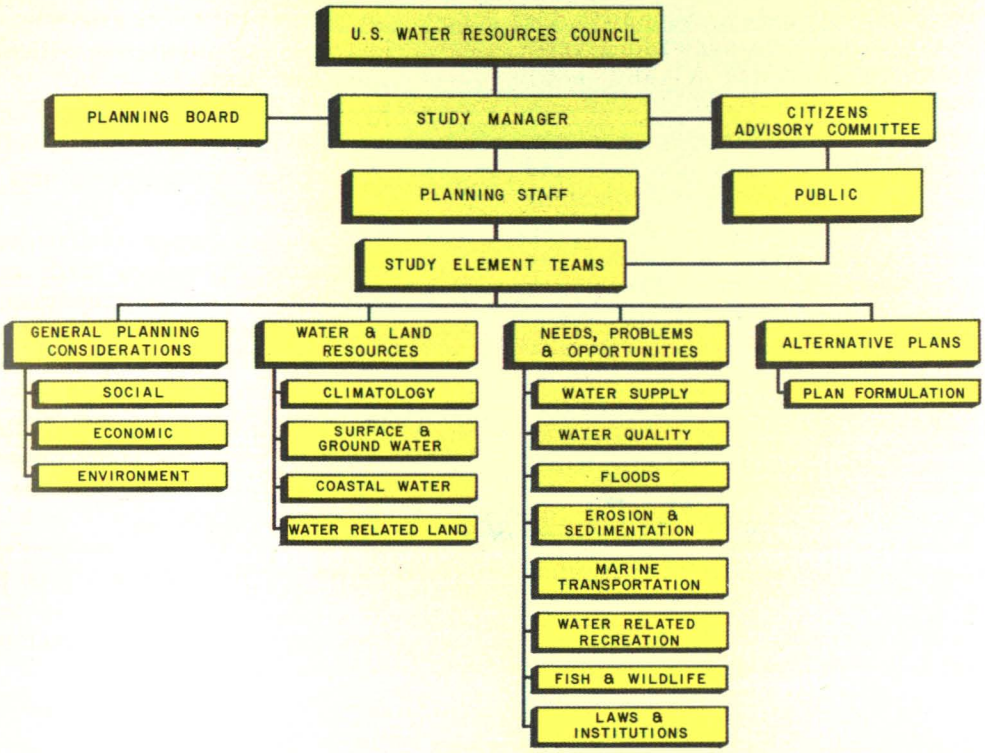


Figure 1. **ORGANIZATION**

4. To identify major data gaps.
5. To integrate research with planning needs.
6. To foster strong commitment and participation by state and local governments.

The U.S. Water Resources Council has coordinated the study, resulting in this *Hawaii Resources Plan,* which will be submitted to the Governor, the Legislature, the President, and Congress. The report is intended to serve as a general guide to aid decision makers in the evaluation, choice, and implementation of water resource project proposals within the State of Hawaii. It is expected to help establish priorities, scheduling, and budget requiremnts.

Study Organization and Procedures

The study's active participants have represented those agencies with major programs or responsibilities in Hawaii. They include the advisory planning board comprised of agency heads, the full-time planning staff, and the part-time agency resource personnel assigned to study element teams. Citizens have participated both through citizens advisory committees and by public review of draft plans.

The study was organized to cover 15 subjects, or elements, under three major headings. See Figure 1. A study element team was assigned to each of these subjects, and the planning staff handled plan formulation.

The three teams assigned to general planning considerations were concerned with the people, economy, and environment of Hawaii — past, present, and future. The future was derived from projections which cover a range of probabilities; that is, alternative futures keyed to various population and employment levels viewed from federal, state, and local perspectives. Projected future population and economic conditions and environmental goals provided the planning base for this plan.

The four study element teams covering water and related land resources were concerned primarily with the quantity, quality, and distribution of those resources. Resource data were provided for the use of

other study element teams. Similarly, the laws and institutions team analyzed government and private programs relating to all other study elements.

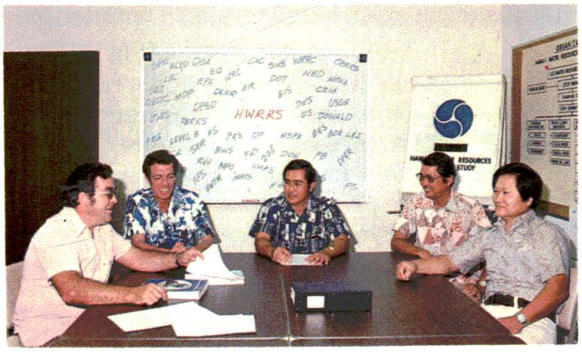
The remaining seven teams were concerned with the management of water and related land resources. Using the planning base projections, these teams estimated future demands. Available resources were then matched with demands in order to focus upon Hawaii's water related needs, problems, and opportunities. Conflicts and issues were also identified. Possible management alternatives were then determined.

Plan Formulation

Plan formulation consisted of an orderly series of steps, starting with identification of needs and problems and culminating in recommended actions. Each step required systematic analysis and communication of ideas among those involved in the process, including the interested public.

The plan formulation process developed by the U.S. Water Resources Council in its *Principles and Standards,* and generally followed in preparing this plan, includes the following steps:

1. Determine present needs and range of future demands.
2. Evaluate the adequacy of resources to satisfy present and future needs.
3. Identify problems within near-term (1975-1990), mid-term (1990-2000), and far-term (2000-2020) periods.
4. List possible alternative actions to resolve problems.
5. Evaluate economic, environmental, and social effects of alternative actions.
6. Reconsider alternative actions as necessary.
7. Assemble selected alternatives into multi-objective plans wtih economic emphasis and environmental emphasis.
8. Evaluate possible conflicts or complementary effects among selected alternatives assembled in each plan.
9. Suggest further or modified alternative actions to achieve compromises, minimize conflicts, and optimize beneficial interactions.
10. Select those alternatives best suited to compatible interaction from the economic plan and the environmental plan and assemble into a "recommended" regional plan.
11. Suggest schedules and priorities for implementing the plan.

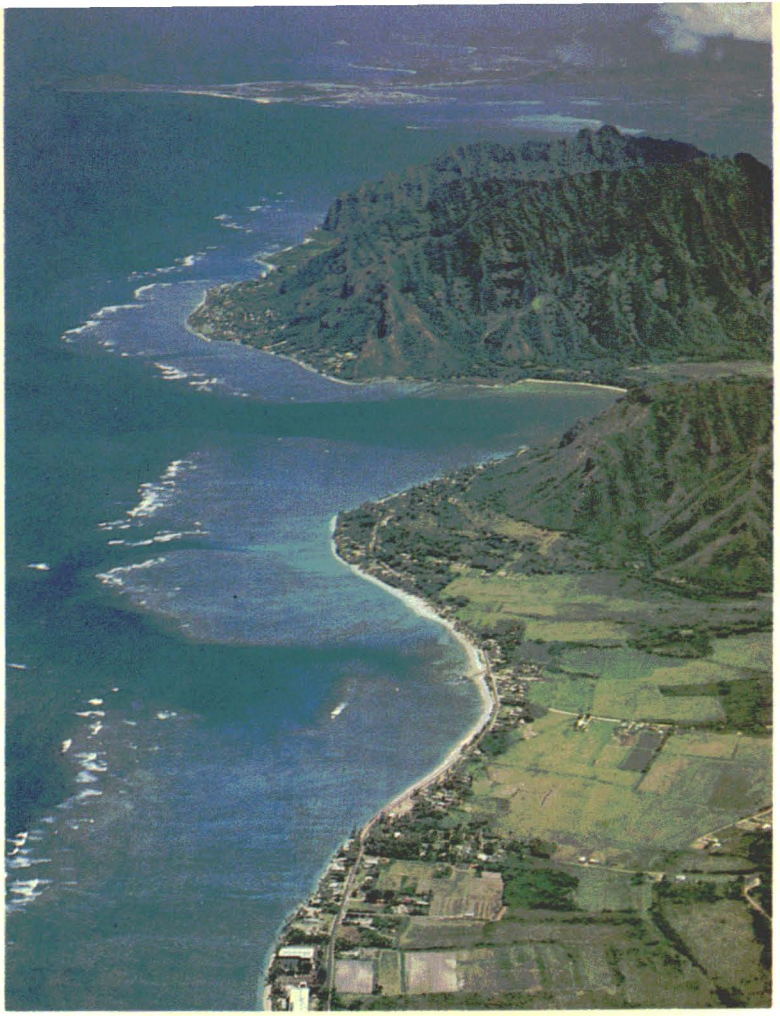


Planning staff, Hawaii Water Resources Regional Study.

Planning efforts culminating in this report have been responsive to and anticipatory of shifting public priorities and situation changes occurring in our social, economic, and physical environments. The recent increased emphasis upon environmental considerations has necessitated flexibility.

Recommendations presented in this report, beginning with Chapter 7, are substantive approaches to significant water and related land resource needs, problems, and opportunities now prevalent and expected to emerge through the year 2000 (15 to 25 years). The discussion and recommendations are arranged by water related activities for ease of comprehension. Chapter 30 presents an implementation schedule for all recommendations set forth in Chapters 7 to 27.

Only the end product of the plan formulation process is presented in this report. Appendices A and B are adapted from the review draft of April 1977, which has been substantially restructured in this final draft. The process of selecting appropriate actions and detailed analyses are presented in the *Plan Formulation Study Element Report.*



Windward Oahu.

General Planning Considerations

This comprehensive water and related land resource regional plan, or statewide plan, is based upon existing *social, economic,* and *environmental* conditions and reasonable projections of future conditions.

These projections have been derived from policy expressions of federal, state, and county governments. They have been influenced by preferences and priorities determined in the course of public review of progressive drafts of this plan.

Figure 2. **WATER RESOURCES REGIONS OF THE UNITED STATES**

1. THE HAWAII REGION

The Hawaii Region, comprising the Hawaiian Archipelago, is one of 21 water resource regions in the United States defined by the U.S. Water Resources Council (Figure 2).

The Hawaiian Archipelago is located north of the equatorial currents, in the belt of northeast tradewinds, with no land upwind for 2,000 miles (Figure 3). It trends northwest to southeast more than 1,600 miles across the central Pacific from approximately 155° to 179°W. longitude and 19° to 28°N. latitude. Honolulu is about 2,400 miles southwest of San Francisco.

Waimea Canyon, Kauai.

The 132 islands, shoals, and reefs of the archipelago within the State of Hawaii contain a total area of 6,450 square miles. The eight major islands at the southeastern end of the chain comprise 99.9 percent of the land area. In order of decreasing size, they are (in square miles): Hawaii (4,038), Maui (729), Oahu (608), Kauai (553), Molokai (261), Lanai (139), Niihau (73), and Kahoolawe (45).

For purposes of this *Hawaii Water Resources Plan,* the eight major Hawaiian Islands have been designated Subregions 1 to 8 from southeast to northwest, and the Northwestern Hawaiian Islands, Subregion 9 (Figure 4).

Hawaii ranks 47th among the 50 states in land area. The tidal shoreline aggregates 1,052 miles, ranking Hawaii 17th among the states and territories in this respect.

The six major islands have been divided into 27 hydrographic areas (Figure 5). The boundaries of these areas, based on sur-

face topography, represent Hawaii's major drainage basins.

Hawaii is unique among the states in that it has only two levels of government—state and county. The state capital of Honolulu is located on the Island of Oahu. The four counties are Hawaii (Island of Hawaii), Maui (Islands of Maui, Kahoolawe, Lanai, and Molokai*), Honolulu (Island of Oahu and Northwestern Hawaiian Islands), and Kauai (Islands of Kauai and Niihau). The city of Honolulu, the only community in Hawaii with city limits, is governed jointly with the county as the City and County of Honolulu.

The eight major islands are divided into 28 judicial districts. By and large, U.S. census tracts are defined as segments of judicial districts.

*County of Kalawao, located on an isolated peninsula on the northern coast of Molokai, is treated as a portion of Maui County for purposes of this plan.

Hamakua Coast, Hawaii.

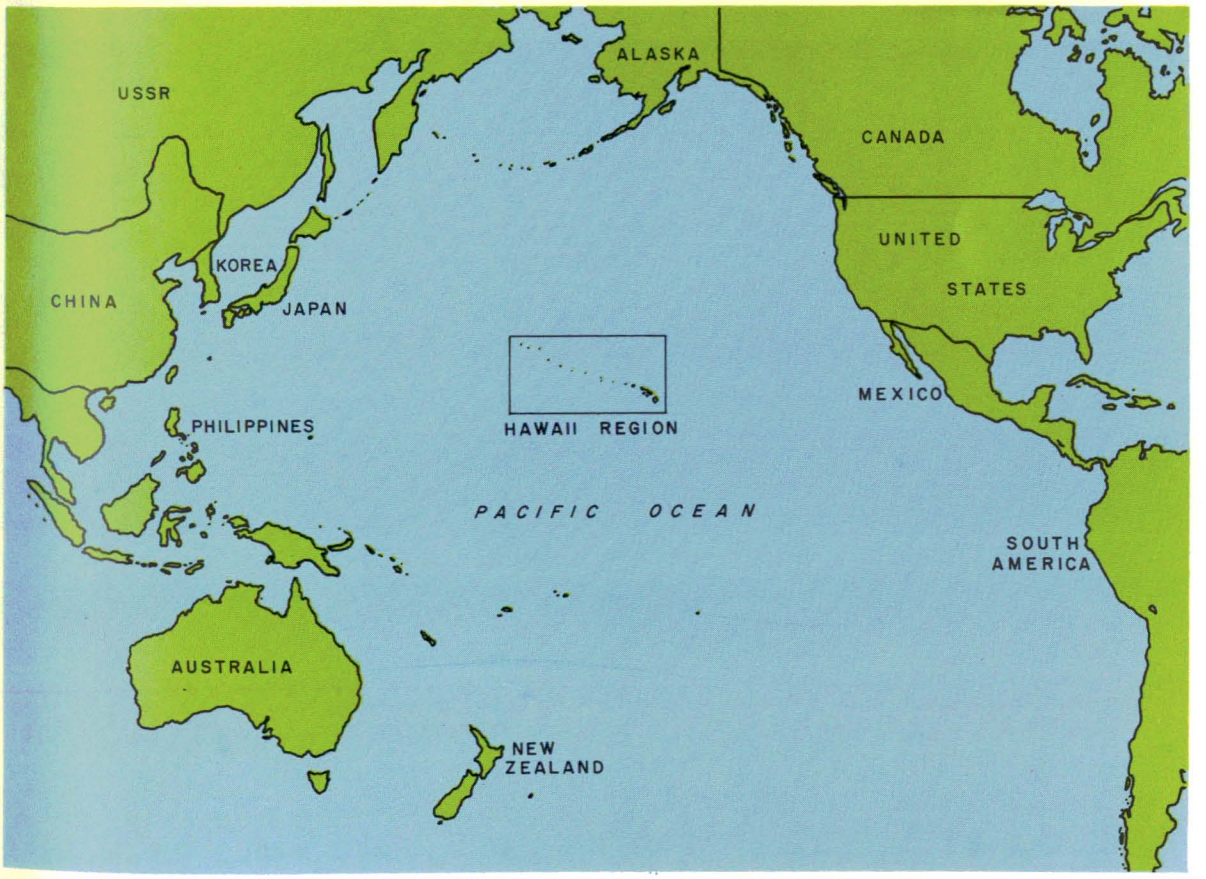


Figure 3. **CENTRAL PACIFIC LOCATION OF THE HAWAII REGION**

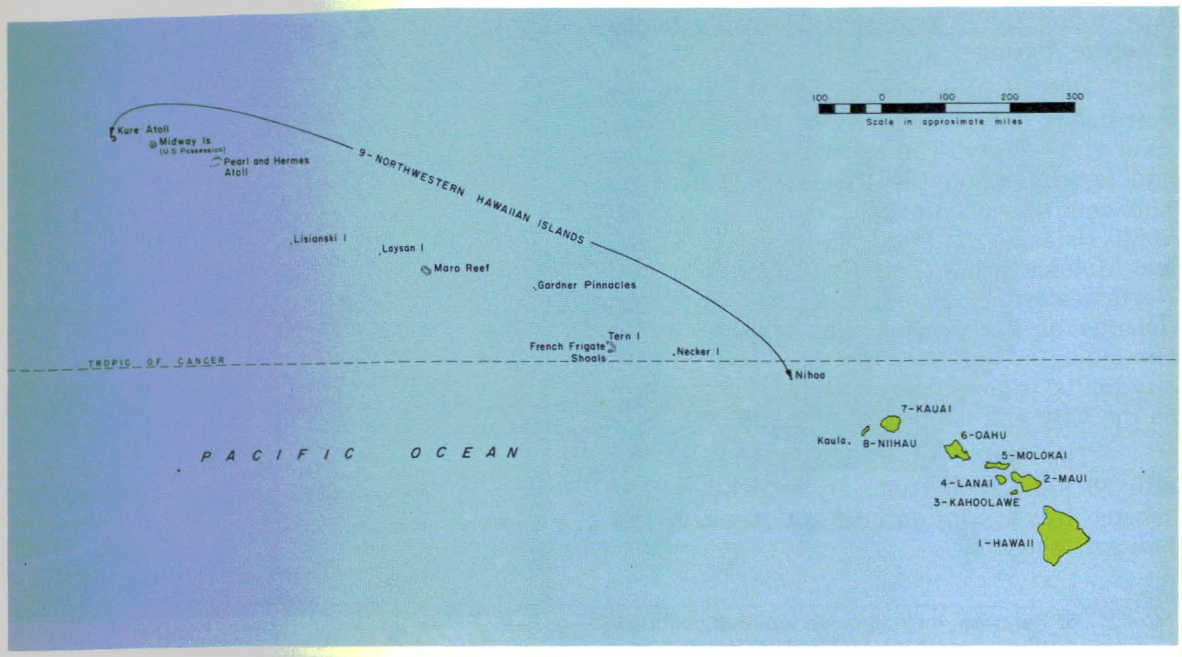


Figure 4. **THE HAWAII REGION, SHOWING SUBREGIONS**

North shore, Molokai.

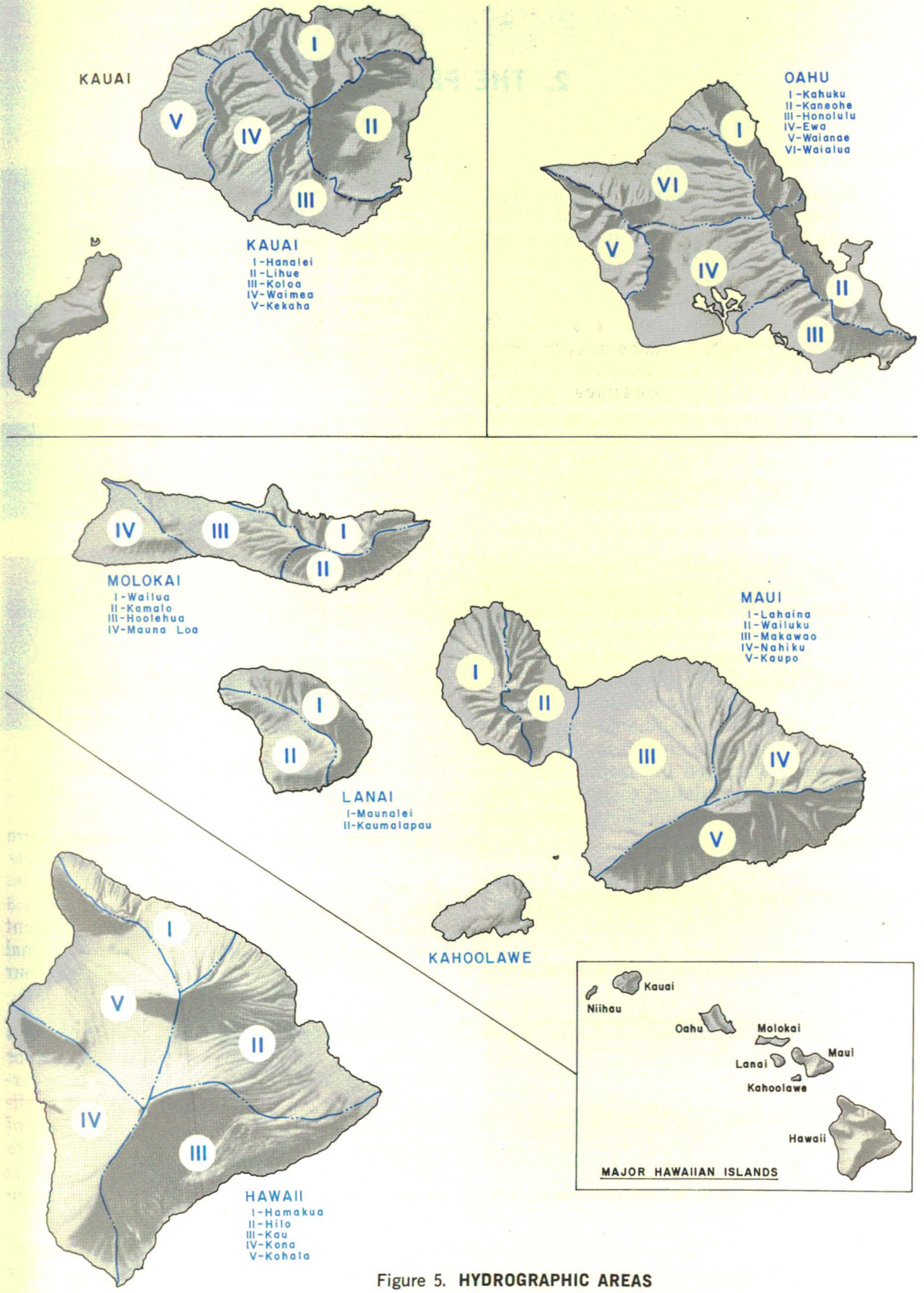


Figure 5. **HYDROGRAPHIC AREAS**

2. THE PEOPLE

Historic Population

Because of its Central Pacific location, Hawaii has become a cultural and ethnic crossroads, where the varied traditions and races of Polynesia, the Occident, and the Orient have combined to create an unusual society.

Hawaii achieved Statehood in 1959, after 61 years as a federal territory. Prior to 1898, except for a brief provisional government, Hawaii was a Polynesian monarchy. The various islands of the Hawaiian Kingdom were united by Kamehameha I in 1810. Western concepts of real property rights were established in 1848 by Kamehameha III, who also promulgated Hawaii's first constitution.

The unique qualities of its culture, the beauty of its insular setting, and its pleasant subtropical climate make Hawaii a desirable place to live and to visit. Consequently, there has been a rapid increase in both the resident and visitor populations since World War II. In 1960 the resident population exceeded 630,000; in 1975 it was estimated to be nearly 865,000. Resident population includes military personnel stationed in Hawaii. See Figure 6 for historic population to 1970 and Figures 7 and 8 for population distribution and characteristics in 1970.

The median age of Hawaii's population in 1970 was 25 years. More than 35 percent were under 18, and 5.8 percent were over 65. The 203,088 households in the State in 1970 averaged 3.59 persons. The population 25 years and older had a median 12.3 years of schooling. However, 24.8 percent completed only 8 years or less of formal schooling, and 14.0 percent completed four years or more of college.

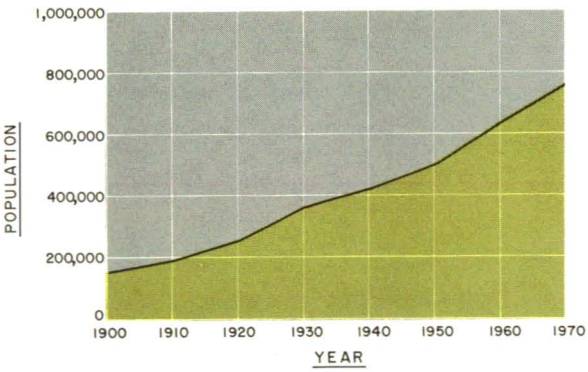


Figure 6. **HISTORIC POPULATION**

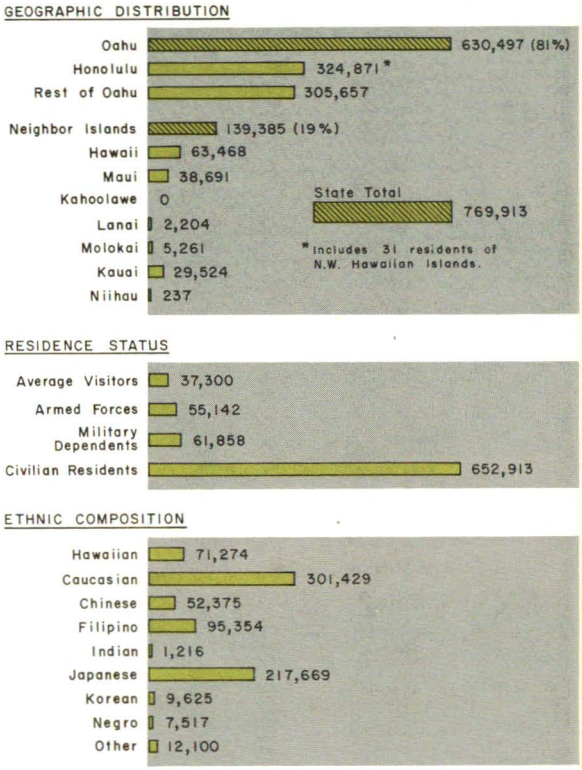


Figure 7. **POPULATION PROFILE, 1970**

Total civilian employment in 1970 was 285,556, or 97 percent of the civilian labor force. The labor force in 1970 was 58.9 percent male and 41.1 percent female. The median income of families was $11,554, and of unrelated individuals, $2,981. Families with incomes less than $10,000 totalled 70,471; those with incomes of $25,000 or more numbered 13,305.

The ethnic make-up of Hawaii's population has been influenced largely by labor

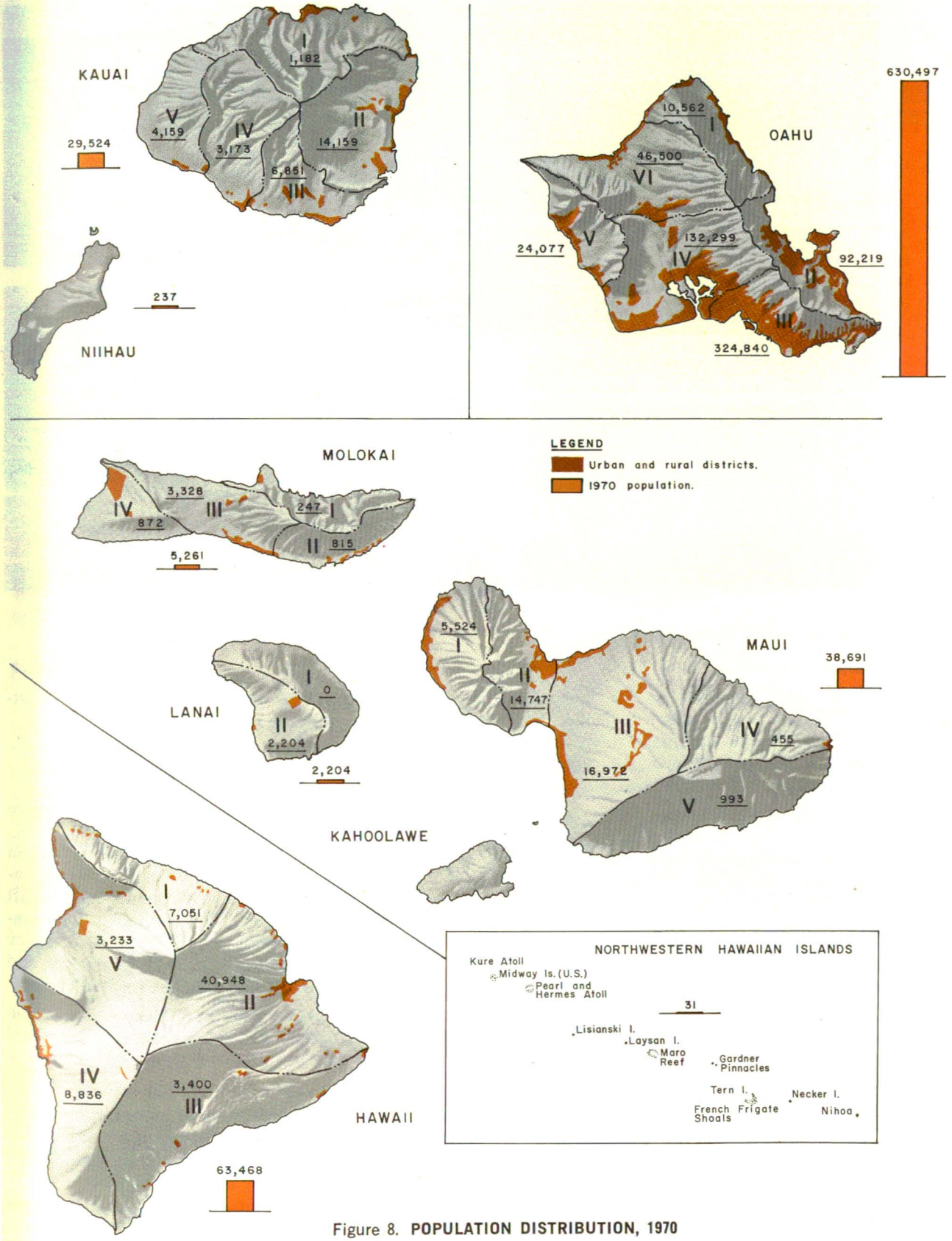


Figure 8. **POPULATION DISTRIBUTION, 1970**

Hawaii: cultural and ethnic crossroads.

recruitment practices of the sugar industry and the cultural patterns of the immigrant laborers. The predominant races are Oriental and Caucasian. More than a quarter of the population is racially mixed. See Figure 8.

Of Hawaii's 769,913 population in 1970, about 49 percent were of Far Eastern ethnic background, including 28 percent of Japanese nationality. Caucasians accounted for 39 percent and Hawaiians (including many part-Hawaiians), 9 percent.

Hawaii's traditional life styles, beginning with the ancient Polynesians, have been heavily dependent upon water—in the ocean surrounding the islands and upon and within the land. Witness the frequency of the Hawaiian word *"wai"* (water) in place names of the state.

The earliest social orders were concerned with allocation of land and water for growing staple crops such as taro. Many coastal fish ponds, some still in use, testify to a sophisticated system of aquaculture. Naturally, many leisure activities in Hawaii, such as surfing, swimming, fishing, and boating, are water based.

Population Growth Policies

In 1972, the Hawaii Legislature adopted a quality growth policy (H.R.S., Chapter 223), its purpose being to halt urban sprawl, preserve and conserve open space, enhance and protect the environment, and uplift the quality of life. The governor was empowered to develop a comprehensive policy framework to identify growth objectives and to direct growth and land use accordingly.

Growth variables affecting population that are considered amenable to government control include:

1. The rate of population growth.
2. The distribution of population within the state, particularly the relative distribution between Oahu and the Neighbor Islands.
3. The methods of transporting people within the state.

4. The provision of housing for residents of the state.

The following specific problems affecting the population have been identified as reflecting public concern:

1. The impact of rapid population growth experienced over the past several years, particularly on Oahu.
2. The uncertainty of employment opportunities to match the needs of Hawaii's increasing population of working age.
3. The increasing costs and problems of providing public and private facilities and services, including transportation, housing, education, and welfare, as the population expands.

The environmental policy established by the Hawaii Legislature in 1974 (H.R.S., Chapter 344) also relates to population growth. It is the policy of the state to enhance the quality of life in Hawaii by limiting population to a level that provides for mutually beneficial interaction with the environment. Hawaii's communities should have a sense of identity, aesthetically and socially harmonious with the unique characteristics of the Hawaiian environment.

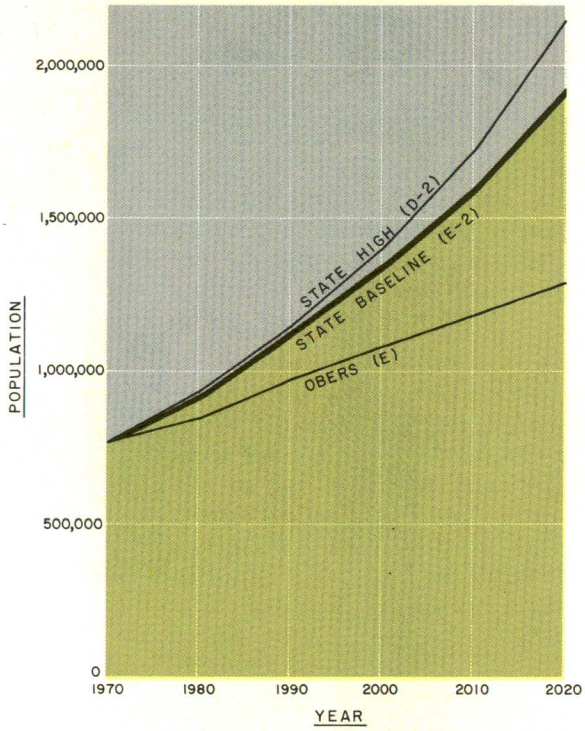


Figure 9. **COMPARISON OF POPULATION PROJECTIONS**

Population Projections

Nine series of population projections were calculated by the state Department of Planning and Economic Development for comparison with findings of a state economic model. Three fertility assumptions, three migration assumptions, and a single mortality assumption were used.

One of the most important economic assumptions is that tourism, will increase at a progressively slower rate, finally leveling off after 2000. The economic findings are most consistent with population projections based upon replacement-level fertility and an eventual doubling of the net in-migration rate.

TABLE 1
Comparison of Population Projections

YEAR	OBERS "E"	STATE E-2	STATE D-2
1970	767,913	767,913	767,913
1980	847,500	930,000	932,900
1990	978,600	1,131,700	1,150,100
2000	1,085,200	1,349,200	1,400,500
2010	1,185,600	1,606,100	1,722,800
2020	1,289,700	1,927,400	2,151,800

Population projections produced jointly by the U.S. Departments of Commerce and Agriculture for the U.S. Water Resources Council (OBERS* projections) are based upon nationally consistent criteria and methodology, which is important when considering water and related land resource development in adjoining Mainland regions. OBERS "E" projections are used as the lower bound for the range of future populations considered in this water resources plan. See Table 1 and Figure 9.

Hawaii's most likely future population is the state's E-2 projection, characterized by a moderate reduction in the historical population trend (Figure 9, state baseline). See

*Office of Business Administration, Department of Commerce, and Economic Research Service, Department of Agriculture.

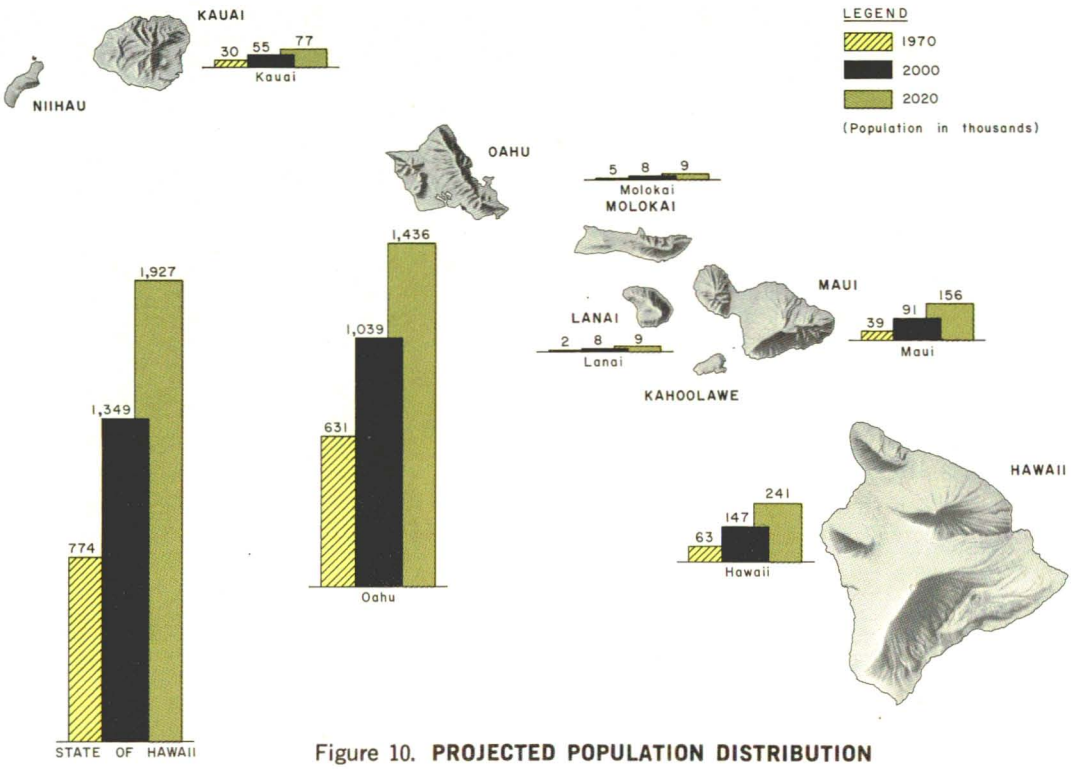


Figure 10. **PROJECTED POPULATION DISTRIBUTION**

Figure 10 and Table 2 for distribution of projected population by islands.

The higher population level depicted in Figure 9 (the state's D-2 projection) is based upon a fertility rate of 2,500 births per 1,000 women and doubled annual net in-migration over 50 years.

OBERS "E" projections for Hawaii fall below most of those prepared by the state. The region's relatively small size, isolated location, and unique economic conditions undoubtedly contribute to the difference. In general, the OBERS projections depict a future of slowed economic growth in which in-migration is virtually zero and births equal deaths. These projections do not take into account the high proportion of military population on Oahu, that a high percentage of military wives are of child-bearing age, and that most military children do not grow to maturity in Hawaii. The statistics used for the Neighbor Islands are for a period of decreasing population, a trend that has been reversed. Further, in-migration is a significant factor in Hawaii.

TABLE 2
Projected Population, by Islands

YEAR	STATE	HAWAII	MAUI	LANAI	MOLOKAI	OAHU	KAUAI	NIIHAU
1970	769,913	63,468	38,691	2,204	5,261	630,497	29,524	237
1980	930,000	83,800	53,100	2,000	5,000	749,500	36,500	200
1990	1,131,700	113,400	70,200	6,000	5,000	891,000	45,900	200
2000	1,349,200	146,900	91,600	8,000	8,000	1,039,400	55,200	200
2010	1,606,100	185,700	117,700	8,000	9,000	1,221,200	64,200	200
2020	1,927,400	240,700	156,200	9,000	9,000	1,436,000	76,300	200

3. THE ECONOMY

Economic History

Hawaii has served for nearly two centuries as the commercial crossroads between Asia and North America.

Hawaii's economy was based upon subsistence farming and fishing until the arrival of whalers, missionaries, merchants, and planters. The sugar industry was founded in 1835 and was the mainstay of the economy during the last third of the 19th century and the first third of the 20th. In the latter period the pineapple industry also achieved prominence.

During World War II, the federal government became the largest source of income in Hawaii and has remained so in recent years. The visitor industry, started about 1920, has shown the most growth in the last two decades. Diversified agriculture and manufacturing (other than sugar and pineapple processing) also have grown. Education and research are playing an increasingly important role in the economy. Figure 11 shows employment, industrial output, and household income from principal sources in 1970.

Most of Hawaii's employment, income, and diversified business activity is centered around the City of Honolulu on Oahu. Agriculture dominates the economy of the other islands (referred to as "Neighbor Islands"). However, the visitor industry is rapidly growing in economic significance on Hawaii, Maui, and Kauai, is gaining a foothold on Molokai, and is planned for Lanai. Most visitors come to Honolulu by air, stay in hotels, and visit at least one Neighbor Island.

The judicious allocation of water and land resources between agricultural and other uses is of major concern to economic stability.

Sugar mill.

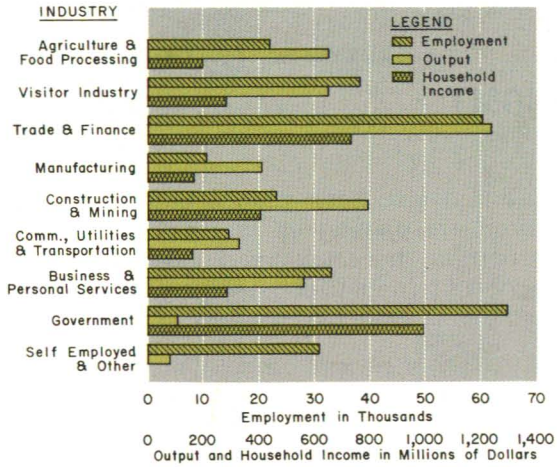


Figure 11. **EMPLOYMENT, INDUSTRIAL OUTPUT AND HOUSEHOLD INCOME, 1970**

Economic Growth Policies

As noted earlier, in 1972, the Hawaii Legislature adopted a quality growth policy (H.R.S., Chapter 223). Growth variables affecting the economy that are considered amenable to government control include:

1. The role and significance of agriculture, both for export and domestic consumption.
2. The role and significance of tourism.
3. The role and significance of other employment bases.
4. The methods of transporting goods within the state.

The following specific problems affecting the economy have been identified as reflecting public concern:

1. The uncertainty of employment opportunities to match the needs of Hawaii's increasing population of working age.
2. The desire for a more self-sufficient and diversified economy less subject to recessions.
3. The increasing costs and problems of providing public and private facilities and services, including transportation, as the economy expands.

Hawaii's environmental policy (H.R.S., Chapter 344) is also concerned with maintaining conditions under which man can live in productive harmony with nature and fulfill economic requirements. To this end, the policy favors diverse and stable economic activities in balance with the environment. Wise use of land, efficient transportation, and efficient use of energy resources are also encouraged.

Specific economic development guidelines include the following:

1. Encourage industries in harmony with Hawaii's environment.
2. Promote and foster agriculture; preserve and conserve productive agricultural land.
3. Encourage environmental protection by all industries and federal activities in Hawaii.

Transportation guidelines include:

1. Encourage transportation systems in harmony with the Hawaiian life style and environment.
2. Alleviate environmental degradation caused by motor vehicles.
3. Encourage safe and convenient vehicles and transportation systems that

Pineapple, plantation crop.

Beach at Waikiki.

conserve energy and reduce pollution, including noise.

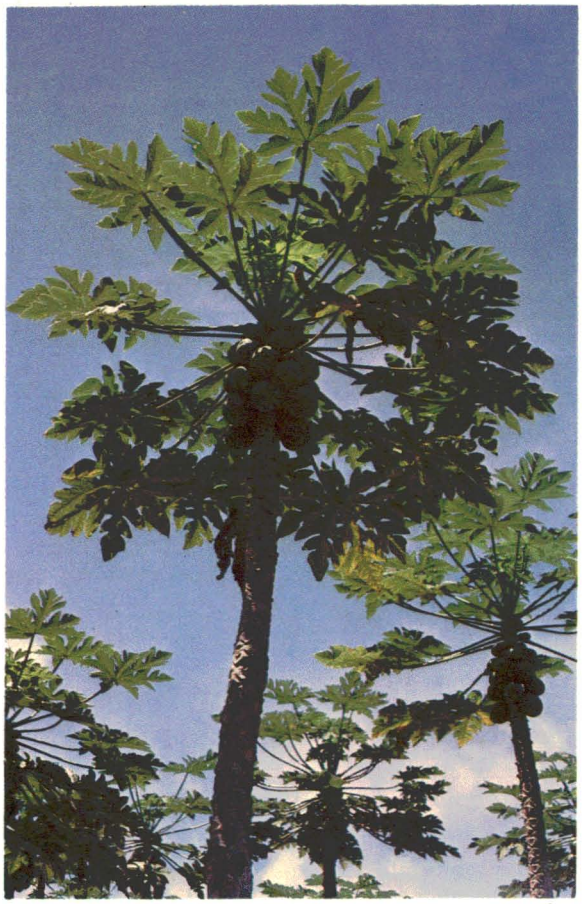
Guidelines for utilization of natural resources include the following:

1. Encourage management practices which conserve and fully utilize all natural resources.
2. Promote irrigation and wastewater management practices which conserve and fully utilize water resources.
3. Promote the recycling of wastewater and solid wastes.
4. Encourage management practices which conserve and protect watersheds and water sources, forests, and open space.
5. Maintain an integrated system of state land use planning which coordinates state and county general plans.

Guidelines pertinent to recreation, are as follows:

1. Establish, preserve, and maintain park and recreation areas, including shorelines.
2. Protect shorelines from encroachment of man-made improvements, structures, and activities.
3. Promote open space as a natural resource and as an ennobling environment.

Mauna Kea Beach Hotel (lower right), Kawaihae, Hawaii.



Papaya, diversified crop.

Economic Planning Considerations

Basic assumptions made in projecting Hawaii's economic future for purposes of this plan are the following:

1. There will be no major wars or major recessions.
2. Factors affecting the economy will be of local origin; outside economic influences will remain about the same.
3. There will be a continuing demand for sugar products.
4. Any declines in present crop production will at least be offset by increased production of other crops.
5. Hawaii will continue to be a desirable tourist destination area.

Within these basic assumptions, a range of economic activity may be projected, based on growth rates of population and industry. The most likely future population discussed earlier is characterized by a moderate reduction in the historical population trend.

As noted, population projections calculated by DPED were compared with findings of a state economic model. One of the most important assumptions is that tourism, both on Oahu and the Neighbor Islands, will increase at a progressively slower rate, finally leveling off after 2000.

A summary of projections resulting from the economic model is given in Tables 3 to 5 and Figures 12 to 14.

National Economic Development Objective

The national economy is enhanced by increasing the value of goods and services and improving economic efficiency. Components of the national economic development objective specified by the U.S. Water Resources Council for water resources planning include:

1. Improvement of public services by providing adequate supplies of muni-

TABLE 3
Projected Industrial Output
(Millions of 1970 Dollars)

YEAR	STATE OF HAWAII	CITY AND COUNTY OF HONOLULU	NEIGHBOR ISLAND COUNTIES			
			TOTAL	HAWAII	MAUI	KAUAI
1970	4,823	3,997	826	364	285	177
1980	7,807	6,459	1,348	602	469	277
1990	12,398	10,167	2,231	1,010	789	432
2000	18,601	15,250	3,351	1,548	1,202	601
2010	28,110	23,185	4,925	2,323	1,784	818
2020	44,432	36,625	7,807	3,750	2,869	1,188

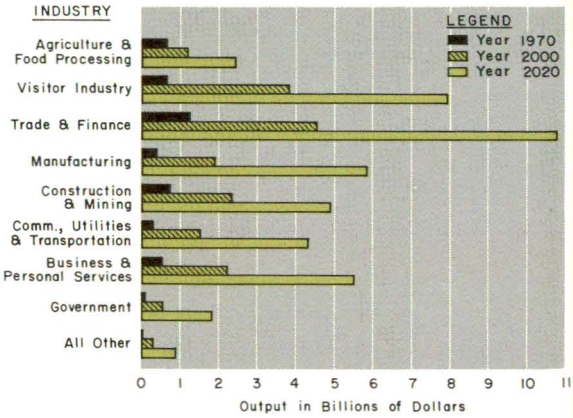


Figure 12. **PROJECTED INDUSTRIAL OUTPUT**

cipal water and efficient systems for disposal of wastewater.

2. Production of food and fiber by providing adequate supplies of irrigation and livestock water and by allocating resources to assure efficient use of fisheries and forests.
3. Enhancement of land productivity by providing protection from damaging floods and by stabilizing the soil to prevent erosion.
4. Encouragement of industry by providing an adequate supply of suitable water and promotion of water related industries.
5. Enhancement of energy production by increasing hydroelectric, ocean thermal, and geothermal power production.
6. Improvement of transportation services by expanding transocean shipping links, by improving inter-island service, and by using seacraft in commuter systems.
7. Expansion of recreational opportunities to meet the demands of a growing population, including boating facilities, beach and marine parks, surfing sites, and inland water related recreation facilities.

These objectives may be accomplished by developing additional land and water resources, or by more efficient use of existing resources. Both direct and indirect benefits and costs must be considered in evaluating the effects of a water resources plan to accomplish these objectives.

Increases in crop yields, expanding recreational opportunities, and greater peaking capacity for power systems are examples of direct increases in the nation's output which result from water and related land resources development. Such development often improves the productivity of natural resources, as well as labor and capital utilizing the resources.

Indirect effects include the benefits derived from a plan through the increased value of land as goods and services become abundant, or the release, through increased efficiency, of resources for use elsewhere.

TABLE 4
Projected Employment
(Thousands of Persons)

YEAR	STATE OF HAWAII	CITY AND COUNTY OF HONOLULU	NEIGHBOR ISLAND COUNTIES			
			TOTAL	HAWAII	MAUI	KAUAI
1970	297.9	239.5	58.4	26.3	19.5	12.6
1980	395.6	313.9	81.7	37.6	27.3	16.7
1990	506.5	393.4	113.1	53.1	38.3	21.7
2000	598.9	455.8	143.1	67.7	49.8	25.6
2010	694.4	522.5	171.9	82.9	60.2	28.8
2020	824.3	608.6	215.8	105.7	76.5	33.6

TABLE 5
Projected Household Income
(Millions of 1970 Dollars)

YEAR	STATE OF HAWAII	CITY AND COUNTY OF HONOLULU	NEIGHBOR ISLAND COUNTIES			
			TOTAL	HAWAII	MAUI	KAUAI
1970	3,232	2,725	507	242	162	103
1980	5,221	4,373	848	410	272	166
1990	8,300	6,877	1,423	696	464	263
2000	12,565	10,393	2,172	1,082	718	372
2010	19,169	15,928	3,241	1,646	1,082	513
2020	30,487	25,300	5,187	2,676	1,757	754

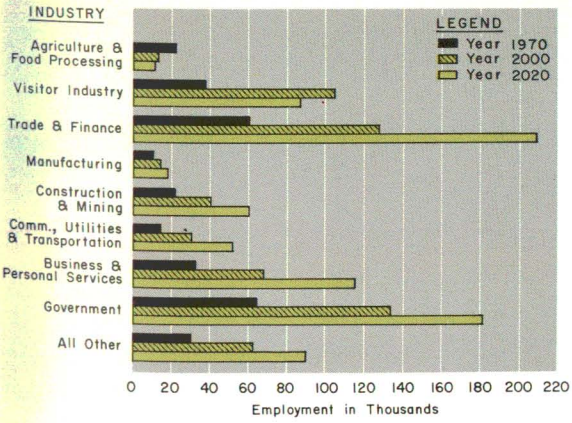


Figure 13. **PROJECTED EMPLOYMENT**

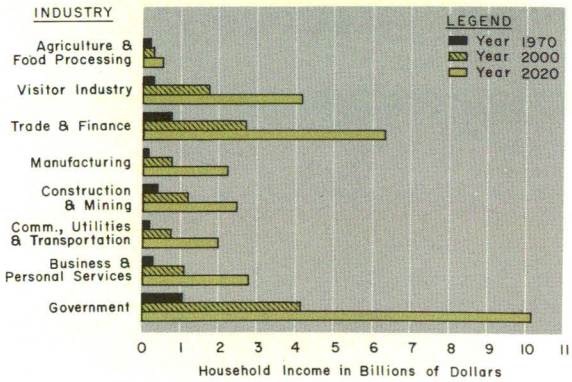
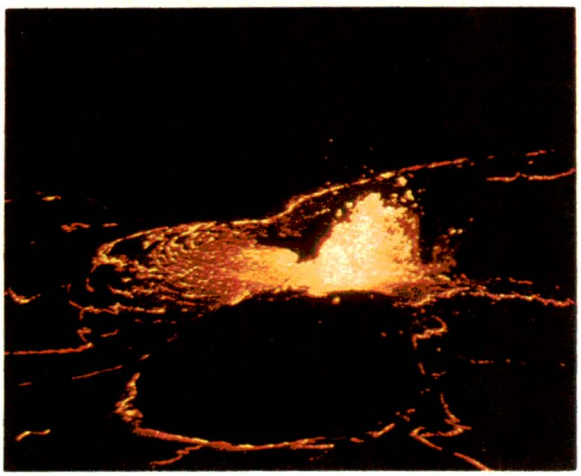


Figure 14. **PROJECTED HOUSEHOLD INCOME**

4. THE ENVIRONMENT



Active Kilauea Volcano, Hawaii.

Natural Environment

The eight major islands of Hawaii are the summits of a largely submerged range of volcanic mountains. Volcanic eruptions are still occurring at the southernmost end of the chain, on the Island of Hawaii. In the Northwestern Hawaiian Islands beyond Kauai, the earliest island masses have been leveled to shoals and coral reefs or basaltic remnants.

Construction of Hawaii's coastal zone by volcanism, living organisms such as coral, and sedimentation has been countered by wave action and erosion. Coastal topography generally consists of cliffs formed by wave action, broad bays between volcanic headlands, smaller bays which once were river mouths, shallow lagoons, and beaches

Dormant Haleakala Crater, Maui.

of rock and sand. Much of the coastline is rugged and inaccessible.

Rains and prevailing northeasterly tradewinds have been the dominant factors in the weathering and erosion of Hawaii's mountain masses, affecting chiefly the wet windward sides of the islands. The drier leeward sides of the islands have longer and more gentle slopes.

Kauai, Maui, and Oahu have the highest percentages of steep land due to more advanced erosion. Hawaii, geologically the youngest island, has the greatest percentage of land with less than ten percent slope.

On the windward side of most of the islands, heavy rains send water cascading over high cliffs and down steep streams directly into the sea. Perennial streams are found in areas of adequate rainfall where the weathered ground surface sustains runoff. Drainage on the more circular domes follows the radial pattern of the lava flows. There is insufficient dendritic (branching) drainage to form a tributary system of most streams, lakes, and rivers.

The first organisms established on the Islands from other lands were probably plants. Spores and seeds drifted in the wind or floated on the ocean surface. Others were attached to the feathers of birds or were passed in their droppings. Probably only a small percentage of these new arrivals successfully established on the bare lava flows, but each new colonist changed the natural environment in some way, and a succession of species began.

An extensive adaptive radiation of new species in Hawaii resulted from isolation. The several islands, each with many valleys, peaks, and lava flows, made it possible for the descendants of these early arrivals to embark on new evolutionary pathways. Climate and topography played major roles in the development of a variety of unique ecosystems.

Birds, insects, and other invertebrates arrived, began an adaptive radiation of their own, and became important components of the native Hawaiian biota. Mammals, reptiles, and freshwater fish were represented by only a few species, due to the geographic isolation of the Islands.

Over time, the descendants of new colonists changed in many ways. Examples are flightlessness in many insects and birds, arborescence in plants, loss of competitiveness, altered feeding and pollination relationships, and other behavioral and morphological changes. The natural environment in Hawaii before the arrival of man was truly unique.

Koolau rainforest, Oahu.

Due to the Islands' remoteness, ecosystems have developed with a surprisingly small diversity of species, poorly equipped to compete with introductions of foreign plants and animals.

The Islands are mantled today by communities of plants and animals that are still adjusting to the stresses of recent immigrations and to changes in land and water use. The remnants of the Hawaiian ecosystems of 200 years ago exist only in enclaves where man's resource utilization has disturbed them least.

Man's Impact

Hawaii is one of the most remote inhabited regions on earth. The first men to reach the Islands arrived more than one thousand years ago, probably from the Marquesas and Society Islands in southeastern Polynesia. They were dependent upon the sea for food, but they brought many species of food plants with them. Successive immigrations brought pigs, fowl, dogs, and probably rats as well.

The relationship of the early Hawaiians with nature was one of intimate dependency; for food, clothing, shelter, and medicine. Life within their biological requirements had minimum per capita impact on the environment. Yet, the forested lowlands changed with the pressure of primitive agriculture, and feral animals began an attack on the native biota that continues to this day. Perhaps the early Hawaiians also began the elimination of some native species, particularly through the collection of birds for feathers and food.

Taro patch, Wainiha, Kauai.

Descendants of many early introductions (i.e. junglefowl, pig, goat, sheep) have become the managed game animals of recent years. Of the four big game species most successfully introduced to the Islands, the axis deer has provided the greatest recreational hunting opportunity. The first birds brought specifically for hunting arrived in 1788. Since that time, over 75 species of game birds have been introduced, and approximately 15 of these have established breeding populations.

The effects of man's land use patterns on the natural environment in Hawaii have been influenced by several contributing factors, including soils and slope, the historical development of land ownership, the limited total land area and prime agricultural land, and the biological characteristics of species evolving on isolated oceanic islands.

Soil characteristics directly affect agriculture, housing, recreation, wildlife habitat, and water quality. Hawaii's soils are basically of volcanic origin with some marine sediments and coral. Generally, they are easily tilled, exceptionally porous, and permeable to air and water. Due to the wide range of climate in Hawaii, the soils are suitable for many types of vegetation and crops.

Topography determines, to a large degree, potential agricultural use of a given area. If the slope is too steep or rocky, mechanical farming is difficult. Slope and soil may present problems in initial development for urban use but are not significant later on. Many of the characteristics of prime agricultural land—stable soil, gentle slope, access to water—are also desirable in potential urban sites.

In Hawaiian culture, land was divided into self-sufficient strips called *ahupuaa*, each designed to provide all the resources necessary to sustain the lower chieftain who controlled it and the tenants who shared it. With the coming of Kamehameha I, the Islands became unified under one ruler. Later, in the land division of 1848 ("great *mahele*"), King Kamehameha III divided the land into classes. At that time, less than 1 percent of the land was set aside for the common people. Soon after, Westerners became involved in the division of land and have played a dominant role ever since.

Land use in Hawaii has been strongly influenced by the land ownership pattern. Historically, government and major private

owners have controlled most of the land (Table 6). Sugarcane, which received first priority in utilization of agricultural land, claimed most of the irrigable lowlands in dry areas and prime uplands where rainfall is adequate. Pineapple, which requires less water, utilizes most of the remaining land suitable for cultivation. The balance of the usable land has been devoted primarily to beef cattle grazing. Land use in Hawaii is summarized in Table 7 and depicted in Figure 15.

Hawaii was the first state to pass a land use law, in 1961. This law is intended to prevent scattered urban development and urban sprawl into prime agricultural land. The Land Use Act provides for four land use districts: conservation, agricultural, rural, and urban. (Rural districts are lands composed primarily of small farms mixed with low density residential lots of one-half acre minimum.) The estimated acreage of each land use district is listed in Table 8 and depicted in Figure 16.

Environmental Goals

In the preceding chapters on population and the economy, pertinent aspects of the state environmental policy enacted in 1974 (H.R.S., Chapter 344) have been discussed. Those aspects which particularly concern the natural and social environment are considered here.

The legislative purpose of Chapter 344 is to establish a state policy which will encourage harmony between man and his environment, prevent or eliminate environmental damage, stimulate public health and welfare, and foster the understanding of Hawaii's ecological systems and natural resources.

It is the policy of the state to conserve natural resources and safeguard Hawaii's unique natural environment in a manner which will promote the general welfare, foster productive harmony between man and nature, and fulfill the social, economic, and other requirements of Hawaii's people.

Pertinent guidelines include the following:

1. Establish and maintain natural area preserves, wildlife preserves, forest reserves, marine preserves, and unique ecological preserves.
2. Protect endangered species of indigenous plants and animals; introduce new plants or animals only upon assurance of negligible ecological hazard.
3. Foster the planting of native and other trees, shrubs, and flowering plants compatible with the environment.
4. Encourage transportation systems in harmony with the life style and environment of Hawaii.
5. Alleviate environmental degradation caused by motor vehicles.
6. Foster life styles compatible with the environment.
7. Develop communities which provide a sense of identity and social satisfaction in harmony with the environment.
8. Reduce environmental pollution which

TABLE 6
Generalized Land Ownership, 1968

ISLAND	FEDERAL GOVERNMENT (Acres)	FEDERAL GOVERNMENT (Pct.)	STATE GOVERNMENT (Acres)	STATE GOVERNMENT (Pct.)	MAJOR PRIVATE (Acres)	MAJOR PRIVATE (Pct.)	MINOR PRIVATE AND OTHER (Acres)	MINOR PRIVATE AND OTHER (Pct.)	TOTAL LAND AREA (Acres)
Hawaii	241,858	9.4	1,106,126	42.8	1,052,583	40.7	183,753	7.1	2,584,320
Maui	26,478	5.7	204,895	43.9	221,223	47.4	13,843	3.0	466,439
Kahoolawe	28,800	100.0	0		0		0		28,800
Lanai	8	0.1	0		87,832	98.3	1,440	1.6	89,280
Molokai	78	0.1	53,019	31.8	110,444	66.1	3,563	2.0	167,104
Oahu	56,241	14.5	64,810	16.7	221,820	57.0	46,057	11.8	388,928
Kauai	2,306	0.6	153,305	43.3	176,953	50.0	21,548	6.1	354,112
Niihau	0		0		46,705	99.9	15	0.1	46,720
NW Haw'n. Is.	0		2,560	100.0	0		0		2,560
Total	355,769	8.6	1,584,715	38.5	1,917,560	46.4	270,219	6.5	4,128,263

TABLE 7
Generalized Land Use, Six Major Islands, 1968

USE	ACRES	PERCENT
Sugar Cane	262,377	6.5
Pineapple	69,276	1.7
Diversified Crops	47,154	1.2
Grazing	1,150,534	28.4
Forest & Forest Reserve	1,479,993	36.5
Urban	155,705	3.8
Other (Military, recreation Pali and barren land, quarry, water)	885,137	21.9
Total	4,050,176	100.0

may degrade a community.

9. Foster culture and the arts and promote their linkage to enhancement of the environment.
10. Encourage both formal and informal environmental education.
11. Encourage all individuals in Hawaii to adopt a moral ethic to respect the natural environment.

Hawaii's Future Environment

Future environmental quality in Hawaii depends on actions taken by all levels of government, private organizations, and individuals.

The environmental concerns of this water resources plan encompass all actions that affect water and related land resources and all activities affected by water and related land resource management. These concerns include environmental damage to water and related land resources from external causes, and environmental improvement opportunities arising from management activities.

Basic assumptions made in projecting Hawaii's environmental future are the following:

1. Environmental quality is affected by economic activity and social conditions generally related to population levels.
2. Increased population results in greater environmental stress.
3. A high-quality environment is best achieved by preventing degradation.
4. A degraded environment will be rehabilitated wherever feasible.
5. Irreversible environmental degradation will always be avoided.
6. Pertinent environmental laws will be enforced within the time frame of this plan.
7. The enforcement of laws will result in positive actions such as improved waste treatment, as well as constraints such as closing some areas to fishing and hunting.

Significant differences in future environmental conditions may occur despite the implementation of pertinent laws. The future environmental conditions might be described as better than, no worse than, or worse than present conditions.

The Optimum. Some criteria for future measurement of improved environmental conditions are the following:

1. Ecosystems in their near natural condition have been protected. Those degraded ecosystems capable of rehabilitation have been restored.
2. Populations of rare and endangered species have increased and are no longer faced with extinction or further habitat degradation.
3. Water, land, and air quality have been maintained at least at present levels, and some improvements have been made.
4. Economic development of natural resources maximizes nonconsumptive uses. Developed natural resources, such as forests and cropland, are managed on the basis of sustained yields.
5. Waste disposal problems are minimized by effective recycling and the use of systems that minimize waste production.
6. Appropriate land management practices, and only such structural facilities as are necessary, have minimized the threat of stream and ocean flooding, landslides, and erosion and sediment damage.
7. There is balanced quantity, quality, and distribution of open space.
8. People can fully enjoy passive and active outdoor recreation at beaches and streams, in the mountains, and upon the open seas.
9. An environmental ethic is widely ac-

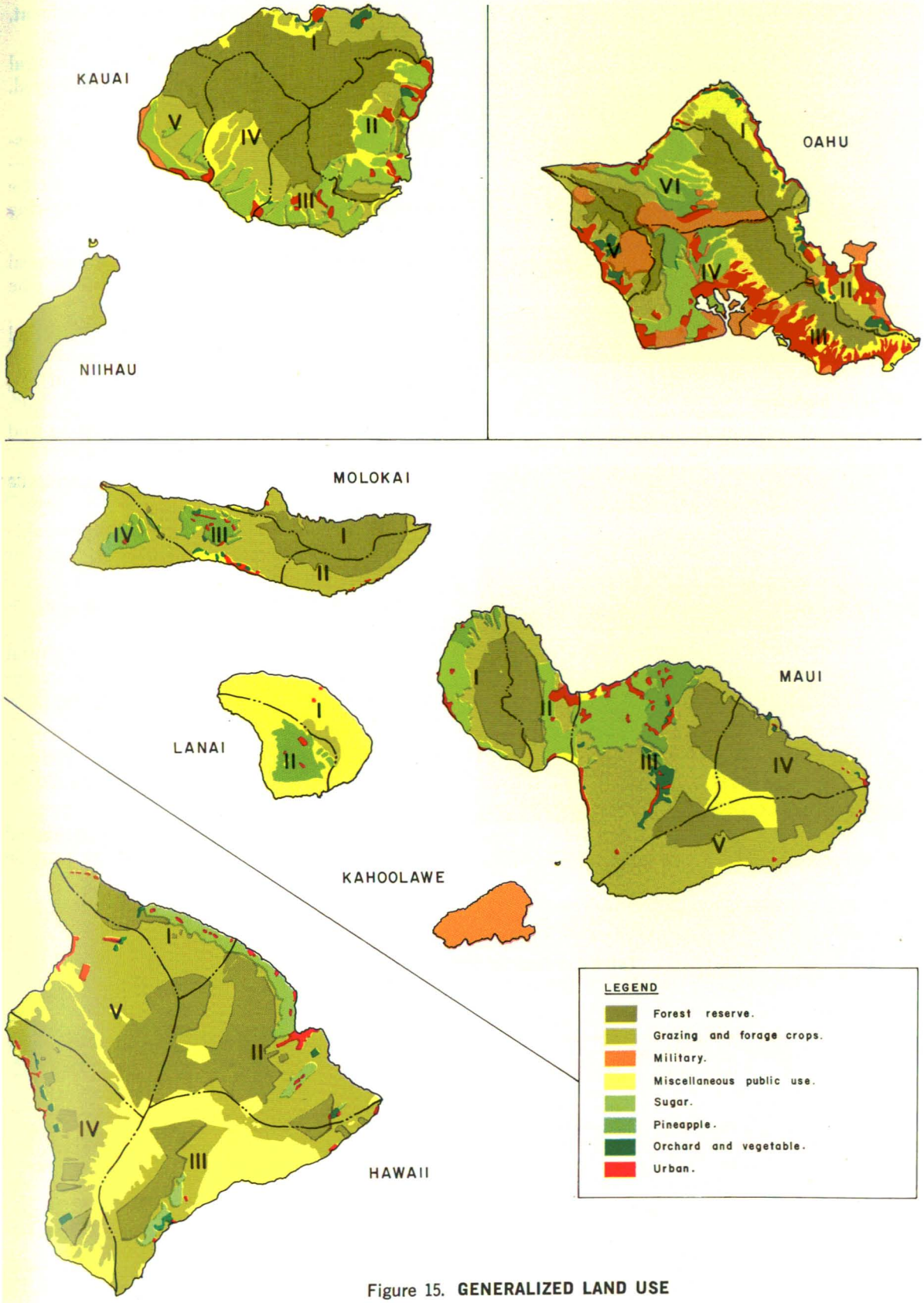
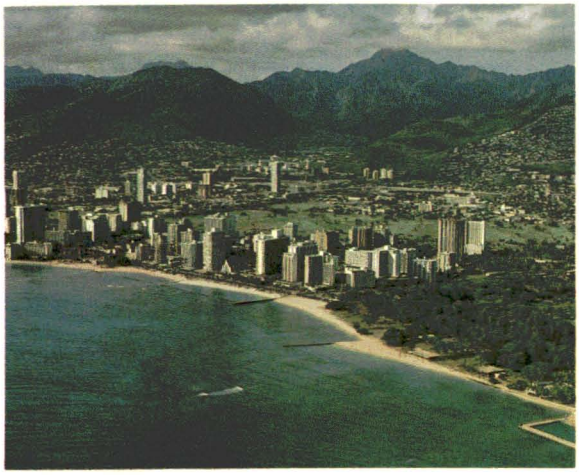


Figure 15. **GENERALIZED LAND USE**



Waikiki highrises.

Subdivisions surround Kaelepulu Pond, Oahu.

cepted and applied by government, private interests, and individuals.

10. Archaeological, historical, and cultural treasures are protected, maintained, and restored when appropriate.

The Middle Path. Maintenance of present environmental conditions, with improvements balancing any degradation might be determined in the future by the following criteria:

1. Representative samples of all natural ecosystems have been protected (the museum approach).
2. All populations of rare and endangered species have been maintained and some have increased because of improved habitat.
3. No deliberate reduction of water and air quality has been permitted.
4. All water and air quality standards have been met.
5. Economic development of renewable natural resources is on the basis of sustained yields.
6. Soil erosion has been controlled at today's levels.
7. Archaeological, historical, and cultural treasures have been protected, maintained, and restored when appropriate.

The Minimum. Even if the environment deteriorates below today's conditions, the following minimum standards should be maintained:

1. The habitat of rare and endangered species has been protected to provide for their survival.

TABLE 8
Estimated Areas of State Land Use Districts
(Acres)

	URBAN			RURAL			AGRICULTURAL			CONSERVATION		
ISLAND	1964	1969	1974	1964	1969	1974	1964	1969	1974	1964	1969	1974
Kauai	7,300	9,121	9,115	1,000	1,141	1,136	172,500	145,983	145,955	173,100	197,654	197,681
Maui	12,800	13,406	14,725	3,700	3,735	3,512	277,600	255,321	254,225	171,700	193,336	193,336
Molokai	1,500	5,039	5,154	900	904	890	120,800	110,076	110,004	42,600	49,780	49,751
Lanai	500	514	2,134	0	0	2,720	37,700	32,536	50,536	52,300	57,450	35,110
Hawaii	20,000	29,489	32,249	1,100	593	612	1,311,900	1,220,352	1,218,009	1,240,400	1,322,965	1,322,528
Oahu	75,700	82,512	84,093	0	0	0	158,200	145,906	144,285	151,400	156,801	156,920
Niihau	0	0	0	0	0	0	45,700	45,700	45,700	0	0	0
Kaula & Lehua	0	0	0	0	0	0	0	0	0	400	400	400
Kahoolawe	0	0	0	0	0	0	0	0	0	28,800	28,800	28,800
Outlying Islands	0	0	0	0	0	0	0	0	0	1,900	1,900	1,900
Total	117,800	140,163	148,470	6,700	6,375	8,871	2,124,400	1,955,875	1,968,727	1,862,600	2,009,086	1,986,428

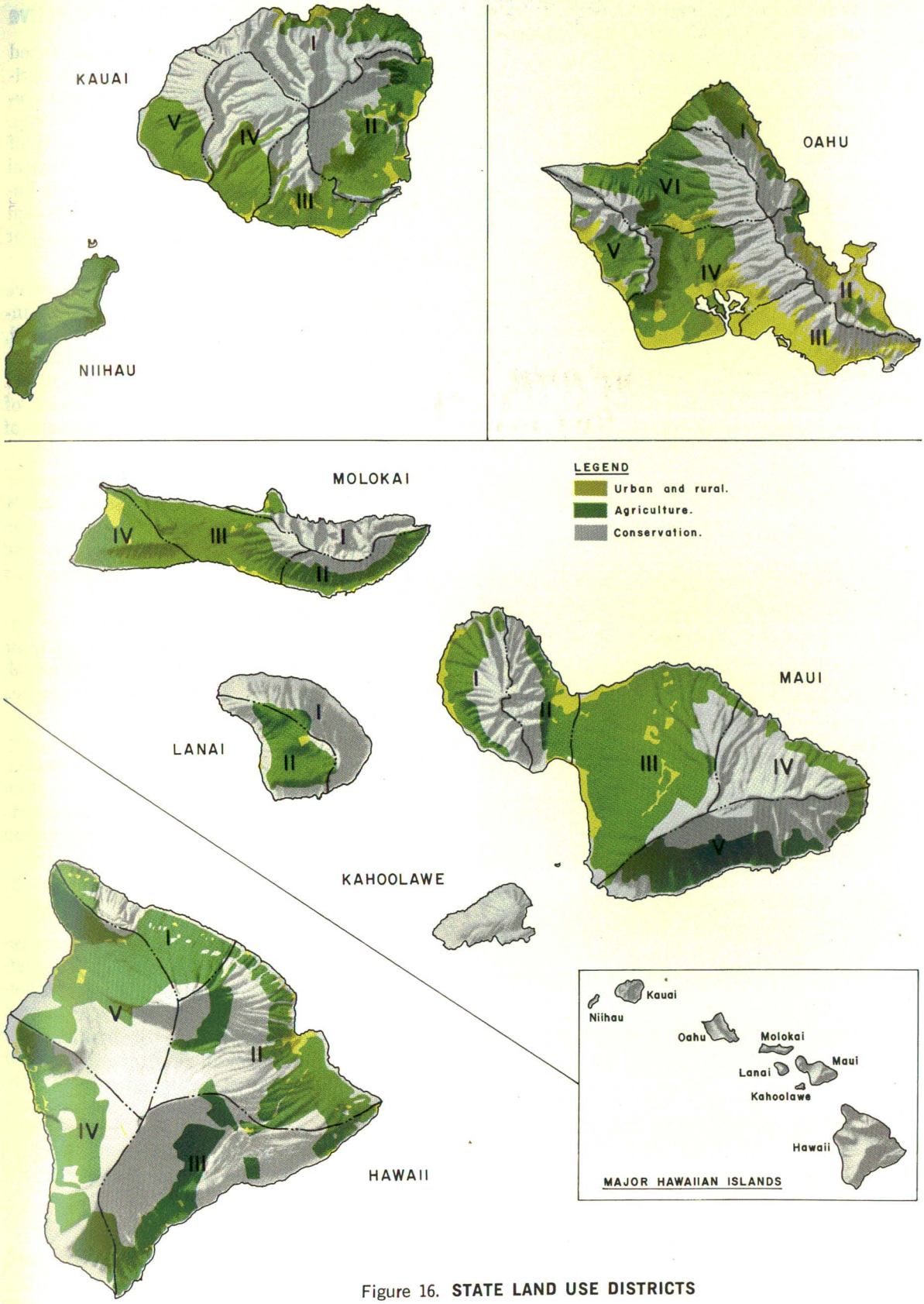
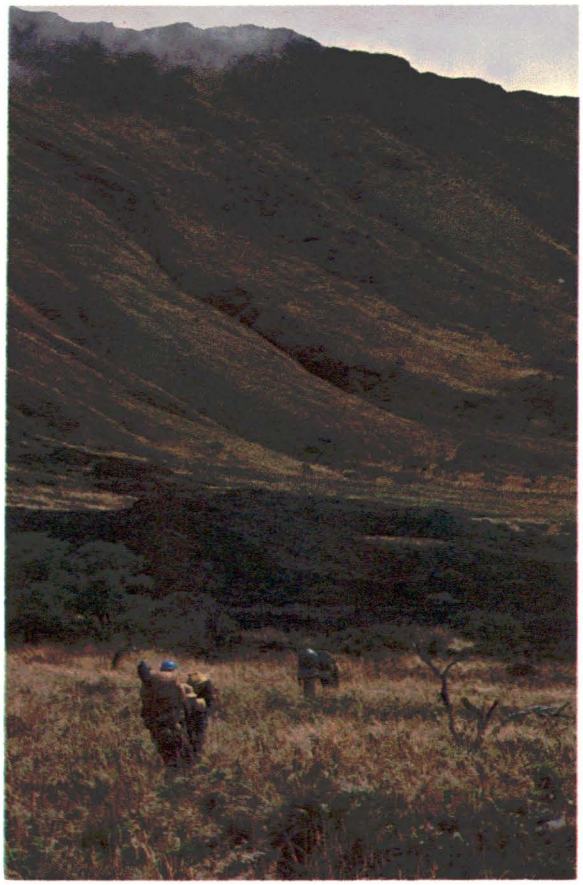


Figure 16. **STATE LAND USE DISTRICTS**

2. Water and air quality standards and other pertinent legislative requirements have been met.
3. Economic development of renewable natural resources on the basis of sustained yields is encouraged.
4. Structural solutions to flood and erosion problems are utilized to permit economic development of land and water resources within allowable limits of environmental disturbance.

In formulating this plan, the middle path has generally been followed, except where optimum opportunities exist or where present laws prescribe optimum conditions. In some situations, it may be necessary to achieve minimum conditions as a step toward the middle path.



Hiking at Haleakala, Maui.

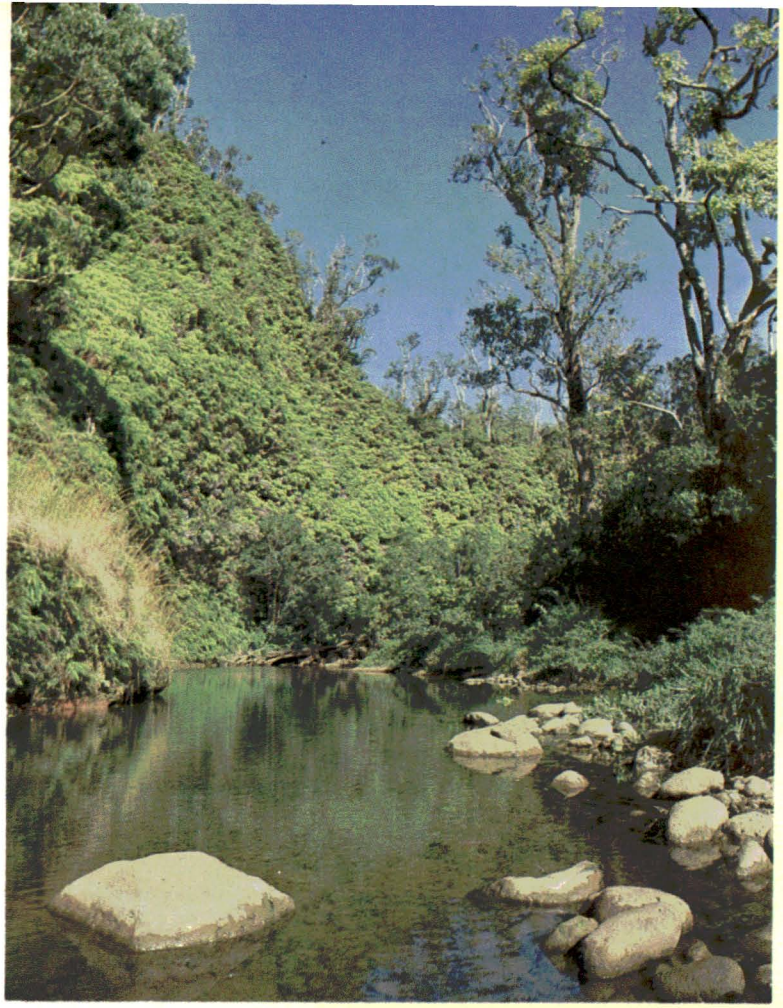
National Environmental Quality Objective

The national environment is enhanced as a source of present enjoyment and a heritage for future generations by the management, conservation, preservation, creation, restoration, or improvement of the quality of natural and cultural resources and ecological systems. As incomes and living standards improve, society becomes less willing to accept environmental deterioration in exchange for additional goods and services.

The national environmental objective specified by the U.S. Water Resources Council is responsive to spiritual, psychological, recreational, and material needs, and reflects man's abiding concern with the quality of the natural physical-biological system of which all life is sustained. Components of the objective include the following:

1. Management, protection, enhancement, or creation of areas of natural beauty and human enjoyment such as open and green space, scenic streams and rivers, beaches, shores, estuaries, and mountain wilderness areas.
2. Management, preservation, or enhancement of especially valuable or outstanding archaeological, historical, biological, and geological resources and ecological systems.
3. Enhancement of the quality of water, land, and air by control of pollution, prevention of erosion, and restoration of eroded areas, harmonizing economic land use objectives with conservation of the resource.
4. Avoidance of irreversible commitments of resources to future uses.

While all forms of land and water resource utilization affect the balance of aquatic and terrestrial ecosystems, all possible impacts on such systems are not fully known at present. In the absence of methods for reliably predicting ecological change, Water Resource Council planning standards emphasize the need for caution in the development and use of water and related land resources in order to minimize or preclude undesirable and irreversible changes in the natural environment.



Kaukonahua Stream, Koolau Mountains, Oahu.

Water and Related Land Resources

Needs, problems, and opportunities discussed in subsequent sections of this plan have been determined in the context of the quantity and quality of Hawaii's water and related land resources.

Water resources include rainfall, surface water, fresh and saline ground water, and coastal ocean water. Water related land includes watersheds, irrigated cropland and land suited for crops with irrigation, flood plains and urban land, wetlands, the shoreline, and submerged land.

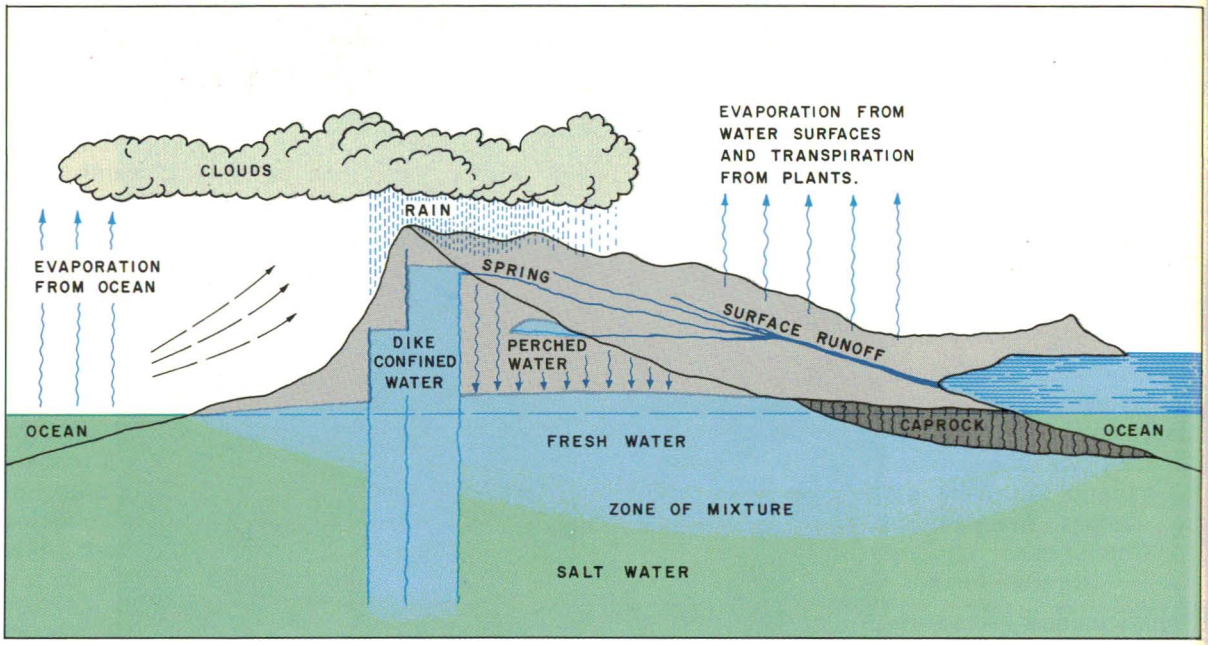
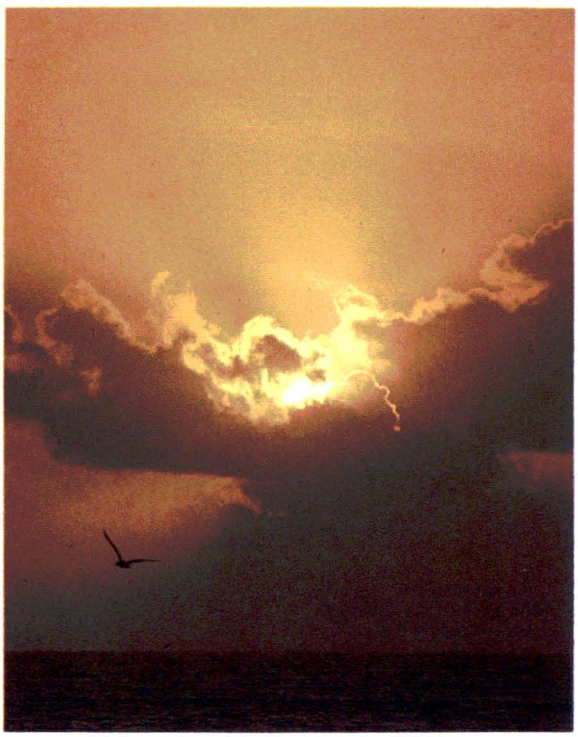


Figure 17. **HYDROLOGIC CYCLE**

5. HYDROLOGIC CYCLE



Seabird soars at sunset.

Solar energy and gravity cause a constant movement of moisture from water surfaces to the atmosphere, and back to the earth (Figure 17). During this cyclic process, impurities are removed and the water again becomes suitable for consumption by living creatures, including man. Although the hydrologic cycle is continuous, the amount of water present in any stage of the cycle varies greatly with both season and location.

Hawaii's fresh water supply is derived from precipitation upon the various islands. Precipitation may be lost through evaporation; it may be used by plants; it may run off in streams and ditches; or it may infiltrate into the ground.

A high percentage of Hawaii's rainfall infiltrates into the ground. Unless intercepted for use, such water ultimately reaches the sea either as subterranean inflow or, it it returns to the ground surface, as streamflow.

Water resources planning is concerned with the various aspects of the hydrologic cycle: rainfall, evapotranspiration, runoff, and ground water recharge.

6. CLIMATE

Hawaii's subtropical climate varies locally with elevation and orientation to the tradewinds. In general, the climate is characterized by two seasons a year, with mild and fairly uniform temperatures except at high elevations.

Wind

The wind pattern in Hawaii is the primary influence upon rainfall and also affects humidity and evaporation. Tradewinds from northeast to east normally prevail 80 to 85 percent of the time. Winds of 10 to 18 miles per hour are typical.

During the cooler winter months, the trades are replaced by cold fronts or other winter storms migrating from the North Pacific, and southerly "Kona storms." Tropical storms pass near the Islands almost every year; but only three times in the past 25 years have hurricanes come close enough to cause substantial damage. See Figure 18 for tropical storms and hurricanes.

Rainfall

Most of the rainfall in windward areas results from cooling of the moisture-laden trades as they rise up the mountain slopes.

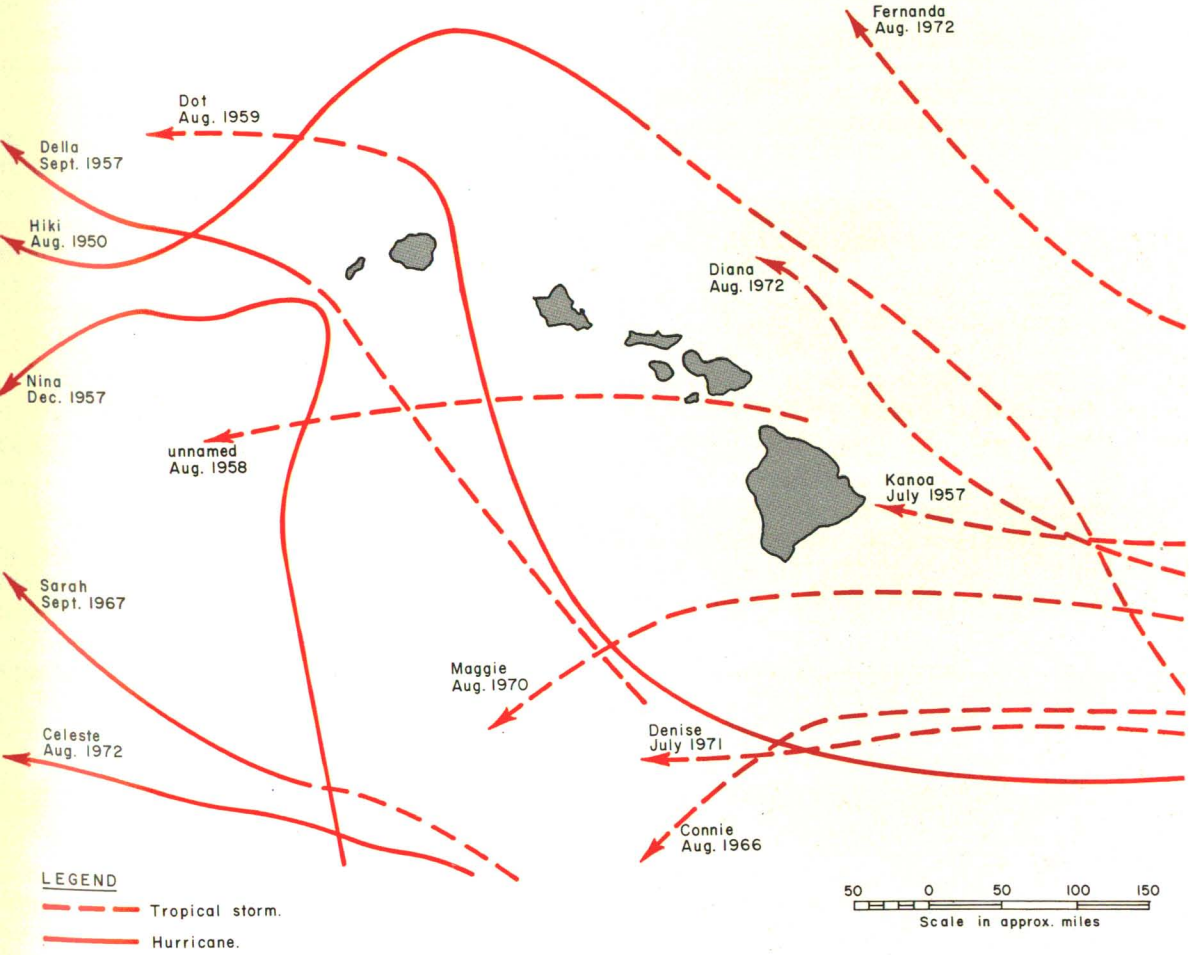


Figure 18. **TROPICAL STORMS AND HURRICANES, 1950–1972**

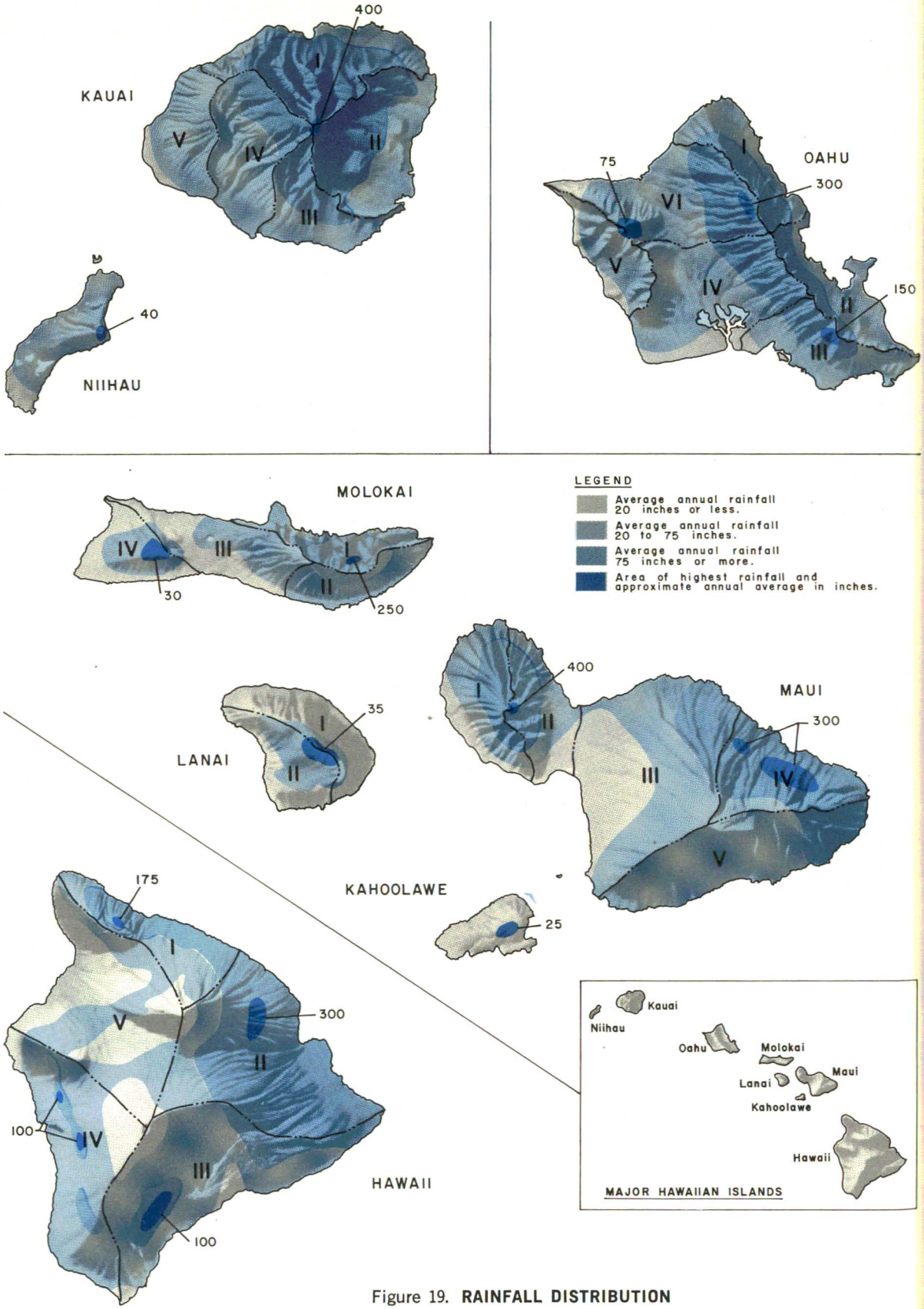


Figure 19. **RAINFALL DISTRIBUTION**

The winter storms and southerlies which disrupt the tradewinds cause most of the annual rainfall in leeward areas. Thunderstorms do not contribute significantly to Hawaii's water resources, except in Kona on the Island of Hawaii.

Mean annual rainfall in Hawaii is about 73 inches, ranging from 6.5 to 461 inches. The range on each of the six major islands, except Lanai, is from less than 18 inches to more than 250 inches. The range on Lanai is from 10 to about 40 inches. See Figure 19 for rainfall distribution.

Annual rainfall differences of 100 inches or more within three miles are not uncommon in Hawaii. Annual variations also are excessive, often more than 300 percent. Extreme rainfall intensities are common, with more than 12 inches of rain falling in a single day at least once a year, somewhere in the Islands. In contrast, drought periods are at least moderately frequent in all lowland areas and on the leeward slopes of large mountains.

On Maui and Hawaii, where large mountains split the tradewinds, maximum rainfall occurs on the windward side at 2,000 to 3,000 feet elevation. Upper slopes are semi-arid. On the other islands, where the mountains are smaller and lower, maximum rainfall occurs along or just leeward of the crestline. The driest areas of all islands, except Lanai, are along the leeward coasts.

Generally, the dry months are May through September, and the wet months are October through April. However, summer is the wet season in Kona.

Fog or mist provides considerable moisture to vegetation in mountainous areas frequently enshrouded in clouds. The summits of Mauna Kea and Mauna Loa on Hawaii are often covered with snow in winter, and occasionally snow falls on the summit of Haleakala on Maui. Frost rarely occurs below 4,000 feet elevation.

Temperature

Temperature depends primarily on elevation, although affected somewhat by slope, wind exposure, and solar radiation. The uniformly mild temperatures of the ocean waters surrounding Hawaii are generally reflected in the temperature of the air moving over the Islands.

Temperatures above 90°F. and below 55°F. are unusual; the mean annual temperature in Honolulu is 76°F. August and September are the warmest months; January and February are the coolest.

Humidity

Relative humidity at lower elevations is roughly 70 to 80 percent in windward areas, as compared to 60 to 70 percent in the drier leeward areas.

Solar Radiation

Solar radiation in the stratosphere over Hawaii is at a maximum during the summer and at a minimum during the winter. However, differences in cloud cover result in variable radiation at ground level.

In general, windward localities at low elevations have the greatest cloud cover and the least incoming radiation. Dry west coast areas and high mountain areas have the least cloud cover and receive the highest radiation.

Evapotranspiration

Evapotranspiration—that is, loss of water from the soil, both by evaporation and by transpiration from growing plants—must be subtracted from total precipitation to determine the residual rainfall which contributes to Hawaii's surface and ground water supplies.

In Hawaii, evapotranspiration varies markedly in both time and space. Minimum evaporation occurs in the wet month of February, and the maximum occurs during the dry months of June through August. The seasonal difference is substantial.

In dry areas, potential evapotranspiration exceeds 80 inches per year. In the wetter areas, frequent showers and high relative humidity tend to reduce evapotranspiration to perhaps 20 inches per year. All or most of the rainfall may be consumed in evapotranspiration in low rainfall belts, whereas evapotranspiration losses may be only a small percentage of the total precipitation in areas of heavy rainfall.

7. SURFACE AND GROUND WATER

Surface Water Occurrence

Numerous streams, most of them short and steep, originate in heavy rainfall belts on the major islands. Streamflow not diverted for use quickly finds its way to the sea. See Figure 20.

Surface geology and topography largely determine stream characteristics. Where the ground surface is essentially impervious, as on much of Kauai, perennial streams are the rule. In geologically youthful areas, such as Hawaii, there are fewer perennial streams.

Streamflow is very flashy, particularly in mountainous areas. Maximum flows resulting from heavy rains reflect typically rapid surface runoff; minimum flows may consist of ground water seepage and spring discharges.

In mountainous windward areas, more than half the rainfall may reach the sea as streamflow. At the other extreme, large leeward areas may contribute no runoff to the sea. It is estimated that rainfall runoff over almost two-thirds of the Hawaiian Islands fails to reach the coast.

Streamflow near Akaka Falls, Hawaii.

Because of steep, narrow valleys and generally pervious rock formations, there are few good sites in Hawaii for large surface storage reservoirs. The many small reservoirs in use are primarily for temporary storage. Since diversion and use of stream water has been geared largely to dry weather flows, ditch and reservoir capacities are exceeded during heavy rains.

With the increasing cost of petroleum, a few good sites on Kauai, Molokai, and Hawaii are more attractive for combined power production, water storage, and flood control. Storage of surface water for transmission by gravity flow is also more feasible as pumping costs increase. The use of small headwater dams to increase infiltration to ground water storage might also be worthwhile in many areas.

Unsettled Surface Water Rights

"Surplus" water under Hawaiian case law is that exceeding private appurtenant and prescriptive water rights. Historically, normal daily surplus water has been held by the courts to belong to the owner of the land on which it arose. Large and complex private irrigation systems have been developed over the years by sugar plantations to divert and transport such water from one watershed to another. Several domestic water systems are also dependent upon inter-watershed transfers. See Figures 28 to 32.

A 1973 decision by the Hawaii Supreme Court involving water rights on Kauai, commonly referred to as the "Hanpepe decision," holds that the state is the owner of all surplus water, subject to and in trust for riparian owners. The decision further holds that neither appurtenant, prescriptive, nor surplus water may be transferred outside the watershed where it originates.

The Hanapepe decision has been adjudged unconstitutional by the federal court in Ha-

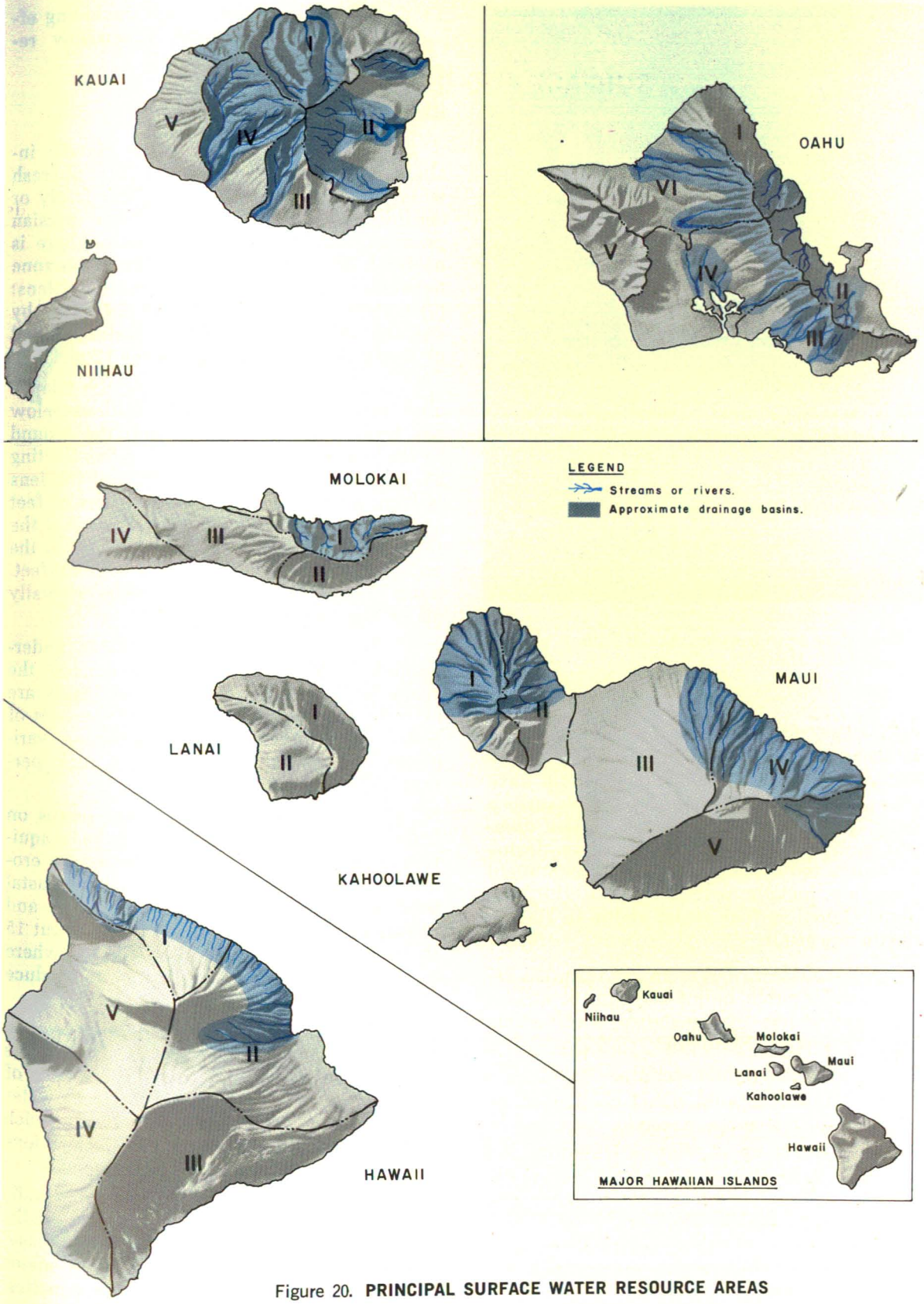
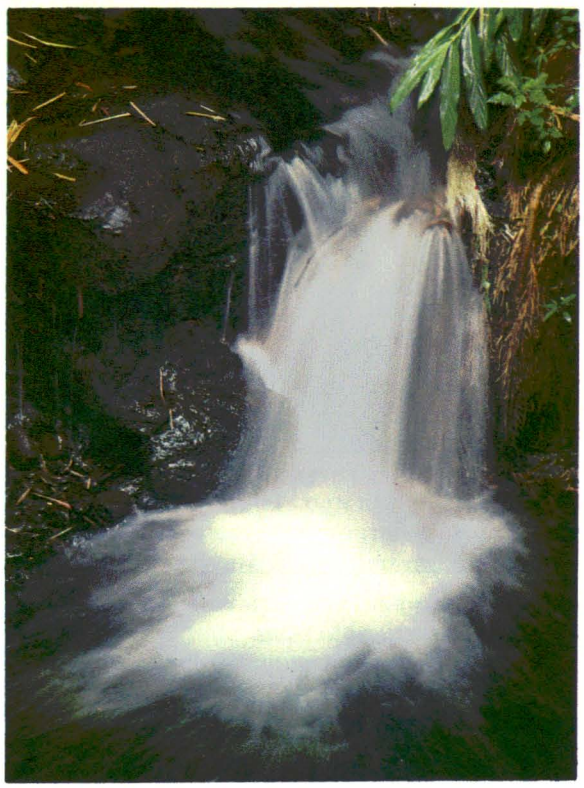


Figure 20. **PRINCIPAL SURFACE WATER RESOURCE AREAS**



Cascading surface water, Akaka Falls State Park, Hawaii.

waii, whose judgment has been appealed by the state. Should the constitutionality of the Hanapepe decision be upheld, it would have a far-reaching effect upon the use of surface water by sugar plantations and certain domestic water systems. In the meantime, during the protracted appellate process, which might ultimately include review by the U.S. Supreme Court, surface water rights in Hawaii remain uncertain.

- *RECOMMENDATION 7-1.* Express decisive public policy on rights to surface water use by legislative codification, with due regard for:
  - * General public welfare.
  - * Vested private rights challenged by the Hanapepe decision.
  - * Impact upon existing irirgation and domestic water systems dependent upon transfer of water from one watershed to another.
  - * Impact upon agricultural production, urban requirements, and the economy.
  - * Environmental impact, including effect on minimum streamflow requirements.

Ground Water Occurrence

Ground water sources in Hawaii include: (1) lens-shaped basal aquifers of fresh water floating on salt water, either freely or confined by coastal caprock under artesian pressure; (2) brackish water where there is no fresh basal lens, or in the transition zone between salt water and the fresh basal lens; (3) water impounded at higher elevations by volcanic dike systems; and (4) water perched on impervious strata. See Figures 17 and 21.

Ocean water surrounding the islands also fills the voids in rock formations below sea level. Rain percolating into the ground forms lens-shaped fresh water bodies floating on sea water. The upper surface of the lens is from a foot or two to several tens of feet above sea level; and, for every foot that the fresh water table stands above sea level, the underlying saltwater is depressed 40 feet. Such fresh water lenses underlie virtually all of the major islands.

Because movement of water underground follows the laws of dynamics, the shape and extent of fresh water lenses are affected by tidal movements, withdrawals of water by natural and artificial means, variations in rainfall recharge, and rock permeability.

The Honolulu-Pearl Harbor lenses on Oahu are exceptionally productive basal aquifers. A sedimentary caprock formed by erosion of the uplands has created a coastal barrier that confines the ground water and causes artesian heads ranging from about 15 to 30 feet. Most of the shoreline elsewhere in Hawaii has little or no caprock to produce artesian conditions.

In coastal areas with permeable rock formations where caprock is absent, the thrust and pull of tides in the shore zone of the aquifer causes mixing of the fresh water and salt water. Fresh water lenses in such areas are too brackish for use at elevations low enough for economical development.

Basal water is developed by dug wells along the coast, by vertical drilled wells, and by inclined shafts which skim the basal aquifers. Salt water intrusion is a major concern in developing basal water supplies.

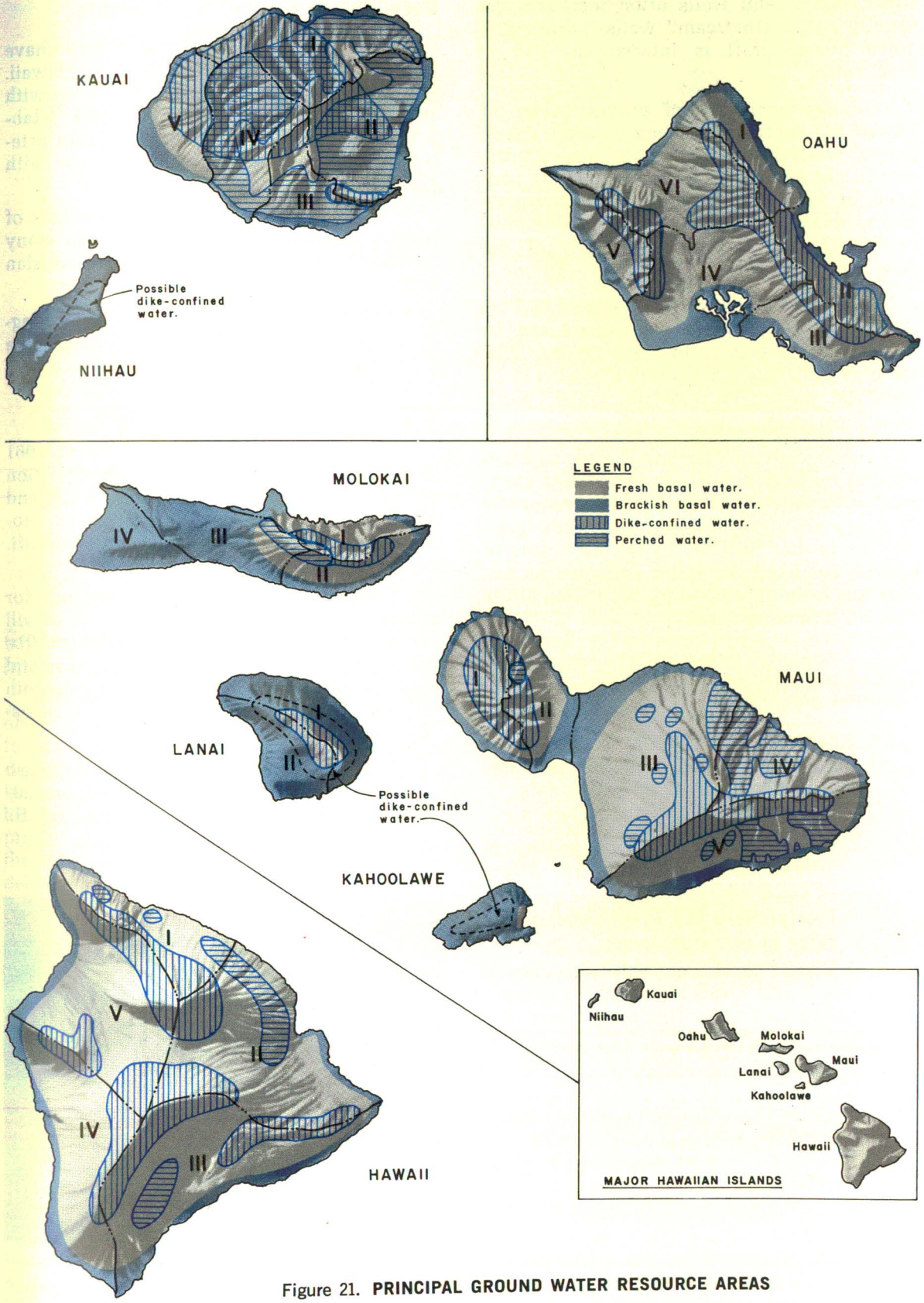


Figure 21. **PRINCIPAL GROUND WATER RESOURCE AREAS**

Draft from inland wells often increases the salinity of "downstream" wells, particularly when inland draft is intermittent and at high rates.

Large quantities of ground water in Hawaii are confined between volcanic dikes, formed when liquid lava cooled under pressure in cracks and vents. Water may be confined at high levels within dike compartments, the amount depending upon rainfall and the height and impermeability of the dike walls. See Figure 17.

Dike-confined water developed by horizontal tunnels at higher elevations can be transported by gravity to areas of use. Dike water is utilized for irrigation and also is an important source of domestic water, particularly on Oahu.

Ash beds or weathered rock surfaces covered by later lava flows sometimes cause perched bodies of water. Springs frequently discharge where such impervious beds intersect the ground surface. In the Ka'u area of Hawaii, for example, water collected on ash beds has been developed by tunnelling at the sites of former springs.

Augmented data programs and specific lines of research would be helpful for water resources planning.

- *RECOMMENDATION 7-2.* Augment programs for the collection, storage, and retrieval of the following data:
  * Ground water occurrence.
  * Chemical and biological quality of ground water, including the effects of cesspools.
  * Precipitation and evapotranspiration rates in recharge areas.
  * Dynamics of the transition zone of salt and fresh water in basal aquifers.

- *RECOMMENDATION 7-3.* Pursue the following specific lines of research:
  * Methods of increasing ground water recharge.
  * Ground water exploration techniques.
  * Techniques for drilling in basaltic terrain.
  * Mechanics of ground water movement in basal lenses.

Definition of Ground Water Rights

Rights to the use of ground water have been only generally established in Hawaii. The principal reported case is concerned with artesian ground water. The doctrine established is that all land owners over an artesian system own the water in common, with rights to "reasonable use."

Left unanswered are the questions of what constitutes reasonable use, and many questions regarding rights to non-artesian ground water sources.

- *RECOMMENDATION 7-4.* Enact legislation to codify rights to reasonable use of ground water resources.

Regulation of Ground Water Use

The Ground Water Use Act of 1961 (H.R.S., Chapter 177) provides for regulation of ground water by the Board of Land and Natural Resources, where existing or proposed development might cause an overdraft. Such designation has never occurred.

However, increasing competition for ground water in many areas of the state will eventually make it necessary to fully enforce the powers granted under the Act. Rules and regulations are needed to allow the smooth implementation of the law when the necessity arises.

- *RECOMMENDATION 7-5.* Establish rules and regulations for implementing the Ground Water Use Act (H.R.S., Chapter 177).

Ground water source, Halawa Tunnel, Oahu.

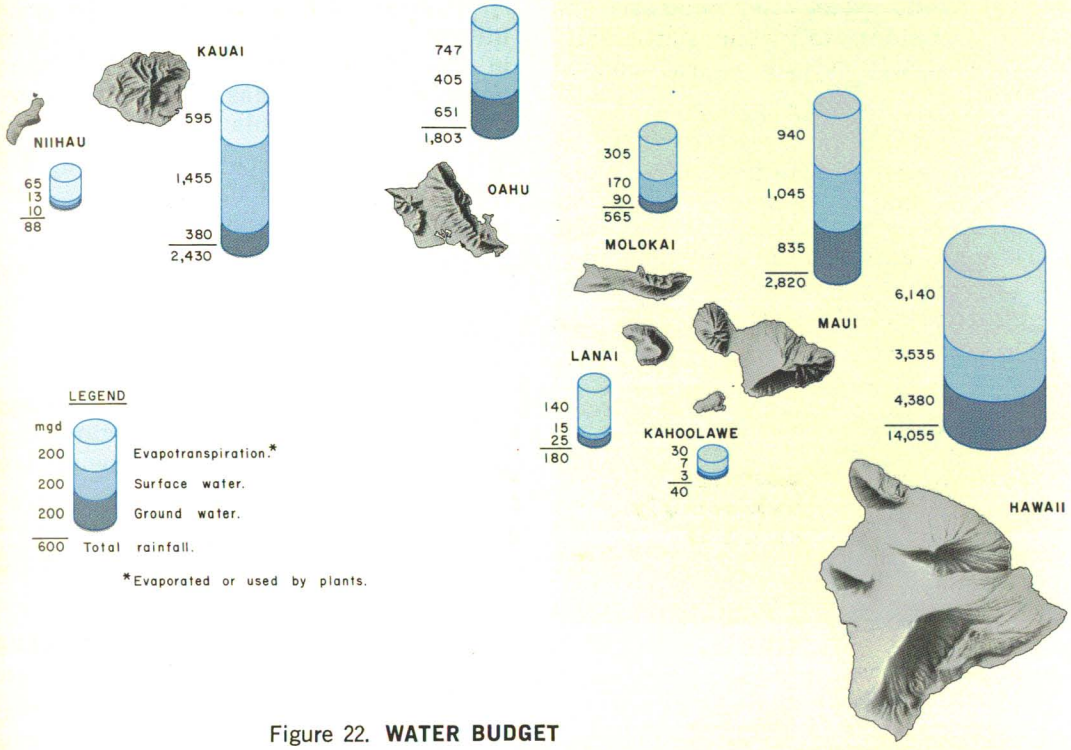


Figure 22. **WATER BUDGET**

Ground and Surface Water Interrelationships

Ground water and surface water are often naturally interrelated. Ground water feeds springs and streams, and surface water recharges ground water aquifers. However, because water laws have evolved from a long history of use and custom, in many cases predating the era of scientific hydrology, they do not clearly reflect the interdependence of surface and ground water sources.

As laws are revised and regulations updated, there is a need to ensure that the interrelationships are reflected.

- *RECOMMENDATION 7-6.* Improve laws and regulations to reflect the substantial interrelation between ground water and surface water sources.

Comprehensive and Coordinated Water Resources Management

Single-purpose development of surface and ground water over the years has not resulted in the optimum utilization and conservation of these resources. Also, there has been and continues to be piecemeal and overlapping regulation of these resources by agencies at all government levels. Consequently, there is an urgent need for a more comprehensive and efficient approach to water resources management.

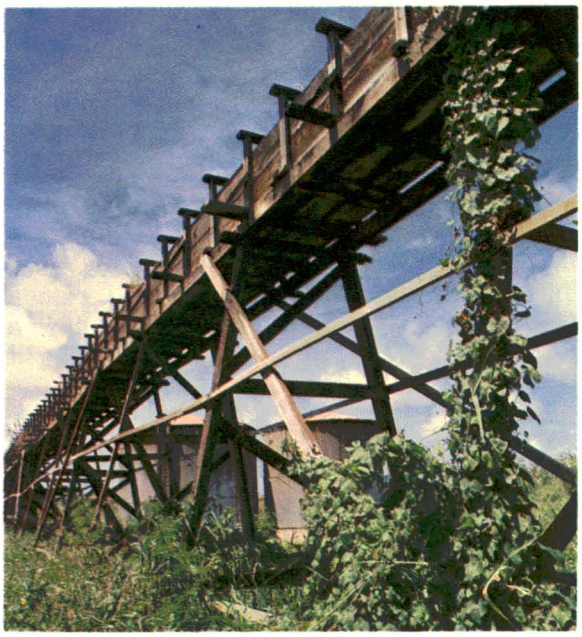
- *RECOMMENDATION 7-7.* Consider legislation to grant appropriate administrative authority for comprehensive and coordinated management of all surface and ground water resources on each island.

Water Availability and Use

Hawaii's available fresh water supply is determined by subtracting evapotranspiration from total rainfall. See water budget depicted in Figure 22.

About 55 percent of the water used in Hawaii is from streams and ditches fed partly by ground water seepage, spring flow, and tunnel discharge. Streamflow diverted for use is estimated to be approximately five percent of the total rainfall.

The remaining 45 percent of Hawaii's water supplies, including most of the domestic water, is from ground water sources. Ground water is also an important source of irrigation water on Oahu and Maui.



Sugar irrigation flume.

TABLE 9
Water Withdrawn for Various Uses, 1975
(Million Gallons per Day)

ISLAND	USE	SOURCE: GROUND WATER	SOURCE: SURFACE WATER	TOTAL
Hawaii	Mun.	7.0	8.0	15.0
	Agr.	2.0	29.0	31.0
	Ind.	20.0	97.0	117.0
	Total	29.0	134.0	163.0
Maui	Mun.	6.0	7.0	13.0
	Agr.	189.0	278.0	467.0
	Ind.	65.0	20.0	85.0
	Total	260.0	305.0	565.0
Kahoolawe	Mun.	NO WITHDRAWALS		
	Agr.			
	Ind.			
	Total			
Lanai	Mun.	.3	--	.3
	Agr.	2.2	0	2.2
	Ind.	0	0	0
	Total	2.5	0	2.5
Molokai	Mun.	.2	.2	.4
	Agr.	--	2.0	2.0
	Ind.	0	0	0
	Total	.2	2.2	2.4
Oahu	Mun.	161.0	0	161.0
	Agr.	229.0	92.0	321.0
	Ind.	70.0	60.0	130.0
	Total	460.0	152.0	612.0
Kauai	Mun.	4.0	3.0	7.0
	Agr.	54.0	298.0	352.0
	Ind.	2.0	70.0	72.0
	Total	60.0	371.0	431.0
Niihau	Mun.	.02	0	.02
	Agr.	0	0	0
	Ind.	0	0	0
	Total	.02	0	.02

Table 9 and Figure 23 summarize the utilization of surface water and ground water in Hawaii for various purposes. In recent years, competition has developed among water users for available resources.

Water resource planning would benefit from augmented data programs and specific lines of research.

- *RECOMMENDATION 7-8.* Consider legislation to grant express administrative authority to allocate water resources among competing uses.
- *RECOMMENDATION 7-9.* Augment programs for the collection, storage, and retrieval of the following data:
  - * Cost of water for various uses from various sources.
  - * Per capita use of domestic water from all systems.
- *RECOMMENDATION 7-10.* Pursue the following specific lines of research:
  - * Identification and economic feasibility of alternative or supplementary water supplies for drought periods.
  - * Uniform basis for projecting per capita demand.
  - * Improved methods of water storage and distribution.
  - * Potential application of desalting to Hawaii.
  - * Engineering design of fog drip systems and catchments for isolated homesteads and ranches.
  - * Methods of increasing rainfall through weather modification.
  - * Methods of reducing evapotranspiration.

Increasing Fresh Water Supplies by Innovative Methods

Additional supplies of fresh water might be obtained through developments which alter the hydrologic cycle, create fresh water from salty or polluted water, or transfer and store water. Each of these offer the opportunity for using new or improved technology.

A number of innovative methods for increasing water supplies are considered physically feasible at present; others would require perhaps 10 to 30 years or more before they could be made physically feasible.

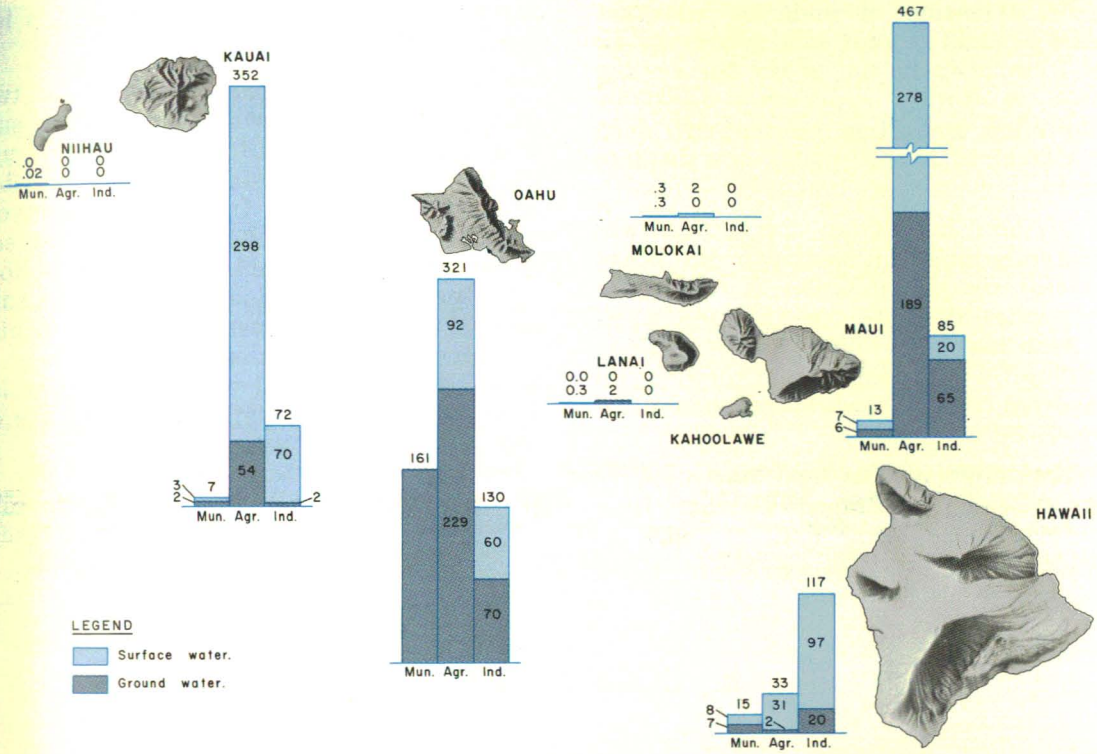


Figure 23. **WATER WITHDRAWN FOR VARIOUS USES, 1975**

Economic feasibility would also have to be determined.

The following potential means of increasing water supply are presented without evaluation as to practicality or desirability. They illustrate some innovative ideas for future investigation.

Household Desalting Units. Desalting efforts have been concentrated primarily on large-scale facilities for communities and cities. However, individual household units might be suitable in areas having only saline water sources. Each residential unit would purify only water needed for drinking and cooking; the saline supply could be used for sanitary needs. Some home desalting units are already in use.

Ocean Transport of Fresh Water. Petroleum products can be transported over the ocean in large water-tight bladders fabricated from reinforced synthetic rubber or plastic film. The same method could be used for fresh water.

The folded or rolled empty bladder would be moved to the loading point, filled with water, and then towed by ship to its destination. It would then be pumped out, collapsed, and returned for reuse. Quantities exceeding 100,000 gallons could be transported in this way. Water towing might provide water supplies competitive with desalted water or with water transported over long distances by pipeline.

Undersea Aqueducts. Fresh water might be transmitted along the coast or between islands by undersea aqueducts. Because of its higher density, salt water would support a buoyant fresh water aqueduct. Foundation problems would thus be limited to the relatively simple matter of holding down the aqueduct.

The density of the sea water would also reduce the conduit strength required to withstand pressures needed to produce flow. Materials for such an aqueduct should be relatively inexpensive. In theory, a large diameter plastic pipe could be laid from a specially designed vessel. The pipe would lead from a pumping station on the coast; additional pumping stations would be provided along the route as required.

An extension of undersea aqueduct technology might permit cold water to be drawn from deep in the ocean for cooling purposes. A further application might be the controlled updraft of nutrient-rich deep ocean waters to supply major new inshore fisheries.

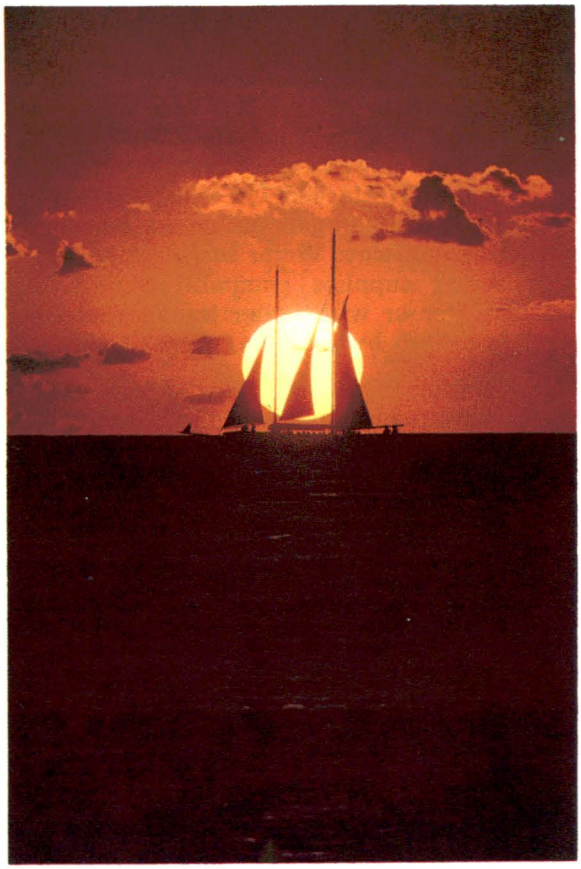
Offshore Reservoirs. Large fresh water reservoirs might be created in the ocean near major centers of water use by techniques similar to those for undersea aqueducts. Such reservoirs might provide a means for holding flood discharges until they could be processed through a waste treatment plant for beneficial use.

They might also be used for temporary storage of fully reclaimed effluent from waste treatment systems until recycled, or as terminals for undersea aqueducts where reservoir sites are inadequate or land is too costly.

Offshore reservoirs might take two forms, depending on whether the ocean surface could be reserved for their exclusive use or not. If such reservation should be possible and enforceable, the fresh water reservoir could but made of material denser than sea water so that it would sink to the bottom when not in use and float when filled. A submerged fresh water reservoir would require sufficient ballast (perhaps sand) to hold it down when filled and would need to be located so as not to interfere with the use of the ocean surface.

- *RECOMMENDATION 7-11.* Investigate potential technological advances that might increase water supplies.

8. COASTAL WATER



Sunset at Waikiki.

This plan is concerned with ocean waters as they affect coastal recreation, fish habitat, marine transportation and industries, new energy sources, and damage by tsunami and storm wave inundation. It is also concerned with ocean waters affected by rainfall runoff and discharges.

Jurisdictional Limits

The coastal zone is variously defined as extending seaward three miles or twelve miles from the shore or to a depth of about 600 feet. The State of Hawaii has legal jurisdiction within the three-mile limit, while the federal government retains control of the ocean and its resources at least to the twelve-mile limit.

The Fisheries Conservation and Management Act of 1976 established federal control over fisheries to 200 miles. This zone, extending some 2,000 miles from southeast of the Big Island to northwest of Kure Atoll, comprises about 800,000 square miles.

- *RECOMMENDATION 8-1.* Enact legislation to apply the "archipelago doctrine" to the Hawaiian Islands, giving the United States the right to control the waters around the Islands, and delegating administration to the state.

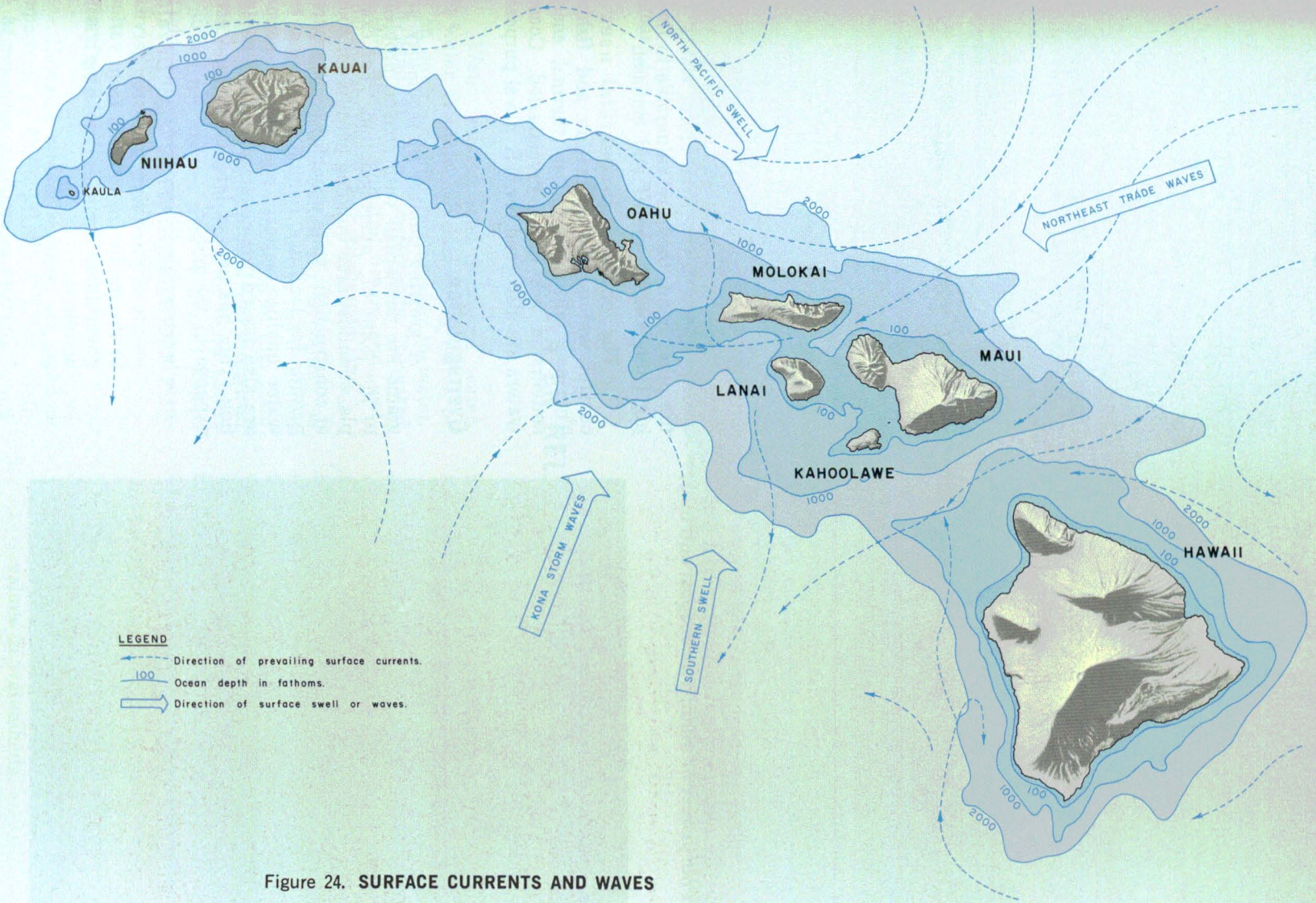


Figure 24. **SURFACE CURRENTS AND WAVES**

Physical Characteristics

Northeast tradewinds generate the dominant waves in Hawaii and also drive surface currents generally westward at 0.4 to 0.6 knots. Patterns of the currents, as well as characteristics of waves, salinity, and water temperature vary moderately with the seasons, as the cyclonic storms move closer in winter.

Surface currents are modified by the shapes of the islands and, very close to shore, by the tides as well. See Figure 24. Eddies are common in the lee of islands, especially west of the Island of Hawaii, and probably result from high winds funneled between the Islands of Maui and Hawaii. Hawaii has a mixed tide with a low range; spring tides nowhere exceed 3 feet. Waves near shore originate in seas and swells which vary seasonally and variously affect different exposures of the coasts. Tsunami waves have ranged up to 28 feet high in Hilo and up to 55 feet elsewhere in the state.

Submarine canyons are most pronounced north of Molokai, northeast of Oahu, and northwest of Maui. The deepest and most extensive terrace, named the Waho Shelf, is tilted to the north and ranges between 3,000 and 3,600 feet deep.

Rugged south shore of Maui.

Utilization

Recreational uses of coastal waters include swimming, surfing, fishing, and boating. About 40 unimproved harbor sites and anchorages along the coast of the major islands are used by local boats and occasional transient craft. These sites include stream estuaries, lower channelized reaches of srteams, small bays or coves, inlets or natural openings in reefs, and sheltered beach zones where boats are landed or moored in shallow water.

Some of these sites are seldom used; others are used frequently. A few accommodate a substantial number of regularly based craft. Nearly all of these sites become untenable or dangerous for boats when storm waves strike from their exposed sides, although they may provide good to fair shelter during storms from other directions. Exceptions are stream estuaries, which generally afford a good haven from storm waves. On the other hand, they are vulnerable to flooding from rainfall runoff and tsunami.

The principal commercial uses of coastal waters are navigation and fishing. The possibilities of ocean thermal energy conversion are being investigated. Coastal waters are also used for U.S. naval purposes.

Overregulation

A growing number of regulatory programs are concerned with coastal problems, to the point of "overregulation." For example, counties issue building permits for coastal construction; state agencies issue separate permits for land use, fishing, navigation, and water quality matters; and federal permits are also issued for construction and navigation. This has caused long delays and great expense to the public.

- *RECOMMENDATION 8-2.* Develop means of providing "one-stop service" to the public for permits from various government agencies regulating coastal activities.
  - * Consolidate programs.
  - * Execute interagency agreements.
  - * Transfer funds as necessary.

Mountain wetlands, Alakai Swamp, Kauai.

9. WATER RELATED LAND

Water related land produces water, uses water, is subject to damage by water, or has an environmental relationship to water. Such land includes watersheds, irrigated cropland, flood plains and urban land, wetlands, the shoreline, and submerged land.

Those lands suited for irrigation, as well as lands presently in urban use or suited for urban use are also included in this plan. Urban land requires municipal and industrial water supplies. Development of flood plains for urban use creates a flood hazard potential which must be considered in general planning, zoning, and construction.

Watersheds

Hawaii's stream systems are small in comparison to many Mainland areas, drainage basins usually consisting of one principal stream and minor tributaries. Hawaii's 27 major drainage basins, or hydrographic areas, are shown in Figure 5.

Nearly half of Hawaii (some 2 million acres) is in forest, ranging from mountain scrub to subtropical rain forest. See Figure 25 for forest reserve areas. These areas constitute the principal watersheds. Forests slow erosion and sedimentation and are very effective in maintaining high rates of rainwater percolation to ground water sources. They provide habitat for many unique types of flora and fauna, as well as recreational opportunities.

- *RECOMMENDATION 9-1.* Pursue the following specific lines of research:
  - * Water consumption by plants in forested areas.
  - * Soil characteristics and resource values in watersheds.
  - * Wildlife values of watersheds.

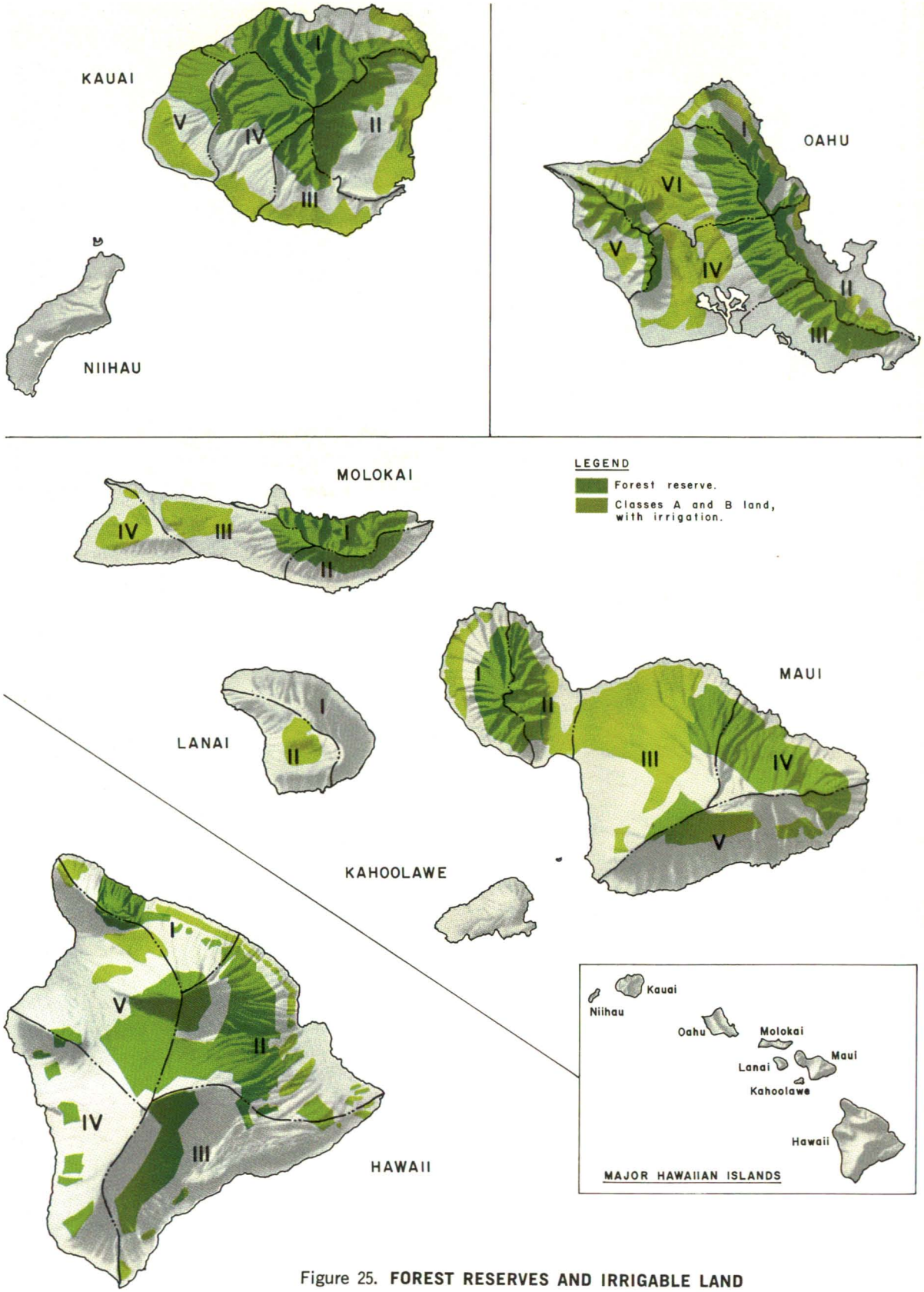


Figure 25. **FOREST RESERVES AND IRRIGABLE LAND**

Irrigated Cropland

Sugarcane is cultivated on 262,400 acres in Hawaii, of which 118,800 acres are irrigated. All other crops occupy 116,400 acres. Principal diversified crop acreage under irrigation is at Lalamilo, Hawaii (310 acres), Hoolehua, Molokai (145 acres), and Waimanalo, Oahu (1,000 acres), where the state operates irrigation systems. The Molokai system also serves 5,000 acres of pineapple. Diversified crops (1,100 acres) are also irrigated from the county domestic system at Kula, Maui. Taro (462 acres) and watercress (37 acres) are cultivated in flooded paddies.

It is estimated that, with irrigation, 200,000 acres of land in Hawaii could be upgraded for crop production. See Figure 25 for irrigable land.

Flood Plains and Urban Land

A flood is the inundation of usable lands which are not normally covered by water. (In this context, "usable" means actually being used as well as potentially usable). A flood may be caused by a temporary rise of the water level of a stream, inundating adjacent lands (stream flood plains). Or a flood may be caused by a temporary rise of the ocean, inundating border lands normally above water (ocean flood plains). In Hawaii, stream floods are usually caused by storm rainfall; ocean floods are caused by abnormal storm waves and tsunami. See Figure 35 for flood problem areas.

Floods of damaging proportions occur frequently in Hawaii because of the rainfall pattern and the short, steep watersheds. Where drainage areas are small, comprised of a main stream and a few small tributaries within a precipitous and narrow valley, the effects of intense rainfall are quickly felt on the coastal plain. Runoff to the sea may be impeded when stream mouths become clogged with sand, silt, and debris, causing high waters to back up and overflow lowlands.

Most of the communities in the Islands are situated on the coastal plains. See Figure 8. Urban developments, particularly on Oahu, have added to the flood problem by denuding watershed slopes of trees and vegetation.

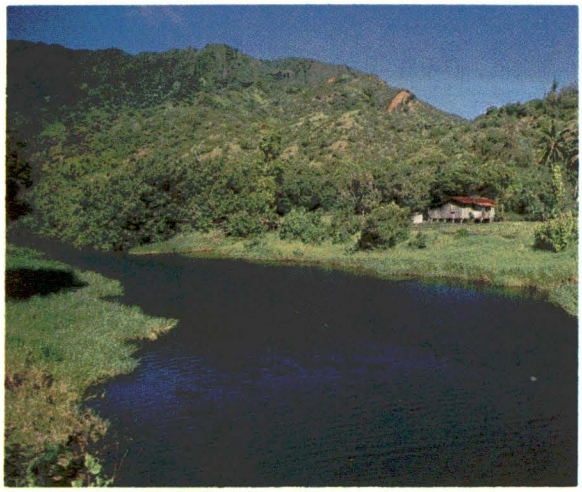
Sugarcane irrigated from ditches and portable flumes.

Urban concentration, Honolulu.

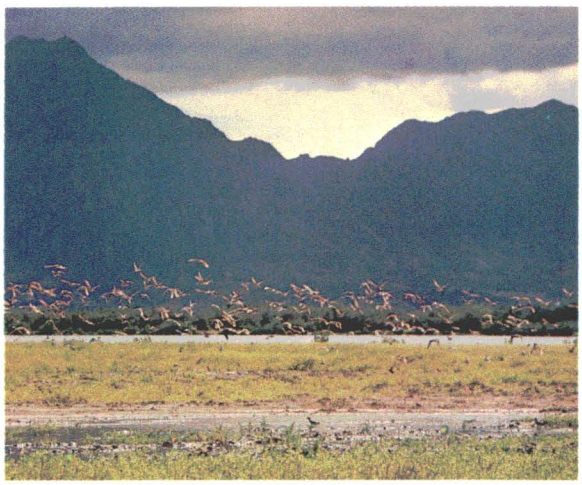
TABLE 10
Tidal Shoreline Characteristics
(Miles)

ISLAND	SANDY BEACH	NON-SANDY BEACH ROCK & GRAVEL	MUD	STRUCTURES	TOTAL
Hawaii	21.8	279.8	0	3.9	305.5
Maui	33.7	121.4	0	3.7	158.8
Lanai	18.2	34.0	0	0.1	52.3
Molokai	24.6	66.7	7.1	7.5	105.9
Oahu	55.9	78.3	13.4	50.9	198.5
Kauai	49.6	60.6	0	3.2	113.4
Total	203.8*	640.8	20.5	69.3	934.4

*Includes 18.9 miles of seasonally sandy beaches.



Wainiha Stream flood plain, Kauai.



Coastal marshland, Nuupia Ponds, Oahu.

Wetlands

There are no large natural lakes or ponds in Hawaii. A few small ponds and stream pools store very limited amounts of water.

Swamps in coastal areas are generally brackish, and the water has only limited use. Upland swamps are found where the surface rock has weathered to form impervious beds, such as clay blankets, or where the ground surface is composed of tight *pahoehoe* lava flows. While these swamps do not have free-flowing water in the usual sense, the soil is saturated and stores some water to feed surface streams. The largest upland swamp in Hawaii is the Alakai Swamp on Kauai, which covers about 4,000 acres. See Figure 26.

The Shoreline

Although only 47th in total area among the states, Hawaii ranks 17th in the length of its tidal shoreline. Table 10 summarizes and Figure 26 depicts shoreline characteristics of the six major islands.

In Hawaii, title to all shoreline below the high water mark lies with the state government, unless specifically withheld by the federal government or transferred to private owners by conveyance or by prescriptive right. Table 11 summarizes the ownership of land above the mean high water mark in 1962. Shoreline ownership has not changed significantly since that time.

TABLE 11
Shoreline Land Ownership, Six Major Islands

OWNER	TOTAL SHORELINE MILES	TOTAL SHORELINE PERCENT	SANDY SHORELINE MILES	SANDY SHORELINE PERCENT
Federal	106.7	11.4	13.5	7.3
Public (non-Federal)	267.0	28.5	50.0	27.0
Private	560.7	60.1	121.4	65.7
Total	934.4	100.0	184.9	100.0

TABLE 12
Shoreline Land Use, Six Major Islands

LAND USE	TOTAL SHORELINE MILES	TOTAL SHORELINE PERCENT	SANDY BEACH MILES	SANDY BEACH PERCENT
Recreational--Public	93.7	10.1	22.7	12.3
Recreational--Private	4.5	0.5	2.5	1.4
Non-recreational Development	203.5	21.8	40.9	22.1
Undeveloped	632.7	67.6	118.8	64.2
Total	934.4	100.0	184.9	100.0

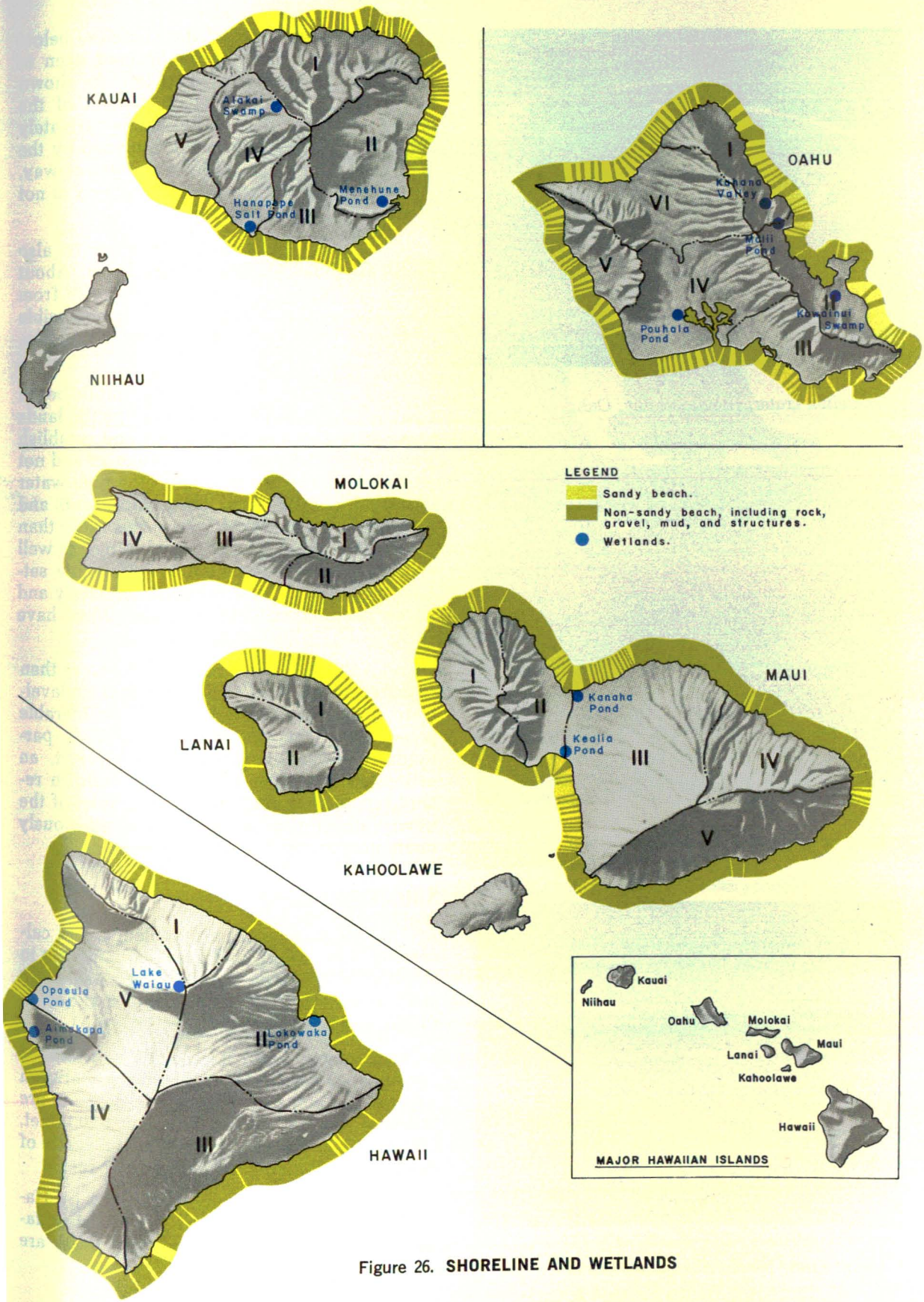


Figure 26. **SHORELINE AND WETLANDS**

Shoreline crater, Hanauma Bay, Oahu.

Lava outcropping, Waimea Bay, Oahu.

Broad sandy beach, Hanapepe, Kauai.

Although most of the shoreline below the high water mark is public land open to all, access is generally restricted. As shown in Table 12, as much as 60 percent of the lands abutting the shoreline is privately owned, and only 28 percent is owned by the state and counties. Without a right-of-way, the shoreline abutting private property is not accessible to the public.

Much of Hawaii's shoreline is also physically inaccessible, or nearly so. About 64 percent consists of cliffs which rise from the water's edge. Many marginally accessible areas are used for water related recreation, primarily by residents.

State statutes require that public beach rights-of-ways be reserved when public lands along the coast are disposed of and establish shoreline setbacks of not less than 20 and not more than 40 feet inland from the high water mark. Removal of sand, coral, rocks, soil, and other beach materials for purposes other than reasonable domestic use is prohibited, as well as construction of structures within the setback other than those required for safety and shore protection. The counties also have enacted shoreline setback laws.

Table 12 shows that in 1962 more than two-thirds of Hawai's shoreline was undeveloped. Since then, there has been considerable growth of resort and recreational uses, particularly in sandy reaches. As a result, an estimated 125 miles of shoreline were in resort and recreational use in 1970. Most of the newly developed shoreline was previously open pasture or brush-covered land.

Submerged Land

Soil washed from the islands, and calcareous sand, mud, and gravel originating in shallow water, are the principal nearshore sediments. Pelagic brown clays cover most of the deep-sea floor.

Precious coral has been discovered at various localities in Hawaii at depths between 1,000 and 1,600 feet. Manganese deposits are common on old terraces below 1,200 feet, and there are a few billion cubic yards of sand at depths shallower than 100 feet.

Coastal fish ponds were used by Hawaiians for a sophisticated system of aquaculture. Some are still in use, and many are of historic interest.

Safe drinking water, federal mandate.

Water and People

A major objective of water resources planning is to provide adequate quantities of water of suitable quality for human needs. A corollary concern is the efficient disposal of domestic wastewater, with due consideration for its beneficial reuse.

The protection of residential property and human lives from the ravages of tsunami, high surf, storm flooding, and dam hazards is another critical concern.

Full enjoyment of water related recreational opportunities — in coastal water, on beaches, and inland from the shore — is also important in planning for human needs.

10. DOMESTIC WATER

Orderly economic development will require improvement in the quantity and quality of domestic water supply services. Water planning must focus on the major requirements which follow.

Potable Water for Domestic Needs

Recoverable water supply on each island in average and dry years with present water development technology is summarized in Table 13. The total quantity considerd recoverable is derived from surface and ground water resources available in accordance with Hawaii's generalized water budget, depicted in Figure 21.

Domestic water demand is expected to increase on all major islands as population increases and economic activity expands. This is due partly to a projected increase in per capita consumption based upon historical trends. See Table 14.

A comparison of recoverable water supply and demand by islands is presented in Figure 27, by hydrographic areas for each island in Figures 28 to 32. Water supply surplus or deficit by hydrographic areas in average and dry years is summarized in Table 15.

TABLE 13
Recoverable Water Supply With Present Technology

ISLAND	TOTAL RECOVERABLE (mgd) AVE. YEAR	TOTAL RECOVERABLE (mgd) DRY YEAR*	DEVELOPED 1975 (mgd)	BALANCE RECOVERABLE (mgd) AVE. YEAR	BALANCE RECOVERABLE (mgd) DRY YEAR
Hawaii	2,940	2,664	176	2,764	2,488
Maui	1,159	983	569	590	414
Lanai	5	5	3	2	2
Molokai	115	94	12	103	82
Oahu	796	725	587	209	138
Kauai	1,009	636	449	560	187

* A year in which streamflow is 60 percent of normal.

TABLE 14
Effect of Increased Per Capita Consumption of Municipal Water, Year 2000

ISLAND	PROJECTED DEMAND, YEAR 2000 AT 1975 RATE PER CAP. (gd)	AT 1975 RATE TOTAL	INCREASED RATE PER CAP. (gd)	INCREASED RATE TOTAL	DIFFERENCE
Hawaii	160	39.6	190	44.0	4.4
Maui	200	30.1	246	34.1	4.0
Lanai	135	1.8	142	1.8	0
Molokai	75	1.3	160	2.0	0.7
Oahu	200	271.0	239	311.0	40.0
Kauai	160	17.5	223	20.9	3.4
Total		361.3		413.8	52.5

Fresh water supplies available for development are adequate to satisfy year 2000 needs on all islands except Oahu. If present consumption trends and wastewater disposal methods continue, projected islandwide water demand on Oahu could equal the total supply recoverable on the island during the period 2000-2020.

Under present conditions, recoverable water supplies on each of the Neighbor Islands will continue to exceed demand for the foreseeable future, on an islandwide basis. However, water development generally is lagging behind demands for new urban water supplies. An accelerated water development program is needed for orderly community growth on those islands.

Local domestic water supply deficits will occur in one hydrographic area on Maui and in three on Oahu. See Figure 33 for those hydrographic areas requiring the development of at least 3 mgd of domestic water to meet 2000-2020 projected demands. Quantities required during the periods 1975-2000 and 1975-2020 are given in Table 16.

With projected increases in domestic water consumption and present technology, virtually all of the existing or planned sources of domestic quality water on Oahu might be developed to their limits by the year 2000. Additional domestic water sources must be developed to meet needs beyond the year 2000.

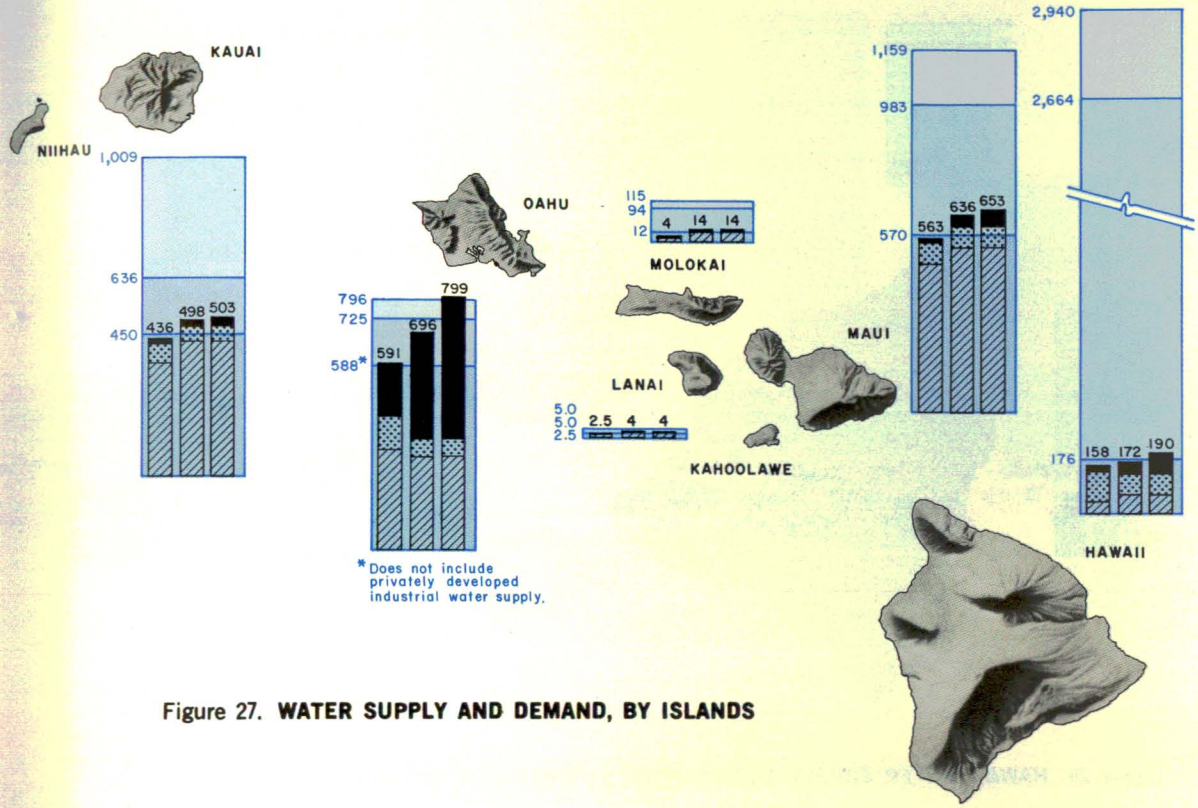


Figure 27. **WATER SUPPLY AND DEMAND, BY ISLANDS**

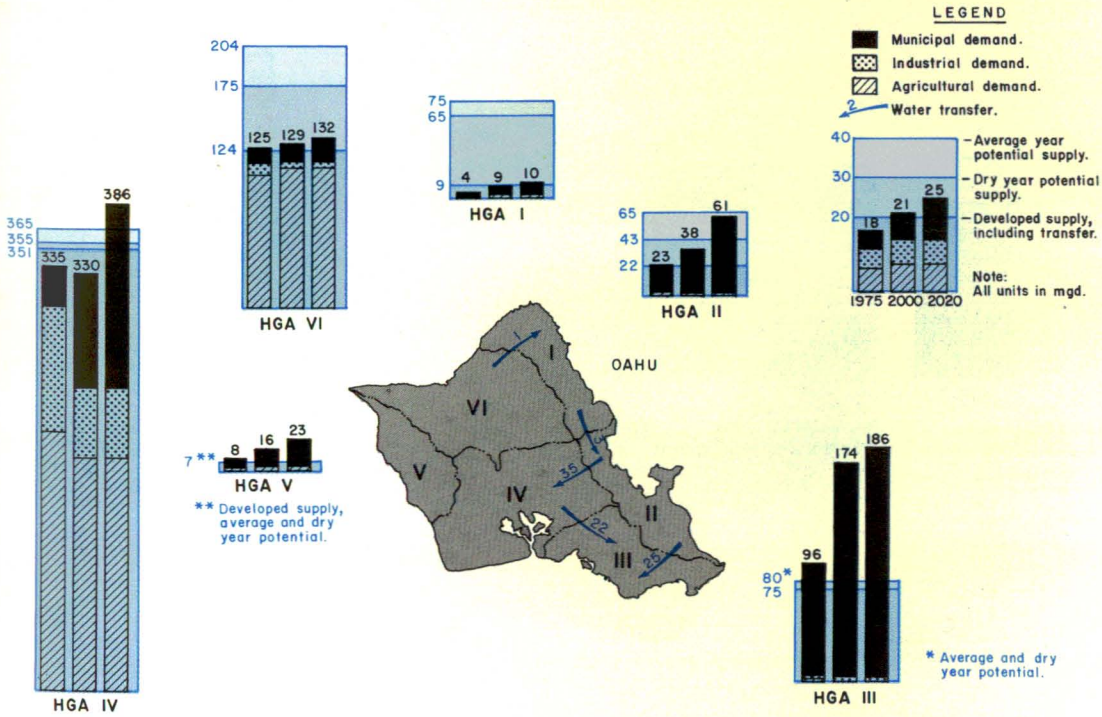


Figure 28. **OAHU WATER SUPPLY AND DEMAND, BY HYDROGRAPHIC AREAS**

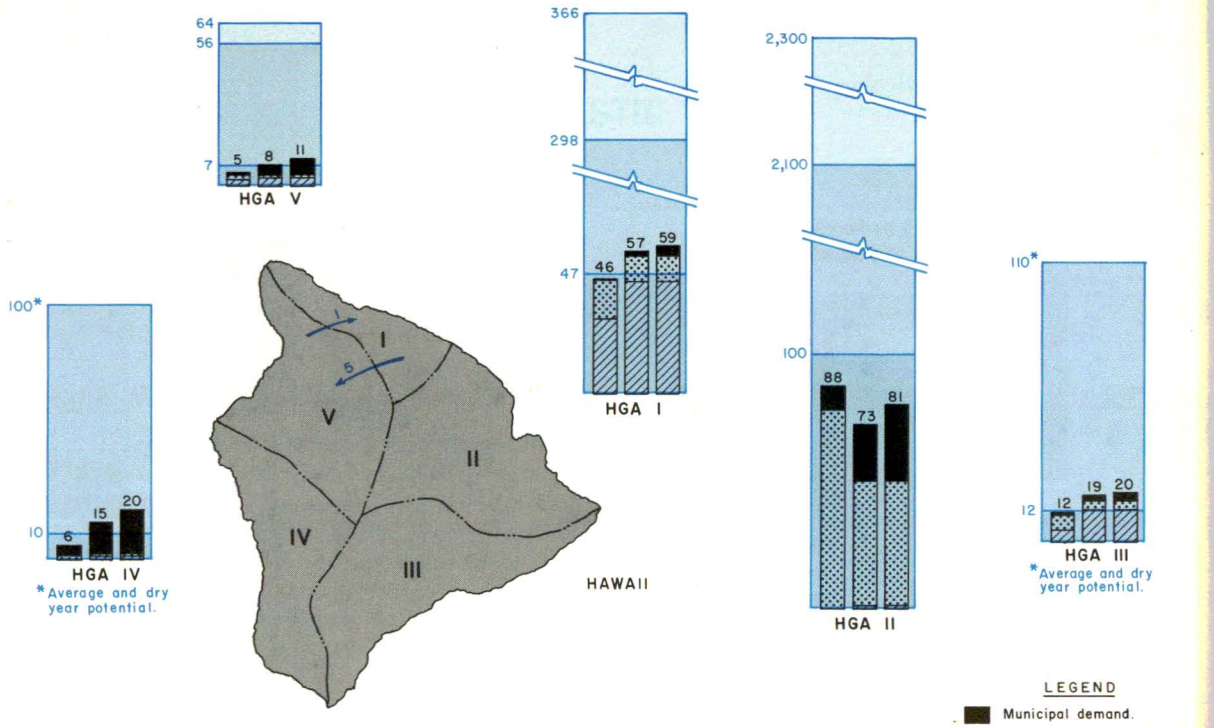


Figure 29. **HAWAII WATER SUPPLY AND DEMAND, BY HYDROGRAPHIC AREAS**

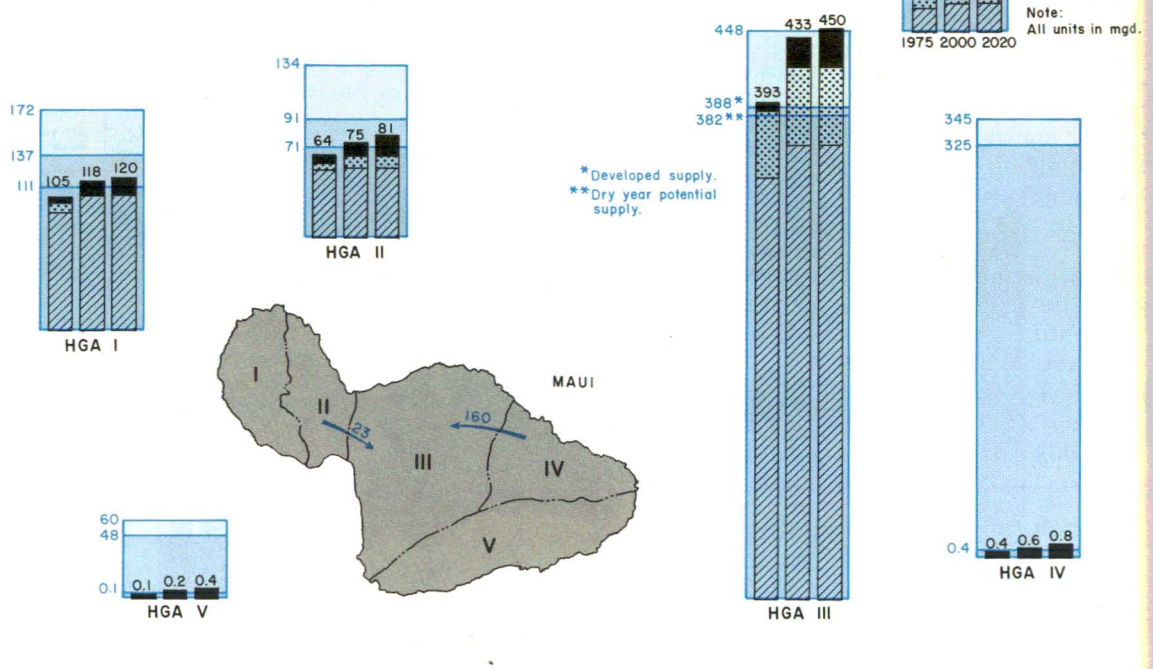


Figure 30. **MAUI WATER SUPPLY AND DEMAND, BY HYDROGRAPHIC AREAS**

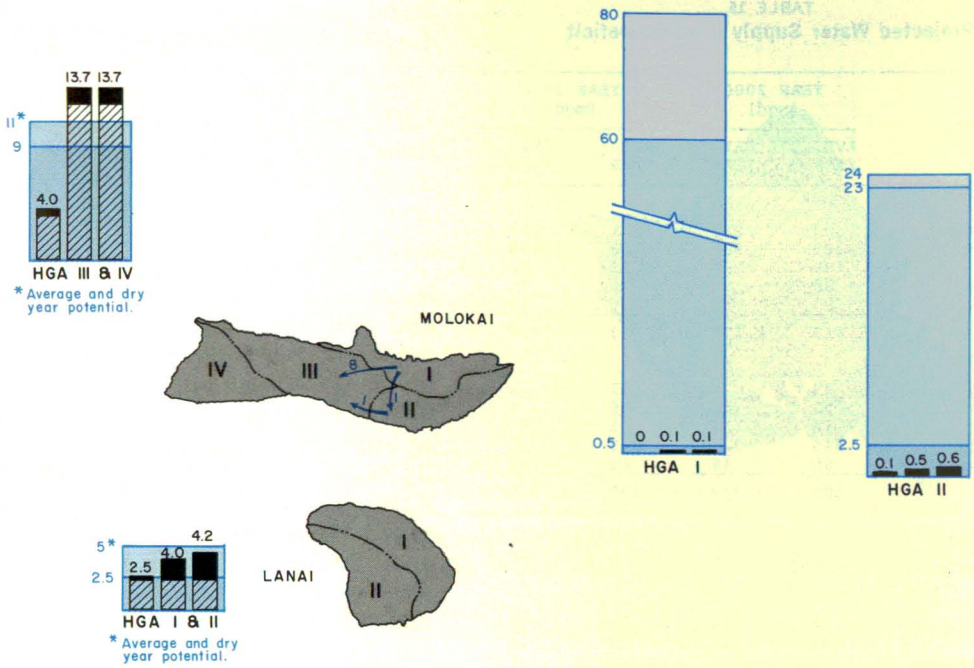


Figure 31. **MOLOKAI AND LANAI WATER SUPPLY AND DEMAND, BY HYDROGRAPHIC AREAS**

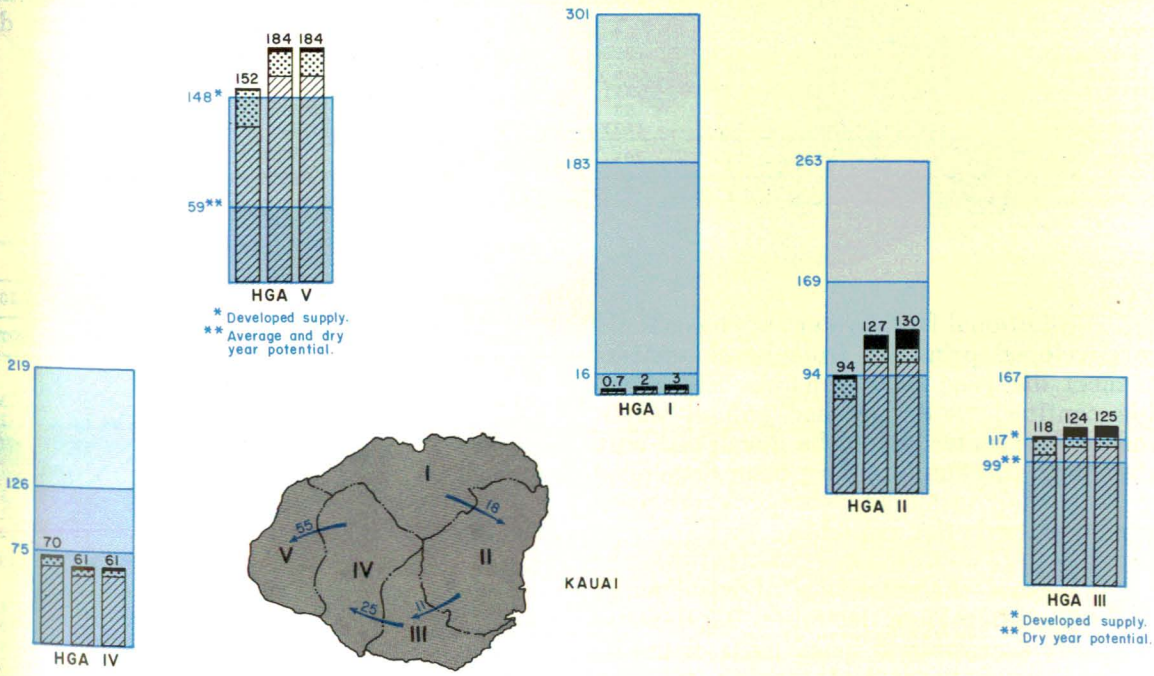


Figure 32. **KAUAI WATER SUPPLY AND DEMAND, BY HYDROGRAPHIC AREAS**

TABLE 15
Projected Water Supply Surplus/Deficit

ISLAND and HGA	YEAR 2000 (mgd) AVE. YEAR	YEAR 2000 (mgd) DRY YEAR*	YEAR 2020 (mgd) AVE. YEAR	YEAR 2020 (mgd) DRY YEAR*
Hawaii				
I-Hamakua	303	235	301	233
II-Hilo	2,185	1,985	2,178	1,978
III-Kau	89	89	88	88
IV-Kona	80	80	76	76
V-Kohala	53	45	50	42
Total	2,710	2,434	2,693	2,417
Maui				
I-Lahaina	39	4	37	2
II-Wailuku	52	10	46	4
III-Makawao	10	(50)	2	(58)
IV-Nahiku	345	325	345	325
V-Kaupo	60	48	60	48
Total	506	337	490	321
Lanai				
I-Maunalei, II-Kaumalapau	0.5	0.5	0.5	0.5
Molokai				
I-Wailau	79	59	79	59
II-Kamalo	21	20	20	19
III-Hoolehua, IV-Mauna Loa	(8)	(8)	(8)	(8)
Total	92	71	91	70
Oahu				
I-Kahuku	60	50	59	49
II-Kaneohe	28	6	5	(17)
III-Honolulu	(77)	(77)	(89)	(89)
IV-Ewa	(24)	(34)	(71)	(91)
V-Waianae	(8)	(8)	(15)	(15)
VI-Waialua	72	43	68	39
Total	51	(20)	(43)	(124)
Kauai				
I-Hanalei	283	165	283	165
II-Lihue	132	38	130	36
III-Koloa	40	(10)	39	(11)
IV-Waimea	151	58	150	57
V-Kekaha	(41)	(41)	(42)	(42)
Total	565	210	560	205

* A year in which streamflow is 60 percent of normal.

Additional fresh water supplies should be developed primarily from basal aquifers to meet the year 2000 demands. High level dike-confined water, perched ground water, and surface water should be developed only after the basal aquifers have been developed to the level of sustained yields or where basal ground water is not available.

Several characteristics of basal water make this alternative desirable. Basal water is readily accessible in many parts of the islands; little water is lost through evaporation; no construction is required to provide storage capacity; and water is of good quality, requiring no treatment. Marginal quality basal water would be the most likely source for desalination where feasible.

On Oahu, restoration of dike storage by bulkheading tunnels and decreasing withdrawals during wet weather could make available up to 30 mgd of additional high level water.

In leeward Oahu about 140 mgd of basal water is used for sugarcane irrigation and mill operations. Of this total, about 50 mgd is high quality water suitable for domestic use. Another 20 mgd can be converted to domestic quality by blending with water of lower mineral content. Thus, if lower quality water suitable for cane irrigation can be developed, up to 70 mgd of fresh basal water might be exchanged with agricultural interests. Preliminarily, the Pearl Harbor Springs surface water at Waiawa, Waikele Stream, and the sewer treatment plant (STP) effluent from Mililani and Honouliuli offer possibilities of exchange for high quality cane irrigaton water.

Other alternative sources such as desalting brackish water, blending of brackish and fresh water, surface water diversion, reuse of domestic wastewater, and desalting of sea water all have long-range possibilities which should be investigated to meet demands beyond the year 2000.

TABLE 16
Hydrographic Areas Needing Additional Municipal Water

ISLAND and HGA	1975 DEMAND	FUTURE NEEDS 1975-2000 ADD.	FUTURE NEEDS 1975-2000 TOTAL	FUTURE NEEDS 1975-2020 ADD.	FUTURE NEEDS 1975-2020 TOTAL
Hawaii					
II-Hilo	9	14	23	21	30
IV-Kona	4	10	14	14	18
V-Kohala	1	3	4	6	7
Maui					
I-Lahaina	4	8	12	10	14
II-Wailuku	4	6	10	12	16
III-Makawao	5	7	12	15	20
Oahu	161	172	333	276	437
I-Kahuku	3	5	8	6	9
II-Kaneohe	21	17	38	40	61
III-Honolulu	89	82	171	94	183
IV-Ewa	31	57	88	114	145
V-Waianae	6	8	14	15	21
VI-Waialua	11	3	14	7	18
Kauai					
II-Lihue	4	9	13	11	15
III-Koloa	2	3	5	4	6

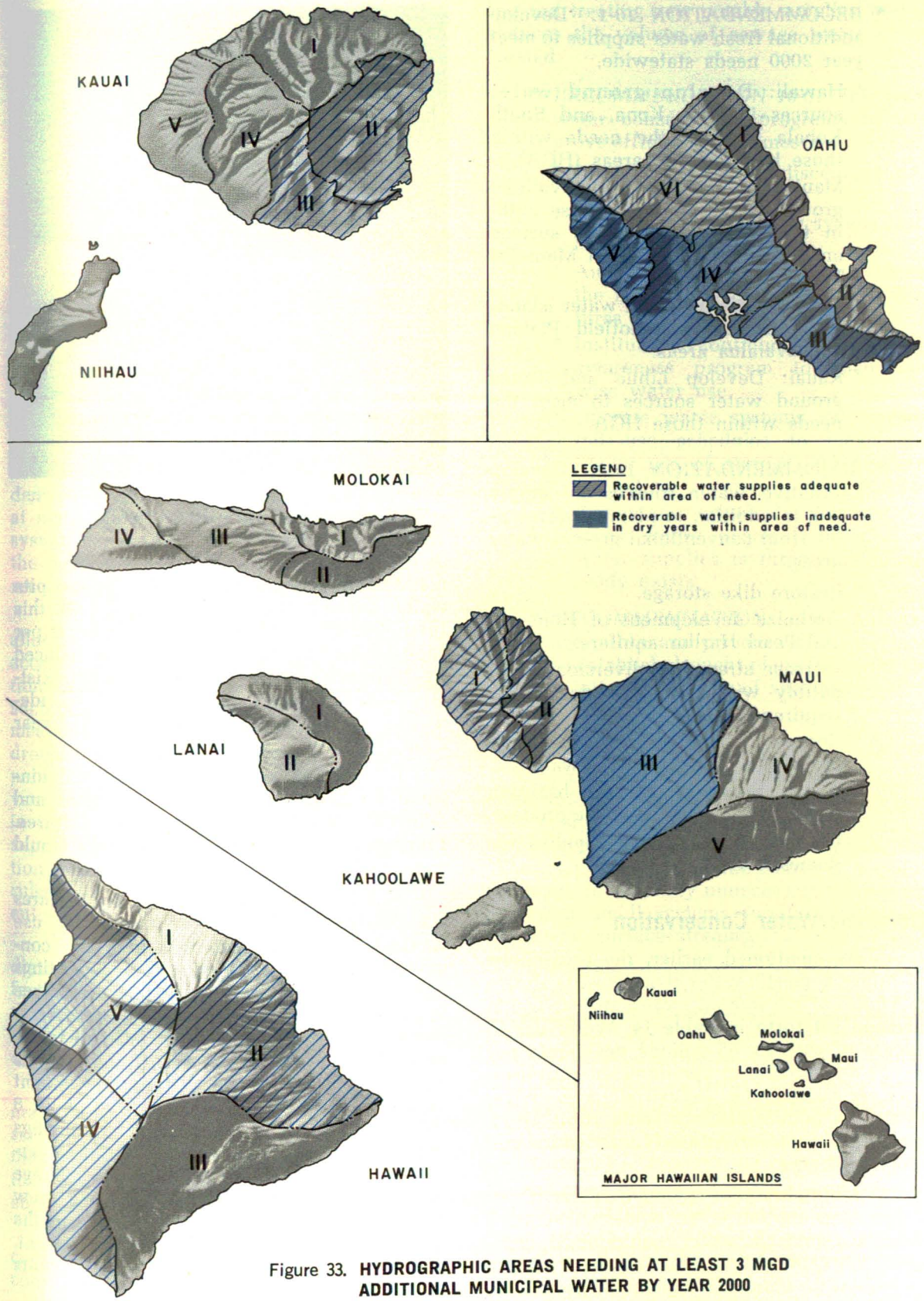


Figure 33. **HYDROGRAPHIC AREAS NEEDING AT LEAST 3 MGD ADDITIONAL MUNICIPAL WATER BY YEAR 2000**

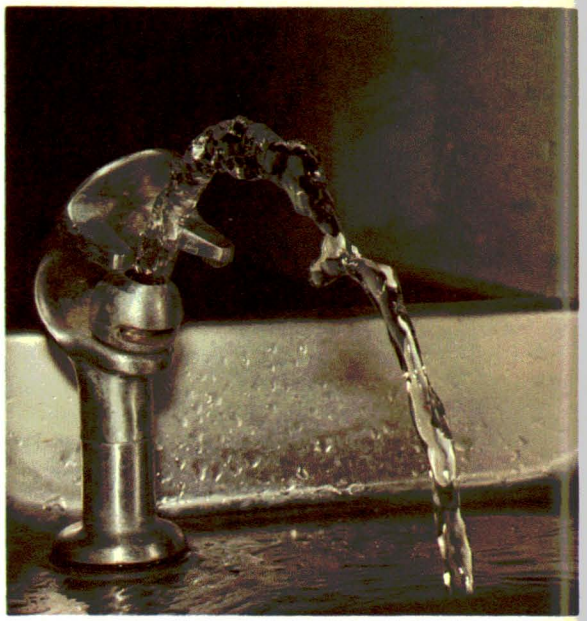
- *RECOMMENDATION 10-1.* Develop additional fresh water supplies to meet year 2000 needs statewide.
  * Hawaii: Develop ground water sources in Hilo, Kona, and South Kohala to meet the needs within those hydrographic areas (HGA).
  * Maui: Develop Lahaina and Wailuku ground water sources for use within the HGA; and develop surface and ground water in East Maui for Makawao HGA needs.
  * Oahu: Develop ground water island-wide, especially Schofield Plateau and Waialua areas.
  * Kauai: Develop Lihue and Koloa ground water sources to meet the needs within those HGA.

- *RECOMMENDATION 10-2.* Develop alternative water sources to supply Oahu, in addition to planned development from conventional ground water sources.
  * Restore dike storage.
  * Optimize development of Honolulu and Pearl Harbor aquifers.
  * Increase streamlow diversions compatibly with minimum streamflow requirements.
  * Recycle wastewater and exchange for high quality irrigation water.
  * Blend potable water with brackish water for a usable domestic product.
  * Desalt brackish water supplies for domestic use.

Domestic Water Conservation

As mentioned earlier, the projections of future domestic water requirements shown in Figure 27 assume an increasing per capita demand set forth in Table 14. Water use in excess of roughly 80 gallons per capita per day is attributable to non-domestic purposes, such as commercial, industrial, lawn irrigation, and public uses. In some rural areas, municipal water is also used for irrigation and stock watering.

Maintaining or reducing present per capita consumption levels would substantially reduce domestic water requirements, especially on Oahu, Maui, and Hawaii. Potential reduction of about 53 mgd in projected demand could be achieved by holding per capita water consumption at 1975 levels. Of this total, 40 mgd could be saved on Oahu. If per capita water consumption could be reduced by 25 percent under 1975 levels, most existing domestic water systems would be adequate with minor additions through the year 2000.



Potable water demand will increase.

Municipal water supplies are diminished by leaks in distribution systems and defective connections, valves, and fixtures. Programs to detect and correct leaks would conserve available supplies.

Reasonably priced plumbing fixtures are on the market that reduce water use without causing inconvenience to the consumer. Shower, lavatory, and sink fittings have floor regulators and valves to reduce water use. An average shower, which requires 35 to 40 gallons of water, can be reduced by about 50 percent. Toilet fixtures are available which can reduce the amount of water used for each flush from about 8 gallons to less than 4, an important savings inasmuch as toilets account for about 45 percent of all the water used in the average household. Appliances and fixtures now available can reduce total water use in the average household by as much as 35 percent, and savings for commercial establishments can be as high as 50 percent.

Most systems have assessed progressively lower charges per unit as more water is consumed. Hence, there has been little incentive to avoid excessive use. Such rate structures have been justified by the increased efficiency of large-scale systems. Now, in the light of higher energy costs and the trend toward conservation of resources, the rate structures are being questioned and, in some cases, revised to require an increase in rates above certain threshold use levels. Complicating this procedure is the fact that some small farming operations are supplied from municipal systems, and large increases in water rates could work against the avowed state policy of encouraging diversified agriculture.

Municipal water management might include a sequence of uses and reuses. For example, sprinkler irrigation of parks and golf courses as well as private lawns and gardens could be scheduled for off-peak periods at night. This would more efficiently utilize system capacity and might obviate or limit the need for new investments in additional reservoir or pipeline capicity.

The need to conserve water and to allocate the existing supply among users is accentuated during times of drought. Restrictions are usually applied as needed during such periods. The public's acceptance of such measures would be enhanced if general drought plans were developed and widely publicized. Water users would know in advance what arrangement must must be made in order to assure themselevs of a certain supply in times of shortage. Standard allocation rules, rather than sporadic emergency rules, would also encourage the most efficient and equitable water use allocation.

Conservation of water offers an immediate, low-cost method of increasing the effective supply, but in order to fully realize these advantages, educational institutions must increase their commitment to teaching conservation to the public.

By means of a public relations program, consumers might be encouraged to conserve water. Consumers should respond once they are aware of resource limitations and the cost of developing and distributing new supplies.

Wise use of domestic water not only conserves available supplies for use by more consumers; it also saves the cost of developing and treating new potable supplies, and it reduces the volume of sewage water to be treated.

- *RECOMMENDATION 10-3.* Intensify water conservation programs to improve efficiency of domestic water use.
  - * Set water rates to discourage excessive use.
  - * Institute rigorous water system leak control programs.
  - * Amend plumbing codes to require the installation of water-saving fixtures and appliances.
  - * Institute a continuous community awareness program to encourage wise water use.
  - * Operate water systems on sequential use schedules to make optimum use of storage and pipeline capacities.
  - * Discourage urban development in areas where overdraft of ground water supplies is threatened or already exists.
- *RECOMMENDATION 10-4.* Encourage public and private water suppliers to establish drought plans for water allocation in periods of shortage.

Safe Drinking Water

Except for chlorination, most of the domestic water supplied to consumers in Hawaii does not undergo any significant treatment for physical or biological contaminants. Where ground water is the source of supply, treatment is generally unnecessary. However, numerous small systems supply water from ditches or surface streams.

Potable "drinking" water systems cannot tolerate—and are prohibited by law from tolerating—any compromise with public health. Such water systems have to deliver water free from pathogenic (disease causing) organisms, toxic material, and other substances that could be harmful to consumers.

The Safe Drinking Water Act of 1975 (PL 93-523) has brought the present municipal and privately owned water systems under state surveillance. The Act mandates strict water quality standards for water systems serving 25 or more persons. Compliance with the new standards generally will be difficult

and expensive. Many existing sources will require additional treatment in order to comply with the new standards.

At least 143 water systems in Hawaii supplying 25 people or more are subject to the Safe Drinking Water Act. Of these systems, 56 are operated by county governments and 87 are private. Many of the rural systems rely on surface water supplies which often have undesirable taste, odor, turbidity, and bacterial levels, especially during rainy seasons. Some of the older systems have seriously deteriorated storage and transmission facilities.

Many of the smaller systems will be unable to meet the requirements of the Act without large capital investments. As a result, some plantations may have no choice but to close facilities, thus requiring extension of county systems to meet the needs of present consumers.

Even those systems meeting the quality standards of the Act will be required to conduct extensive water sampling and monitoring programs. The law also requires that the states set standards for the quality of ground water sources used for domestic supplies.

Federal and state assistance will be required to construct treatment facilities needed to improve drinking water quality.

- *RECOMMENDATION 10-5.* Improve domestic water systems to insure that water quality meets minimum standards of the Safe Drinking Water Act of 1975.
  - * Obtain federal and state assistance for construction.
  - * Conduct research on the chemical and biological quality of surface water in watersheds.
  - * Construct water treatment plants for systems utilizing surface water sources.
  - * Where feasible, convert systems from surface water to ground water sources.
  - * Prevent pollution of existing sources by controlling land use in watersheds, waste injection, and overdraft of basal sources.
  - * Initiate water quality monitoring and control.

Rural Domestic Water Service

Rural water systems must be improved in order to supply adequate quantities and maintain sufficient pressures for domestic consumption and fire-fighting purposes. Particular attention must be given to source dependability under drought conditions.

Maintenance of fire-fighting capability is an important function of a water system. Insurance premiums are determined largely through the fire insurance "classification" system. This insurance rating is established by volume, rate, pressure, and dependability requirements for the water system.

Many small rural systems are approaching the end of their useful lives and will require extensive renovation or reconstruction in order to continue to supply even a minimum of service. The prohibitive cost of renovating small plantation systems may accelerate an already growing tendency to close plantation housing. This will shift the burden of providing water on public systems nearer urban centers.

Where rural water systems rely on surface sources, especially run-of-the-stream diversions, lack of adequate storage facilities tend to accentuate the impact of droughts. Hawaii County Civil Defense Agency hauls water for domestic use during droughts at Hamakua, Waimea, Kona, and Kohala. Drought at Kula, Maui, has at times required rationing of domestic water.

- *RECOMMENDATION 10-6.* Improve rural domestic water systems to deliver a dependable supply in adeqaute quantities and at sufficient pressures for droughts and fire-fighting.
  - * Provide county water departments with legal authority to acquire control of surface and ground water sources for each system.
  - * Develop sources by stages to meet year 2000 demands.
  - * Replace deteriorated pipelines and storage tanks and provide additional storage.
  - * Design systems to meet average and peak demands at adequate pressures.
  - * Include adequate fire-fighting capabilities in system design.

11. DOMESTIC WASTEWATER

Historically, wastes from Hawaii's land area have been disposed of in the ocean. Until the last decade, most urban sewage was disposed of in cesspools or as raw discharge through shoreline outfalls. Sewage in rural areas is generally discharged into cesspools even today.

Emphasis on water pollution control has resulted in the construction of numerous treatment plants for urban sewage in recent years. Also, the resource value of wastewater is now being considered.

Planning for future wastewater services must focus on the following matters.

Reuse of Treated Sewage Effluent

At many locations, substantial quantities of high quality wastewater are being discharged into the ocean or into disposal wells only a few miles from an area of potential use. A policy of reclaiming all substantial waste discharges for beneficial use could greatly reduce the need to develop new water sources. Fertilizer costs might also be reduced and the aquatic environment improved.

A growing body of evidence suggests minimal hazards from the use of adequately treated domestic wastewater for sugarcane irrigation. However, continuing research is needed to determine the safe level of treatment. (See Chapter 14, Irrigation Water Supply.)

The allocation of costs to the various users of such water must also be resolved, including agreements for trades of high and low quality water and the construction of distribution facilities. Coordination is needed to assure that plants are located as near as possible to an area of potential reuse. Such coordination will require close cooperation between the agencies supplying water and those planning for its disposal as waste.

Existing and proposed sewage treatment plants are shown in Figure 34, together with irrigable land and agricultural parks.

Sewage treatment plant, Kaneohe, Oahu.

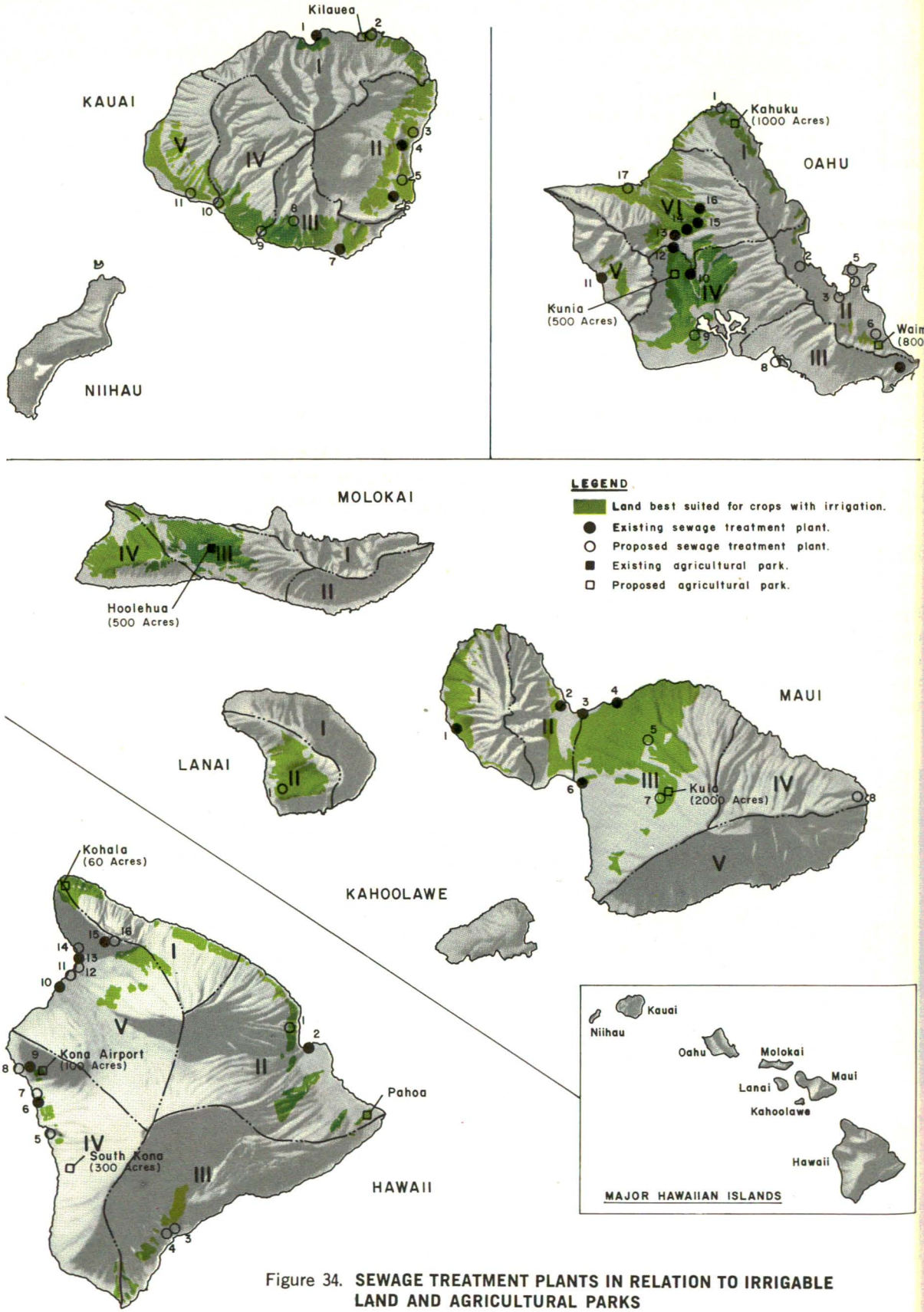


Figure 34. **SEWAGE TREATMENT PLANTS IN RELATION TO IRRIGABLE LAND AND AGRICULTURAL PARKS**

Estimated quantities of effluent available by 1985 are given in Table 17.

- *RECOMMENDATION 11-1.* Reuse treated sewage effluent water for beneficial purposes.
  - * Locate new treatment plants near agricultural operations.
  - * Encourage agricultural operations to locate near existing sewage treatment plants where feasible.
  - * Use effluent water for industrial cooling or processing.
  - * Apply treated effluent to forest watersheds where compatible.
  - * Design waste treatment and reuse as part of a single system to irrigate golf courses, lawns, or other open space.

Integrated Wastewater and Water Supply Management

Wastewater is a resource that can be used either directly or in exchange for other sources of water supply. However, administration of wastewater and water supply services is segregated at both state and county levels. Integrated management at each government level is desirable for more effective reclamation and reuse of wastewater.

- *RECOMMENDATION 11-2.* Consider integration of domestic water supply and wastewater management functions at both state and county levels.

Consolidated Urban Sewer Systems

Hawaii is embarked on an extensive program for the collection and treatment of municipal waste. Wastewater treatment facilities (municipal, military, and private) treat domestic sewage by conventional processes, the majority by biological secondary treatment. A few sewage plants are strictly primary treatment facilities, and only one advanced (tertiary) wastewater treatment plant is in operation, at Kahaluu on Oahu. Private plants which handle domestic or industrial

TABLE 17
Major Sewage Treatment Plants

ISLAND and MAP NO.	LOCATION	CAPACITY (mgd)	STATUS
Hawaii			
1	Papaikou-Paukaa	0.5	o
2	Hilo	7.0	●
3	Punaluu	0.8	o
4	Honuapo Bay	0.6	o
5	Kealakekua Bay	1.2	o
6	Keauhou Bay	1.0	●
7	Kamoa Point	0.8	o
8	Kailua-Kona	1.5	o
9	Kailua-Kona	0.3	●
10	Boise Cascade	0.25	●
11	Signal Oil	0.5	o
12	Hapuna Bay	0.35	o
13	Maunakea Beach Hotel	0.25	●
14	Kawaihae	0.75	o
15	Waimea	0.25	●
16	Waimea	0.75	o
Maui			
1	Lahaina	6.0	●
2	Wailuku	3.4	●
3	Kahului	3.9	●
4	Paia	0.5	●
5	Pukalani Terrace	1.0	●
6	Kihei	1.0	●
7	Kula	1.0	o
8	Hana	0.2	o
Lanai			
1	Lanai		o

ISLAND and MAP NO.	LOCATION	CAPACITY (mgd)	STATUS
Oahu			
1	Kahuku	2.3	o
2	Kahaluu	1.2	o
3	Kaneohe	5.6	●
4	Kailua	8.4	●
5	MCAS	2.0	●
6	Waimanalo	1.7	●
7	Hawaii Kai	4.0	●
8	Sand Island	77.0	o
9	Honouliuli	21.0	o
10	Mililani	5.0	●
11	Waianae	5.7	●
12	Schofield	1.64	●
13	Wahiawa	1.9	●
14	Whitmore Village	0.18	●
15	NCS (U.S. Navy)	0.3	●
16	Halemano	0.5	●
17	Waialua	2.1	o
Kauai			
1	Hanalei	2.4	●
2	Kilauea	0.6	o
3	Kapaa	5.3	o
4	Wailua	2.5	●
5	Hanamaulu	1.4	o
6	Nawiliwili	7.1	●
7	Koloa-Poipu	5.2	●
8	Kalaheo	0.5	o
9	Hanapepe	3.8	o
10	Waimea	1.2	o
11	Kekaha	2.2	o

● Existing o Proposed

wastes are generally package treatment units.

With a growing urban population and legal requirements for elimination of point-source discharges, municipal sewer systems are becoming more cost-effective. Advantages of scale can be realized in the disposal of wastewater from municipal plants, whether the water is to be reused, disposed of by ocean outfall, or injected into saline aquifers.

The large volume of urban sewage can best be treated by a consolidated system of waste collection, treatment, and disposal, including distribution facilities to use treated wastewater for irrigation.

- *RECOMMENDATION 11-3.* Provide consolidated sewer systems for urban areas.
  - * Expand existing systems and provide new interceptors and treatment facilities.
  - * Dispose of wastewater by deep ocean outfalls or underground injection where reuse is infeasible.

Effluent Treatment in Rural Communities

Improved methods of sewage disposal other than cesspools and seepage pits are needed for rural communities located upstream of surface water sources, over ground water sources, and along shorelines.

Low-cost service of an intermediate scale is needed to protect the health of the populace and to preserve the environment. Such facilities are particularly urgent where present sewage disposal methods pose a contamination hazard to surface, ground, and coastal water.

- *RECOMMENDATION 11-4.* Provide adequate treatment facilities for individual houses and towns located in rural areas.
  - * Use package treatment systems or septic tanks.
  - * Separate wastewater from various sources to reduce treatment needs.
  - * Use waterless systems and on-site disposal of solid wastes.

12. FLOOD PROTECTION

Flood damage in Hawaii has been large and extensive, aggregating $102,690,000 from 1900 to 1070. See Figure 35 for flood problem areas in Hawaii. Major water resource planning goals relating to floods are the following.

Storm flooding.

Losses Caused by Storm Flooding

Although substantial sums have been expended to provide a high degree of flood protection in many areas, other areas are still vulnerable. This was demonstrated when a flood of unusual magnitude struck the Kamooalii-Kaneohe drainage area of Oahu in February 1969, taking at least three lives and causing damage, estimated at $554,000 at Keapuka subdivision alone. Table 18 lists those areas depicted in Figure 35 which are subject to serious storm flooding.

Damage from storm floods may be reduced by structural measures to lower flood peaks or channelize flow, by flood proofing to protect developments in the flood plain, by controlling land use in flood-prone areas, and by protection of watersheds.

Increasingly, the emphasis is on zoning to prevent urbanization of flood plains and on flood proofing. This trend has been accelerated by requirements of the federal flood insurance program. The program pro-

Inundated flood plain, Hanalei, Kauai.

vides low-cost insurance for existing structures, but requires high premiums for new development unless adequate measures are taken for flood protection.

A continuing program of mapping flood-prone areas is needed to fully define hazard levels and to guide future development. Present programs defining the flood hazard for all built-up areas and those subject to development in the next five years are being pursued through county flood insurance coordinators.

- *RECOMMENDATION 12-1.* Reduce the loss of life and property damage caused by storm flooding.

  * Provide non-structural measures such as regulation of flood plain use, zoning, building codes, and flood insurance.

  * Provide structural measures such as dams, lined channels, and flood proofing where non-structural measures are inadequate.

  * Improve flood peak records, flood mapping, and damage surveys.

Losses Caused by Tsunami and High Surf

The toll in human lives and damages is, by far, the greatest from tsunami flooding. The most vulnerable area is Hilo. Since 1819, 352 lives have been lost due to tsunami; a total of 234 lives were lost during the April 1946 and May 1960 tsunami alone. Damages from those two tsunami were in excess of $55 million. See Table 19 for those areas shown on Figure 35 which have been damaged by tsunami flooding.

High surf generally affects the exposed

northerly sections of each island. Damage has been heaviest on Oahu because of extensive development in the coastal zone of the north shore. Table 20 lists areas subject to flooding from high surf, shown in Figure 35.

The Hawaii legislature in 1975 enacted

TABLE 18
Storm Runoff Flooding

ISLAND and MAP NO.	LOCATION
Hawaii	
3	Honokaa
8	Wailuku River, Lower Waiakea Homestead, Alenaio Stream and Waiakea-Uku
8a	Mountain View
10	Volcano Farm Lots
11	Volcano Area
16	Honuapo Area
18	Waiohinu
22	Honaunau-Napoopoo
24	Kailua-Kona
26	Puako
27	Waimea
Maui	
2	Olowalu Stream
3	Puamana-Kahoma
4	Honolua Stream
5	Honolua Area
6	Honolua Area
11	Iao Stream-Happy Valley
12	Kahului
16	Wailua
21	Kihei-Makena Area
22	Kihei-Makena Area
23	Kihei-Makena Area
24	Kihei-Makena Area
25	Kihei-Makena Area
Molokai	
5	Kapaa Kea Homestead
6	Kaunakakai
Oahu	
1a	Kahaluu Area
2	Keaahala Stream
3	Kawa Stream
5a	Waimanalo
10	Wailupe Stream, Waialae Iki
11	Makiki, Palolo, Manoa Stream
13	Kalihi-Moanalua Stream
15	Waiawa Stream
16	Waikele Stream
17	Honouliuli Stream
19	Nanakuli
22	Makaha
23	Waialua
25	Haleiwa Area
Kauai	
2	Wainiha Valley
3	Hanalei River
9	Anahola Stream
11	Kapaa-Kealia
12	Wailua River
14	Pauli Stream
15	Poipu-Koloa
18	Lawai Stream
19	Hanapepe
22	Waimea
23	Kekaha

TABLE 19
Tsunami Flooding

ISLAND and MAP NO.	LOCATION	YEAR OF MAXIMUM TSUNAMI	MAXIMUM TSUNAMI RUN-UP (feet)
Hawaii			
2	Waipio Bay	1946	40
4	Laupahoehoe	1946	30
5	Hakalau	1946	37
7	Hilo Bay	1946	35
9	Olaa	1946	24
12	Cape Kumukahi to Kalapana	1946	20
14	Punaluu	1946	13
16	Honuapo	1946	13
20	Hoopuloa	1957	5
21	Hookena to Kailua	1946	13
25	Kiholo	--	--
26	Kawaihae	1946	12
29	Mahukona	1946	14
Maui			
1	Olowalu to Lipoa Point	1946	10
7	Honokohau	1946	27
8	Kahakuloa	1946	33
9	Waihee to Pauwalu Point	1946	28
13	Keanae	1946	12
14	Pauwalu Point	1964	5
15	Wailua	1946	30
17	Hana Bay	1946	13
18	Hana	1946	23
19	Kihei-Makena	1946	13
Lanai			
1	Kaumalapau	--	--
2	Manele Bay	--	--
Molokai			
2	Kalaupapa	1946	20
3	Halawa	1946	31
4	Waialua to Kaunakakai	1946	39
7	Papohaku to Ilio Point	1946	39
9	Kawaaloa Bay	1946	44
Oahu			
1	Kaena Point to Kualoa Point	1946	34
4	Mokapu Peninsula	1946	21
5	Kapoho Point to Makapuu Beach	1946	37
7	Kaloko to Palea Point	1946	31
8	Hanauma Bay	1946	11
9	Koko Head to Diamond Head	1960	8
12	Diamond Head to Keehi Lagoon	1960	9
14	Ahua Point to Barbers Point	1946	12
20	Nanakuli to Makua	1946	34
Kauai			
1	Haena Point to Puu Poa Point	1957	53
5	Kalihiwai Bay	1946	28
6	Moloaa Bay	1946	40
7	Papaa-Anahola Bay	1946	17
10	Kealia to Hanamaulu	1946	40
13	Nawiliwili Bay	1946	14
16	Poipu to Maka O Kahai	1957	9
20	Hanapepe to Barking Sands	1946	24

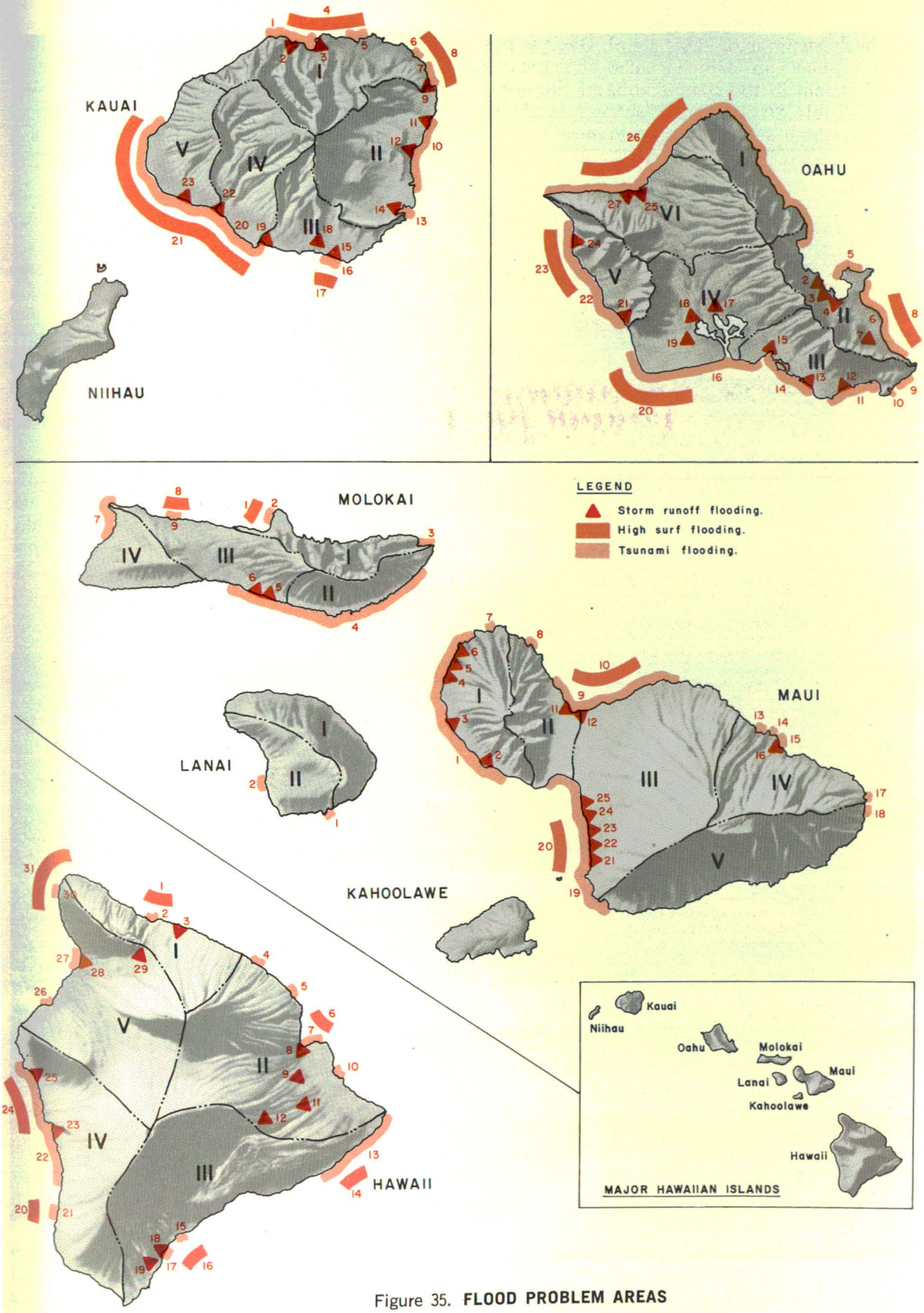


Figure 35. **FLOOD PROBLEM AREAS**

TABLE 20
High Surf Flooding

ISLAND and MAP NO.	LOCATION
Hawaii	
1	Waipio Bay
6	Hilo Bay
13	Kalapana
15	Nahuluhulu Point to Kimo Point
19	Kailua to Cook Point
23	Haena
28	Honoipu Landing
Maui	
10	Naiehu to Maliko Bay
20	Kihei to Makena
Molokai	
1	Kalaupapa
8	Moomomi
Oahu	
6	Kapoho Point to Makapuu
18	Ewa Beach to Barbers Point
21	Nanakuli to Makua
24	Kahuku to Kaena Point
Kauai	
4	Haena Point to Kilauea Point
8	Kepuhi Point to Kahala Point
17	Poipu to Maka O Kahai
21	Hanapepe to Barking Sands

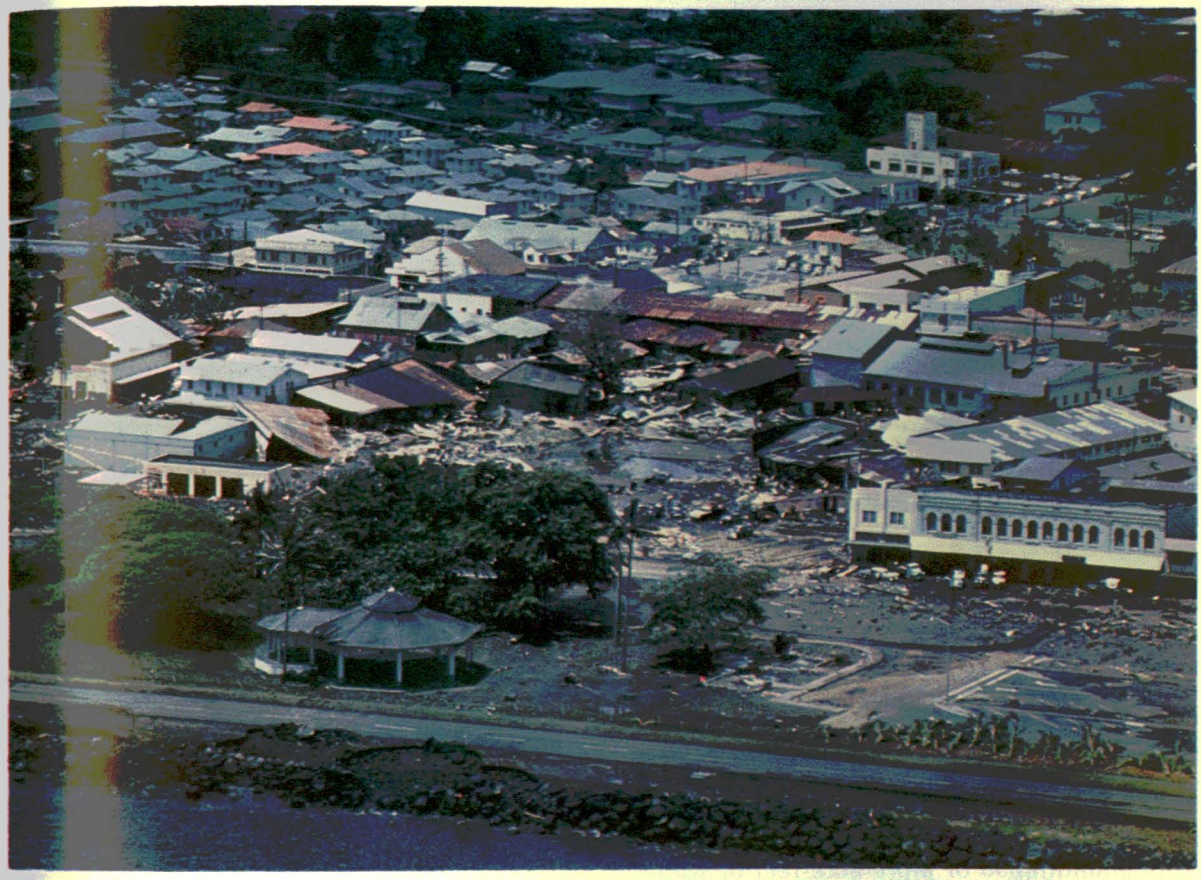
the Hawaii Shoreline Protection Act, which requires shoreline setbacks and special management zones. Implementation by the counties will restrict coastal development and reduce future damages from tsunami and high surf.

- *RECOMMENDATION 12-2.* Reduce the loss of life and property damage caused by tsunami and high surf.
  - * Provide non-structural measures such as regulation of flood plain use, zoning, building codes and flood insurance.
  - * Control coastal development in areas most subject to tsunami and high surf.

Flood Forecasting and Warning

Since 1867, 123 persons in Hawaii are known to have drowned in rainstorm floods. The greatest hazard in many areas is from local flash floods. A flash flood is caused by rainfall of high intensity and short duration

Stream channelization.



Tsunami devastation, Hilo, Hawaii.

which produces maximum runoff and rapid recession.

Flash floods are frequent in Hawaii, where drainage areas are small and slopes are relatively steep. It is not uncommon for a flash flood to occur in a sunny and dry area as a result of intense rainfall in upper reaches of a watershed. There is very little time to warn of an impending flash flood.

Although earth satellite imagery has aided greatly in forecasting the general weather over Hawaii, prediction of flash floods is difficult at best. Specially designed radar equipment for analyzing the growth of storm intensity is not available in Hawaii. Such equipment would improve flash flood prediction enough for effective warning in many cases.

The prediction of flash floods can be enhanced by taking full advantage of the latest equipment and techniques under joint state-federal programs.

There was little or no warning of a recent tsunami on the Island of Hawaii generated by a local earthquake. At least one life was lost, and several persons were caught in tidal waves. This recent occurrence emphasizes the need to develop an adequate warning system for tsunami generated by local earthquakes.

- *RECOMMENDATION 12-3.* Enhance flood forecasting and warning systems.
  - * Obtain most advanced radar systems for detecting storm conditions prior to flash flooding.
  - * Develop methodology for flash flood forecasting in an island environment.
  - * Develop adequate warning system for tsunami generated by local earthquakes.
  - * Conduct education programs concerning warning systems and flood hazards.

Alexander Dam, Kalaheo, Kauai.

Dam Safety

After disasters caused by failure of dams in West Virginia and South Dakota, Congress enacted the National Dam Inspection Act of 1972 (PL 92-367), calling for an inventory of dams 25 feet or more in height or impounding 50 or more acre-feet of water. The act also requires a comprehensive national program of inspection and regulation of all dams for safety purposes, to be conducted by federal, state, and local governments and by private interests.

The inventory phase of the program has been completed by the U.S. Army Corps of Engineers. In Hawaii, 119 dams are included in the inventory. Of these, 63 are rated as having high or significant hazard potential, based upon downstream population. See Figure 36 and Table 21.

Cost of the initial inspection of all the inventoried dams in Hawaii is estimated at $900,000. Annual cost of inspecting the high-hazard dams is estimated at $55,000. To date, no funds have been appropriated for dam inspection in Hawaii.

A state-federal program is needed to assure regular safety inspection of major dams in the state.

- *RECOMMENDATION 12-4.* Ensure the safety of existing dams.
  - * Fund and implement dam inspection provisions contained in PL 92-367.
  - * Determine the safety of dams included in Corps of Engineers inventory by field inspection and analysis.
  - * Inspect smaller dams not included in Corps of Engineers inventory at locations where failure would pose downstream hazards.
  - * Take corrective action to remove hazards.

TABLE 21
Dams with High and Significant Hazard Potential

ISLAND and MAP NO.	DAM	NEAREST DOWNSTREAM COMMUNITY	YEAR BUILT
Hawaii			
1	Hawi No. 5 Reservoir	Hawi Village	1930
2	Puuokumau Reservoir	Hawi Village	1930
3	Kehena Reservoir	Hawi Village	1930
4	Lalakea Reservoir	Kukuihaele	1971
5	Puukapu Watershed Retarding Dam R-1	Waimea	1965
6	50 M.G. Waikoloa Reservoir	Waimea	1957
Maui			
1	Honokowai Reservoir	Honokowai	1918
2	Upper Field 30 Reservoir	Honokowai	1926
3	Hanakaoo Reservoir	Puukolii	1918
4	Horner Reservoir	Puukolii	1918
5	Kahoma Reservoir	Lahaina	1918
6	Wahikuli Reservoir	Lahaina	1918
7	Reservoir 73	Kahului	1908
8	Reservoir 74	Kahului	1916
9	Reservoir 60	Spreckelsville	1917
10	Reservoir 25	Upper Paia	1917
11	Reservoir 22	Upper Paia	1917
12	Reservoir 24	Upper Paia	1917
13	Reservoir 21	Upper Paia	1913
14	Reservoir 14	Kuau	1913
15	Haiku Reservoir	Haiku	1904
16	Pauwela Reservoir	Haiku	1904
17	Olinda Reservoir	Makawao	1910
Molokai			
1	Kualapuu Reservoir	Kualapuu	1969
Oahu			
1	Nuuanu Dam No. 4	Honolulu	1910
2	Reservoir 545A	Pac. Palisades	1935
3	Reservoir 530	Pearl City	1935
4	Reservoir 510	Pearl City	1935
5	Reservoir 410B	Waipahu	1930
6	Reservoir 205A	Waipahu	1925
7	Reservoir 220B	Waipahu	1925
8	Reservoir 155A	Waipahu	1925
9	Reservoir 245A	Waipahu	1935
10	Reservoir 245B	Waipahu	1935
11	Wahiawa Dam	Waialua	1906
12	Ku Tree Reservoir	Wahiawa	1924
13	Kemoo 5 Reservoir	Waialua	1920
Kauai			
1	Puu Ka Ele	Kilauea	1932
2	Upper Kapahi Reservoir	Kapahi	1910
3	Lower Kapahi Reservoir	Kawaihau	1920
4	Twin Reservoir	Wailua	1920
5	Wailua Reservoir	Wailua Homesteads	1920
6	Kapaia Reservoir	Kapaia	1910
7	Okinawa Reservoir	Kapaia	1920
8	Mauka Reservoir	Koloa	1910
9	Puu O Hewa Reservoir	Koloa	1915
10	Pia Mill Reservoir	Koloa	1910
11	Waita Reservoir	Koloa Mill	1905
12	Aepoeha Reservoir	Kukuila	1915
13	Aepo Reservoir	Kukuila	1910
14	Aepoalua Reservoir	Kukuila	1915
15	Aepoekolu Reservoir	Kukuila	1910
16	Huinawai Reservoir	Lawai	1902
17	Piwai Reservoir	Omao Homesteads	1915
18	Alexander Dam	Kalaheo	1931
19	Elima Reservoir	Kalaheo	1901
20	Elua Reservoir	Kalaheo	1910
21	Ipuolono Reservoir	Numila	1910
22	Mau Reservoir	Kalaheo	1901
23	Hukiwai Reservoir	Numila	1910
24	Kapa Reservoir	Eleele	1910
25	Kaawanui Reservoir	Kaawanui	1950
26	Puu Opae Reservoir	Mana	1930

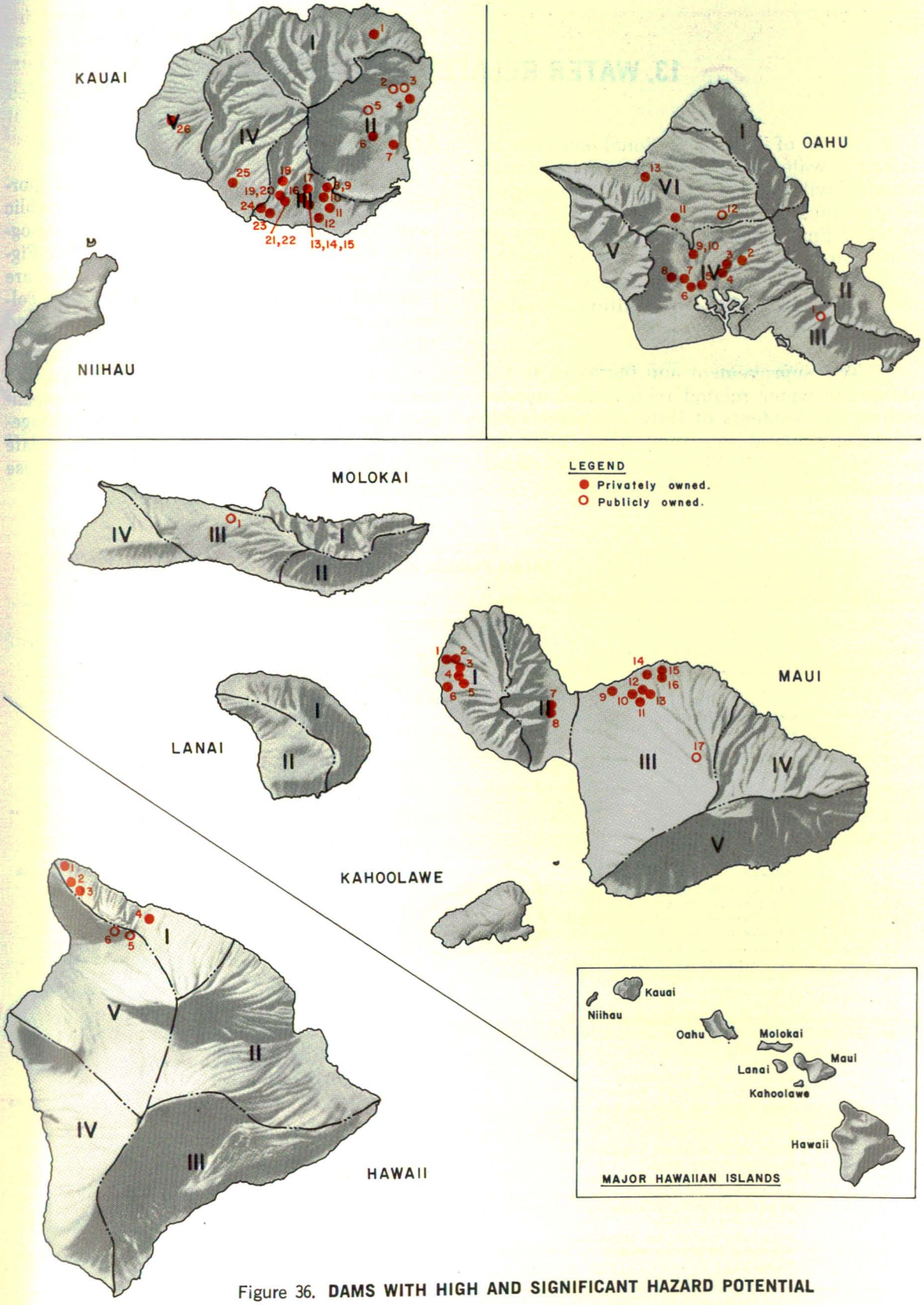


Figure 36. **DAMS WITH HIGH AND SIGNIFICANT HAZARD POTENTIAL**

13. WATER RELATED RECREATION

Much of the recreational activity in Hawaii is water oriented. Future recreational planning will be concerned with increasing the facilities for water related recreation. Principal limitations upon the availability of recreation resources are private ownership of lands, inaccessibility of many publicly owned lands, and the competition of other land uses.

The improvement and increases in facilities for water related recreational opportunities for residents of Hawaii involve both coastal and inland recreation. Major planning concerns in providing increased water related recreation include the following.

Access to Shoreline and Inland Sites

Even though the wave-washed portions of shorelines are deemed to be public property, access is often restricted by topography or by private land ownership. See Figure 37 and Table 22. Where access lanes are provided, lack of patrolling and rubbish collection may create nuisances for users and adjacent land owners.

Continued shoreline development will make acquisition of access lanes more expensive and difficult. The Coastal Zone Management Plan and recent legislation to regulate shoreline development may alleviate these problems somewhat.

TABLE 22
Access Problem Areas

ISLAND and MAP NO.	LOCATION
Hawaii	
1	Waipio Valley to Pololu Valley
2	Keaa, Hanapai, Kapulena & Honokaia
3	Nienie & Ahualoa
4	Kalopa
5	Paauilo
6	Hoea Kaao
7	Manowaialee
8	Humuula
9	Laupahoehoe
10	Piha
11	Opea
12	Kamaee
13	Kawiki & Honomu
14	Leleivi Point to Papai
15	Kamehame Hill to Naliikakani
16	Kapapalu & Kau Forest Reserves
17	Pohue Bay to Puu Hou
18	Lae O Kamoi to Awili Point
19	Okoe Bay to Kanewaa Point
20	Kipahoehoe
21	Kuuhako Bay
22	Olelomoana Opihihali
23	Kikuiopae
24	Papa Bay
25	Kaohe
26	Mahaiula to Honokahau
27	Mauna Loa Forest Reserve
28	Pauoa Bay to Kiholo Bay
Maui	
1	West Maui Forest Reserve
2	Puunoa Point Area
3	West Maui Forest Reserve
4	Kaanapali to Hanakoo Point
5	West Maui Forest Reserve
6	Hawea Point Area
7	Nakalele Point to Keawalua
8	Papaula Point to Wawau
9	Uaoa Bay
Maui	
10	Muolea Point
11	Apole Point
12	La Perouse Bay
13	Maalaea Bay Area
14	Maalaea Bay Area
15	Maalaea Bay Area
Molokai	
1	Molokai Forest Reserve
2	Molokai Forest Reserve
3	East Molokai Coastline from Kaumana Point to Paualaia Point
Oahu	
1	Kahuku Point Area
2	Makalii Point to Kaipapau Point
3	Pyramid Rock to Pukaulua Point
4	Mokapu Point to Kapoho Point
5	Lanikai to Bellows Air Force Base
6	Makapuu Point
7	Koko Head Area
8	Kahala Beach Area
9	Diamond Head
10	Fort Armstrong Area
11	Ewa Forest Reserve
12	Keahi Point Area
13	Barbers Point Naval Air Station Area
14	Nanakuli Forest Reserve
15	Kuaokala, Makua-Keaau, Waianae Kai & Mokuleia Forest Reserves
16	Mokuleia Beach Area
Kauai	
1	Halelea Forest Reserve
2	Moloaa & Kealia Forest Reserves
3	Mana
4	Barking Sand Areas (Kokole Point to Nohili Point)

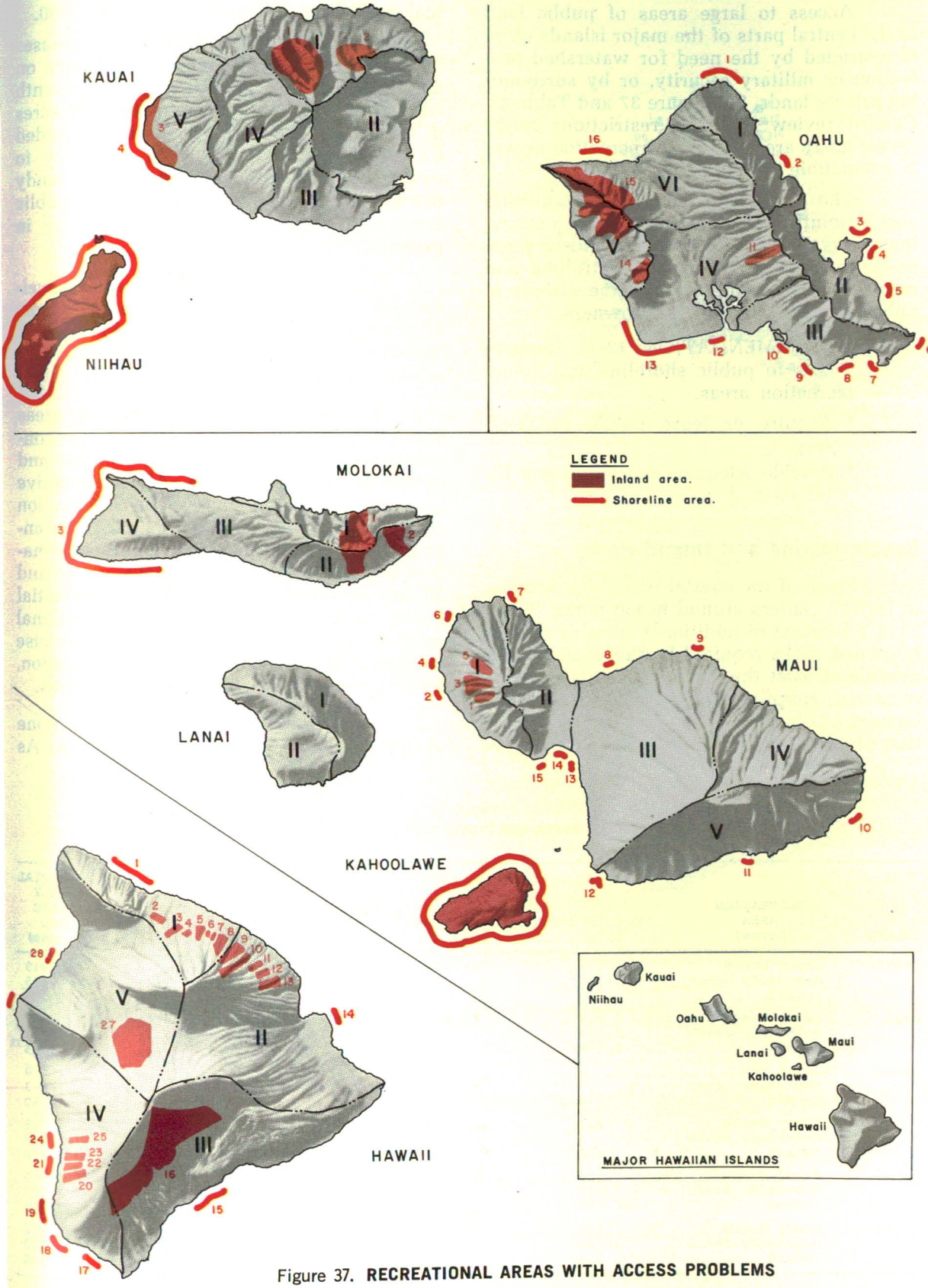


Figure 37. **RECREATIONAL AREAS WITH ACCESS PROBLEMS**

Access to large areas of public land in the central parts of the major islands often is restricted by the need for watershed protection or military security, or by surrounding private lands. See Figure 37 and Table 22. Careful review of these restrictions might reveal many areas in which recreation access is compatible with other uses.

The state and county governments should jointly develop priorities for improving access. Full consideration should be given to the necessity of adequate patrolling and maintenance to minimize adverse effects of public use on adjacent land owners.

- *RECOMMENDATION 13-1.* Improve access to public shoreline and inland recreation areas.
  - * Acquire or lease public rights-of-way.
  - * Provide adequate patrolling and litter control.

Beach, Marine and Inland Parks

Much of the coastal recreation activity in Hawaii centers around beach parks. Table 23 is a forecast of additional acres of publicly owned parks required by the year 2000 to provide at least the same per capita outdoor recreation space as today. The figures should be used cautiously, as they represent a projection of existing conditions rather than an actual prediction of demand in the year 2000.

By the year 2000, substantial increases in beach park acreage will be necessary on all major islands, as shown in the seventh column of Table 23. Approximately 130 acres of sandy beach park acreage will be needed by the year 2000. It will be necessary to develop almost all publicly owned sandy beaches on Oahu into parks. Surplus public lands on Neighbor Islands may not be in proximity to demand areas.

Prospects of commercial resort development on private lands can increase the cost of public acquisition beyond fiscal resources; therefore, property must be acquired well in advance of development trends.

Marine parks are underwater areas which are formally set aside for the conservation of certain ecological features and public enjoyment of them. All consumptive uses are prohibited, but public observation and aesthetic enjoyment of the parks are encouraged. Hanauma Bay, on Oahu, is a marine park. See Figure 38 and Tables 24 and 25 for the location of existing and potential beach parks and marine parks. Additional marine parks should be established because of their high value for recreation, education, and the preservation of marine ecosystems.

Most camping and picnicking is done at already crowded state beach parks. As

TABLE 23
Projected Beach and Inland Park Needs, Year 2000

ISLAND	RECREATION AREA (Acres)	PEOPLE/ACRE 1970	POPULATION 2000	SUPPLY 1970 (Acres)	DEMAND 2000 (Acres)	DEVELOP BY 2000 (Acres)	POTENTIAL SUPPLY PUBLIC LAND (Acres)
Hawaii	Sandy Beach	627	146,900	85	315	230	849
	Non-sandy Beach	3,740		112	243	131	6,495
	Inland	50		2,250	4,548	2,298	229,220
Maui	Sandy Beach	622	91,600	84	187	103	681
	Non-sandy Beach	2,833		34	75	41	3,259
	Inland	1,109		38	80	42	19,645
Lanai	Sandy Beach	0	8,000	--	--	--	0
	Non-sandy Beach	0		--	--	--	3
	Inland	0		--	--	--	80
Molokai	Sandy Beach	523	8,000	12	16	4	13
	Non-sandy Beach	0		--	--	--	658
	Inland	680		10	20	10	3,550
Oahu	Sandy Beach	918	1,039,400	1,335	1,960	625	1,966
	Non-sandy Beach	7,095		423	670	247	2,527
	Inland	24,833		120	170	50	17,250
Kauai	Sandy Beach	254	55,200	122	240	118	876
	Non-sandy Beach	3,780		4	10	6	722
	Inland	114		102	190	88	35,270

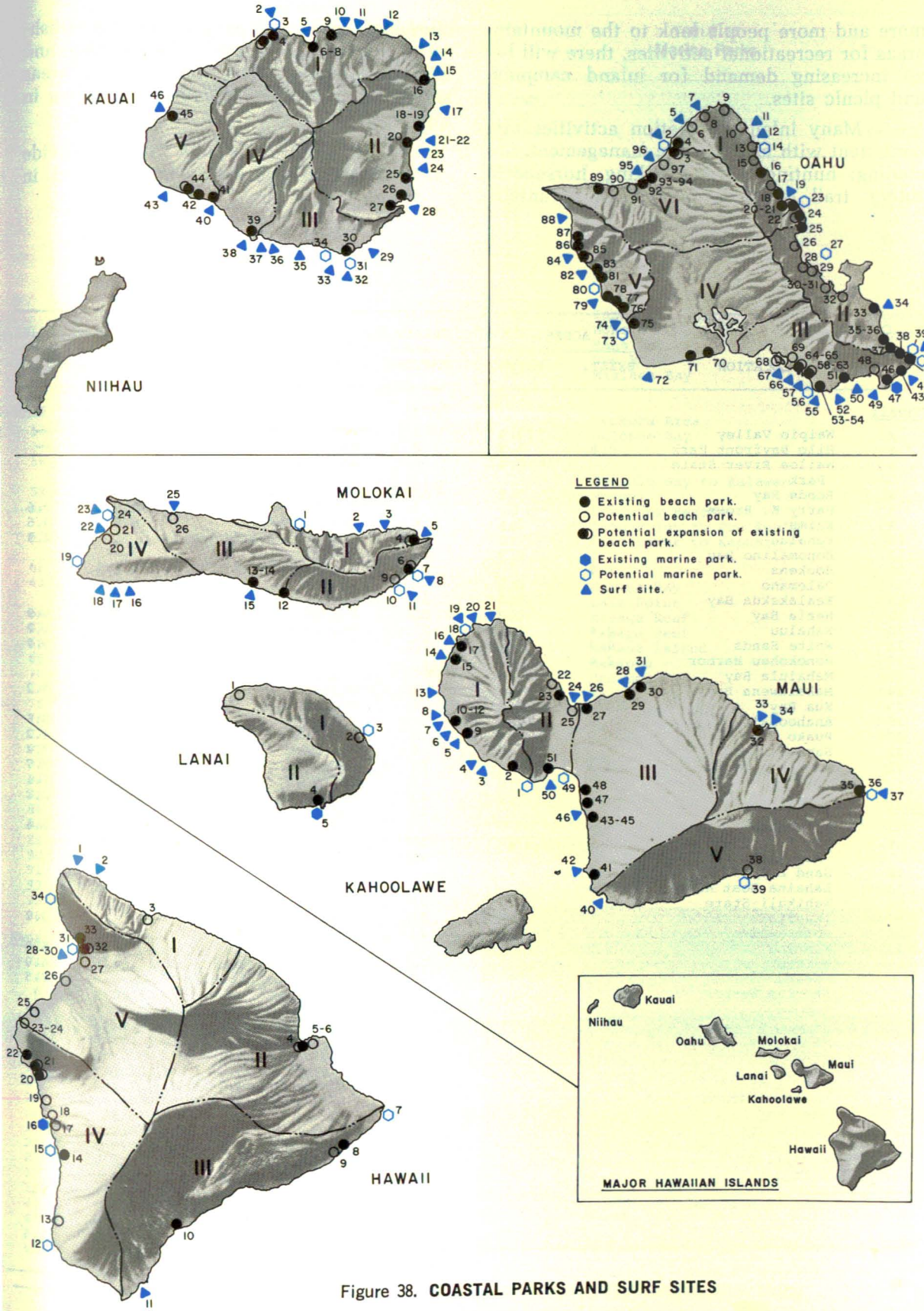


Figure 38. **COASTAL PARKS AND SURF SITES**

more and more people look to the mountain areas for recreational activities, there will be an increasing demand for inland camping and picnic sites.

Many inland recreation activities are consistent with multiple use management, including: hunting, fishing, hiking, horseback riding, trail camping, picnicking, mountain climbing, fruit picking, photography, freshwater swmming, off-road vehicle riding, and wilderness and nature study. Inland areas suited for intensive recreation are shown in Figure 40.

- *RECOMMENDATION 13-2.* Provide additional parks at beaches and in watershed areas.

TABLE 24
Beach Parks

ISLAND and MAP NO.	LOCATION	ACRES EXIST.	ACRES POTEN.
Hawaii			
3	Waipio Valley		18.4
4	Hilo Bayfront Park	0.8	2.8
5	Wailoa River State Park		3.4
6	Reeds Bay		0.9
8	Harry K. Brown	2.1	
9	Kaimu		2.8
10	Punaluu	1.5	
13	Honomalino Bay		0.9
14	Hookena	1.4	
17	Palemano		0.8
18	Kealakekua Bay		1.8
19	Heeia Bay		0.8
20	Kahaluu	0.4	1.1
21	White Sands	0.3	0.7
22	Honokohau Harbor	2.4	
23	Mahaiula Bay		3.4
24	Makalawena Bay		4.2
25	Kua Bay		2.8
26	Anahoomalu Bay		2.3
27	Puako Bay		2.4
32	Samuel Spencer	1.5	1.4
33	Kawaihae Harbor Ramp	0.3	
Maui			
2	Ukemehame	3.8	
9	Launiupoko State Wayside	0.3	
10	Sand Box	1.4	
11	Lahaina Boat Harbor	0.9	
12	Wahikuli State Wayside	0.5	
15	Honokawai	0.5	
17	Fleming	5.7	
22	Waihee		7.3
23	Waiehu	1.6	
25	Kahului Harbor		1.8
27	Kanaha	3.6	
29	H. A. Baldwin Park	3.4	
30	Hookipa	3.3	
32	Honomanu	0.3	
35	Hana	1.6	
38	Nuu Landing		0.5
41	Puu Olai State Wayside	2.0	
43	Kamaole #1	1.2	
44	Kamaole #2	1.6	
45	Kamaole #3	2.7	
47	Kalama	2.8	
48	Kihei Memorial Park	6.9	
51	Maalaea Boat Harbor	0.6	
Lanai			
1	Polihua Beach		--
2	Keomoku Beach		--
4	Hulopoe	3.4	
Molokai			
4	Halawa	0.3	0.6
6	Moanui Park	0.3	0.6
9	Honomuni Beach		2.3
12	One Alii	3.7	
13	Kaunakakai Boat Harbor	0.2	
14	Kaunakakai	3.0	
20	Popohaku Beach		6.9
21	Kepuhi Beach		1.2
26	Moomomi Beach		0.7
Oahu			
3	Waimea	1.4	4.2
4	Pupukea	2.1	
6	Sunset		8.6
8	Waialee		4.2
9	Punamano		3.2
10	Kahuku		9.7
13	Laiewai		1.1
15	Laie		2.2
16	Hauula	1.5	
17	Aukai		0.6
18	Punaluu	2.1	
20	Kahana Valley State Park	4.8	
21	Kahana Bay	3.0	
22	Kaaawa	1.7	
24	Kalai-Oio	0.6	0.2
25	Kualoa	18.0	
26	Waiahole		5.0
28	Awa Island Park		6.0
29	Heeia Boat Harbor Park		2.5
30	Heeia Biological Park		2.3
30A	Aku Island Park		12.0
31	Ono Island Park		3.0
32	Kailua	6.8	
34	Waimanalo Bay State Rec. Area	2.9	
35	Waimanalo	13.5	
36	Kaiona	0.5	
37	Kuapo	2.3	
41	Makapuu	1.0	
42	Koko Head Sand Beach	6.7	
43	Koko Head Rec. Park	9.6	
45	Hanauma Bay	2.9	
47	Kuliouou		2.5
50	Waialae	1.2	
52	Kuilei Cliffs	4.4	

* Lease or acquire important shoreline areas.
* Encourage multi-purpose use of watersheds.
* Provide facilities for park use.
* Maintain trails and appropriate facilities.

ISLAND and MAP NO.	LOCATION	ACRES EXIST.	ACRES POTEN.
Oahu			
53	Diamond Head	0.1	
57	Fort DeRussey	0.8	
58	Waikiki Beach Center	0.3	
59	Kuhio	4.4	23.9
60	Kapiolani Beach Center	2.0	
61	Kapiolani Beach Park	1.0	
62	Kapiolani Rec. Park	3.6	
63	Aina Moana State Rec. Area	10.0	
64	Ala Moana	13.8	9.3
67	Sand Island		21.0
68	Kewalo		3.4
69	Ewa	0.7	
70	Oneula	1.2	
74	Kahe Point	0.1	
75	Nanakuli	4.5	
76	Ulehawa	9.2	
77	Maile	4.6	
80	Lualualei	4.5	
82	Pokai Bay	2.3	
84	Mauna Lahilahi	1.4	1.6
85	Makaha	7.4	
86	Keaau	6.1	
88	Mokuleia	1.3	
89	Makaleha		2.7
90	Kamananui		1.0
91	Wailua	2.5	
92	Haleiwa Boat Harbor	0.8	
93	Haleiwa	2.5	
96	Kawailoa		2.5
Kauai			
1	Haena State Park	6.2	6.2
4	Haena	7.6	
6	Hanalei	2.5	
7	Hanalei Pavilion	3.2	
8	Waioli	5.7	
9	Anini Park	3.4	
16	Anahola	2.7	
18	Kapaa	2.3	
19	Waiakea Canal	0.5	
20	Wailua River State Park	5.7	
25	Hanamaulu	1.2	
26	Nawiliwili	2.9	
27	Niumalu	0.6	
30	Poipu	0.5	3.4
39	Salt Pond	4.2	
41	Lucy Wright Park	1.0	
42	Kikiaola Harbor	0.4	
44	Kekaha	24.1	24.1
45	Polihale State Park	7.8	

TABLE 25
Marine Parks

ISLAND and MAP NO.	LOCATION	STATUS
Hawaii		
7	Kumakahi Ponds	○
12	Manuka Bay	○
15	Honaunau Bay	○
16	Kealakekua Bay	●
31	South of Kawaihai	○
34	Koaie Cove	○
Maui		
1	Papawai Point	○
18	Honolua Bay	○
36	Hana Bay	○
39	Nuu Bay	○
49	Maalaea Bay	○
Lanai		
3	Keomoku Area	○
5	Hulopoe Bay	○
Molokai		
1	Waikolu Bay to Kalawao	○
7	Moanui	○
10	Honomuni Beach	○
19	Laau Point to Puu Koa'i	○
24	Ilio Point to Kepuhi	○
Oahu		
2	Waimea Bay	○
14	Laie Point	○
23	Kaaawa Reef	○
27	Kapapa Reef	○
38	Manana Island	○
40	Makapuu	○
46	Hanauma Bay	●
55	Waikiki Beach	○
72	Kahe Point	○
79	Waianae Coast	○
Kauai		
3	Haena Beach	○
31	Poipu	○
34	Reef Area Front-Koloa Park	○

● Existing ○ Potential

Marine park at Hanauma Bay, Oahu.

Inland campsite, Volcano National Park, Hawaii.

* Increase controlled hunting in watershed areas.
* Improve habitat and fish population in streams and reservoirs.

- *RECOMMENDATION 13-3.* Establish additional marine parks for public enjoyment and preservation of marine life.

Surf Sites

Construction on the shoreline may affect coastal currents and tides and cause erosion of nearby sandy beaches and destruction of surf sites. Sandy beach and surfing areas are most elusive of human engineering. Efforts to alter beaches or even to replenish sand on eroded beaches have not always succeeded. Surf sites are even less tolerant of human alteration. Being almost entirely related to natural conditions, they are a very sensitive water resource. However, with improved knowledge of hydraulics it may be feasible to create artificial surf sites at particularly desirable locations. Surf sites are shown in Figure 38 and listed in Table 26.

In considering surfing resources, a breaking surf alone is not enough. There must be enough water above the rocks to allow safe surfing. There must also be sufficient safe area to recover boards. Proximity

Canoe races, Kailua Beach Park, Oahu.

TABLE 26
Significant Surf Sites

ISLAND	MAP REF. NO.	LOCATION
Hawaii	1	Upolu Point
	2	Kapanaia
	11	Kaalualu Bay
	28	Puako Bay
	29	Waialea Bay
	30	Hapuna Bay
Maui	3	Hekili Point
	4	Olowalu
	5	Makila
	6	South Lahaina
	7	North Lahaina
	8	Puunoa Point
	13	Hanakoo
	14	Honokawai
	16	Fleming Beach
	19	Honolua Bay
	20	Windmill Beach
	21	Honokohau Bay
	24	Kahului Bay
	26	Kanaha Beach
	28	Paia Bay
	31	Hookipa Park
	33	Honomanu Bay
	34	Keanae Point
	37	Hana Bay
	40	La Perouse Bay
	42	Puu Olai Beach
	46	Kamaole
	50	Maalaea
Molokai	2	Wailau
	3	Pohakuloa
	5	Halawa Bay
	8	Honouliwai
	11	Pauwalu Harbor
	15	Kaunakakai Harbor
	16	Halena
	17	Lono Harbor
	18	Kanalukaha
	22	Popohaku Beach
	23	Kawakiunui Bay
	25	Moomomi
Oahu	1	Waimea Bay
	5	Sunset Beach
		Banzai Beach and
		Banzai Pipeline
		Pupukea
		Rocky Point
		Sunset Beach
	7	Kawela Bay
	11	Kahuku
		7th Hole
		Pounders
		Kekela
	12	Laie-Hukulau
	19	Kahana Bay
	33	Lanikai
Oahu	39	Makapuu
	44	Sandy Beach
	48	Portlock
	49	Aina Haina
	51	Black Point
	54	Diamond Head
	56	Waikiki
		Tonggs
		Ricebowl
		Suicides
		Castle's
		Public's Reef
		Cunha's
		Queen's & Canoe's
		Popular's & Paradise
		Kaiser's
		Rock Pile
	65	Kewalo-Ala Moana
	66	Sand Island
	71	Barbers Point
	73	Tracks
	78	Maili
	81	Pokai Bay
	83	Makaha
	87	Yokohama
	94	Haleiwa
	95	Chun's Reef & Laniakea
Kauai	2	Cannons
	5	Hanalei Bay
		Waikoko
		Pine Tree
		Impossible
	10	Anini Beach
	11	Kalihiwai Bay
	12	Rock Crusher
	13	Moloaa Bay
	14	Papaa Bay
	15	Anahola Bay
	17	Kealia
	21	Horner's
	22	Wailua Beach
	23	Wailua River Mouth
	24	Kawailoa Beach
	28	Kalapaki
		Lighthouse
		Hang Ten
	29	Kalae Paoo
	32	Poipu Beach
	33	Waiohai
		Horseshoe
		Longhouse
	35	Lawai Bay
	36	Wahiawa Bay
	37	Port Allen
	38	Salt Pond
	40	Waimea River Mouth
	43	Kekaha
	46	Polihale

to beaches adds both to safety and enjoyment for surfers; yet there must be separation of surfing from swimming and body surfing. Ideal conditions are so limited and valuable a resource that protection of appropriate surf sites should take high priority.

- *RECOMMENDATION 13-4.* Protect surf sites.
  - * Provide areas of non-conflicting recreational use.
  - * Protect against damaging development, by conservation zoning and other regulatory measures.
  - * Determine feasibility of developing artificial surfing reefs at suitable sites.

Surfing off the Ala Wai, Oahu.

Inshore Fishing

Three kinds of recreational fishing are popular along the shores of Hawaii: spearfishing, net fishing (throw-net and *hukilau*), and pole fishing. Each of these is suitable for certain types of shoreline common in Hawaii. Other popular activities include collecting seaweed, *opihi, puka* shells, and sea urchins and catching crabs with nets.

A recreational fishing survey in 1972 indicated that more than 80 percent of the 122,400 fishermen in Hawaii are inshore fishermen, 68 percent fishing from the shore and 12 percent from boats.

Diversity of ownership and land use objectives affect inshore fishing in many ways. For instance, inaccessibility to the shoreline through private and military land has caused excessive resource depletion in accessible areas. Conversely, many shoreline areas which are inaccessible appear to contain fish populations that could withstand additional harvest.

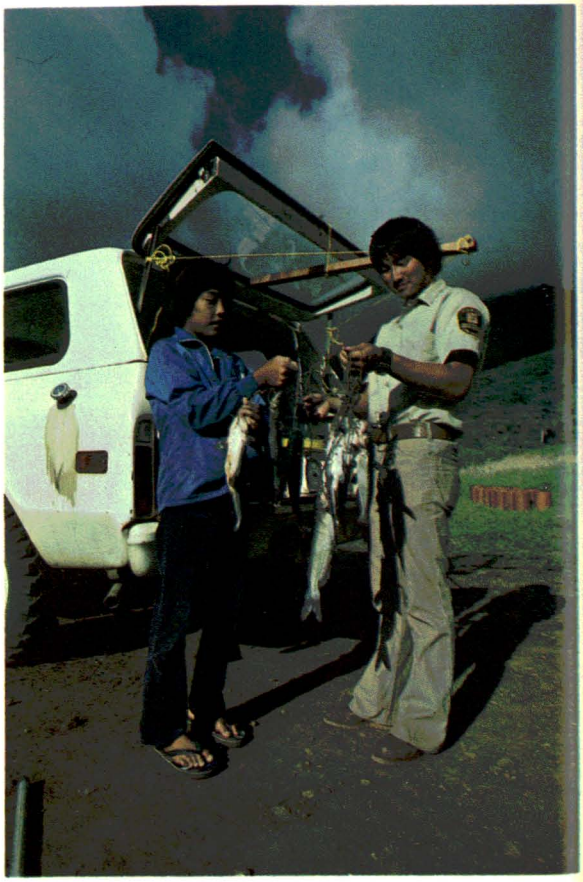
Different land use policies have prevented coordinated management of resources that range outside a single jurisdiction.

- *RECOMMENDATION 13-5.* Improve inshore fishing opportunities.
  - * Provide access to shoreline areas with ample fish populations.
  - * Harmonize land use policies and coordinate resource management.

Freshwater Fishing and Swimming

Stream systems of major watersheds offer opportunities for limited freshwater fishing and swimming. Many hiking trails follow stream banks into inland valleys. Reservoirs located on these streams could also be used for inland water recreation. Several pilot programs to stock streams and reservoirs have brought encouraging responses from fishermen.

- *RECOMMENDATION 13-6.* Include freshwater fishing and swimming as planned multiple uses in water storage projects.



Freshwater fishing, Nuuanu Reservoir, Oahu.

Catamarans beached at Kailua, Oahu.

TABLE 27
Projected Demand for Small Boat Berths, Year 2000

ISLAND	EXISTING HARBOR CAPACITIES	PROJECTED WET STORED REQUIREMENTS
Hawaii	241	440
Maui	156	457
Lanai	21	70
Molokai	31	111
Oahu	2,130	5,197
Kauai	88	831
Total	2,476	7,106

TABLE 28
Projected Demand for Boat Launching Ramps, Year 2000

ISLAND	EXISTING RAMP LINES	PROJECTED DEMAND 2000
Hawaii	17	28
Maui	8	17
Lanai	1	3
Molokai	1	5
Oahu	32	156
Kauai	12	18
Total	71	227

Recreational Boating Facilities

Recreational boating continues to grow in popularity in Hawaii. There were more than 12,000 small boats in the state at the end of 1973, or nearly 15 boats per thousand population. Per capita boat ownership has increased almost 50 percent over the last ten years.

Assuming that the current boat ownership trend continues, the number of small boats in Hawaii could reach 35,000 to 40,000

TABLE 29
Small Boat Harbors

ISLAND and MAP NO.	LOCATION	NO. OF BERTHS EXIST.	NO. OF BERTHS POTEN.
Hawaii			
3	Radio Bay	12	12
4	Wailoa Harbor	35	
5	Reeds Bay	27	270
16	Keahou Harbor	13	
18	Kailua-Kona Harbor	49	
20	Honokohau Harbor	57	
23	Kawaihae Harbor	48	300
Maui			
2	Lahaina Area		268
4	Lahaina Harbor	93	
6	Maalaea Harbor	63	198
9	Kahului Harbor	(Anch.)	
Lanai			
2	Makaiwa		N/A
4	Manele Harbor	21	97
Molokai			
1	Kalaupapa Harbor	(Anch.)	
4	Kaunakakai Harbor	31	250
Oahu			
4	Kaneohe Bay Area		N/A
6	Heeia Kea Harbor	75	300
7	Kaneohe Bay Marina	90	
8	Kaneohe Marine Corps Air Station	25	
11	Kaneohe Yacht Club	200	
12	Kailua Area		300
16	Waimanalo Area		N/A
17	Hawaii Kai Marina	40	
19	Maunalua Bay		250
21	Ala Wai Harbor	705	30+
22	Waikiki Yacht Club	135	
24	Kewalo Basin	N/A	
26	Keehi Harbor	342	N/A
29	La Mariana	50	
32	Pearl Harbor	100	
34	Barbers Point		300
37	Waianae Area (Pokai Bay)	89	
38	Waianae Harbor	N/A	300
43	Haleiwa Harbor	88	200
Kauai			
1	Hanalei Bay		180
8	Nawiliwili Harbor	28	166
10	Kukuiula Harbor	9	
12	Port Allen Harbor	43	
14	Kikiaola Harbor	8	130

N/A - Not available.

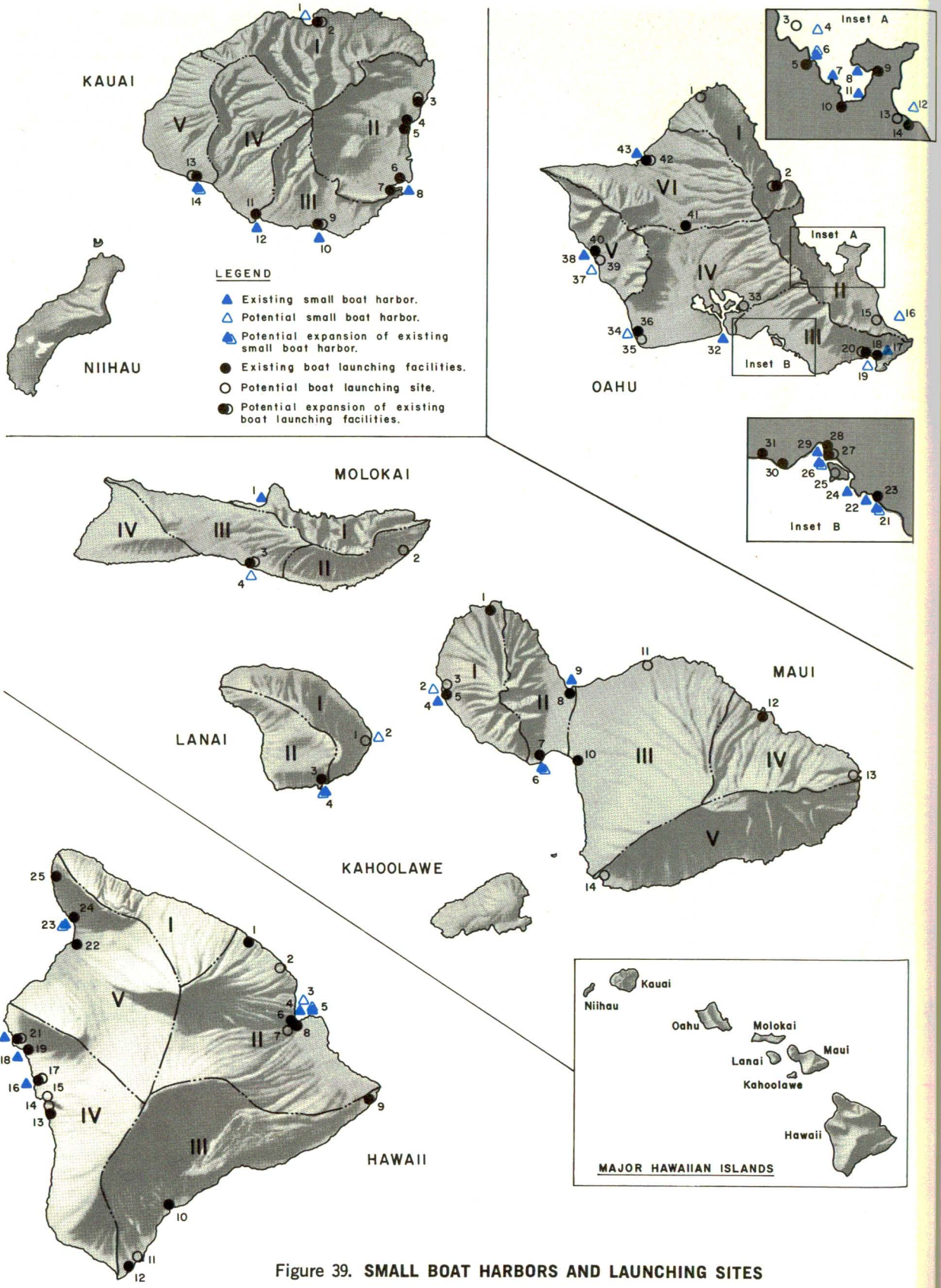
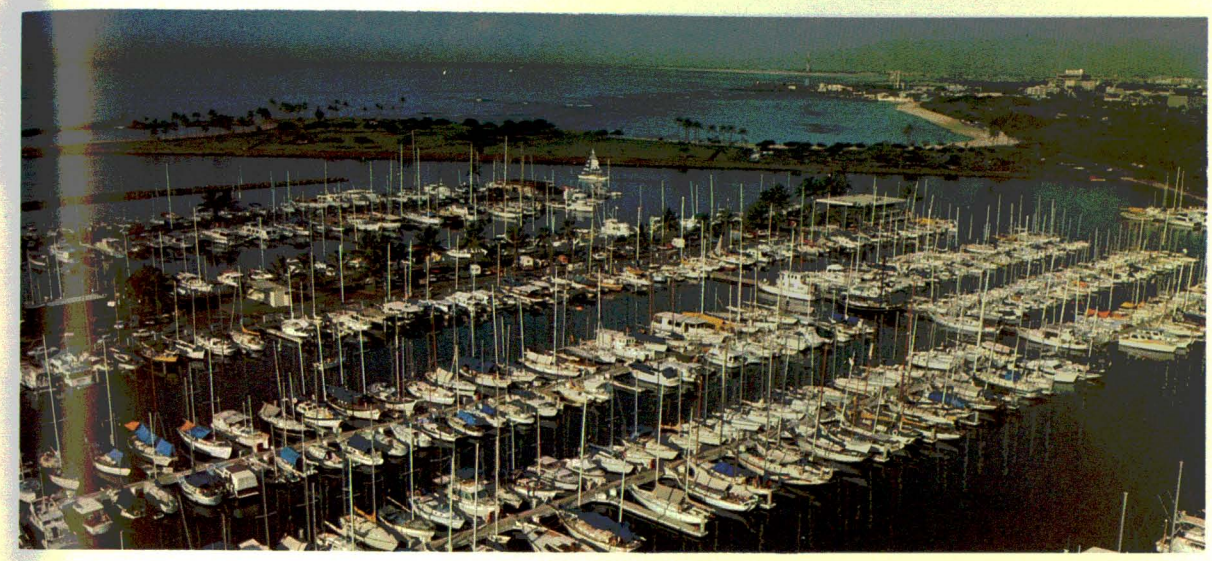


Figure 39. **SMALL BOAT HARBORS AND LAUNCHING SITES**



Sailboats berthed at Ala Wai Yacht Harbor, Oahu.

TABLE 30
Boat Launching Ramps

ISLAND and MAP NO.	LOCATION	NO. OF LANES EXIST.	NO. OF LANES POTEN.
Hawaii			
1	Laupahoehoe	1	
2	Hakalau Bay		N/A
6	Wailoa River	2	
7	Hilo Bay		N/A
8	Wailoa River State Park	2	
9	Pohoiki	1	
10	Punaluu	1	
11	Kaalualu Bay		N/A
12	Kaulana	1	
13	Honaunau	1	
14	Palemano Point Area		N/A
15	Kealakekua Bay		N/A
17	Keahou Bay	2	2
19	Kailua Bay	1	
21	Honokohau	1	6
22	Puako	1	
24	Kawaihae	2	
25	Mahukona	1	
Maui			
1	Honolua	1	
3	Lahaina Area (Mala)		2
5	Lahaina Boat Harbor	1	
7	Maalaea	1	2
8	Kahului	1	
11	Maliko	1	1
12	Keanae	1	
13	Hana Bay	1	1
14	La Perouse Bay		1
Lanai			
1	Makaiwa		N/A
3	Manele	1	
Molokai			
2	Honouliwae		N/A
3	Kaunakakai Harbor	1	2
Oahu			
1	Kawela Bay		N/A
2	Kahana Bay	1	N/A
3	Kaneohe Bay Area		N/A
5	Heeia-Kea	3	
9	Kaneohe Yacht Club	1	
10	Kaneohe Bay Marina	1	
13	Kailua Area		2
14	Kailua Bay	1	
15	Waimanalo Area		5
18	Hawaii Kai Marina	7	
20	Maunalua Bay	1	7
23	Ala Wai	2	
25	Sand Island		4
27	Keehi Lagoon	1	16
28	Airport	1	3
30	Pearl Harbor Yacht Club	2	
31	Hickam	1	
33	Pearl Harbor		11
35	Barbers Point		4
36	Campbell Industrial Harbor	1	
39	Waianae Area		7
40	Pokai Bay	3	
41	Wahiawa Reservoir	1	
42	Haleiwa	5	4
Kauai			
2	Hanalei River	1	1
3	Waiakea Canal	1	1
4	Kaumualii	1	
5	Wailua Marina	1	
6	Nawiliwili	3	4
7	Niumalu	1	
9	Kukuiula Area	1	1
11	Port Allen	2	
13	Kikiaola Area	1	N/A

N/A - Not available.

Launching power boat from trailer, Hawaii Kai, Oahu.

by the year 2000. Since 20 to 25 percent of the boats are stored in the water, the less than 3,000 berths and moorings in existing small boat harbors are inadequate to meet present demand in some areas.

By year 2000, about 4,000 to 6,000 additional berths will be needed. See Table 27. Long-range studies have supported Congressional authorization of small boat harbor improvements to accommodate approximately 4,000 additional boats. However, because of increasing social, economic, and ecological concerns, it appears that many of these authorized harbor improvements will not be constructed. The authorized improvements, if constructed as planned, could meet the berthing demand on all islands except Oahu and Maui. On these islands, especially on Oahu, the demand will continue far in excess of available facilities.

Facilities for trailer boat launching generally meet current requirements except on Oahu. By the year 2000, approximately three times the existing number of launch lanes will be required. Most of these will be needed on the islands of Oahu and Hawaii. See Table 28.

Existing and potential small boat harbors and launching sites are shown in Figure 39 and listed in Tables 29 and 30.

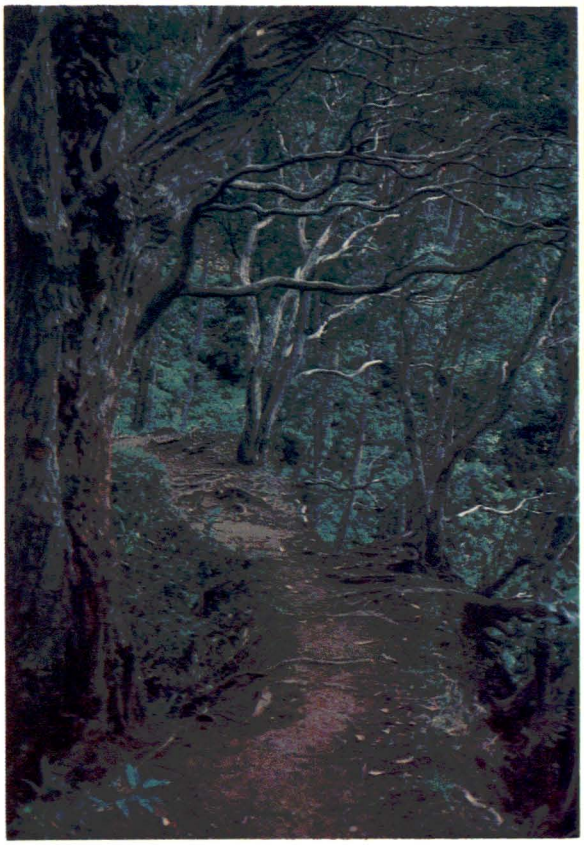
The traditional Hawaiian sport of outrigger canoeing has enjoyed an upsurge of popularity in recent years. Specific facilities and programs to accommodate the sport are needed.

As recreational boating activities increase, there is a corresponding increase in opportunities for boating accidents. Boating safety requires continuing improvement in navigation aids.

- *RECOMMENDATION 13-7.* Provide facilities for recreational boating.
  - * Provide additional boat ramps and dry storage facilities.
  - * Provide additional small boat harbors.
  - * Develop specific facilities and programs to accommodate outrigger canoeing.
  - * Provide additional buoys and other navigation aids for recreational boating safety.

Hiking Trails

One of the features of Hawaii's topography is that natural mountain settings abut major urban centers. Almost 40 miles of



Aiea Loop Trail, Oahu.

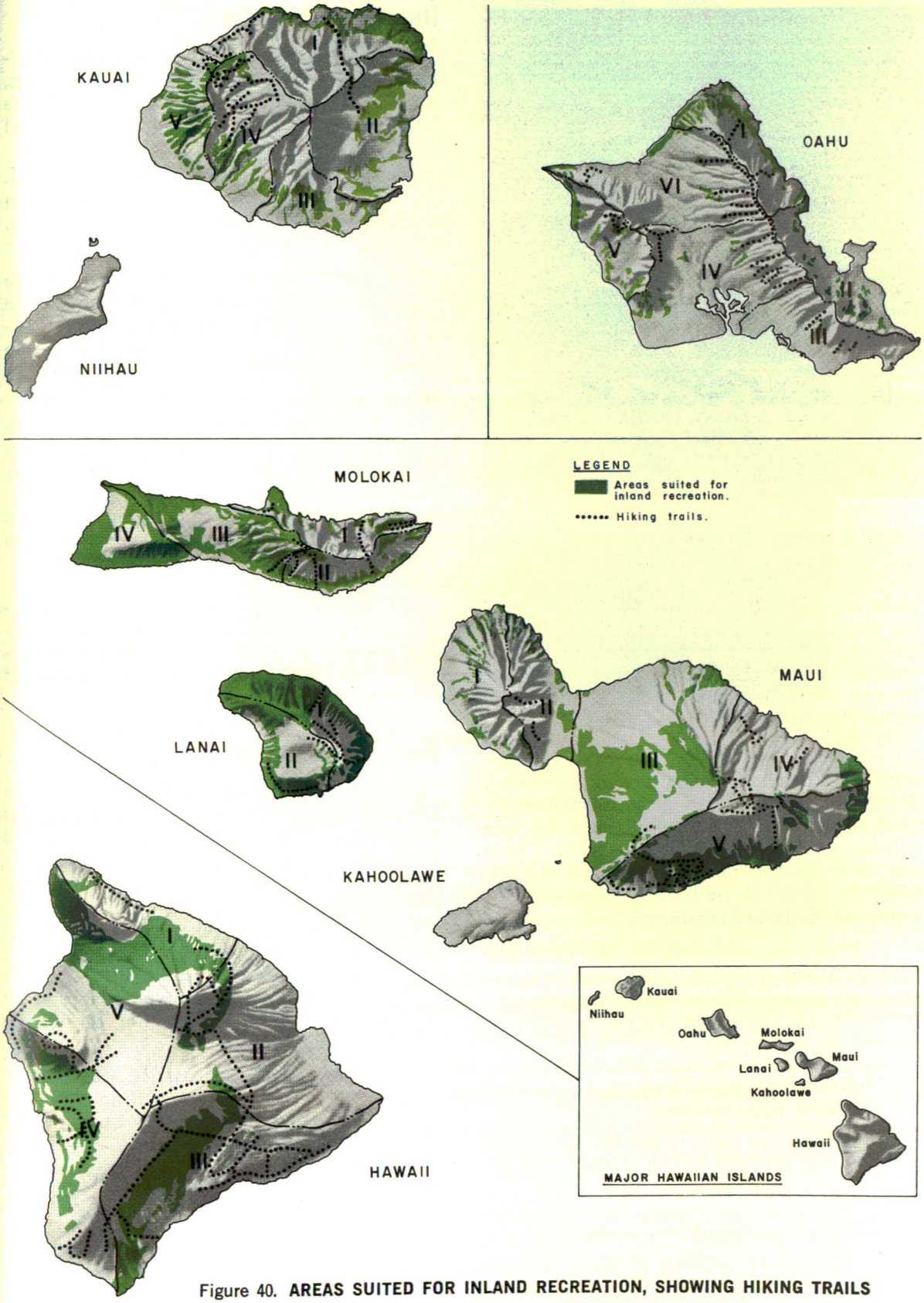


Figure 40. **AREAS SUITED FOR INLAND RECREATION, SHOWING HIKING TRAILS**

Goat hunting on Maunakea, Hawaii.

trails lead into the Koolau Mountains from the residential sections of Honolulu. Within minutes, wilderness mountain areas can be reached, with trails winding along mountain streams to impassable mountain ridges and waterfalls ordinarily hidden from view.

In the late 1930's, the Civilian Conservation Corps developed new trails. During World War II, more trail systems were developed to connect various military bases and defense sites throughout the Islands. These trail systems are more than triple the 678 miles of recorded trails. See Figure 40 for a map of trails in Hawaii.

Unfortunately, most of the CCC and military trails are now overgrown, impassable, and unrecognizable. Many trails through military lands and private lands are off-limits for the general public.

- *RECOMMENDATION 13-8.* Enhance hiking opportunities.
  - * Maintain trails to prevent landslides, soil erosion, and introduction of exotic plant species.
  - * Rehabilitate overgrown, impassable, and unrecognizable trails.
  - * Provide public access to trails through military and private lands.

Hunting in Watersheds

Diverse types of forests in Hawaii offer highly productive habitat for feral pigs, goats, and other game animals and birds. The forest also provides habitats for endemic and exotic nongame animals and birds.

There is a demand for expanded hunting opportunities in watersheds that might be satisfied by cooperative planning for multiple use.

There are some conflicts between the needs for nongame wildlife protection and the interests of hunters. Successful hunting depends upon a high population of exotic game animals and game birds, which compete with native species or degrade habitat.

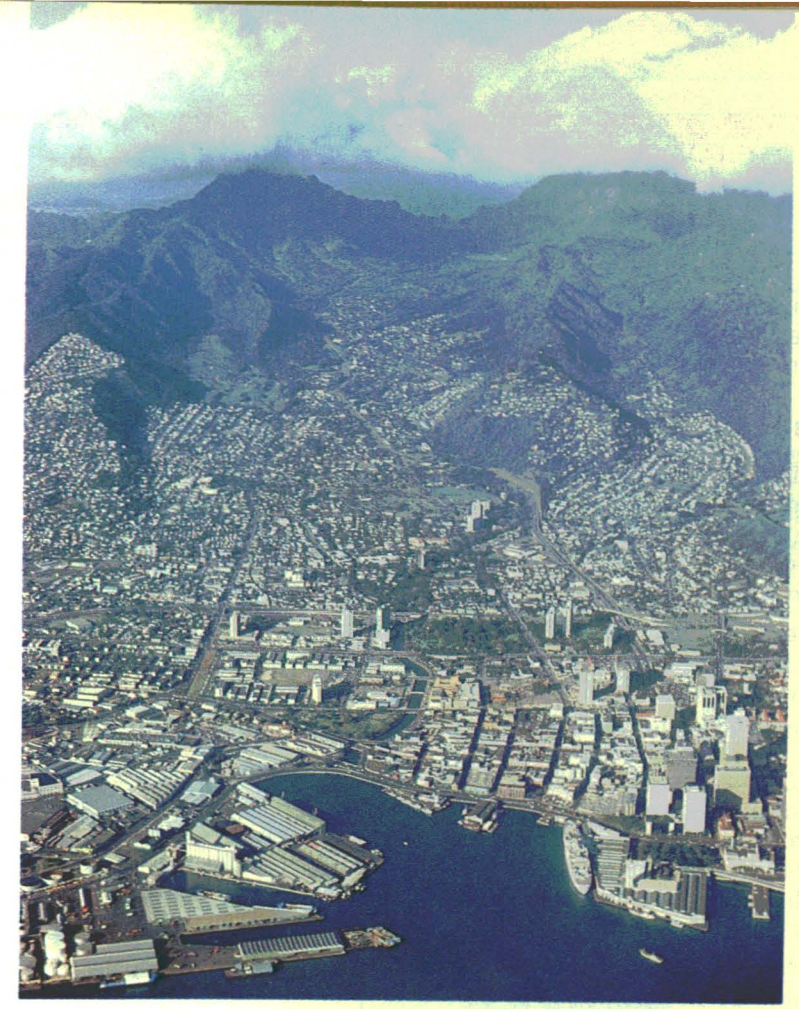
Grazing game animals and feral animals have become so numerous in some areas that severe damage to the environment has resulted. Reduction of game population in these areas by regulated hunting may help preserve the native ecosystems as well as provide recreational opportunities.

- *RECOMMENDATION 13-9.* Investigate possibilities for increasing hunting opportunities in watersheds, where compatible with the preservation of native ecosystems.

Recreational Planning

Statewide recreational plans have been prepared on an *ad hoc* basis, with agencies such as the Departments of Land and Natural Resources and Transportation inadequately represented in their formulation. Under the present system, one agency plans and another develops and maintains facilities.

- *RECOMMENDATION 13-10.* Provide for detailed recreational planning by a permanent staff wthin the implementing agency.
  - * Determine participation rates for water related recreational activities.
  - * Assemble use intensity data for existing recreational sites.
  - * Develop criteria to determine the recreational value of water management alternatives.
  - * Establish relationships between recreational opportunities, population densities, and the quality of life.



Downtown Honolulu and harbor.

Water and the Economy

As mentioned in Chapter 3 on the economy, the national economic development objective is the increased output of goods and services. This objective may be achieved by an additional commitment of resources, or by more efficient use of available resources, or both.

Water supplies for irrigation, livestock, and industrial use are essential to Hawaii's economy. Reservation of land suitable for agricultural use and preservation of land productivity are also essential.

Fisheries and marine industries make a significant contribution to Hawaii's economic base and have a good potential for expansion.

Marine transportation is particularly vital to the economy of this island state. Increased use of water for energy production is also of economic concern.

14. AGRICULTURAL AND INDUSTRIAL WATER

Water resources planning is concerned with water supplies for crop and livestock production and industrial use.

Irrigation Water Conservation

Irrigation water requirements in Hawaii are greater than for any other use. See Figure 27. The availability of irrigation water supplies directly affects the production of sugar, Hawaii's biggest export commodity.

The use of more efficient irrigation methods can not only save water but can increase yields per acre. By substituting drip for furrow irrigation, sugarcane acreage could be increased by 20 to 30 percent with present irrigation supplies; or the water saved could be used for other purposes. Where such methods will make water available for other beneficial uses, government might encourage conversion by adjusting water rate structures, providing technical assistance, and perhaps giving tax incentives.

Table 31 compares potential irrigation water savings by using drip methods (estimated at 30 percent) to the projected municipal needs for the major islands. This quantity of irrigation water, if potable and capable of economical transmission, would be more than enough to supply the total municipal water demand on Maui and Kauai to the year 2000.

- *RECOMMENDATION 14-1.* Use more efficient irrigation methods.
  - * Convert to drip or sprinkler irrigation where feasible.

TABLE 31
Water Savings from Drip Irrigation Compared to Municipal Demand, Year 2000

ISLAND	1975 AGRICULTURAL DEMAND (mgd) TOTAL	10% of TOTAL	MUNICIPAL DEMAND, 2000 (mgd)
Hawaii	33	9.9	46
Maui	467	47	37
Molokai	2	.2	2
Oahu	321	32	276
Kauai	352	35	18

TABLE 32
Hydrographic Areas Needing Additional Agricultural Water

ISLAND and HGA	1975 APPLICATION	1975-2000 NEEDS ADDITIONAL	TOTAL
Hawaii			
I-Hamakua	30	15	45
III-Kau	5	8	13
Maui			
I-Lahaina	93	14	107
III-Makawao	332	37	369
Molokai			
III-Hoolehua	3	9	12
Oahu			
VI-Waialua	106	5	111
Kauai			
II-Lihue	76	28	104
III-Koloa	103	7	110
V-Kekaha	122	40	162

- * Reduce storage and transmission losses.

Irrigation Water Supply

Even with improvements in irrigation efficiency, agricultural water demand is expected to increase between 1975 and 2000 on all major islands because of expanded sugarcane areage and increased irrigation of diversified crops and pastures. Proposed agricultural parks will tend to increase irrigation water requirements and may affect water supplies in areas not now served by irrigation systems. Figure 27 illustrates projected demand.

Those areas where the demand for agricultural water will increase at least 5 mgd by the year 2000 are shown in Figure 41 and Table 32. Thereafter, the demand is expected to level off.

On Oahu, the increased demand will be largely in one hydrographic area, with the overall irrigation water requirements for the island decreasing because of improved appli-

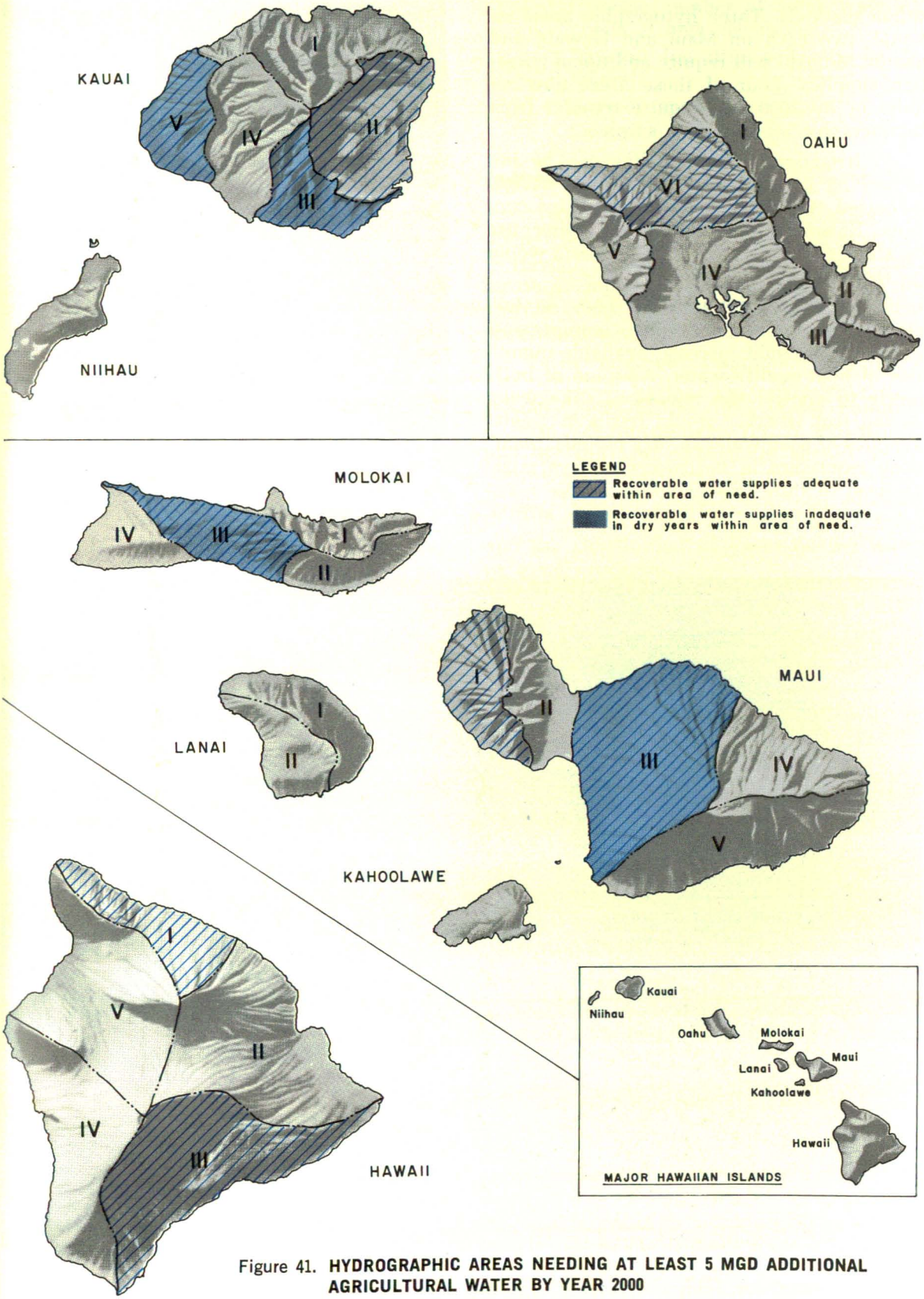


Figure 41. **HYDROGRAPHIC AREAS NEEDING AT LEAST 5 MGD ADDITIONAL AGRICULTURAL WATER BY YEAR 2000**

cation methods. Three hyrographic areas on Kauai, two each on Maui and Hawaii, and one on Molokai will require additional irrigation supplies. Four of these areas now require or by 2000 will require transfer from hydrographic areas with a surplus.

Irrigation water supplies can be improved by careful well spacing and design, increased storage capacity, and leakage controls. Enhanced coordination of water use by state, county, and private interests would be required.

In headwater areas of high rainfall, storage manipulation in dike compartments and tunnels could increase available quantities of high quality water. Addition of bulkheads to control the release of dike water during wet weather would result in greater supplies of such water for dry periods. Small, deep reservoirs in headwater valleys might be used to store freshet water. Where reservoirs could not be perfectly sealed, infiltration to basal water lenses would increase.

Treated domestic wastewater is an important potential source of nutrient-rich irrigation water. Continuing research is needed to determine the safe level of treatment for crop irrigation. With inadequate treatment, sufficient pathogens might survive to pose a danger. Excessive treatment would be needlessly expensive.

Problems to be resolved include undesirable leaf growth caused by nutrients, long-term effects of trace substances present in the effluent, the added cost of transmitting wastewater to the cane fields, and the cost of disposal facilities needed during wet weather. All of these difficulties can probably be overcome by modern technology.

- *RECOMMENDATION 14-2.* Provide additional irrigation water.
  - * Improve diversion, storage, and transmission systems.

Irrigated canefields, Maui.

Water cooled power plant, Kahe Point, Oahu.

* Develop more surface and ground water, compatible with environmental and recreational needs.
* Determine the level of treatment necessary to reuse domestic wastewater for sugarcane irrigation.
* Study the reuse of treated domestic wastewater for irrigating diversified crops and timber.
* Develop systems to reuse treated domestic wastewater as a new source of irrigation water supply.

Livestock Water Distribution

State Department of Agriculture projections show that Hawaii will produce an estimated 136.4 million pounds of meat by 1980, more than triple the 1970 production. The optimistic projection is based upon increased local production of feed grains and animal roughage, as well as better pasture management and water distribution.

Some areas of suitable pasture on Hawaii and Maui are underutilized because of lack of facilities for stock watering. Government and private interests should cooperate to improve watering facilities for more effective use of cattle range.

- *RECOMMENDATION 14-3.* Improve distribution of livestock water for more efficient use of grazing land.
  * Increase number of stock watering ponds at high elevations.
  * Develop fog drip and rain catchments.
  * Develop springs and wells.
  * Expand pipeline and ditch systems.

Industrial Water Supply

Approximately 400 million gallons of water are used daily for industrial purposes in Hawaii. Most of this is process water used by sugar mills and cooling water used by electric power plants. Mill water is recycled for irrigation where feasible.

An important assumption underlying any industrial water supply forecasts is that the objectives of the 1972 Water Pollution Control Act Amendments (PL 92-500) will be met. By the year 1984 there should be no point-source discharges of untreated wastewater. This will require increased adoption of recycling systems by large water users and the substitution of lower quality water in some processes.

Industrial water demand will probably decrease over the next two decades on all major islands, with the possible exception of Maui, largely because of more efficient water use by sugar mills and power plants and enforcement of water quality standards.

Available projections extend only to the year 2000, but a further assumption made for this study is that requirements beyond 2000, up to 2020, will remain essentially constant. See Figure 27.

Industries might use brackish water, municipal or agricultural wastewater, and ocean water for cooling, especially where potable supplies are scarce.

- *RECOMMENDATION 14-4.* Encourage in-plant recycling and the use of lower quality water to replace potable water used for industrial cooling.
  * Gather data on industrial water use, by quality categories and sources.
  * Compile statistics on reuse of wastewater for industry.
  * Continue to update industrial water use projections.
  * Determine potential for using municipal or agricultural wastewater for industrial cooling.

15. LAND PRODUCTIVITY

The following aspects of land productivity are of particular concern in water resources planning.

Prime Agricultural Land

It is estimated that, by the year 2020, Hawaii will have to feed about twice the present resident population. Increase in the visitor population will also increase the demand for agricultural products. Also, an export market for more sugar, pineapple, macadamia nuts, papaya, and flowers is presumed. The rising demand for diversified agricultural products will require the cultivation of more cropland.

An estimated 43,500 additional acres of land will be required for agricultural products other than sugar and pineapple by the year 2000. It is further estimated that about 15,000 acres will be released from sugarcane and pineapple, leaving a projected net requirement of 28,500 additional acres of agricultural land.

The demand for more cropland emphasizes the need to reserve prime agricultural land and to enhance productivity with adequate irrigation water supplies. As part of the state policy to encourage self-sufficiency, agricultural parks are being sponsored by government throughout Hawaii. See Figure 34 for land best suited to crops, with irrigation, and locations of proposed agricultural parks.

- *RECOMMENDATION 15-1.* Reserve prime agricultural land for crop production.
  - * Apply standard criteria for identification of prime agricultural land.
  - * Establish specific restrictive zoning of prime agricultural land.
  - * Acquire or lease prime land for agricultural parks.
  - * Provide low-cost irrigation water and other government incentives to encourage crop production on prime agricultural land.

Commercial Forest Production

There are nearly 2 million acres of forested land in Hawaii. Of this, almost 1.2 million acres are in forest reserves (see Figure 25), and another 781,000 acres are privately owned and managed outside the forest reserves. Some 947,800 acres of forested lands are suited for the production of industrial wood. However, it is estimated that locally produced lumber meets only about one percent of the state's demand.

The remaining 1,038,600 acres of forested land are noncommercial by virtue of legislation, competing uses, or site limitation. See Figure 42 and Table 33.

Since 1903, some 49,000 acres of land have been reforested and rehabilitated, of which 39,000 acres support commercial tree species. Table 33 shows the acreage of forest plantations in Hawaii.

Some private lands are managed by the state Division of Forestry under an arrangement known as a surrender agreement. On the other hand, some state-owned lands are under long-term lease to private and military lessees. Much of the public and privately owned forest lands are within conservation districts regulated by the state Department of Land and Natural Resources.

Publicly owned or administered lands

TABLE 33
Commercial and Noncommercial Forest Land

	COMMERCIAL				
ISLAND	PLANTATIONS	OTHER	TOTAL	NONCOMMERCIAL	TOTAL
Hawaii	18.1	551.3	569.4	583.1	1,152.5
Maui	10.6	56.9	67.5	172.3	239.8
Kahoolawe	--	--	--	15.8	15.8
Lanai	1.0	3.5	4.5	39.4	43.9
Molokai	2.6	31.4	34.0	44.1	78.1
Oahu	8.2	118.3	126.5	78.8	205.3
Kauai	5.6	140.3	145.9	74.0	219.9
Niihau	--	--	--	31.1	31.1
Total	46.1	901.7	947.8	1,038.6	1,986.4

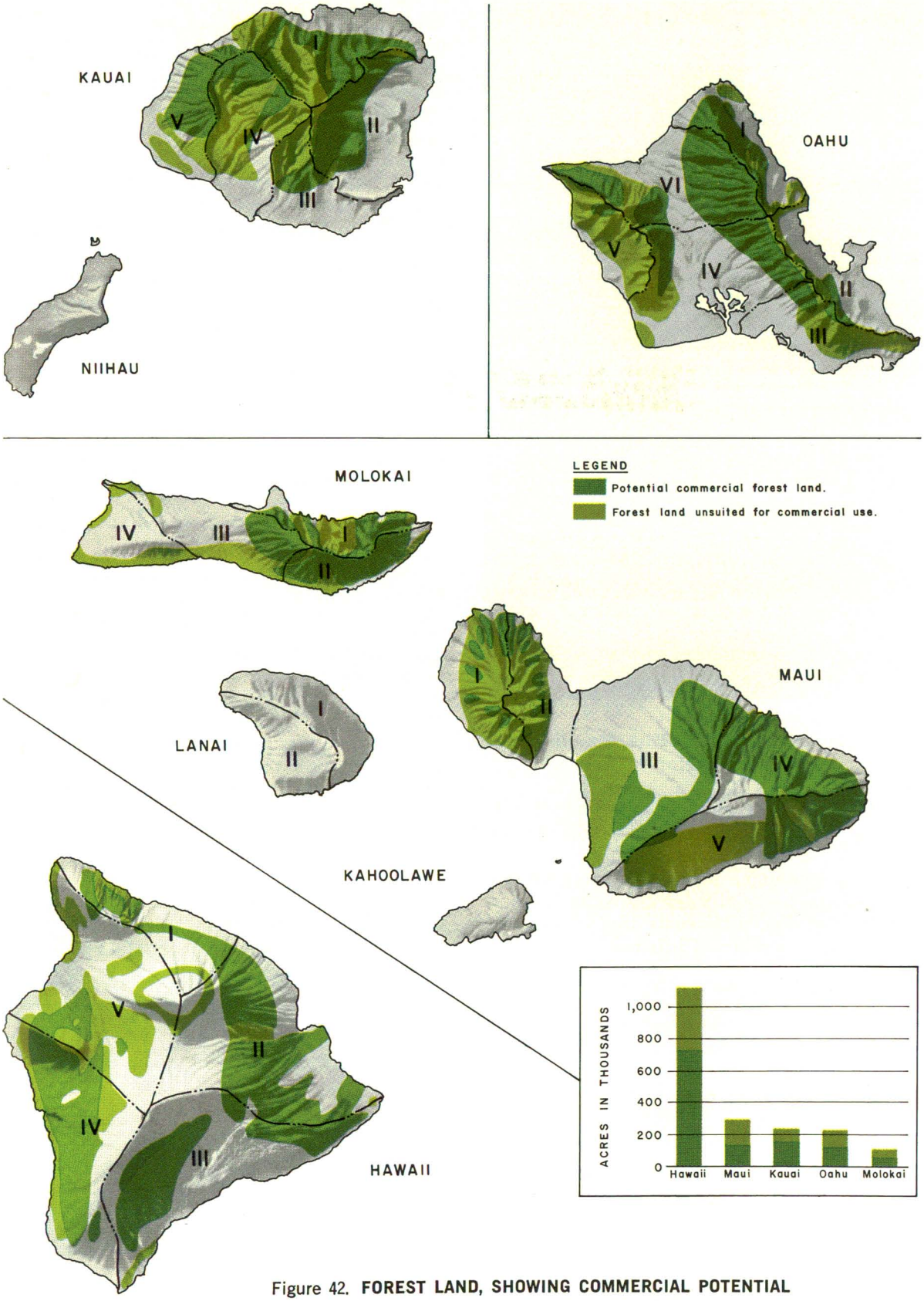


Figure 42. **FOREST LAND, SHOWING COMMERCIAL POTENTIAL**

Reforestation, Kalopa State Park, Hawaii.

in forest reserves have been managed differently than privately owned lands outside the forest reserves. Generally there has been greater commercial activity in the private forest lands, especially for firewood, timber, and grazing. Recently, some tree cutting for wood chips, lumber, Christmas trees, and other forest products has been encouraged, especially on Maui and Hawaii.

The management policy for publicly owned or administered forest reserves, once aimed solely at watershed protection, was changed in 1961 to a multiple-use concept. The present policy is to promote and achieve a use pattern that will best meet the needs of Hawaii's people.

Hawaii's native forests provide important habitat for rare plants and animals. Since reforestation lowers wildlife values of the forest, benefits of commercial use must be weighed against this loss.

- *RECOMMENDATION 15-2.* Increase commercial forest production from selected watersheds, at the same time preventing threats to native forests.
  - * Complete inventory of timber and wildlife resources in watershed lands.
  - * Develop harvesting methods and equipment for Hawaiian conditions.
  - * Improve road networks and marketing systems.
  - * Develop markets for underutilized species and uses for waste products.
  - * Identify and locate unique ecosystems and wildlife resources to avoid incompatible commercial use.

Inland Soil Erosion

Active erosion is prevalent on cultivated land and unforested open land on all islands, the most severe being on Molokai, Lanai, and Oahu. The magnitude of inland soil erosion of cultivated land and severely eroding unproductive areas is shown in Figure 43. Table 34 summarizes estimated total erosion and sediment yield from each island.

Most soil losses occur as sheet or gully erosion. Crop cultivation, overgrazing of pasture land, and uncontrolled feral game mammals are important causes of soil loss. Prevalent cultural practices have tended to intensify erosion on cropland. Cultivation of steep slopes and the harvesting of large areas particularly contribute to erosion.

Sugarcane is harvested on a cycle of 20 to 36 months, depending on cane variety

TABLE 34
Inland Erosion and Sedimentation

ISLAND	TOTAL AREA (Acres)	SOIL LOSS (Tons/Yr.) TOTAL EROSION	SOIL LOSS (Tons/Yr.) SEDIMENT YIELD
Hawaii	2,584,300	2,286,800	502,500
Maui	471,488	2,357,000	310,000
Lanai	90,400	1,242,000	187,000
Molokai	171,329	2,373,000	357,000
Oahu	355,040	1,355,000	330,000
Kauai	349,568	2,493,000	429,000

and climate. Cane harvesting methods, which are highly mechanized and include burning to remove most leaves, contribute to the erosion potential of cane fields. Soil losses occur primarily during the first six months after harvest, before the new crop develops sufficient canopy to protect the soil. Cultivation of sugarcane in steep areas and field roads going up and down slope increase the erosion potential.

Pineapple, like sugarcane, is grown on flat as well as steep land. However, pineapple harvesting methods are not as highly mechanized as sugarcane. Pineapple land is most vulnerable to erosion during the first few months after the slips have been planted. The many pineapple field roads are areas of high and medium erosion potential, especially in steep terrain.

Erosion rates are higher on pastures in dry areas of Hawaii than in wet areas. In dry areas, vegetation is sparse and soils are more exposed to wind and rain. Erosion in dry areas is further aggravated by wild fires, which cause the spread of undesirable plants in addition to removing protective vegetation. Forage production is more consistent and erosion rates are lower in the high rainfall areas. Grass cover provides protection from raindrop impact and sheet flow. In some areas, soil compaction by intensive grazing has reduced infiltration and increased runoff. When concentrated in poorly defined drainageways, runoff has caused gully erosion in pastures.

Severe inland erosion, Napali Coast, Kauai.

Annual sediment yields for sugarcane and pineapple are estimated at more than 4 tons per acre. This rate is higher than for all other land uses with the exception of developing urban land. The average rate for pasture land is about 1.5 tons per acre.

Sediment yield from well managed forest areas (conservation lands) is estimated at 0.1 ton per acre. Areas affected are those cleared of vegetation by fire and landslides, overgrazing, and military bombardment. Overgrazing by domestic and feral animals probably affects the largest acreage.

Erosion is potentially great in land under development for urban uses. Disturbance of soil during construction and destruction of vegetative cover accelerate soil loss and can result in annual sediment yields of more than 5 tons per acre. Completely developed urban areas, on the other hand, may have sediment yields of only 0.09 ton per acre. Erosion of urbanizing land can be controlled by vegetative and structural measures, limiting area exposed at any one time, and construction during the months of least probable erosive rainfall.

- *RECOMMENDATION 15-3.* Reduce erosion of inland areas.
  - * Apply land treatment practices to cropland and pastures, such as contouring, improved vegetative cover, and strip cropping; and use structural measures such as terraces, drop structures, and check dams in gullies.
  - * Enforce erosion control ordinances on new construction.
  - * Enact and enforce ordinances to control feral game and introduced game species in areas of severe erosion.
  - * Improve programs for revegetating eroded areas such as road cuts, abandoned fields and pastures, and military practice areas.
  - * Study effectiveness of various erosion control measures.
  - * Gather data on erosion and sedimentation rates for various soils and land uses.

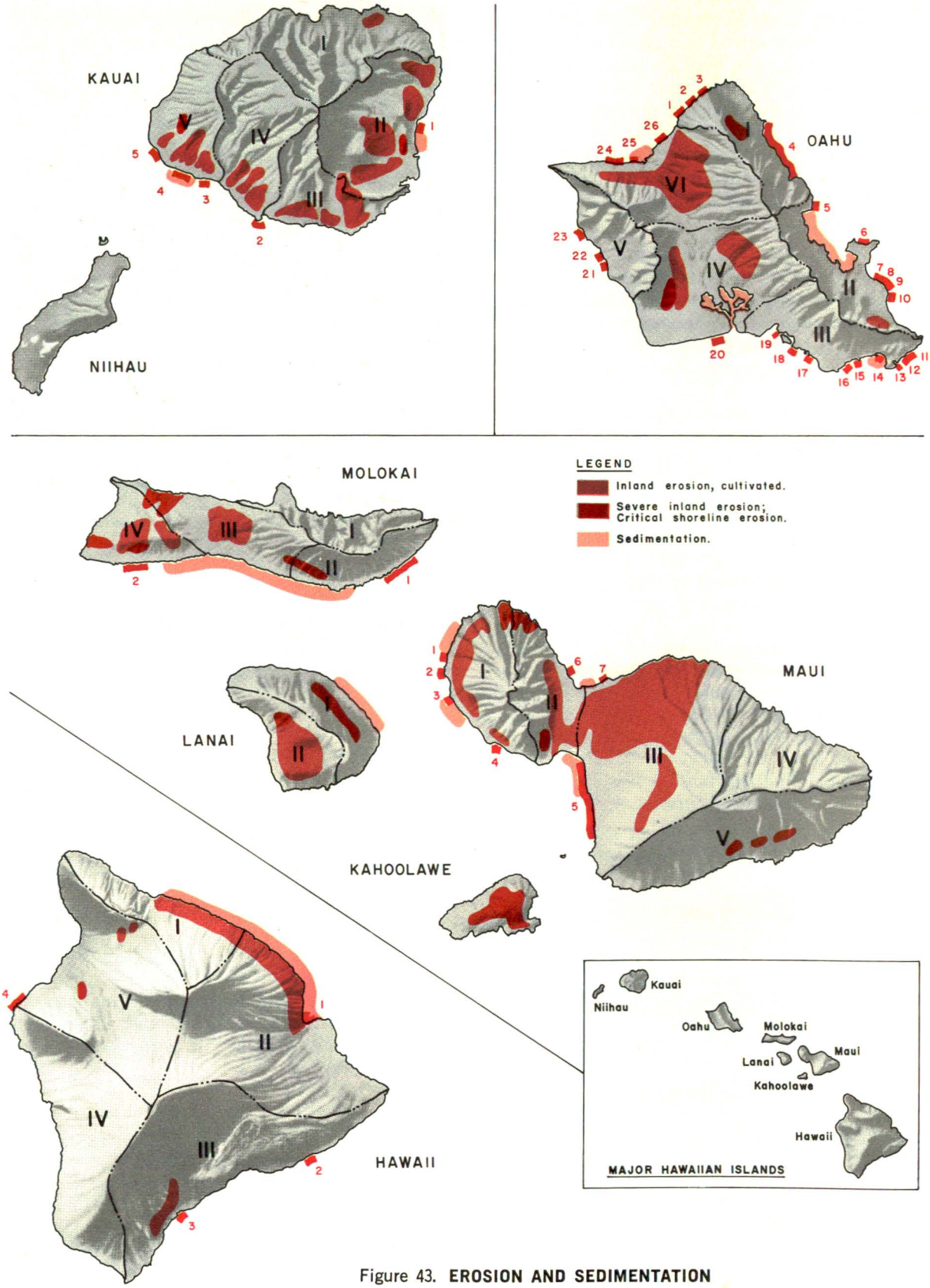


Figure 43. **EROSION AND SEDIMENTATION**

* Determine relationships between hydrologic properties of soils and storm drainage design.

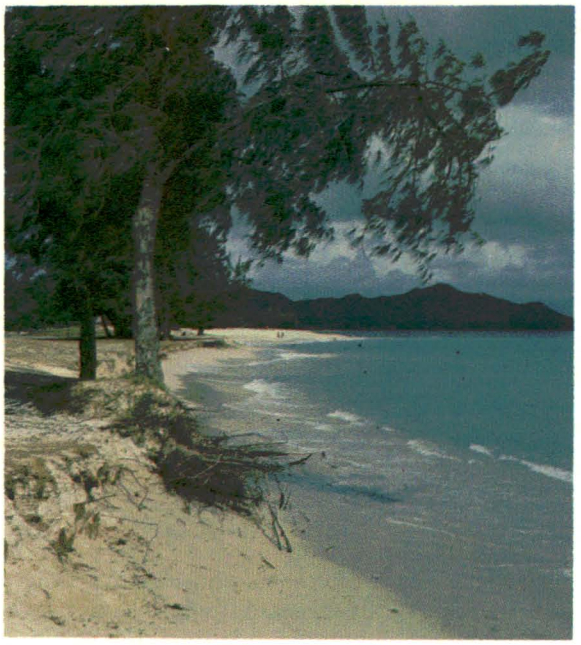
* Determine relationships between soil erosion and sediment yield (delivery rates) for Hawaiian watersheds.

Shoreline Erosion

Erosion is crtical along approximately 31 miles of Hawaii's 934-mile shoreline. See Figure 43 and Table 35. Erosion along another 75 miles of shoreline, although not requiring immediate remedial measures, is expected to become critical during the next 15 to 20 years.

TABLE 35
Areas of Critical Shoreline Erosion

ISLAND and MAP NO.	BEACH	CRITICAL EROSION (1,000 ft.)	TYPE OF LOSS
Hawaii			
1	Hilo Bay	1	Beach
2	Kaimu Black Sand	1	Recreational beach
3	Punaluu Beach Park	1	Recreational beach
4	Kukio Bay to Puu Alii Bay	8	Recreational beaches
Maui			
1	Kaanapali	4	Recreational beaches
2	Hanakoo Point	6	Recreational beach
3	Lahaina Residential	2	Protective beach
4	Olowalu	3	Recreational beach
5	Kihei to Makena	8	Protective beaches
6	Waiehu	3	Protective beaches
7	Sprecklesville	3	Protective beach
Molokai			
1	Pohakuloa to Pukoo	8	Beaches
2	Halena	5	Beach
Oahu			
1	Sunset Residential	6	Major property
2	Waialee Residential	1	Major property
3	Kawela Bay Residential	2	Major property
4	Laie Pt. to Kahana Bay Residential	2	Minor property and beach
5	Roadside	3	Recreational beach
6	Mokapu Marine Corps	1	Beach
7	Kailua Residential	3	Beach
8	Kailua Beach Park	1	Beach
9	Lanikai Residential	3	Beach
10	Bellows Military Beach Park	2	Beach
11	Wawamalu Beach Park	2	Recreational beach
12	Sandy Beach Park	2	Recreational beach
13	Hanauma Bay Beach Park	2	Recreational beach
14	Maunalua Beach Park	1	Recreational beach
15	Kahala Hilton	1	Recreational beach
16	Waialae-Kahala Residential	3	Minor property and beach
17	Waikiki	9	Recreational beaches
18	Ala Moana Beach Park	2	Recreational beach
19	Keehi Lagoon Area	2	Recreational beach
20	Ewa Beach Residential	4	Beach
21	Maili Beach Park	2	Recreational beach
22	Pokai Military	2	Recreational beach
23	Makaha Beach Park	2	Recreational beach
24	Mokuleia Residential	10	Major property
25	Haleiwa Residential	1	Major property
26	Kawailoa Residential	2	Major property
Kauai			
1	Wailua	1	Recreational beach
2	Hanapepe	3	Protective beach
3	Waimea West	3	Protective beach
4	Kekaha	8	Protective beach
5	Barking Sands	8	Protective beach



Shoreline erosion on Windward Oahu.

Shoreline erosion is a major concern when an area is developed or is of recreational significance. These conditions are most common on Oahu, where there is a strong demand for sandy beaches. Repairs, restoration, and protective measures are required to reduce erosion.

- *RECOMMENDATION 15-4.* Reduce shoreline erosion.

  * Regulate shoreline use to prevent damaging development.

  * Provide structural measures such as sea walls, revetments, and beach nourishment to reduce critical shoreline erosion.

Sedimentation of Water Related Lands

Erosion from upland areas results in the sedimentation of bays, estuaries, harbors, and coastal wetlands. Major sources are field cultivation, subdivision development, highway construction, cane wastewater discharge, and overgrazing by cattle and feral mammals.

The most severely affected sites are drainage areas for natural water courses, such as Kaneohe Bay and Pearl Harbor. In other cases, such as the southern shore of Molokai, siltation is not so localized.

Sedimentation of fishponds may render the water too shallow for fish culture, and sedimentation of reef lagoons may smother and kill live coral. Beaches may be undesirable for recreation because of persistently turbid water and dirty sand.

- *RECOMMENDATION 15-5.* Reduce sedimentation of bays, estuaries, harbors, and coastal wetlands.
  - * Implement upstream controls to reduce sediment loads, including control of feral mammals on private lands.
  - * Revise and enforce more efficient grading ordinances.
  - * Install debris and sediment traps.
  - * Install levees and peripheral waterways.
  - * Dredge and clear sediment deposits.
  - * Study effects of soil loss and sediment desposition in estuaries.

16. FISHERIES

Worldwide demand for fishery products continues to increase, and Hawaii's location in the Pacific basin provides a strategic advantage for supplying this demand. Yet the tonnage and real dollar value of Hawaii's commercial fishing catch has generally declined for the last two decades.

Opportunities exist for increasing commercial fishery production in the following categories.

Skipjack Tuna Catch

Hawaii's principal fish catch is skipjack tuna (aku), caught with pole and line using live bait. Over 75 percent of the weight and value of fish landed in Hawaii are high-seas species, including yellowfin and bigeye tuna *(ahi)*, caught with longlines. See Table 36 and Figure 44.

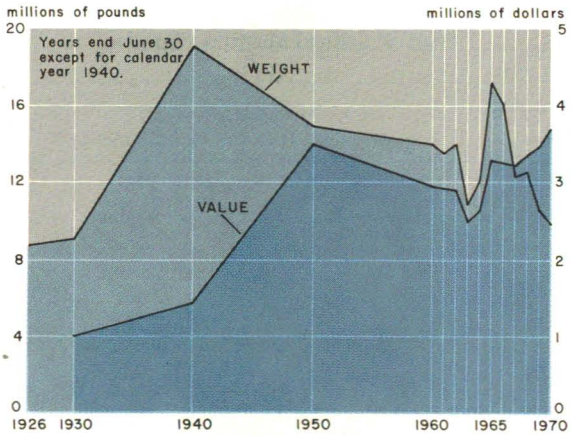


Figure 44. **COMMERCIAL FISH CATCH**

TABLE 36
Commercial Fish Catch, Fiscal Year 1970

SPECIES	POUNDS	VALUE TOTAL (Dollars)	VALUE PER POUND (Cents)
Aku (Skipjack)	5,704,127	1,149,566	20.2
Ahi (Bigeye)	729,672	683,370	93.7
Akule	696,692	253,369	36.4
Ahi (Yellowfin)	586,574	361,113	61.6
Striped Marlin	330,275	212,670	64.4
Hahalalu	271,953	101,982	37.5
Opelu	184,271	94,195	51.1
Pac. Blue Marlin	150,306	52,117	34.7
Ulua	93,203	42,901	46.0
Kahala	86,165	30,085	34.9
Mahimahi	73,876	60,409	81.8
Opakapaka	72,730	48,813	67.1
Uku	50,673	27,964	55.2
Other Species	736,466	455,967	61.9
Total Sea Catch	9,766,983	3,574,521	36.6
Pond Catch	19,743	10,415	52.8

The Mainland demand for canned tuna from Hawaii greatly exceeds the supply. In view of this demand, skipjack represents the last major underdeveloped tuna resource in the Pacific Ocean. The Central and Eastern Pacific probably could yield several hundred thousand tons of skipjack annually. Yet the total catch in these areas runs considerably less than 100,000 tons a year.

- *RECOMMENDATION 16-1.* Foster an increased catch of skipjack tuna (aku) by the Hawaii fishing fleet.
  - * Improve the supply of baitfish.
  - * Improve fishing and fish locating methods.

* Provide low-interest loans and tax incentives for improving fishing boats and equipment.

* Expand and improve harbor facilities.

Inshore and Offshore Fisheries

Limits of the inshore area used for fishery statistics extend two miles seaward of the shoreline. The offshore area extends another 18 miles seaward from the outer limits of the inshore area. Inshore and offshore areas are depicted in Figure 45, which also shows the ten top-ranking segments of the offshore area. Table 37 gives annual production from the top-ranking offshore segments.

A comprehensive assessment of Hawaii's inshore and offshore fishery resources is needed as the basis for regulations to protect populations for maximum sustained yields.

- *RECOMMENDATION 16-2.* Increase inshore and offshore commercial fishing opportunites.
  * Protect and improve habitat for larval fish.
  * Protect breeding population by establishing sanctuaries, closed seasons, and size and bag limits.
  * Use treated wastes to improve productivity.
  * Improve access to underfished areas where compatible with conservation of other natural resources.
  * Evaluate potential for improving yield by using nutrient-laden deep ocean water.
  * Investigate possibilities for artificial propagation of fisheries resources.

Aquaculture Industry

Recent studies show how well early Hawaiians had perfected the art of raising

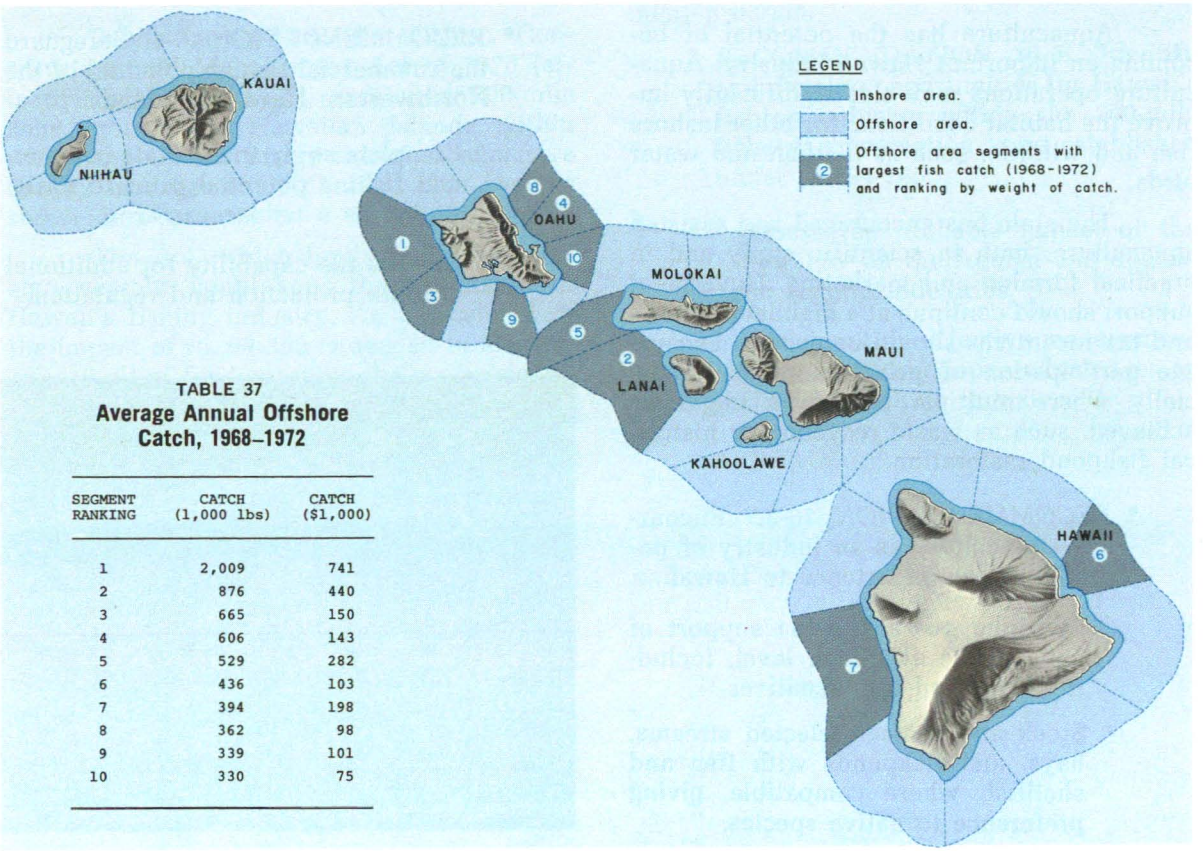
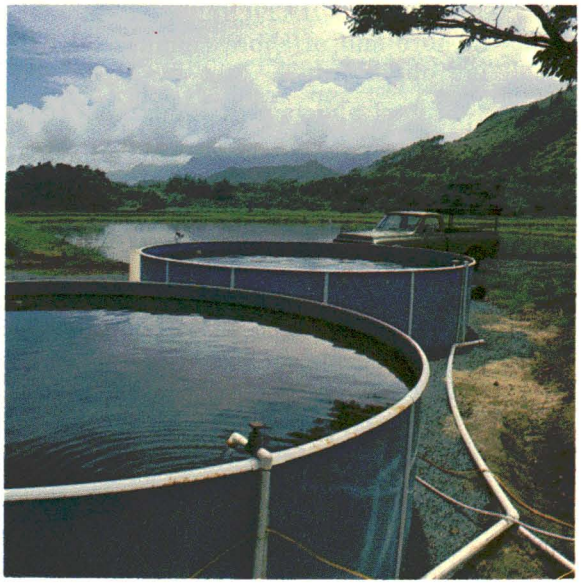


TABLE 37
Average Annual Offshore Catch, 1968–1972

SEGMENT RANKING	CATCH (1,000 lbs)	CATCH ($1,000)
1	2,009	741
2	876	440
3	665	150
4	606	143
5	529	282
6	436	103
7	394	198
8	362	98
9	339	101
10	330	75

Figure 45. **INSHORE AND OFFSHORE FISHING AREAS**



Modern aquaculture, Kualoa, Oahu.

fish in coastal ponds. See Figure 54 for fishpond locations.

Aquaculture has the potential of becoming an important Hawaii industry. Aquaculture operations may also significantly improve the habitat conditions for other inshore fish and wildlife, such as baitfish and water birds.

The state has encouraged and assisted aquaculture, both in scientific study and in practical farming and marketing. Goverment support should continue at a high level. Loans and tax incentives should be used to encourage participation of private industry, especially where multiple objectives might be achieved, such as waste recycling or historical fishpond restoration.

- *RECOMMENDATION 16-3.* Encourage aquaculture as an industry of potential major importance to Hawaii.
  - * Continue government support of aquaculture at a high level, including loans and tax incentives.
  - * Stock and protect selected streams, bays, and fishponds with fish and shellfish where compatible, giving preference to native species.
  - * Refurbish and utilize selected Hawaiian fishponds.

Commercial Fishing in Northwestern Hawaiian Islands

The Hawaiian Island National Wildlife Refuge, which encompasses most of the Northwestern Hawaiian Islands, is a critical area for the conservation of marine birds, endemic land birds and waterfowl, the Hawaiian monk seal, and the green sea turtle. See Figures 4 and 53. The simple island ecosystems of the chain can withstand very little disturbance.

Legislation is pending to have these islands declared a "natural wilderness area," which might limit commercial fishing opportunities.

The fisheries potential of these islands is not well known. Increasing needs for fishery products and the recent availability of vessels capable of fishing these islands economically warrant a survey of their commercial fishery potential prior to any designation as a natural wilderness area. A joint study is now underway by federal and state agencies.

- *RECOMMENDATION 16-4.* Safeguard the commercial fishing potential of the Northwestern Hawaiian Islands.
  - * Complete study to evaluate commercial fishing potential prior to designation as a wilderness area.
  - * Provide the capability for additional wildlife protection and regulation.

Traditional aquaculture, Alii Fishpond, Molokai.

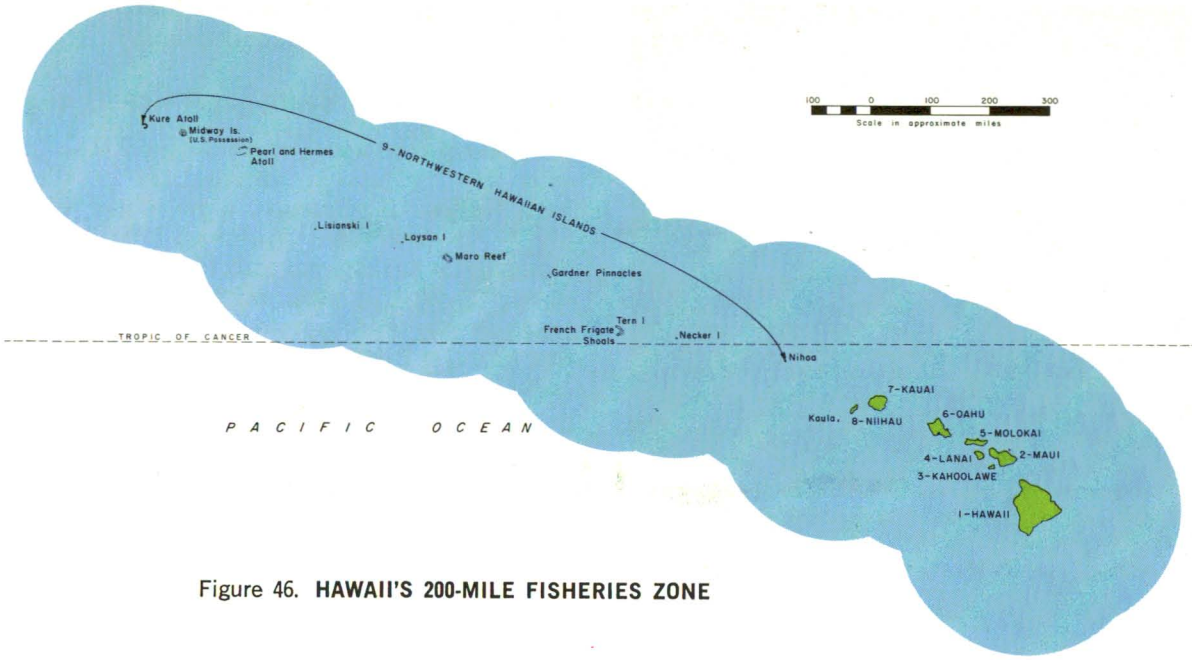


Figure 46. **HAWAII'S 200-MILE FISHERIES ZONE**

Hawaii's 200-Mile Fisheries Zone

Public Law 94-265, the Fishery Conservation and Management Act of 1976 (effective March 1, 1977), created a 200-mile zone around the Hawaiian Islands within which the United States exercises exclusive fishery management authority. This zone is shown in Figure 46.

The Act, which limits fishing by foreign vessels, could spur the expansion of Hawaii's fishing industry. An assessment of the impact of PL 94-265 is needed to identify opportunities for improving the economic advantage to Hawaii's fishing industry and to lay the foundation for an effective management program.

- *RECOMMENDATION 16-5.* Identify and develop opportunities for Hawaii's fishing industry within the 200-mile fishery conservation zone established under PL 94-265.

  * Assess the probable impact of the new law on the foreign and domestic fishing industries.

  * Implement an effective management program to maximize advantages to Hawaii's fishing industry.

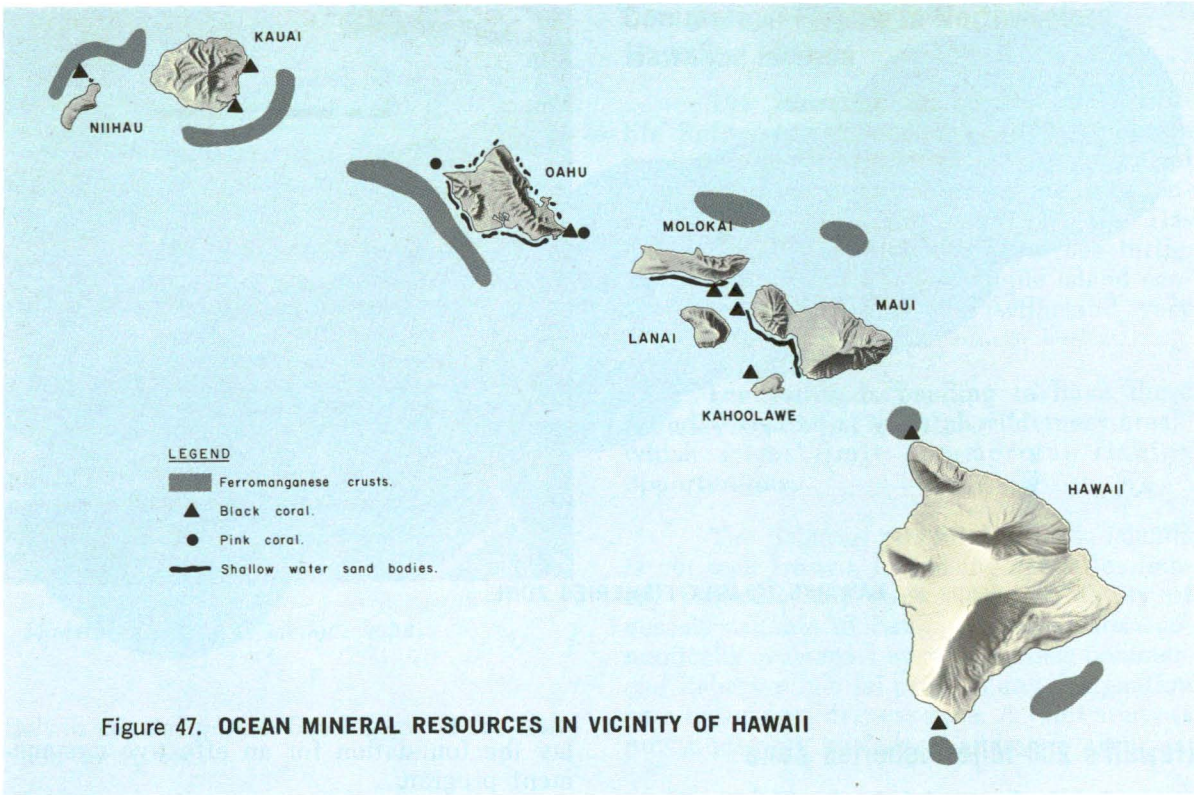


Figure 47. **OCEAN MINERAL RESOURCES IN VICINITY OF HAWAII**

17. MARINE INDUSTRIES

Water resources planning is concerned with the following marine industries.

Precious Coral Harvest

Precious coral is the basis for a small but growing industry. Black, pink, and gold coral colonies are being harvested at depths of 150 to 1,500 feet over a very small portion of their known range (Figure 47). However, increasing demand may stimulate more widespread utilization of these resources.

None of the species is in danger of total depletion because of inaccessibility, but management is needed to ensure a sustained yield at a reasonable level.

- *RECOMMENDATION 17-1.* Protect the precious coral industry.
  - * Conduct an appraisal of precious coral resources.
  - * Manage the precious coral harvest to assure a sustained yield of raw materials.

Offshore Sand Mining

Offshore sand deposits offer a continuing supply of raw material for construction uses. Development of technology by government and private interests would allow use of this resource with minimum environmental disturbance, provided that mining is adequately regulated.

The Hawaii Institute of Geophysics has located over 300 million cubic yards of sand off Oahu and about 4 billion yards of sediments containing some sand off the islands of Maui and Molokai. See Figure 47. These deposits have the potential of meeting Hawaii's needs for many years to come. A number of economic and environmental problems must be resolved before this resource can be exploited.

- *RECOMMENDATION 17-2.* Promote the mining of offshore sand deposits.
  - * Continue to develop methods and technology.

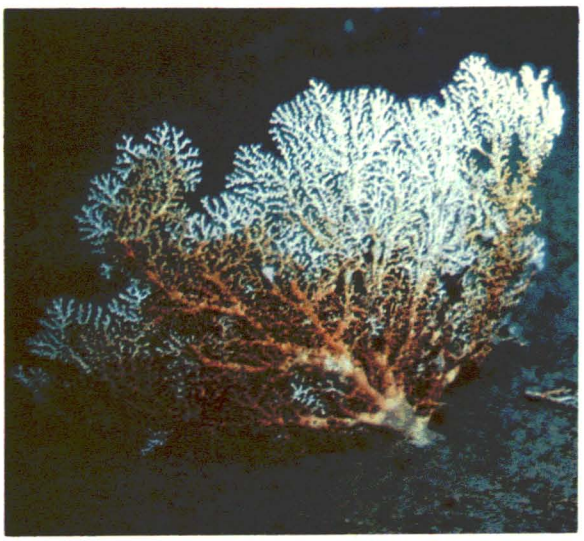
* Establish rules and regulations for resource management.

Deep Ocean Manganese Mining

Mining of deep ocean manganese deposits in the vicinity of Hawaii will very likely begin on a commercial basis before the end of the century. See Figure 47. While there is no doubt that manganese mining will disturb the ocean floor, its effects on biologically significant waters nearer the surface are uncertain. Ore transport and refining will have environmental impacts related to shipping and industrial use of water and land.

Hawaii appears to have an advantage as a base for processing and concentrating ores intended for the Far Eastern market. Vessels conducting exploration and research are presently using Hawaiian supply ports, and the University of Hawaii and state Department of Planning and Economic Development are participating in these efforts. Participation in all phases of the mining and processing operations could generate an income of $1 billion per year.

Uncertainties concerning the mining of these deposits include the economic value and costs of mining the ore, mining and refining methods, location of refining plants, environmental impacts of mining and processing, ownership of deep ocean deposits, and availability of water, land, and electric power.



Precious coral.

Manganese nodules on ocean floor.

Rights to deep ocean mineral deposits beyond the three-mile limit must be established in order to assure participation by the U.S. in a deep ocean mining industry. Long-range economic and environmental benefits would accrue to Hawaii if the entire chain were established as an integral archipelago, or continuous domain, under international law.

The recent discovery of apparently substantial quantities of geothermal energy in the Puna district of Hawaii may make a large surplus of electrical energy available. The area also has a large surplus of ground water, plentiful vacant land, and a nearby deep water port.

Government and private interests should accelerate research and development programs aimed at the optimum use of what appears to be an untapped, almost inexhaustible source of industrial metal ores. It is reasonable to assume that those nations best prepared and best situated to develop these resources will reap the greatest benefits. A continuing program is needed to assure a suitable role for Hawaii in this development.

- *RECOMMENDATION 17-3.* Establish an appropriate continuing role for Hawaii in the mining and processing of manganese deposits.
  * Assess the environmental and economic impact on Hawaii of participation at various levels.
  * Plan the allocation of resources to support an appropriate level of participation.
  * Continue technical and logistic support.
  * Pursue the establishment of archipelago status under international law.

18. MARINE TRANSPORTATION

The movement of people and goods from place to place is an important aspect of economic development. Water resources planning for Hawaii must consider the following aspects of marine transportation.

Transocean Harbor Facilities

The State of Hawaii is deeply committed to and dependent upon water transportation for its welfare, survival, and growth. See Figure 48. Since most of Hawaii's trade moves through its ports, properly developed and managed harbor facilities are essential for efficiency and economy.

Deep-draft harbors are essential to Hawaii's future. Plans for improvements must take into consideration: (1) increased efficiency through modern shipping and handling techniques, (2) direct calls from the Mainland to major islands, (3) possible new harbor sites, (4) possible multiple uses of existing facilities, such as the repair shops at Pearl Harbor, and (5) emergence of new technology, such as hydrofoils.

Additional harbor facilities will be required on all major islands to accommodate increased traffic, because Hawaii will continue to be greatly dependent on transocean shipping for movement of bulk goods.

An average of 1,750 vessels a year

Container ship facilities, Honolulu Harbor.

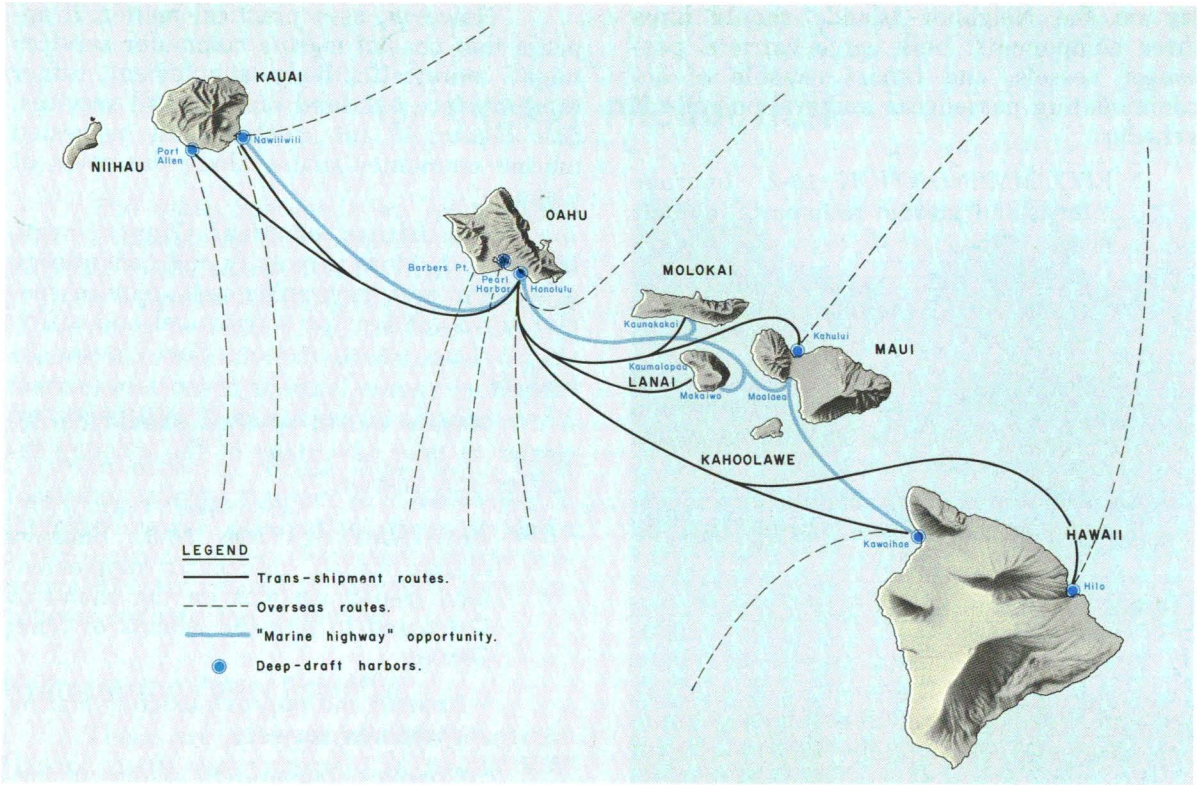


Figure 48. **MAJOR MARINE TRANSPORTATION ROUTES AND PORTS OF CALL**

from many nations now call at Honolulu. Vessel calls have increased from about 850 in 1950, to 1,000 in 1955, 1,400 in 1960, and 1,750 in 1975.

Overseas cargo tonnage moving in and out of Honolulu Harbor has increased from 2,500,000 tons in 1950, to 3,500,000 tons in 1955, 4,000,000 tons in 1960, and about 7,557,000 tons in 1974. The state Department of Transportation projects an increase in cargo tonnage to 16,270,000 tons by 2000.

The cargo capacity of vessels calling at Hawaii's ports has increased due to containerization and the use of larger ships. Container ships spend less time in port than vessels carrying conventional cargo.

Reduction in the number of vessel calls would reduce berth requirements. A container berth can handle about four times as much cargo as a conventional cargo berth, but requires more back-up area.

- *RECOMMENDATION 18-1.* Improve harbor facilities for transocean shipping.
  - * Improve navigability of existing harbors.
  - * Increase cargo storage and handling facilities.
  - * Provide additional deep-draft harbors as needed.

Inter-Island Marine Highway

Hawaii is unique among the 50 states in that it is an archipelago, a small group of land masses at the center of the Pacific basin, isolated from each other by expanses of open ocean.

The cultural, economic, and commercial integration of the Islands can be achieved with only two alternative inter-island modes of transportation—aircraft or seacraft. A "marine highway" system to facilitate routine movement of people and vehicles, as well as improved cargo capability, could help unite the islands of the state. See Figure 48.

A marine system adequate to unite the six inhabited Islands socially and economically and to support expansion of light indus-

try on the Neighbor Islands should have three components: bulk cargo carriers, passenger vessels, and ferries capable of accommodating passengers and roll-on/roll-off vehicles.

- *RECOMMENDATION 18-2.* Improve inter-island marine transportation services.
  - * Develop data on comparative demand for all marine transportation systems.
  - * Continue to investigate methods of improving the surface transportation links between the islands for cargo, vehicles, and people.
  - * Determine enviromnental and economic impacts of a marine highway system.

Marine Transit Services

Water-borne rapid transit has been suggested as an alternative to a fixed-roadbed transit system for Honolulu. Construction costs of approximately $200 million for harbor improvements and terminals would be required.

However, as a practical matter, it appears that coastal marine commuter services might more effectively supplement rather than displace overland rapid transit services. See Figure 49 for existing and suggested marine commuter routes along the coast of Oahu.

The islands of Maui County, being in relatively close proximity and constituting a geologic and geographic unit, require special consideration for economical and efficient surface transportation. See Figures 24 and 49.

Marine transit systems should be designed to take advantage of the existing facilities and vessels.

- *RECOMMENDATION 18-3.* Improve marine transit services to supplement land transit systems on the island of Oahu and to link the islands of Maui County.
  - * Expand and improve existing marine commuter services.
  - * Conduct comparative studies of marine commuter systems.

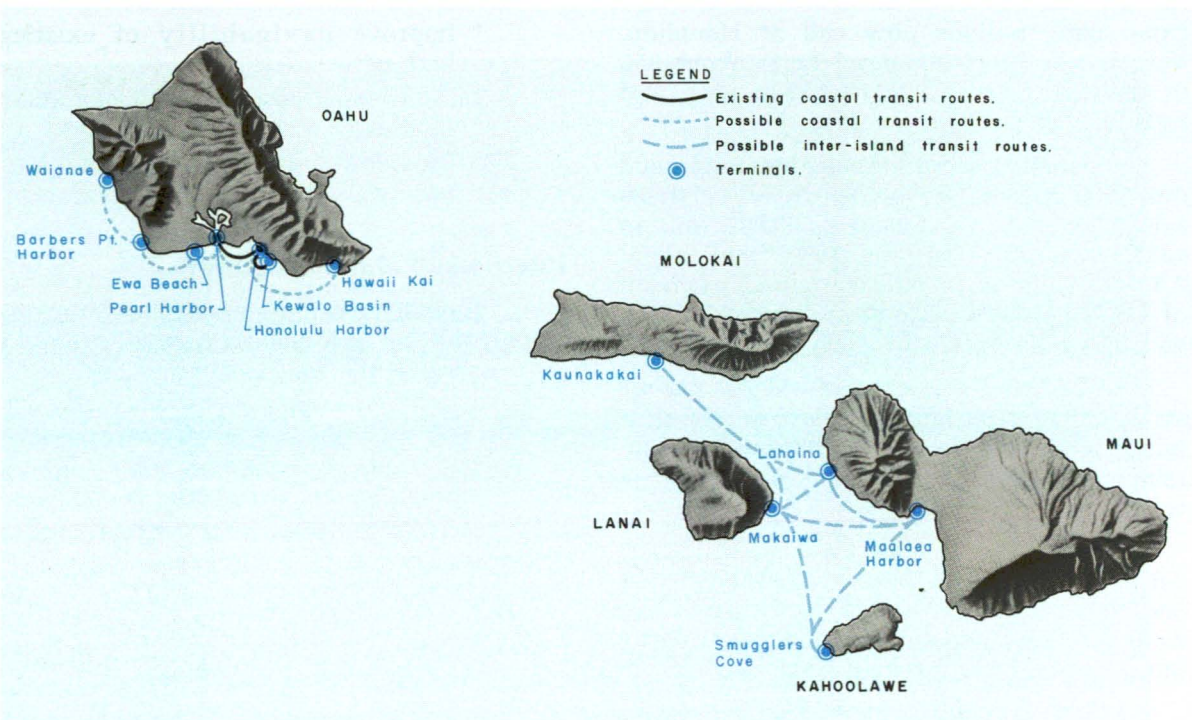


Figure 49. **MARINE COMMUTER ROUTES**

19. ENERGY PRODUCTION

The state has made an encouraging start in combining government and private interests in the search for alternative energy sources. Opportunities exist for providing an increasingly favorable legal and institutional climate for research and development of geothermal and ocean thermal energy in significant quantities to meet Hawaii's future needs.

In order to reduce dependence upon fossil-fuel energy sources, it is necessary to increase power production from Hawaii's water power sources. Potential energy programs directly related to Hawaii's water resources include the following.

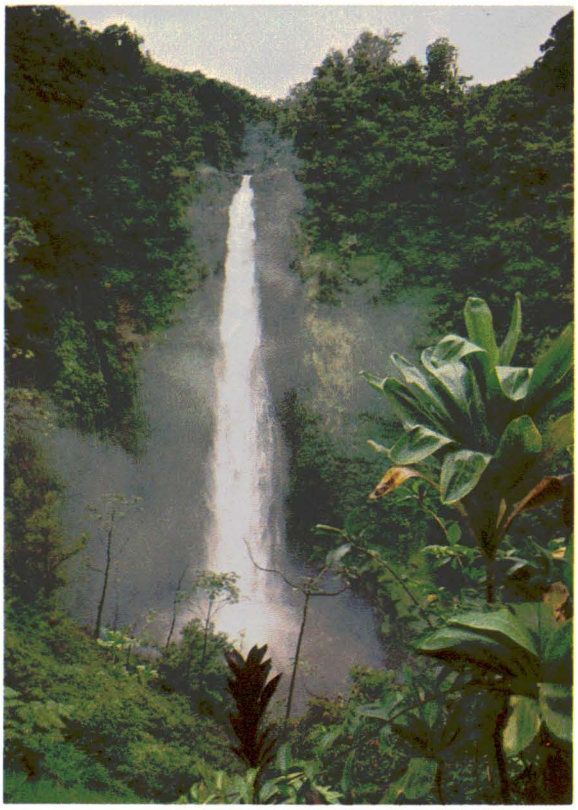
Hydroelectric Power Potential

There are 19 hydroelectric plants in Hawaii, with an aggregate of 20,430 KW generating capacity. Most of these plants were constructed as adjuncts to the development of irrigation water and are operated by sugar plantations for their own use. Some are owned by public utilities on the Island of Hawaii. See Figure 50 and Table 38.

Hydroelectric power production could be increased by improving the efficiency of eixsting plants and by constructing new plants at suitable sites.

A recent survey shows the possibility of developing an additional 56,000 KW of hydroelectric generating capacity in Hawaii. The total potential is not large in comparison with future power demand statewide. However, hydroelectric plants could possibly supply up to 26 percent and 22 percent, respectively, of Kauai's and Molokai's energy demands in 1990. Kauai also has a few excellent water storage sites. On Maui and Hawaii, smaller and more isolated communities might benefit from local hydroelectric power devlopment.

- *RECOMMENDATION 19-1.* Investigate the potential for increasing hydroelectric power production.
  - * Improve efficiency of existing hydroelectric plants.
  - * Improve streamflow records at potential hydroelectric plant sites.
  - * Study potential for hydroelectric power in Hawaii, including power generation from dike compartments.
  - * Assess the impacts of hydroelectric power development on fish and wildlife resources and recreational opportunities.
  - * Develop hydroelectric plants at suitable sites.
  - * Study use of geothermal and ocean thermal energy and surplus hydroelectric power to pump and store water to generate hydroelectric power for peak requirements.
  - * Investigate systems for storing and transporting surplus energy.



Akaka Falls, Hawaii.

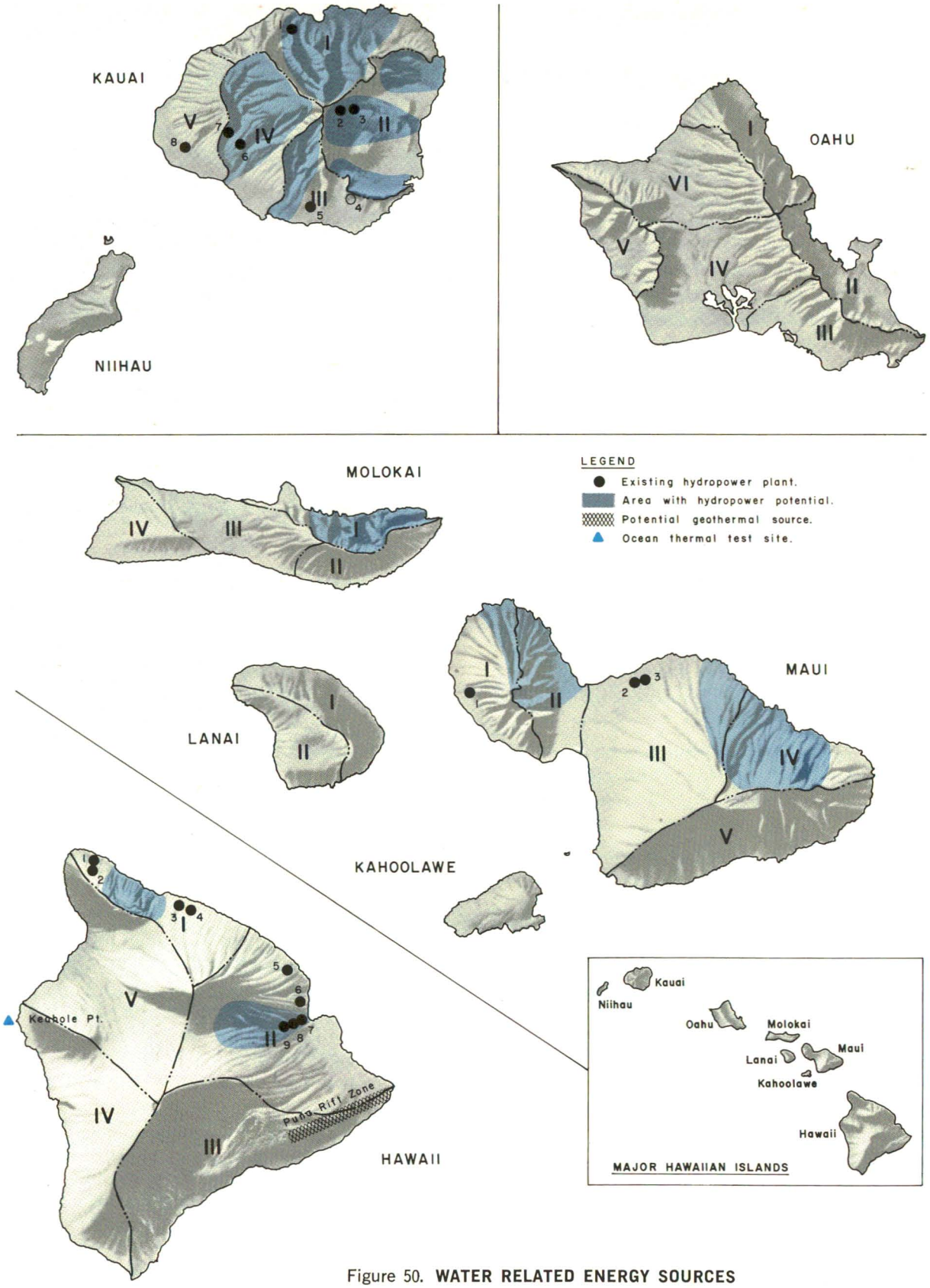


Figure 50. **WATER RELATED ENERGY SOURCES**

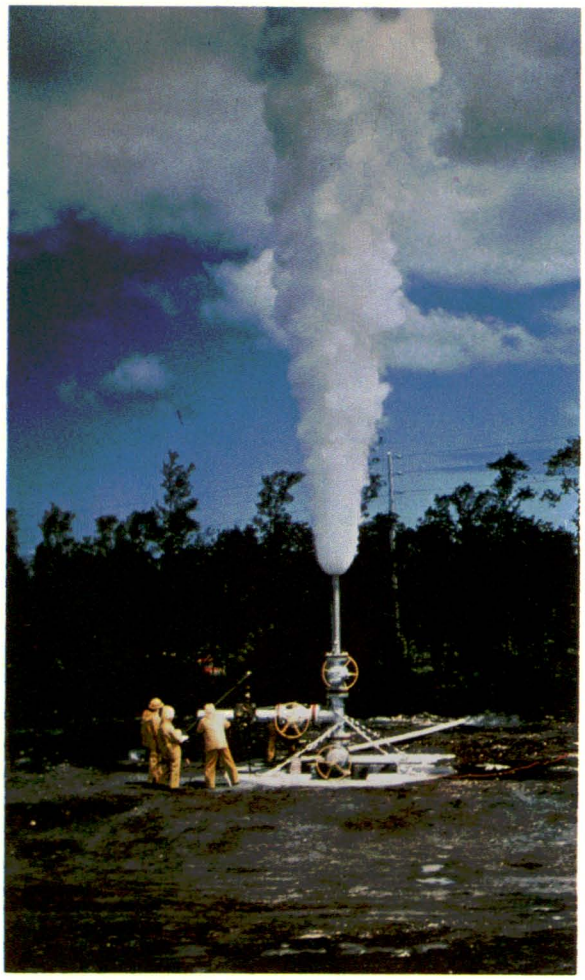
Geothermal Energy Potential

Geothermal energy, natural heat from the interior of the earth, potentially can meet the energy requirements of areas where this resource occurs sufficiently close to the surface to be tapped safely and economically. Geothermal energy has been used for many years throughout the world on a small scale and is steadily gaining greater attention. It has a high potential for electric power production, residential space heating, desalinization, refrigeration, and air conditioning.

The Island of Hawaii has the most promising geothermal resources. Studies of the island's volcanic areas are underway, and an exploratory well has been drilled to a depth of more than 6,000 feet. At this depth, temperatures of more than 400°F prevailed and a significant quantity of steam was generated. Temperature anomalies that may be indicative of geothermal fields are also known to exist at depths on Maui and Oahu.

If all aspects of the program continue on schedule, a prototype geothermal power plant very likely will be in operation on Hawaii within a few years.

Prospects for commercial development of geothermal power are encouraging enough to warrant a joint public and private program of accelerated research and development.



Geothermal exploration, Puna, Hawaii.

TABLE 38
Hydroelectric Power Plants, 1974

ISLAND and MAP NO.	LOCATION	INSTALLED CAPACITY (kw)
Hawaii		
1	Hawi	350*
2	Union	500*
3	Honokaa	800
4	Paauhau	150
5	Hakalau Mill	75*
6	Papaikou Mill	150
7	Wainaku Mill	60*
8	Waiau	1,100
9	Puueo	2,250
Maui		
1	Kauaula	500
2	Paia	800
3	Kaheka	5,799
Kauai		
1	Wainiha	3,600
2	Upper Waiahi	500
3	Lower Lihue	800
4	Malumalu	216**
5	Kalaheo	1,000
6	Nonopahu	500
7	Waimea	1,000
8	Waiawa	500

* Phased out in 1975. **Abandoned site.

- *RECOMMENDATION 19-2.* Develop geothermal energy as a major power source on Hawaii and investigate potential as a supplemental source on Maui and Oahu.
  - Accelerate geothermal source development on Hawaii.
  - Conduct geophysical surveys of potential geothermal areas on Maui and Oahu.

Ocean Thermal Energy Potential

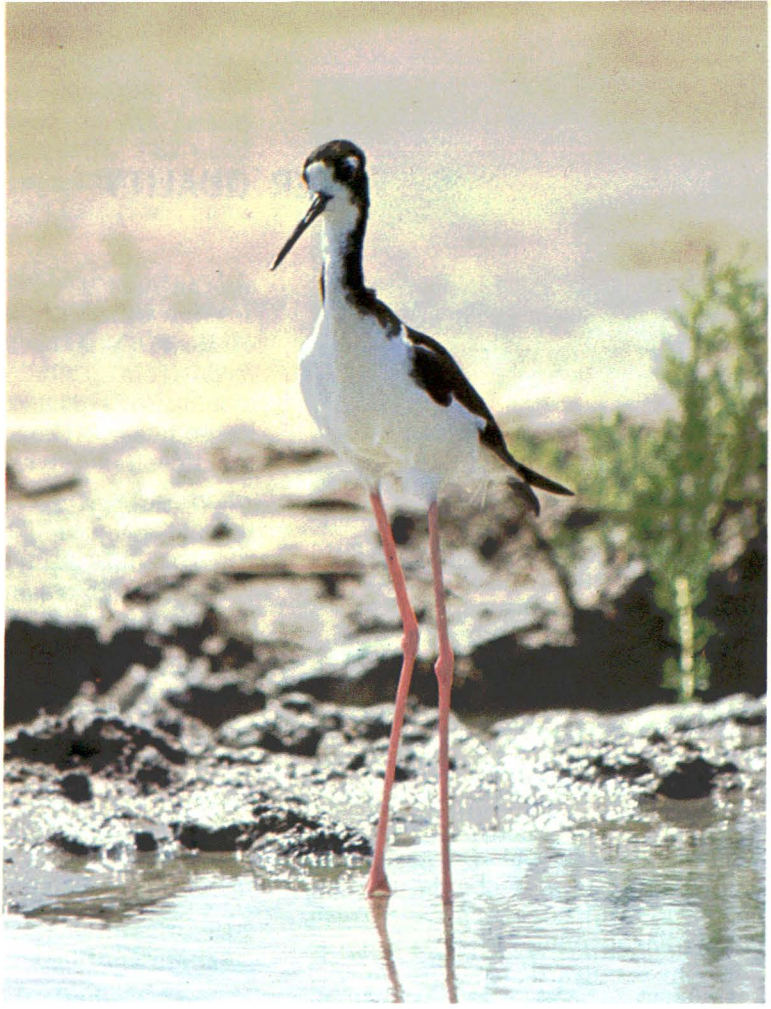
Ocean thermal energy is a form of solar energy in which the "fuel source" is the 40°F temperature difference between the

warm water at the surface of the ocean and the cold water at ocean depths. The equipment used to tap the energy source operates like a steam turbine. Although the "fuel" is free, the efficiency of such a system is extremely low due to the relatively small temperature difference.

Ocean thermal energy project, Ke'ahole Point, Hawaii.

Hawaii is an ideal test site for ocean thermal energy conversion, since there are a number of locations where deep cold water is near land, the temperature differences with the warm surface water are 40-45°F, and the state has a strong technological support base. Research is being conducted to determine the feasibility of a site at Ke'ahole Point on the Island of Hawaii for an ocean thermal energy conversion facility.

- *RECOMMENDATION 19-3.* Assess the potential of ocean thermal energy conversion.
  - * Establish pilot project at Ke'ahole, Hawaii.
  - * Assess environmental effects of construction and operation.
  - * Consider additional sites on Oahu.
  - * Formulate ocean temperature profiles.
  - * Improve data on ocean currents.
  - * Conduct further research into the magnitude of the potential energy resource.



Hawaiian stilt (a'eo), endangered waterbird.

Water and the Environment

In Chapter 4 on the environment, national environmental quality objectives are discussed briefly. Components of the national environmental quality objective have been applied to Hawaii's water and related land resources concerns in the following chapters.

Preservation and enhancement of water and land quality for present and future generations are fundamental environmental concerns.

In planning for the development and use of water resources for human and economic needs, due consideration must also be given to the preservation and enhancement of Hawaii's biological and cultural resources.

Aesthetic values of water and related land, important to quality of life in Hawaii as well as visitor satisfaction, must also be adequately protected.

20. WATER QUALITY

The maintenance and enhancement of water quality requires consideration of ground water, surface water, and coastal water.

Salt Water Intrusion into Basal Fresh Water Aquifers

All major Hawaiian Islands are underlain by basal fresh water lenses. See Figure 17. The largest and most fully developed lenses occur where semipermeable caprock restricts the outflow of fresh water to the sea. Wells drilled into the basal lens in such areas are artesian, and fresh water may stand 30 feet or more above sea level.

Salt water and fresh water mix in the basal lens in a transition zone that varies in thickness with hydrologic conditions. If fresh water is removed from the basal system faster than the rate of recharge, the underlying salt water intrudes upon the fresh water lens. Similarly, pumping from a large well can produce upward currents in the lens, resulting in an increase of salinity in the well and a persistent thickening of the brackish transition zone.

Salt water intrusion of basal aquifers can best be avoided by a program of proper well spacing and pumping schedules, based on an expanded observation well program and applied research.

- *RECOMMENDATION 20-1.* Control salt water intrusion into basal fresh water aquifers.
  - * Design and space new wells and regulate pumping schedules of all wells to prevent excessive thinning of fresh water lenses.
  - * Increase fresh water recharge to basal aquifers.
  - * Determine long-term effects of periodic overdraft on ground water quality.

Subsurface Injection of Wastewater

Subsurface disposal of liquid wastes is being considered more frequently as an alternative to discharges into streams and coastal waters. Since more than 60 percent of Hawaii's domestic water supplies are derived from ground water bodies, subsurface disposal of wastes represents a potential pollution hazard. The approximate extent of such practices is shown in Table 39.

Subsurface injection of wastewater through deep wells should be limited to confined saline aquifers or to highly treated wastes which pose no hazard to the receiving aquifer.

- *RECOMMENDATION 20-2.* Regulate subsurface injection of wastewater to prevent contamination of basal fresh water aquifers and wetlands.
  - * Strengthen design, licensing, and monitoring requirements for effluent injection wells, including treatment of injected wastes.
  - * Allow wastewater injection only into confined saline aquifers.
  - * Compile data on location and extent of underground wastewater disposal.
  - * Conduct research on effects of underground waste disposal on ground water quality and on wetlands.

Cesspools and Similar Disposal Systems

As previously noted, private disposal systems are used in areas where there are no sewer systems and are more prevalent on

TABLE 39
Waste Disposal Sites, 1972

ISLAND	SUBSURFACE INJECTION EXISTING	SUBSURFACE INJECTION PROPOSED	MAJOR POINT SOURCE DISCHARGES INTO STREAMS AND OCEAN
Hawaii	22	4	24
Maui	43	24	12
Oahu	30	24	96
Kauai	19	3	14

the Neighbor Islands. For example, about 95 percent of the population of the Island of Hawaii is served by cesspools. The need for a better system is recognized by the county, particularly for highly urbanized and shoreline areas.

There is a possibility of ground water contamination as well as pollution of coastal waters by cesspool seepage. Presently, new cesspools are generally limited to sparsely populated upland areas where there is no danger of contaminating the ground water supply.

Cesspools should be allowed only in suitable soils and at suitable densities. Seepage pits and land fills should be allowed only where usable ground water supplies will not be polluted.

- *RECOMMENDATION 20-3.* Regulate the use of cesspools, seepage pits, and solid waste dumps to prevent contamination of fresh ground water supplies.
  - * Replace cesspools as needed with sewers or other suitable systems.
  - * Require treatment of wastewater disposed of in seepage pits.
  - * Obtain data on contamination of ground water by leachates from land disposal systems.
  - * Allow solid waste disposal only where leachates will not pose a hazard to ground water.

Point Source Wastewater Discharges

Because of Hawaii's island environment, coastal water quality is of particular significance. See Figure 51 for water classes and water quality segments defined by the state Department of Health pursuant to federal law. Table 40 shows statewide priority ranking of the 10 water quality segments in Hawaii.

Point source discharges are of municipal, industrial, and agricultural origin. Problems created by these discharges usually are readily identified and dealt with by regulating agencies. Principal sources of industrial discharges are sugar mills, pineapple canneries, oil refineries, and electric power plants. Military installations contribute both industrial and domestic wastewaters to the environment. Irrigation tailwater which has been confined for treatment is another point source. The remaining major point source discharges are principally municipal sewage, both treated and untreated.

Waste discharge from sugar mill, Hamakua Coast, Hawaii.

The National Point Dicharge Elimination System (NPDES) is designed to reduce point source discharges to essentially zero by 1985 to conform with PL 92-500. This will greatly improve water quality in streams and coastal waters. Remaining will be the more difficult task of controlling non-point sources.

- *RECOMMENDATION 20-4.* Conduct research on the effects of wastewater discharges, including the following:
  - * Design criteria for deep ocean outfalls.
  - * Effects of treated wastes on the ocean environment.
  - * The fate and effect of nutrients and sediment on estuarine water quality and ecosystems.
  - * Significance of fresh water coral kills in coastal ecosystems.
  - * Mercury and toxic metal cycling in estuaries.
  - * Level of health hazards from sewage-borne human pathogenic viruses in both marine and terrestrial ecosystems.

Non-Point Source Discharges

Even after all point sources of pollution are eliminated or controlled, certain areas will still be seriously affected by pollution from non-point sources. In those areas

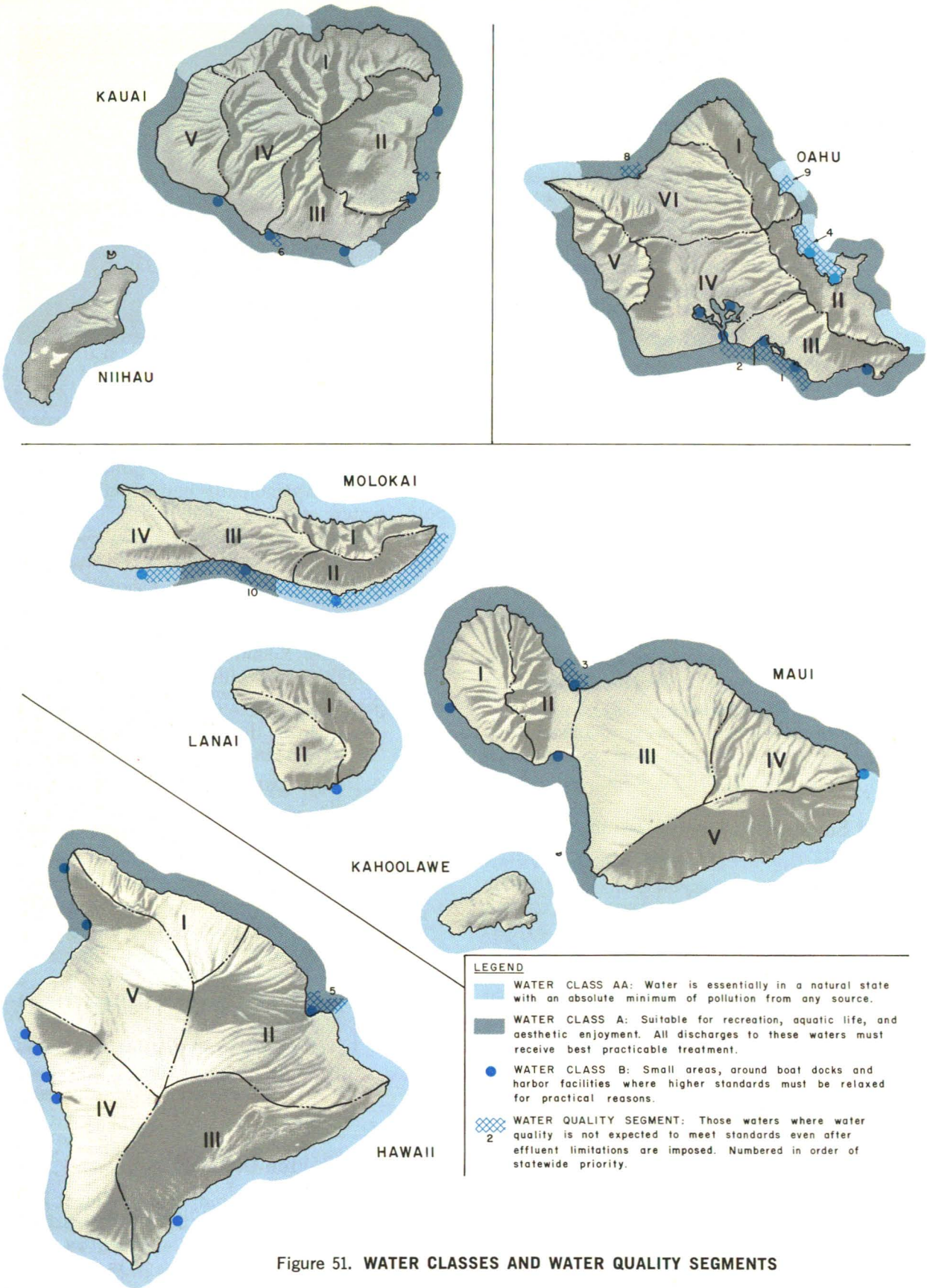


Figure 51. **WATER CLASSES AND WATER QUALITY SEGMENTS**

TABLE 40
Statewide Ranking of Water Quality Segments

ISLAND	STATEWIDE PRIORITY	LOCATION
Hawaii	5	Hilo Bay, Paukaa Point to Leleiwi Point
Maui	3	Kahului Bay, Nehe Point to Hobron Point
Molokai	10	South Molokai, Cape Halawai to Haleolono Harbor
Oahu	1	Mamala Bay, Diamond Head Light to Ahua Point
	2	Pearl Harbor, Ahua Point to Keahi Point
	4	Kaneohe Bay, Kuloa Point to Pyramid Rock
	8	Kaiaka Bay, Kaiaka Point to foot of Kaimanu Place
	9	Kahana Bay, Makalii Point to Mahie Point
Kauai	6	Port Allen, Puolo Point to Port Allen Pier
	7	Hanamaulu Bay, north point of bay to Ahukini Landing

designated as "water quality segments" by the state Department of Health (Figure 51), water quality will still not meet standards even after point sources are eliminated. The potential for non-point source pollution from urbanizing areas, intensively cultivated and overgrazed areas, and forest reserves will increase with population growth.

Urban pollutants include sediment from land development, grease, oil, and chemicals from streets, urban litter, and industrial spillage. Sediment from crop cultivation and overgrazed pasture land is the most prevalent agricultural pollutant, along with fertilizer and pesticides. Erosion in forests may be accelerated as a result of fires and landslides or from human and animal activities.

The population of pigs, goats, sheep, cattle, and deer may increase to the point where animal feces make a measurable contribution of nutrients, oxygen consuming materials, and bacteria to runoff from the watershed. It is not known whether any of the bacteria produced are harmful to humans, but their presence interferes with standard bacterial quality tests, and the other pollutants make the water less desirable for domestic use. In addition, the grazing and rooting activities of large animal populations disturb soil cover and increase erosion potential, thus contributing to stream water turbidity.

Reduction of non-point source pollution of coastal waters will generally improve surface water quality. However, contamination of potable surface water supplies by concentrations of animal populations in source areas will continue to require preventive measures. Laws and regulations restricting human activties in *kapu* watersheds result in a high degree of protection for feral and game animals.

- *RECOMMENDATION 20-5.* Reduce non-point source pollution of streams and coastal waters.
  - * Develop coordinated programs within each county to improve control over non-point source pollutants.
  - * Minimize erosion and floods by limiting soil-disturbing activities in urban areas and watersheds.
  - * Maintain sanitary conditions in streams and drains by litter controls, street sweeping, and control of open storage in industrial and commercial areas.

Urban litter in Ala Wai Canal, Oahu.

* Implement improved soil conservation practices on croplands and grazing lands.
* Reclaim severely eroded areas.
* Increase controlled hunting of pigs and garzing animals in *kapu* watersheds to reduce pollution of surface water.
* Gather data on pollutant loads in urban runoff.

National Water Quality Standards

Wastewater treatment and receiving water standards developed for Mainland river systems, bays, and estuaries are in many cases inappropriate for Hawaii's coastal waters.

As presently interpreted, the standards often require inordinately expensive facilities for the treatment and disposal of municipal and industrial wastes, such as both secondary treatment *and* deep ocean outfalls. These requirements may limit or preclude reclamation of wastewater for beneficial use on land.

An example of inappropriate receiving water standards is Kahana Bay, where coastal water is affected by relatively undeveloped land. Nutrient deposits in the bay from Kahana Stream are small; yet the measured nitrogen and phosphorous levels fail to meet state Class AA water quality standards. Even in the contiguous open ocean water, nitrogen and phosphorous also exceed the Class AA tolerence levels.

Also inappropriate for Hawaii is the state temperature standard, which limits temperature changes in coastal waters to not more than 1.5°F from natural conditions. Oceanographic studies indicate an upper limit of about 84.2°F for preservation of coral and other marine life, which is 5-7°F above normal ocean temperature.

- *RECOMMENDATION 20-6.* Revise wastewater treatment and receiving water standards to suit Hawaii's conditions.
  * Lower the treatment level for disposal by deep ocean outfalls or by injection into confined saline aquifers.
  * Seek legislative or administrative relief where receiving water classes and effluent standards are determined to be unrealistic.

Major Oil Spills

Continuing dependence on petroleum fuels in Hawaii requires increasing imports. The probability of a major oil spill will increase accordingly, especially along transocean shipping lanes.

A major oil spill could have a catastrophic effect on the shoreline ecology of Hawaii, devastating birds and reef fish populations. Some parts of the state where such a spill might occur, such as the Northwestern Hawaiian Islands, are isolated from manpower and equipment centers.

A task force on oil spills headed by the lieutenant governor is concerned with the problem.

- *RECOMMENDATION 20-7.* Reduce potential hazard to the environment from a major oil spill.
  * Enhance the readiness of men and equipment to enforce navigation and safety regulations in such event.
  * Develop contingency plans for protection and restoration of fish and wildlife resources.

Oil spill clean-up by Coast Guard.

Forest cleared of hapuu fern, Volcano, Hawaii.

21. LAND QUALITY

In water resource planning, the following four aspects of land quality are considered.

Forests and Open Land

More than half of Hawaii's land area is forest or open land. Management of these lands is aimed at preserving environmental values such as the quality of soil and natural ecosystems, preserving hydrologic properties, and protecting aesthetic values.

Insects and disease are major problems in forest maintenance. Native *ohia* trees are dead or dying in a 200,000-acre area on the Island of Hawaii. No cause has yet been determined. With the exception of this area, infested forest acreage has not been quantified. Biological pests attacking both native and exotic tree species in other forest areas are being identified. These include fungi, insects, and exotic plant pests.

Forest fires are a continuing problem on most of the islands, particularly in the drier, leeward sections. Each of the past five years, an average of 15,850 acres of protected lands have been burned over. Frequently, vegetal cover is lost; reestablishing native cover is almost impossible. Plants that invade burns are often undesirable.

Areas protected from forest fires include both forests and adjacent pasture and open land. Less than five of every 1,000 acres of protected area are burned each year. Better equipment and coordination between fire-fighting agencies are reducing this further. Access continues to be the worst problem, slowing response and limiting the use of fire-fighting equipment.

Forest lands, being usually steep and subject to high rainfall, have a high erosion potential. However, where vegetation is not disturbed, erosion rates are generally low.

Less than 224,000 acres of forest lands are classed as eroding, and most of that (190,600 acres) is classed as sheet and gully erosion. Barren lands cause water quality

Forest fire damage, Volcano, Hawaii.

problems and lessen surface water infiltration into ground water reserves. Since 1903, some 49,000 acres of land have been reforested and rehabilitated.

Some forest areas are highly valued for their unique native flora and fauna. Because of Hawaii's remote location and geologic history, many plants and animals native to the state are found nowhere else in the world. They have evolved into unique life forms of great scientific interest, but are not aggressive enough to compete with exotic life forms introduced since the coming of man. Protection of native plants from invasion by noxious plant species is a major concern.

- *RECOMMENDATION 21-1.* Preserve and enhance the quality of forests and open land.
  - * Prevent and control forest diseases, insect damage, fires, and the spread of noxious plants.
  - * Control erosion by establishing and maintaining adequate vegetation, installation of structures, and control of grazing and roaming animal populations.
  - * Improve fire-fighting capability by development of program to assess fire hazard, limitation of conflicting use, and improved interagency coordination.
  - * Identify and protect unique ecosystems and habitats for rare plants and animals.

Agricultural Land

Agricultural land use maintains greenery, open space, and wildlife habitat. About 57.3 percent of all the land in Hawaii (2,354,450 acres) is designated agricultural under the Land Use Act. Preservation and enhancement of the quality of this resource for future generations is a major environmental concern.

Alternating strips of protective vegetation in sugar and pineapple fields can reduce the soil loss during harvesting, as well as improve the appearance of agricultural areas. Such measures as pasture rotation, fencing, irrigation, seeding, and fertilization can increase vegetative cover and reduce erosion.

- *RECOMMENDATION 21-2.* Preserve and enhance agricultural land quality.
  - * Reduce erosion of cropland by applying appropriate conservation measures, and by ensuring cover on abandoned or inactive fields.

Pineapple fields, Maui.

* Increase strip cropping practices for sugar and pineapple to minimize soil loss and to improve the aesthetic values of agricultural landscapes.
* Contol grazing on pasture lands to ensure adequate cover conditions.

Urban Land and Highway Corridors

New zoning ordinances now being implemented promise to alleviate many of the problems associated with urban development. However, a supplemental program to rehabilitate exposed soil areas is needed. This is particularly true of exposed highway cuts and fills along older roads, where maintenance funds are inadequate to provide for seeding, fertilization, and irrigation.

- *RECOMMENDATION 21-3.* Preserve and enhance the quality of urban land and highway corridors.
  * Enforce erosion controls ordinances on all new construction.
  * Establish and maintain vegetative cover on exposed road cuts and fills.
  * Use structural measures where they are needed.

Wetlands, Shorelines, and Submerged Lands

Hawaii's wetlands, shorelines, and submerged lands provide habitat for many native and endangered species of wildlife, fish, and plants. Quality of wetlands and submerged lands is preserved when outlets to the ocean are protected and adequate streamflows are maintained.

Development of flood plains throughout the state has led to the channelization and diversion of natural watercourses, in order to increase property values of neighboring land and to prevent periodic flood damage. The impact on stream ecosystems has often been severe, particularly when the affected fauna includes species that migrate back and forth to the sea.

Development usually increases stream velocity, but when the flow is slow water temperature is often increased. Development may also reduce the depth of the water, duration of runoff, and ground water levels. The quality of habitat for stream organisms is further degraded by the removal of vegetation and other natural barriers to direct water flow.

Waterfowl habitat, Kawainui Marsh, Oahu.

The use of Hawaii's limited estuarine habitat by endangered waterbirds has recently attracted considerable attention to the management of these areas. Both state and federal legislation protects the individual species, but the habitat itself has been inaequately protected from disturbance. Much of the original wetland habitat in Hawaii has been depleted by industrial, housing, and resort development. The 1973 federal Endangered Species Act includes several provisions for habitat protection, the implications of which are not yet entirely clear.

Silt-laden runoff entering the inshore environment smothers coral reefs and renders the water unsightly and unsafe. Large areas can become biological deserts. It is particularly significant that the areas most affected are often the most critical areas in fisheries and waterbird resource production, such as estuaries, coral reefs, and fish ponds.

- *RECOMMENDATION 21-4.* Preserve and enhance wetlands, shorelines, and submerged lands.
  * Ensure adequate water circulation in bays, estuaries, and wetlands by careful maintenance of channels and adequate streamflow levels.
  * Protect wetlands and submerged lands from excessive sedimentation and erosion.
  * Identify and protect wetlands of prime value as wildlife habitat.

22. BIOLOGICAL RESOURCES

The protection of Hawaii's biological resources is of great concern in water resources planning. More than one-half of the endangered species of fish, wildlife, and plants in the United States are found naturally only in Hawaii. Protection of biological resources focuses upon the following matters.

Rare and Endangered Animals and Plants

The large number of rare and endangered plants and animals in Hawaii can be preserved only if their natural habitats are protected as reserves, refuges, and sanctuaries. However, balancing the need for protection of rare and endangered species of plants and man's use of water related land will be extremely difficult.

The requirements of the 1973 Endangered Species Act will have far-reaching effects. Although some 800 species of plants in Hawaii may actually be rare and endangered, little is known about them. Few would be recognized by anyone except specialized scientists. Endangered species might be found by a detailed vegetation survey almost anywhere in Hawaii. Full implementation of the Act will require careful planning of sanctuaries and reserves and the coordination of concerned public and private interests.

Endangered Hawaiian monk seal.

Wetlands on Kauai, Oahu, and Molokai have been given federal refuge status under a program of habitat acquisition and development to preserve Hawaii's endangered waterbirds. However, the program suffers from inadequate funds for habitat management.

Serious game management conflicts have arisen in areas where endangered species appear to be threatened by habitat destruction. The endangered *palila* on Mauna Kea is an example. Considerable evidence suggests that maintenance of feral sheep populations sufficient to support substantial recreational hunting will eventually lead to destruction of the *mamane-naio* forest and, with it, the extinction of the *palila*. The range of native forest birds and vital habitat for endangered forest bird species are shown in Figure 52.

The Hawaiian monk seal is on the federal list of endangered species. Both this species and the Hawaiian population of the green sea turtle reproduce only in the Northwestern Hawaiian Islands. Little is known about the movements or the inshore habitat requirements of either species. However, undisturbed breeding beaches appear to be critical to both.

O'opu, Hawaii's only native fresh water fish, may be threatened through predation of its eggs and fry by introduced fishes such as tilapia. While not listed as endangered, better protection should be sought for the *o'opu*.

The hump-backed whale has been adopted as the official Hawaiian marine mammal. Protection of breeding and nursery areas off Lahaina and Maalaea, Maui, must be considered in any development plans for these areas.

- *RECOMMENDATION 22-1.* Preserve rare and endangered animals and plants.

  * Refine endangered species lists.

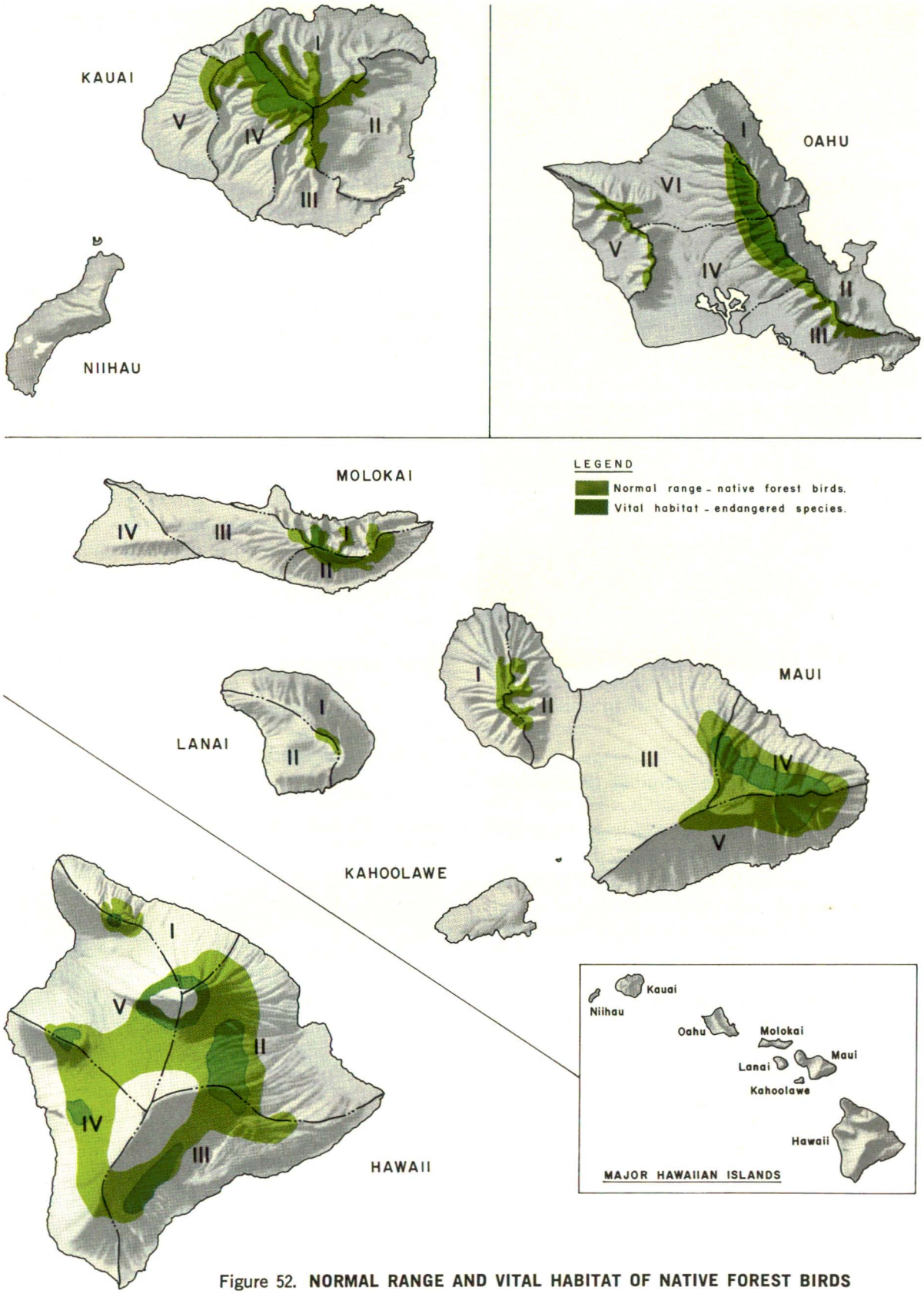


Figure 52. **NORMAL RANGE AND VITAL HABITAT OF NATIVE FOREST BIRDS**

Endangered Kauai o'o.

* Improve delineation of crticial habitat areas.
* Improve data on fish and game species and habitat charactistics.
* Establish natural area reserves where rare and endangered plants and animals are a significant part of the ecosystem.
* Establish wildlife and plant sanctuaries in critical areas.
* Manage native forests to protect and preserve rare and endangered species.
* Create new habitat as part of water development and storage projects.

Unique Ecosystems

There are approximately 20 major coastal water ecosystem categories in Hawaii which can be conveniently grouped into major biotopes. Several biotopes are considered transitional between terrestrial and water habitats, others are aquatic, still others are transitional between aquatic and marine, and the remainder are classified as marine.

There are 54 principal natural terrestrial ecosystems falling within six ecological zones described by dominant genera or species, of which 29 are considered to be predominantly native vegetation.

Nearly one-half of the total native higher plant flora in Hawaii may be extinct or threatened with extinction. This compares with approximately 10 percent of the total native flora in the continental U.S.

The reserve system should be used to preserve entire ecosystems unique to Hawaii. A suitable buffer zone should be included in the reserve to prevent the introduction of harmful species and degradation of the ecosystem.

In some areas, protection of aquatic ecosystems will require establishment of criteria for maintaining minimum flows in streams and the preservation of wetlands and nearshore areas. Minimum flows can be maintained by limiting the amount of water withdrawn under a permit or license. Setting of minimum flows would also protect water rights of abutting land owners, public interest in fish and wildlife resources, and recreation and aesthetic values.

- *RECOMMENDATION 22-2.* Preserve unique coastal and terrestrial ecosystems.
  * Define and locate native ecosystems.
  * Identify and protect unique natural ecosystems under the Natural Area Reserve or Marine Life Conservation District programs.
  * Establish buffer zones around unique natural ecosystems to minimize potential harmful impacts.
  * Study stream habitat changes and ecological affects of water control and development.
  * Establish criteria for maintaining minimum flows in streams and preserving wetlands and nearshore areas.
  * Maintain low flow in perennial streams where possible to protect relatively undisturbed ecosystems.

* Develop methodology for monitoring gradual adverse effects on coral reef ecosystems.
* Protect coastal ecosystems from excessive fresh water flood flows.
* Determine impacts of power generation on terrestrial and coastal water resources.

Fish and Wildlife Habitat

A major impediment to development of a management plan for inshore fish and wildlife is confusion over habitat jurisdiction. The State of Hawaii retains title to all shoreline below the high tide line, unless title has been withheld by the federal government or has been transferred to private ownership. Above the high tide line, shoreline ownership is approximately 60 percent private, 28.5 percent state and county, and 11.5 percent federal. The diversity of ownership and land use objectives affects inshore fish and wildlife in many ways.

Nearly all federal land in Hawaii of significance to fish and wildlife is under protective status or under military control. Most of the nonmilitary federal land is within Haleakala National Park and Hawaii Volcanoes National Park. Fish and wildlife management polices within the parks are intended to "preserve for all time scenic beauty, wilderness, native wildlife, indigenous plantlife, and areas of scientific significance or of antiquity."

Sooty tern colony, Manana Island, Oahu.

The military lands of primary concern to wildlife management include forests, open lava lands, grasslands, wetland habitat, and marine bird nesting sites. In the past, military land has been managed under a single-use concept, with little regard for the management or public use of wildlife resources. More recently, however, fish and wildlife management has been integrated into the planning programs of several military installations. Priority is being given to indigenous over exotic species.

Conflicts between the state and the military have arisen over certain wildlife issues. The continued bombing of Kahoolawe is a case in point. If the island were returned to the state, its recreational and wildlife potentials might be realized by the elimination of feral animals, removal of ordnance, and restoration of vegetative cover. Bombing of Kaula Rock, off Niihau, threatens the continued breeding of more than 10 seabird species.

Military use of other land areas, particularly forests on Oahu and Molokai, threatens ecosystem integrity by the introduction of exotic plants and insects and the destruction of habitat by fire and equipment operations.

Inaccessibility to the shoreline through private and military land has caused excessive resource depletion in accessible areas. Different land use policies have prevented coordinated management of resources that range outside a single jurisdiction.

Existing and proposed wildlife and plant sanctuaries are located on Figure 53 and tabulated in Table 41.

- *RECOMMENDATION 22-3.* Protect fish and wildlife habitat.
  * Improve delineation of critical habitat areas for endangered and threatened species.
  * Establish sanctuaries to protect seabird nesting sites, especially offshore islands.
  * Minimize jurisdictional and management conflicts.
  * Integrate fish and wildlife management into land use planning for state and federal lands.

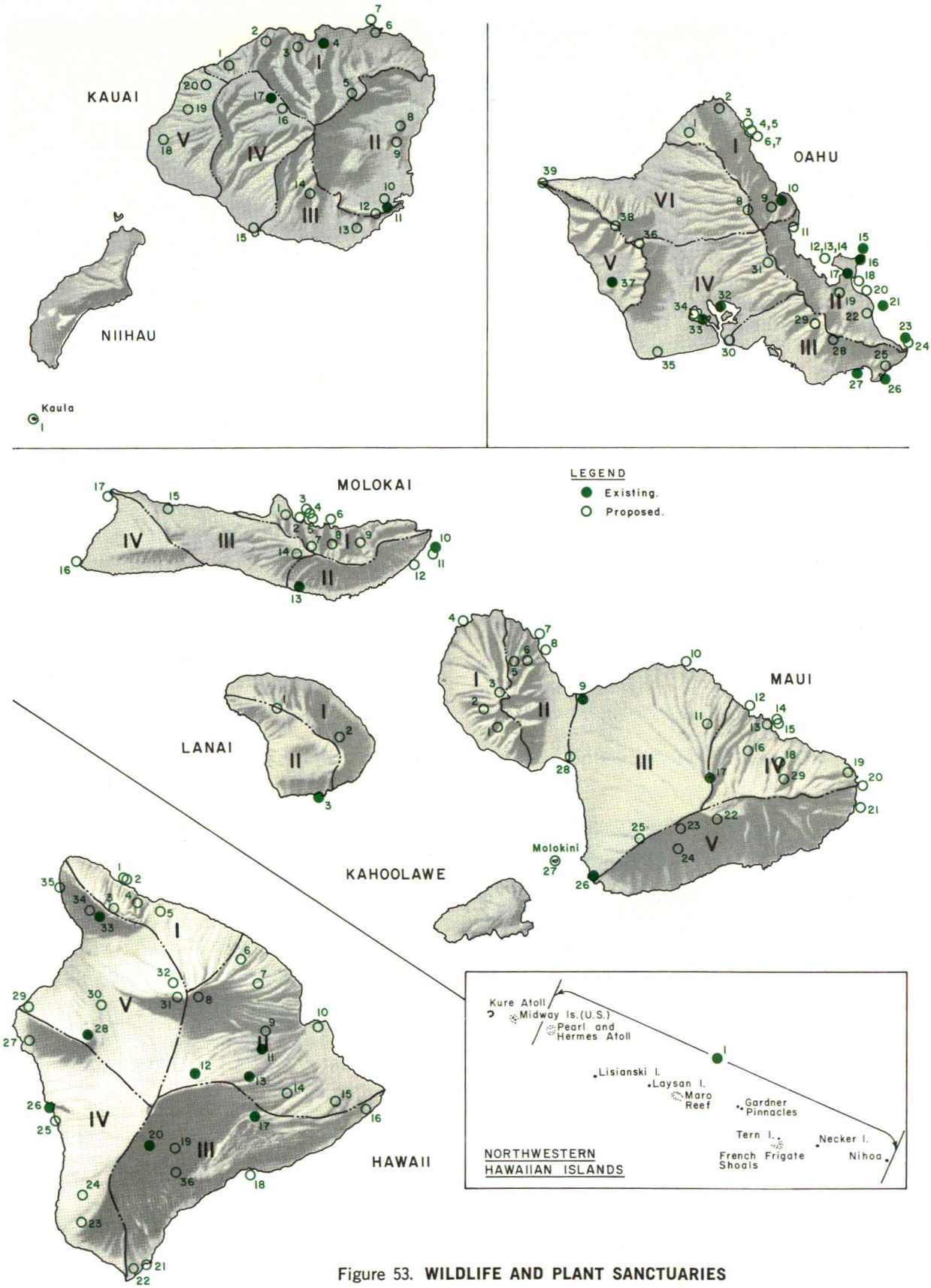


Figure 53. **WILDLIFE AND PLANT SANCTUARIES**

TABLE 41
Wildlife and Plant Sanctuaries

ISLAND and MAP NO.	LOCATION	TYPE	STATUS
Hawaii			
1	Paokalani Island	Bird Sanctuary	o
2	Mokupuku Island	Bird Sanctuary	o
3	Kohala Mountains	Natural Area Reserve	o
4	Waimanu Valley	Natural Area Reserve	o
5	Keaa	Natural Area Reserve	o
6	Laupahoehoe	Natural Area Reserve	o
7	Piha	Natural Area Reserve	o
8	Kahinahina	Natural Area Reserve	o
9	Waiakea	Natural Area Reserve	o
10	Lokowaka Pond	Wildlife Refuge	o
11	Waiakea 1942 Lava Flow	Natural Area Reserve	●
12	Kipuka Ainahou	Nene Sanctuary	●
13	Keahou	Nene Sanctuary	●
14	Puu Makaala	Natural Area Reserve	o
15	Puna	Natural Area Reserve	o
16	Malama Ki	Natural Area Reserve	o
17	Hawaii Volcanoes	National Park	●
18	Keaoi Island	Bird Sanctuary	o
19	Kapapala	Natural Area Reserve	o
20	Kahuku	Nene Sanctuary	●
21	Kaalualu Bay	Natural Area Reserve	o
22	Lua O Kalahemo	Natural Area Reserve	o
23	Manuka	Natural Area Reserve	o
24	South Kona	Natural Area Reserve	o
25	Honaunau	Marine Life Conservation District	o
26	Kealakekua Bay	Marine Life Conservation District	●
27	Aimakapa Pond	Wildlife Refuge	o
28	Keahou II	Nene Sanctuary	●
29	Opaeula Pond	National Wildlife Refuge	o
30	Puuwaawaa	Natural Area Reserve	o
31	Mauna Kea Ice Age	Natural Area Reserve	o
32	Puu Kauha	Natural Area Reserve	o
33	Koaia	Plant Sanctuary	●
34	Koaia	Natural Area Reserve	o
35	Koaie Cove	Marine Life Conservation District	o
36	Kau	Kau Wilderness Preserve	o
Maui			
1	West Maui	Natural Area Reserve	o
2	West Maui	Natural Area Reserve	o
3	West Maui	Natural Area Reserve	o
4	Honolua Bay	Marine Life Conservation District	o
5	West Maui	Natural Area Reserve	o
6	West Maui	Natural Area Reserve	o
7	Mokeehia Island	Bird Sanctuary	o
8	Hulu Island	Bird Sanctuary	o
9	Kanaha Pond	National Natural Landmark	●
10	Papanui O Kane	Bird Sanctuary	o
11	Honopou	Natural Area Reserve	o
12	Keopuka Reef	Bird Sanctuary	o
13	Pauwalu Point	Natural Area Reserve	o
14	Moku Mana	Bird Sanctuary	o
15	Moku Hala	Bird Sanctuary	o
16	Keanae Valley	Natural Area Reserve	o
17	Haleakala	National Park	●
18	Hanawai Stream	Natural Area Reserve	o
19	Wainapanapa	Natural Area Reserve	o
20	Puuku Island	Bird Sanctuary	o
21	Alau Island	Bird Sanctuary	o
22	Kahikinui	Natural Area Reserve	o
23	Puu Keokea	N/A	
24	Kanaio	Natural Area Reserve	o
25	Puu Makua	N/A	
26	Ahihi-Kinau	Natural Area Reserve	●
27	Molokini	Natural Area Reserve	o
28	Kealia Pond	National Wildlife Refuge	o
29	East Maui	Koolau Wilderness Preserve	o
Lanai			
1	Kanepuu	Natural Area Reserve	o
2	Kaiholena	Natural Area Reserve	o
3	Hulopoe Bay	Marine Life Conservation District	●
Molokai			
1	Kauhako	Natural Area Reserve	o
2	Waikolu-Kalawao	Marine Life Conservation District	o
3	Mokapa Island	Bird Sanctuary	o
4	Okala Island	Bird Sanctuary	o
5	Huelo	Bird Sanctuary	o
6	Mokumanu	Bird Sanctuary	o
7	Waikolu	Natural Area Reserve	o
8	Olokui	Natural Area Reserve	o
Molokai			
9	Wailau	Natural Area Reserve	o
10	Mokuhooniki Island	Bird Sanctuary	●
11	Kanaha Reef	Bird Sanctuary	o
12	Moanui	Marine Life Conservation District	o
13	Kakahaia	National Wildlife Refuge	●
14	Kamiloloa	Natural Area Reserve	o
15	Moomomi	Natural Area Reserve	o
16	Laau Point	Marine Life Conservation District	o
17	Ilio Point	Marine Life Conservation District	o
Oahu			
1	Paumalu	Natural Area Reserve	o
2	Kahuku	National Wildlife Refuge	o
3	Kihewamoku Island	Bird Sanctuary	o
4	Mokuauia Island	Bird Sanctuary	o
5	Pulemoku Reef	Bird Sanctuary	o
6	Kukuihoolua	Bird Sanctuary	o
7	Mokualai	Bird Sanctuary	o
8	Poamoho-Kahana	Natural Area Reserve	o
9	Kahana Valley Wetlands	Wildlife Refuge	o
10	Huilua Fishpond	National Historic Landmark	●
11	Molii Pond	Wildlife Refuge	o
12	Kapapa Island	Bird Sanctuary	o
13	Ahu O Laka Island	Bird Sanctuary	o
14	Kekepa Island	Bird Sanctuary	o
15	Moku Manu Island	Bird Sanctuary	●
16	Ulupau Head Refuge	U.S. Marine Corps	●
17	Nuupia Refuge	U.S. Marine Corps	●
18	Mokulea Reef	Bird Sanctuary	o
19	Kawainui	Wildlife Refuge	o
20	Popoia Island	Bird Sanctuary	o
21	Makulua Island	Bird Sanctuary	●
22	Bellows Air Force Base	Wildlife Refuge	o
23	Manana Island	Bird Sanctuary	●
24	Kaohikaipu Island	Bird Sanctuary	o
25	Koko Crater	Natural Area Reserve	o
26	Hanauma Bay	Marine Life Conservation District	●
27	Paiko Lagoon	Wildlife Sanctuary	●
28	Waahila Ridge	Natural Area Reserve	o
29	Nuuanu	Wildlife Refuge	o
30	Fort Kamehameha	Wildlife Refuge	o
31	Waimano	Natural Area Reserve	o
32	Pearl City	National Wildlife Reguge	●
33	Honouliuli	National Wildlife Refuge	●
34	Pouhala Pond	Wildlife Refuge	o
35	Ewa Coral Plain	Natural Area Reserve	o
36	Puu Kanehoa	Natural Area Reserve	o
37	Niulii Refuge	U.S. Navy	●
38	Mokuleia-Mt. Kaala	Natural Area Reserve	o
39	Kaena Point	Natural Area Reserve	o
Kauai			
1	Hono O Napali	Natural Area Reserve	o
2	Limahuli Stream	Natural Area Reserve	o
3	Lumahai Stream	Natural Area Reserve	o
4	Hanalei	National Wildlife Refuge	●
5	Kualapa	Natural Area Reserve	o
6	Kilauea	Natural Area Reserve	o
7	Mokuaeae Island	Bird Sanctuary	o
8	Opaekaa	Wildlife Refuge	o
9	Wailua River	Wildlife Refuge	o
10	Menehune Pond	Wildlife Refuge	o
11	Huleia	National Wildlife Refuge	●
12	Haupu	Natural Area Reserve	o
13	Koloa	Natural Area Reserve	o
14	Kanaele Bog	Natural Area Reserve	o
15	Hanapepe Salt Ponds	Wildlife Refuge	o
16	Alakai	Natural Area Reserve	o
17	Alakai	Wilderness Preserve	●
18	Barking Sands	Natural Area Reserve	o
19	Haeleele	Natural Area Reserve	o
20	Milolii	Natural Area Reserve	o
Niihau			
1	Halalii	Wildlife Refuge	o
Kaula			
1	Kaula	Bird Sanctuary	o
NW Haw'n. Islands			
1	See Figure	National Wildlife Refuge	●

N/A - Not available o Proposed ● Existing

Menehune Fishpond, Kauai.

23. CULTURAL RESOURCES

The rapid changes in Hawaii's culture due to outside influences have often obscured ancient and unique cultural resources. Coordinated water resources planning is concerned with cultural resources of archaeological, historical, and geological importance to Hawaii, including the following.

Ancient Hawaiian Fishponds

Early Hawaiians engaged intensively in aquaculture. Nowhere else in the Pacific is there known to have been as many fishponds of such wide variety as in prehistoric Hawaii. Only in the Hawaiian Islands was practically every body of water, from the seashore to the upland forests, utilized either agriculturally or aquaculturally as a source of food.

Fish, crustaceans, shellfish, and seaweed were some of the products of the totally indigenous aquacultural system. Ancient Hawaii's broad aquatic food production system included traps, dams, weirs and other structures designed to catch mature fish, as well as structures and practices of aquaculture. See Figure 54 and Table 42.

Hawaiian fishponds are historically and archaelogically important, have educational value as examples of a cultural heritage based on effective stewardship of biological resources, and can play a practical part in commercial aquaculture. The restoration and protection of Hawaii's ancient fishponds would recognize the continuing significance of an ancient method of food production and its application to modern food culture techniques.

- *RECOMMENDATION 23-1.* Restore and protect selected ancient Hawaiian fishponds.
  - * Improve criteria for evaluating significance of fishponds.
  - * Prevent destruction of all fishponds suitable for listing on National Register of Historic Places.
  - * Manage tributary lands to minimize sediment and other pollutants.
  - * Restore and manage selected ponds either in the ancient Hawaiian tradition or with modern aquaculture techniques.

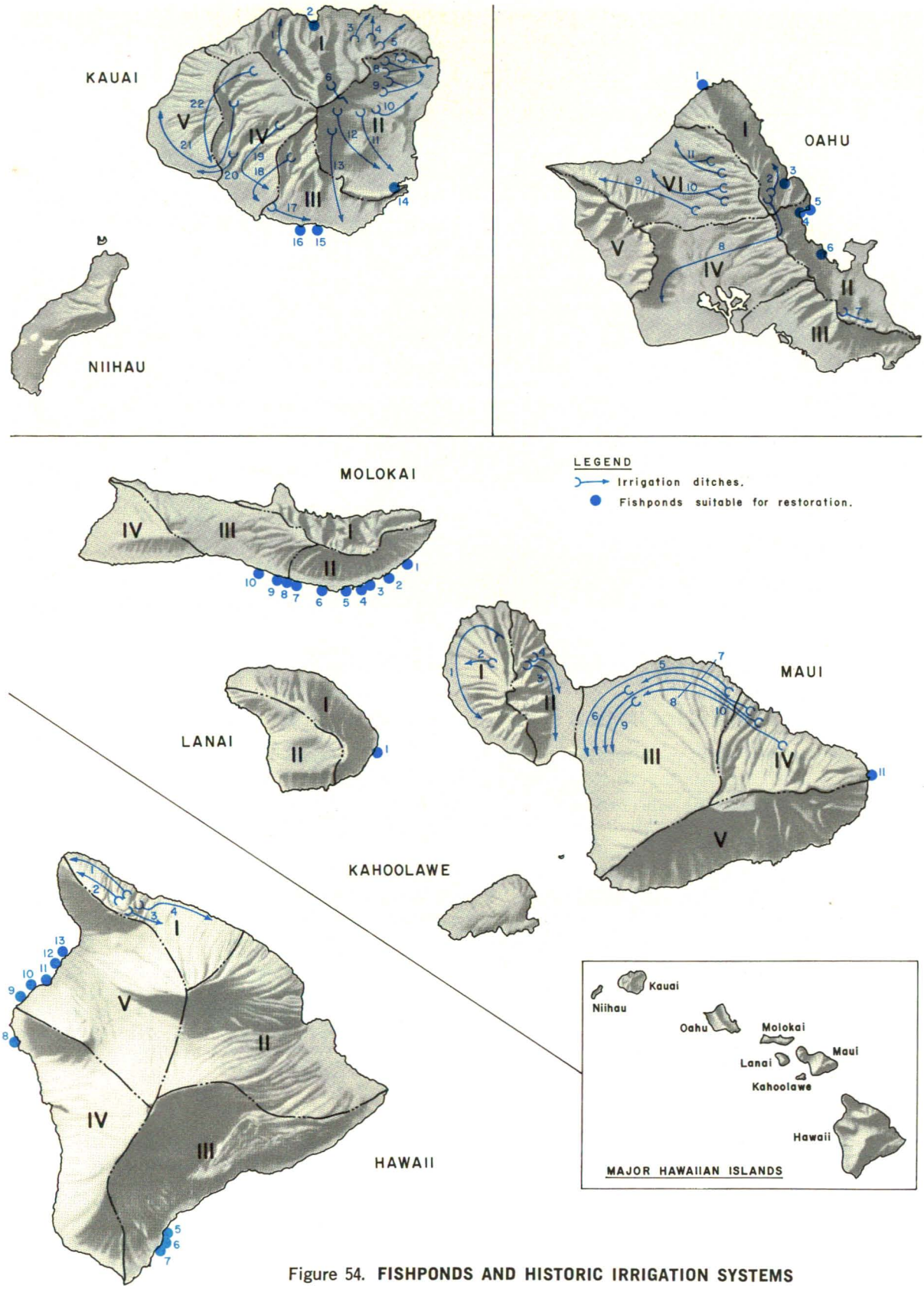


Figure 54. **FISHPONDS AND HISTORIC IRRIGATION SYSTEMS**

TABLE 42
Fishponds Suitable for Restoration

ISLAND and MAP NO.	LOCATION	ACRES
Hawaii		
5	Iloi, Ninole, etc.	4*
6	Kawaa	10
7	Honuapu #1 & #2	3*
8	Kaloko, Aimakapaa, Aiopio	28*
9	Opaeula	7
10	Kaupulehu	2
11	Kiholo	3
12	Kahapapa, etc.	7*
13	Lahuipuaa, etc.	10*
Maui		
11	Loko-Nui, Loko-Iki	13*
Lanai		
1	Lopa	1
Molokai		
1	Kupeke	30
2	Niauhala	34
3	Kaopeahina	19
4	Ualapue	22
5	Kainaohe, Keawanui	71*
6	Pahiomu	20
7	Kipapa	10
8	Kanoa	50
9	Alii	27
10	Kalokoeli	28
Oahu		
1	Kalouwai	1
3	Pukoko	1
4	Molii	124
5	Koholalele	2
6	Heeiauli	88
Kauai		
2	Kanoa	4
14	Alekoko	32
15	Lawai-Kai	2
16	Nomilu	4

* Tentative, subject to verification.

Ancient and Historic Irrigation Systems

Irrigation has long been the dominant water use in Hawaii. History does not record the date many years ago when the early Hawaiians built their first *auwai* (ditch) to irrigate taro, the native staple food crop. During the Hawaiian monarchy, numerous ditch systems were constructed in the Islands, some of which are still in evidence today. The laws covering land ownership and the customs and practices of water use in these earlier years provide the basis for present day law on surface water rights.

The first ditch constructed to provide water for irrigating sugarcane is reported to have been built on the Island of Kauai about 1856. The ditch, some 11 miles long, brought water from a stream to existing cane fields.

Large-scale development of water for sugarcane irrigation started with the completion of the "Old Hamakua Ditch" on the Island of Maui in 1878. This ditch, consisting of unlined sections, syphons, tunnels and wooden flumes, was constructed by hand labor under difficult conditions along the rugged slopes of Haleakala on East Maui. It was the forerunner of other extensive and impressive water development projects constructed by the sugar industry with private funds on the major islands in subsequent

TABLE 43
Historic Irrigation Systems

ISLAND and MAP NO.	LOCATION
Hawaii	
1	Kohala Ditch
2	Kehena Ditch
3	Upper Hamakua Ditch
4	Lower Hamakua Ditch
Maui	
1	Honokohau Ditch
2	Honokowai Ditch
3	Waihee Ditch
4	Spreckels Ditch
5	Haiku Ditch
6	Lowrie Ditch
7	Lower Ditch
8	Kauhikoa Ditch
9	Hamakua Ditch
10	Koolau-Wailoa Ditch
Oahu	
2	Punaluu Ditch
7	Maunawili Ditch
8	Waiahole Ditch
9	Wahiawa Reservoir Ditch
10	Poamoho, Halemano Ditches
11	Opaeula, Kamananui Ditches
Kauai	
1	Wainiha Ditch
3	Hanalei, Koolau Ditches
4	Puu Ka Ele, Lawrence Ditches
5	Kaloko Ditch
6	Hanalei Tunnel
7	Lower Anahola Ditch
8	Upper Anahola, Kealia, Kaneha Ditches
9	Makaleha, Maiakii, Mimino, Kawano Ditches
10	Wailua Ditch
11	Stable Storm, Hanamaulu, Lower Lihue Ditches
12	Iliiliula, N. Wailua, Waiahi, North Intake, South Intake, Upper Lihue Ditches
13	Koloa Ditch
17	Pump Ditch
18	Hanapepe (Koula) Ditch
19	Olokele Ditch
20	Waimea Ditch
21	Kekaha Ditch
22	Kokee Ditch

Historic irrigation works, East Maui.

years. See Figure 54 and Table 43 for historic irrigation systems.

Ancient and historic irrigation systems, important factors in the culture as well as the economy of Hawaii, deserve preservation for the enlightenment and enjoyment of future generations. Examples of both ancient and historic irrigation systems would serve to illustrate the development of irrigation practices in Hawaii.

- *RECOMMENDATION 23-2.* Restore and protect selected ancient Hawaiian and historic irrigation systems.
  - * Establish criteria for evaluating cultural significance of irrigation systems.
  - * Locate, protect, and restore examples of ancient irrigation systems.
  - * Locate, protect, and appropriately mark the pioneer water development systems of the sugarcane industry, including wells, shafts, tunnels, and irrigation ditches.

Unique Natural Lakes and Waterways

Consideration must be given to the protection of unique natural lakes and waterways that may be damaged or obliterated in the course of developing water and related land resources. Lake Waiau on Mauna Kea, reputed to be the natural lake at the highest altitude in the United States, is a prime concern. Lakes Halalii and Halulu on Niihau are also possible candidates.

Many of the lakes and waterways deserving such consideration are already within areas proposed for preservation under other programs providing for sanctuaries or natural area reserves.

- *RECOMMENDATION 23-3.* Protect unique natural lakes and waterways from degradation or alteration.
  - * Establish criteria for evaluating cultural significance of natural lakes and waterways.
  - * Survey and select candidate sites for special protection status, based on their unique characteristics.

Lake Wainapanapa, Maui.

Ancient and Historic Shoreline Structures

The ancient Hawaiians constructed canoe sheds and canoe landings, most of the latter at naturally accessible points along the shoreline. However, some places such as at the City of Refuge on the Island of Hawaii show evidence of artificial modification of the coastline.

Marine railways, piers, channels and other structures built in historic times are often the only remains of forgotten water use practices. The pier built for the Coral Gardens Hotel in Kaneohe Bay, still standing today, is a reminder of the role that tourism had in the development of the Kaneohe community.

- *RECOMMENDATION 23-4.* Protect and restore selected ancient and historic shoreline structures used for water transportation.
  - * Establish criteria for evaluating cultural significance of water transportation structures.
  - * Survey and select structures for protection and restoration.

City of Refuge, Honaunau, Hawaii.

Windward Oahu panorama from Nuuanu Pali.

24. AESTHETIC VALUES

Those aesthetic features of Hawaii which are of particular concern in water resource planning are open space, including mountains, wilderness areas, and the ocean; waterfalls, and scenic streams, rivers, lakes, and reservoirs; beaches and shoreline areas; bays and estuaries; and offshore islands.

Preservation of aesthetic values requires both protection of the beauty of an area and provisions for visual or physical access, or both. In particular, water resources planning focuses upon the following aesthetic concerns.

Open Spaces, Including Mountains and Wilderness Areas

Visual aspects of mountains and wilderness areas as seen from a distance are affected by protection of the landscape from erosion, maintenance of vegetation, and preservation of view channels.

Conservation districts in Hawaii cover about 2 million acres under the control of the state Department of Land and Natural Resources (Figure 55). These districts include the prime mountain and wilderness areas which contribute to Hawaii's scenic beauty.

Open space fulfills only a small part of its role in society as viewed from afar. Open space in the mountains, except for selected areas needing special protection, can serve as the locale for a wide variety of compatible uses, such as hiking, camping, and nature study. See Figure 55 for the location of priority open space areas in the state, listed in Table 44.

- *RECOMMENDATION 24-1.* Protect and provide visual access to open

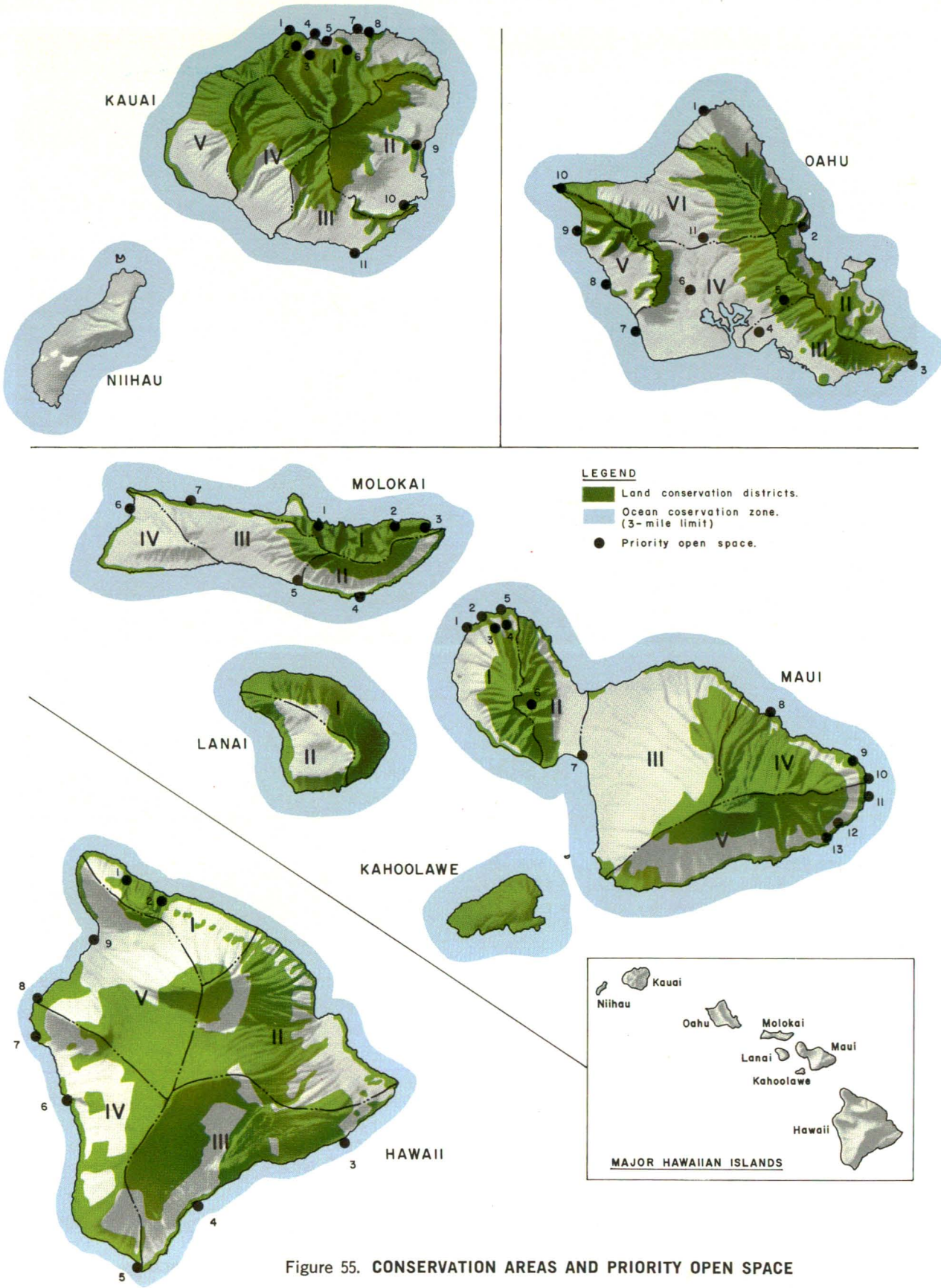


Figure 55. **CONSERVATION AREAS AND PRIORITY OPEN SPACE**

TABLE 44
Priority Open Space

ISLAND and MAP NO.	LOCATION
Hawaii	
1	Honokane Nui-Iki Stream Valley
2	Waipio Valley
3	Kalapana-Kaimu
4	Ninole-Punaluu Bay
5	Kalae
6	Kealakekua Bay Beach Front
7	Kaloko/Honokohau Fishpond Area
8	Kua Bay
9	Puako Beach Front
Maui	
1	Kapalua Beach
2	Honolua Bay
3	Honolua Valley
4	Honokohau Valley
5	Honokohau Bay
6	Iao Valley
7	Kealia Pond
8	Keanae Point
9	Waianapanapa State Park
10	Hana Bay Beach Front
11	Hamoa Beach
12	Wailua Valley
13	Seven Pools/Kipahulu
Molokai	
1	Waikolu Valley
2	Papalaua Valley
3	Halawa Valley
4	Keawanui Fishpond and Kalaeloa
Molokai	
5	Kakahaia Fishpond
6	Papohaku Beach and Access
7	Moomomi Beach
Oahu	
1	Kawela Bay
2	Molii Pond Area
3	Queen's Beach
4	Salt Lake
5	Moanalua Valley
6	Agricultural Lands
7	Kahe
8	Maili
9	Makua
10	Kaena Point
11	Wahiawa Reservoir
Kauai	
1	Kee Beach and Haena Beach Front Areas
2	Wainiha Valley
3	Lumahai Valley
4	Lumahai Beach
5	Hanalei Bay Beach Front
6	Hanalei Valley
7	Anini Beach
8	Kalihikai Bay Beach Front
9	Wailua River Valley
10	Menehune Fishpond
11	Poipu Beach Area

spaces, including mountains and wilderness areas.

* Provide and maintain access to viewing sites.
* Control height and spacing of urban development to preserve mountain vistas.
* Protect forest vegetation and restore vegetation to eroded areas.
* Use lumbering and harvesting methods that protect the environment.
* Develop and maintain a system of trails and facilities for on-site enjoyment where appropriate.
* Catalog pertinent on-site and off-site aesthetic values.
* Develop methods for quantifying relative values.

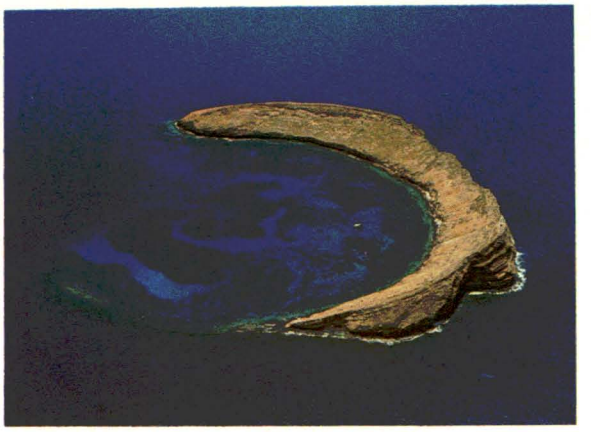
Beaches, Shoreline, Offshore Islands, and the Ocean

Physical and visual access are important to the enjoyment of beaches and offshore areas. Blocking of views by development along coastal highways degrades the aesthetic value of the shoreline.

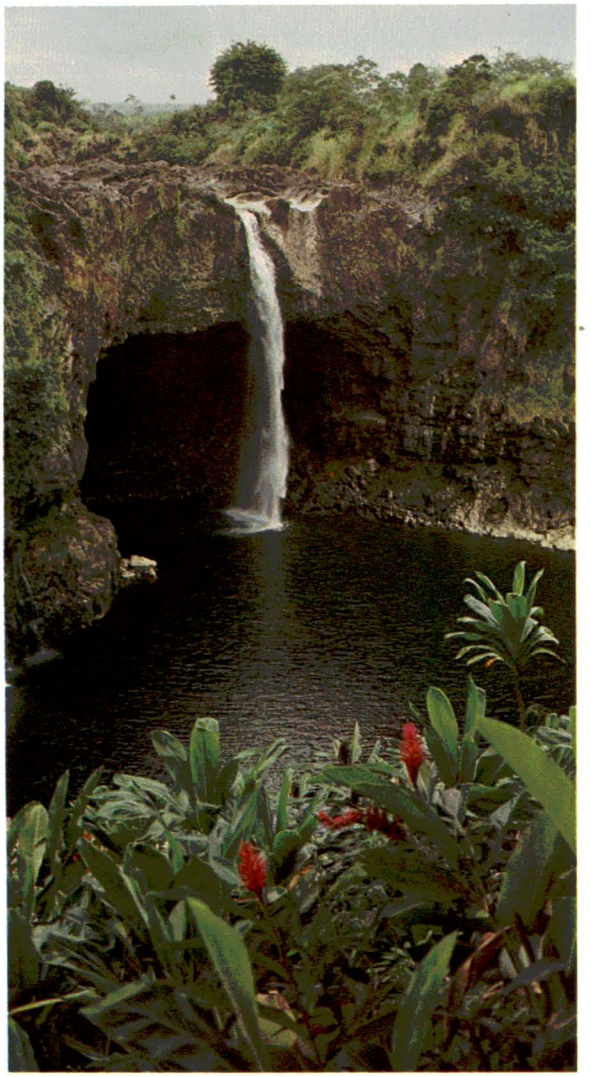
Sediment and floating debris from streams and urban areas degrades the aesthetic value of coastal reaches, at the same time posing a hazard to existing nearshore or marine ecosystems.

Small offshore islands, characteristic of the Hawaii scene, should be preserved for their aesthetic values.

- *RECOMMENDATION 24-2.* Protect physical and visual access to beaches, shorelines, offshore islands, and the ocean.
  * Control density and height of buildings to seaward of coastal highways.
  * Provide and maintain access to the shoreline.
  * Reduce sediment and floating debris from streams and urban areas.
  * Maintain desirable fresh water flows



Molokini Island, Maui.



Rainbow Falls, Hawaii.

and water circulation in bays and estuaries.

* Maintain offshore islands in their natural condition.
* Catalog pertinent on-site and off-site aesthetic values.
* Develop methods for quantifying relative values.

TABLE 45
Waterfalls

ISLAND	MAP NO.	LOCATION
Hawaii	1	Waiilikahi Falls
	2	Kaluahine Falls
	3	Hiilawe Falls
	4	Waioulu Falls
	7	Kahuna Falls
	8	Akaka Falls
	9	Waiemi Falls
	10	Rainbow Falls
	13	Kaimukanaka Falls
	14	Hawaii Falls
	19	Kemole Falls
Maui	3	Honokohau Falls
	5	Iao Valley
	9	Waikamoi Falls
	10	Puohokamoa Falls
	11	Haipuaena Falls
	12	Waiokilo Falls
	13	Waikani Falls
	14	Pua'a Kaa Falls
	15	Hanawi Falls
	17	Waihiumalu Falls
	18	Waimoku Falls
	20	Kipahulu Falls
Molokai	3	Haloku Falls
	4	'Olo'upena Falls
	5	Wailele Falls
	7	Kahiwa Falls
	8	Papalaua Falls
	9	Hipuapua Falls
	12	Moaula Falls
Oahu	2	Kaliuwaa Falls (Sacred)
	10	Manoa Falls
	12	Nuuanu Valley
	13	Waipuhia (Upside Down)
	22	Waihee Falls (Waimea)
Kauai	1	Limahuli Falls
	9	Puwainui Falls
	10	Hinalele Falls
	11	Keanaawi Falls
	12	Hoopouli Falls
	13	Waihunehune Falls
	14	Kapaka Nui Falls
	15	Kapakaiki Falls
	16	Uhauiole Falls
	17	Opaekaa Falls
	19	Kaholalele Falls
	20	Wailua Falls
	21	Halii Falls
	26	Mana Waipuna Falls
	27	Kahili Falls
	28	Waianuenue Falls
	29	Oopulele Falls
	30	Hihinui Falls
	32	Waialae Falls
	33	Mohihi Falls
	34	Awini Falls
	35	Waipio Falls

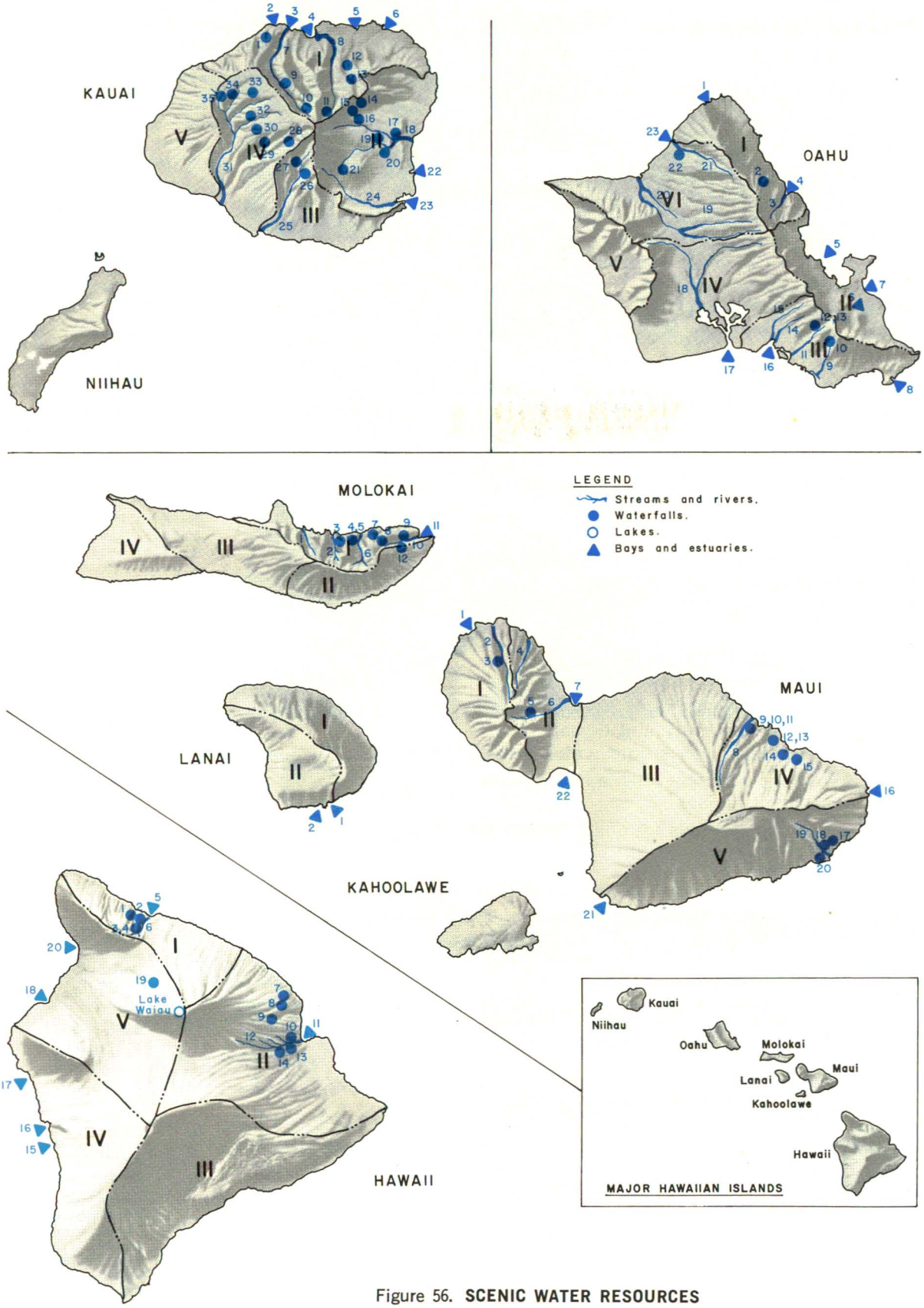


Figure 56. **SCENIC WATER RESOURCES**

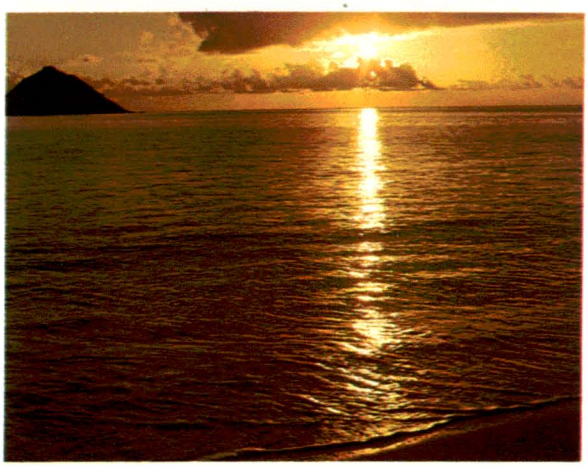
Waterfalls and Other Scenic Water Resources

Hawaii's principal scenic water resources are shown in Figure 56 and listed in Tables 45 to 47.

A waterfall or scenic stretch of river has an aesthetic value particularly vulnerable to water management practices. Past practices of stream channel alteration have diminished aesthetic values in many waterways. Water development plans must include provisions for maintaining the aesthetic values of waterfalls and the scenic reaches of flowing streams.

Land management practices can also have a significant impact upon the aesthetic quality of scenic rivers and streams. Maintenance of uncut strips along streams and plantings to help control runoff and erosion can enhance stream values.

- *RECOMMENDATION 24-3.* Protect the beauty of waterfalls and other scenic water resources.
  - * Preserve visual access to scenic water resources.
  - * Acquire water rights to maintain adequate streamflow and water levels.
  - * Prevent unsightly and damaging encroachments on scenic water areas.
  - * Catalog pertinent on-site and off-site aesthetic values.
  - * Develop methods for quantifying relative values.



Sunrise on Windward Oahu.

TABLE 46
Streams and Rivers

ISLAND	MAP NO.	LOCATION
Hawaii	6	Waipio Stream
	12	Wailuku River
Maui	2	Honokohau Stream
	4	Kahakuloa Stream
	6	Iao Stream
	8	Waikamoi Stream
	19	Palikea Stream
Molokai	1	Waikolu Stream
	2	Pelekuna Stream
	6	Wailau-Pulena Stream
	10	Halawa Stream
Oahu	3	Kahana Stream
	9	Manoa Stream
	11	Nuuanu Stream
	14	Kalihi Stream
	15	Moanalua Stream
	18	Waikele-Kipapa Stream
	19	Kaukonahua Stream
	20	Poamoho Stream
	21	Kamananui Stream
Kauai	7	Wainiha River
	8	Hanalei River
	18	Wailua River
	24	Huleiâ Stream
	25	Hanapepe River
	31	Waimea River

TABLE 47
Bays and Estuaries

ISLAND	MAP NO.	LOCATION
Hawaii	5	Waipio Bay
	11	Hilo Bay
	15	Honaunau Bay
	16	Kealakekua Bay
	17	Kailua Bay
	18	Kiholo Bay
	20	Kawaihae Bay
Maui	1	Honolua Bay
	7	Kahului Bay
	16	Hana Bay
	21	La Perouse Bay
	22	Maalaea Bay
Lanai	1	Manele Bay
	2	Hulopoe Bay
Molokai	11	Halawa Bay
Oahu	1	Kawela Bay
	4	Kahana Bay
	5	Kaneohe Bay
	6	Kawai Nui Swamp
	7	Kailua Bay
	8	Hanauma Bay
	16	Keehi Lagoon
	17	Pearl Harbor
	23	Waimea Bay
Kauai	2	Haena Bay
	3	Wainiha Bay
	4	Hanalei Bay
	5	Kalihiwai Bay
	6	Kilauea Bay
	22	Hanamaulu Bay
	23	Nawiliwili Bay

Regional Study workshop.

Data, Research, and Planning

The collection and analysis of basic data on water and related land resources provide the foundation for effective planning and plan implementation. Research is also an important planning and management aid.

Coordinated water planning by government agencies at all levels, with participation by industry and the community, is essential for optimum conservation, development, and use of Hawaii's water and related land resources.

A permanent Water Resources Interagency Committee would be a suitable institutional arrangement for coordinated water planning on a continuing basis.

25. DATA COLLECTION AND ANALYSIS

Basic data on water and related matters provide the foundation for evaluation, planning, and decision making. A good program includes data collection, storage, retrieval, dissemination, and means for anticipating probable future needs.

Data collection programs have been reviewed in light of the broadening range of water problems and an expanding public interest in water and related environmental matters. This chapter focuses on the policy aspects of data collection and lists primary data needs. Specific data requirements have been included in previous recommendations.

Basic Data Collection

Basic data needs must be assessed in terms of information required to keep abreast of trends in decision making. Multi-objective water resource planning and implementation now require a much broader data base than in the past.

Also, a greater number of people are concerned with water data and predictions than ever before. All types of water data are sought by economists, political scientists, environmentalists, and a wide range of special interest groups. They want to examine and judge for themselves the merits of water projects and to develop and propose alternatives.

The adequacy of basic water resources data to support evaluation, planning, and decision making varies considerably. In the past, water data activity was concerned almost entirely with determining water quantity for development purposes. Now that water quality is regarded as a key aspect of man's environment, there is a need to expand greatly the scope of data collection.

There is an increased demand for hydrologic environmental information; water quantity must be correlated with water quality. Analysis of water quality trends, essential for quality control programs, can be made only in conjunction with an assessment of water quantity.

Environmental impact statements have created a demand for much additional information. Data collection must be expanded to include information such as the ecological and aesthetic aspects of surface water bodies and the identification of aquatic ecosystems.

The need is increasing for information on underground storage capacity and relationships with surface water systems. There is also a growing demand for information on water costs, water use, and waste discharge.

The demand for and importance of socio-economic data related to water use is rapidly increasing. There is also an increasing need to develop socio-environmental indicators (i.e., aggregate measures of data) to better judge program performance and to develop environmental baselines.

A comprehensive program is required to collect flood damage data for planning more effective flood control works.

Although data on surface water quantity generally have been adequate, ground water data are incomplete, even at the general inventory level. Water quality data have not kept pace with interest and demand.

Climatological and hydrological programs, while generally adequate, have not been well coordinated. However, recent developments promise much improved coordination of water quantity and quality data.

Data on the biological and ecological aspects of water are only sketchily included in current data collection programs. Socio-economic data are also spotty, usually gathered to understand specific needs.

Most data collection in the past has concentrated on raw statistics or elementary statistical relationships. While this important function should be continued, future data collection should also provide a general view of an entire system.

Data collection and dissemination must be relevant to current and probable future needs. Presently, individual agencies identify their specific data needs. Data collection for action programs or of a broad scope, such

as the U.S. Geological Survey gaging network, are continually reviewed for relevance.

However, there is a need to focus on probable future data requirements, particularly environmental data. Gaps in the present data base can be identified in the course of planning and evaluation studies and through a periodic assessment of data programs.

- *RECOMMENDATION 25-1.* Improve programs and systems to collect data for the following purposes:
  * Interrelations among precipitation, ground water, streamflow, and water quality.
  * Underground storage capacity and relationships with surface water systems.
  * Determination of policy on flood damage reduction, water quality control, water costs, and water use.
  * Environmental impact analyses.
  * Measurement of program effectiveness.
- *RECOMMENDATION 25-2.* Include an assessment of the data base in all water resource planning reports and environmental impact statements, indicating which decisions or findings are most sensitive to data deficiencies.
- *RECOMMENDATION 25-3.* Make greater use of remote sensing (aircraft and space satellites) for data collection and transmission.

Storage, Retrieval, and Dissemination

A great amount of data is presently available. Practically every federal agency and many state and local agencies and private groups have data which are of interest and potential use to individuals concerned with water resources.

There is presently a greater emphasis on active, rather than passive, data storage whereby routine statistical analysis can give prompt answers to queries. Operations, management, and forecasting require data which are recorded and reported practically simultaneously with the occurrence of the event.

Unfortunately, many people do not know what data are available, where and in what forms, and how to obtain it. This situation could be corrected by establishing a data referral center. The primary purpose of such a center would be to maintain and continually update a reference system for water and related data. The center would neither store data nor fill data requests, but would direct requests to appropriate agencies or data systems. Data would remain in existing storage systems.

The center might also assist data collection agencies in the development of more useful dissemination and retrieval formats. Publication of a periodically updated catalog of water related data sources would obviate the need for many inquiries. When it becomes feasible, such a system might be affiliated with national systems.

Hawaii is the only state not affiliated with the U.S. Geological Survey's National Water Data Exchange (NAWDEX), whose members have immediate access to other national data systems such as STORET and WATSTORE. Although a direct terminal access is not economically justified at this time, changing rate schedules might make such access feasible in the near future.

The state Department of Land and Natural Resources is the logical agency to establish a referral center, since it already provides a working forum and coordinating function for state and federal agencies involved in water and related activities. More extensive cooperation with general data collection and statistical agencies, such as the state Department of Planning and Economic Development, would encourage collection of data useful for water resources planning and management. This may require tranfers of funds.

- *RECOMMENDATION 25-4.* Establish a central water resources data referral center to carry out the following functions:
  * Periodically publish an updated catalog of water related data sources.
  * Identify gaps in the present water data base.
  * Identify long-term basic data requirements to support water resources planning and decision making.
  * Work with agencies concerned to make general data collection more useful for water resources planning and management.
  * Participate in national data exchange programs as soon as feasible.

- *RECOMMENDATION 25-5.* Integrate storage and retrieval systems for economic and environmental data.

- *RECOMMENDATION 25-6.* Design data systems to permit:

  * Feedback from monitoring.
  * Analysis of requests for data at data centers.
  * Analysis of the effects of planned actions on water and the environment.

Data Analysis

Greater attention should be given to methods of data synthesis and transfer. For example, new methods of estimating missing data by using available data have greatly increased the usefulness of stream gaging networks. Water quality information might be similarly analyzed.

Water resources programs and activities have not always taken advantage of knowledge gained from past mistakes. Better information on cause-and-effect relationships in water project construction should be accumulated and made available. Continuing studies before and after project implementation would indicate cause-and-effect relationships and the adequacy of data.

Since planning and operational decisions are only as sound as the data base on which they rest, standards should be developed for gaging the reliability of different types and sources of data.

- *RECOMMENDATION 25-7.* Research and develop improved methods for water data synthesis and transfer.

- *RECOMMENDATION 25-8.* Conduct studies before and after water project implementation to ascertain cause-and-effect relationships and the adequacy of basic data relied upon.

26. RESEARCH NEEDS

Research is essential to better understand, use, and manage water resources. The two general areas for research are evaluation of (1) the relationship between water, economic development, and the environment, and (2) new techniques for the management of water.

This chapter is concerned with general aspects of water research. Specific research recommendations have been included in previous chapters.

Research as a Planning and Management Aid

Rapidly changing social concerns and environmental problems require that research programs be relevant and responsive to actual problems and issues. As demands increase, there is a need for a more broadly based and more intensive research effort to increase water supplies at reasonable costs and to handle the growing volume of wastes in ways that are environmentally and economically acceptable.

The success of a water research program can be measured by its utility to planners, designers, managers, decision makers, and policy makers. A closer tie between planning and research would assure continued success and reinforce the value and relevance of each. It is important not only that planning and management agencies benefit from research efforts, but also that research agencies receive counsel from planners and managers.

The adequacy of a water research program in meeting past needs is relevant only to the extent that it guides development of a program to meet future needs. The key element in assessing a water research program is a vew of the future.

- *RECOMMENDATION 26-1.* Include guidance to research agencies in water resource planning studies.
  - * Assess research needed to support planning objectives.
  - * Recommend research required to develop the scientific and technological base to cope with future management problems.
- *RECOMMENDATION 26-2.* Pursue those lines of research which will provide useful planning and/or management tools.
  - * Develop systems to improve water management decisions.
  - * Improve water resources planning models for insular environments.
  - * Design a clearing house to simplify approval of water projects.
  - * Recommend procedures for reconciling economic, environmental, and social issues in water management.
  - * Project the long-term effects of the Hanapepe decision on the management and use of surface water in Hawaii.
- *RECOMMENDATION 26-3.* Develop guidelines to reflect the impact of technological advances upon both short-range and long-range water resources planning.
- *RECOMMENDATION 26-4.* Maintain a current state-of-the-art assessment of new technology to assist planners and decision makers in developing and evaluating water management alternatives.

Organizational Relationships

The organization of research activities in water resources and related fields is varied and complex. Although federal funding is predominant, actual research is conducted by a variety of government agencies, universities, industries, and independent organizations.

There are 21 federal agencies actively involved in water research. Most of the research carried out by these agencies themselves and by contract researchers is in the context of agency missions. State research relating to Hawaii's water resources prob-

lems is often cooperatively funded by federal agencies. Basic and applied water research on a broad spectrum is conducted by the Water Resources Research Center at the University of Hawaii.

Because research thrives best in a competitive environment, it is not desirable that all water research be centralized. The several mission-oriented organizations involved in water research have functioned well within their respective fields of interest.

Private industry's major research contribution has been directed toward industry problems, such as the development of equipment for more efficient water use and waste disposal. For example, the sugar industry conducts research in recycling industrial wastewater, drip irrigation, and reuse of sewage effluent in cooperation with government agencies.

- *RECOMMENDATION 26-5.* Continue mission-oriented water research by government agencies, universities, industries, and private agencies.

Research Funding and Priorities

The Department of the Interior (mainly Office of Saline Water, Office of Water Research and Technology, U.S. Geological Survey, and U.S. Bureau of Reclamation) administers more than one-third of the total federal water resources research budget.

The next two largest agency commitments to water resources research are by the Environmental Protection Agency (approximately one-quarter) and the Department of Agriculture, including the Agricultural Research Service and the Economic Research Service (approximately one-sixth).

About one-third of the total water resources research budget is allocated to water quality management and protection. The next three largest areas include: (1) the hydrologic cycle; (2) water supply augmentation and conservation, including desalting research, renovation and reuse of low-quality water, and the conservation of water (reduction of demand) in municipal, industrial, and agricultural uses; and (3) water resources planning, including research on the market system, water laws and institutions, nonstructural alternatives in water supply development, and the ecological impacts of all alternatives.

The identification of research needs is a continuing process and to some degree a responsibility of everyone involved in water resources. In particular, researchers should look to planners for substantial direction in identifying problems and priorities.

- *RECOMMENDATION 26-6.* Give priority to research in the following areas:
  - * Economic, social, and environmental impacts of water resources development and management.
  - * Costs and benefits of (a) various levels of wastewater treatment, and (b) changes in water use to achieve required levels of water quality.
  - * Effects on water quality of non-point sources of pollution, including alternative means of control.
  - * Relationships between energy production and water use, including the effects of heat and consumptive use on local water resources.
  - * Means of more efficient and extensive use of existing water supplies.
  - * New and developing water technology, including desalting, weather modification, wastewater reuse, and geothermal resources.

- *RECOMMENDATION 26-7.* Review planning reports for an annual assessment of research priorities.

27. COORDINATED WATER PLANNING

Many problems that arise in the course of developing, managing, and conserving water and water related lands are due to a legal and institutional framework which has evolved over a period of time to meet perceived needs. When conflicts occur between such needs, inconsistencies or gaps in laws and institutions become apparent.

The following discussion relates to legal and institutional aspects of coordinated water planning.

Water Assessment and Appraisal Program

The Water Resources Planning Act of 1965 (PL 89-80) created the U.S. Water Resources Council and provided for regional entities to coordinate federally financed water programs with those of local jurisdictions.

Hawaii, as one of the 21 water resources planning regions designated by the council (Figure 2), participates in a national Water Assessment and Appraisal Program. WAAP provides the council with a national assessment of existing and projected water supply/demand relationships and an appraisal of the adequacy of existing and proposed legislation, goals, policies, programs, and priorities. This assessment is the basis for recommendations to the president and Congress concerning the use of federal resources to meet the nation's water needs.

The three major components of WAAP involving Hawaii are a nationwide analysis, the *Hawaii Water Resources Plan*, and agency plans. The council has established a centralized analytical system for appraising agency programs and projects from the national perspective.

The *Hawaii Water Resources Plan* supplies the principal input to the nationwide analysis, providing a regional perspective of supply and demand, major problems, and recommended solutions.

Agency plans supply the major input to this regional plan and are the basic building blocks of the nationwide analysis, providing an elemental perspective of projects, programs, issues, and policies.

- *RECOMMENDATION 27-1.* Accelerate implementation of the national Water Assessment and Appraisal Program to establish priorities for federally funded water and related land resources programs and projects.

Federal Water Budget Allocation

The Water Resources Planning Act of 1965 (PL 89-80) also provided for coordinated water resources planning by all levels of government and private interests. Amendments to the Federal Water Pollution Control Act (PL 92-500) authorized funding of regional or river basin plans (Level B plans) for the entire United States by 1980. These plans are intended to provide uniform guidelines for expenditure of federal water resources funds.

Each year Congress and the president have made numerous budgetary decisions concerning the national water program, usually project by project, or agency by agency, with only limited knowledge of their relationship to the overall water program in the Hawaii Region. The *Hawaii Water Resources Plan* provides the framework to coordinate all water programs in the region as an aid to allocating federal funds.

- *RECOMMENDATION 27-2.* Use the *Hawaii Water Resources Plan* to guide authorization and appropriation of federal funds for water related agency programs and projects undertaken in the Hawaii Region.

WRC Principles and Standards

Presently the U.S. Water Resources Council's *Principles and Standards for Planning Water and Related Land Resources* is applicable only to those agencies represented on the council. However, program coordination and multi-objective planning required by the 1965 Water Resources Planning Act (PL 89-80) would be enhanced if all federal agencies having substantial water and related land resources programs were to conform to the

same planning principles and standards (appropriately updated and revised).

- *RECOMMENDATION 27-3.* Extend application of the U.S. Water Resources Council's *Principles and Standards for Planning Water and Related Land Resources* to all federal agencies having substantial water and related land resources programs.

Integrated Federal Grant and Loan Procedures

Water resources grant and loan programs are now fragmented among numerous federal agencies with overlapping responsibilities, increasing the need for amalgamation and coordination of programs and centralized, uniform application procedures.

Grant and loan programs of the U.S. Department of Housing and Urban Development, Economic Development Administration, Environmental Protection Agency, and Farmers Home Administration should be coordinated within the region, together with programs of the Corps of Engineers, Soil Conservation Service, U.S. Geological Survey, Coastal Zone Management, and others, to review applications and determine the appropriate agency or agencies to serve the applicant. Integrated application procedures would enable local agencies to apply for all pertinent federal assistance with single application.

- *RECOMMENDATION 27-4.* Establish integrated federal grant and loan application proceduers for water data collection, research, construction, and planning in the Hawaii Region.

Permanent Water Planning Committee

There is a need for a continuing program to coordinate planning, development, and management of Hawaii's water and related land resources. The need is underscored by ever increasing federal, state, and county water resources legislation with environmental emphasis.

For example, recent legislation mandates improvement in the quality of surface and coastal waters, improvement in the quality of drinking water, effective management of the coastal zone, and preservation of water related habitat for rare and endangered species.

In order to minimize confusion and conflicts among the many water resources program underway in Hawaii and to improve the bases for public and political decisions, a permanent coordinating entity is essential. This organization should represent all levels of government and private industry.

- *RECOMMENDATION 27-5.* Establish a permanent water planning committee with membership from federal, state, county, and private agencies having substantial water resources programs in Hawaii (see Chapter 28) to carry out the following functions:
  - * Implement and update the *Hawaii Water Resources Plan* within existing authorities, agency capabilities, and funding arrangements.
  - * Serve as a planning and coordination groups.
  - * Recommend Hawaii's priorities for national planning and appraisal programs in the light of changing circumstances.

State and County Guidelines for Water Planning

Resources planning, such as the Hawaii Water Resources Regional Study, and other functional planning programs should be accomplished within the framework of a statewide policy plan and consistent general plans of the four counties. Also, land use districts established under the state Land Use Act are relevant to resource planning.

In order to be responsive to public needs, statewide water resources planning requires a clear statement of overall state goals. *The Hawaii State Plan,* formuated pursuant to Act 181, S.L.H. 1975, can provide the economic and environmental bases for identifying water needs, problems and opportunities, and determining alternative solutions.

Each of the islands is a distinct hydrologic unit with individual social, economic, and environmental characteristics. Therefore, county general plans that specify local policies consistent with statewide policies are required for detailed assessment of local water needs.

By bringing agencies and individuals into the planning process, the study has linked state and county general plans, functional plans such as the Coastal Zone Management Program, the Areawide Waste Treatment Management "208" Program, Urban Studies, Type IV Studies, and state, county, and private water and related land resource programs.

For example, state and county general planners evaluated the national OBERS projections provided by the Water Resources Council for the study. They concluded, in consultation with OBERS, that the projections were not sufficiently refined for direct application to the study and were not consistent with state and county views. They then developed baseline projections for the state and for each of the counties.

These baseline projections, used by the study in problem analysis, are reflected in recommended actions to be implemented by agencies concerned. General plan revision programs, as well as functional planning programs in Hawaii, have been encouraged by the state to use these baseline projections for coordinated planning.

Greater refinement and clearer linkage of the State Policy Plan, county general plans, and functional plans are needed for the updating of the *Hawaii Water Resources Plan*.

- *RECOMMENDATION 27-6.* Utilize *The Hawaii State Plan's* long-range social, economic, and environmental policies as general planning guides for implementation and future revision of the *Hawaii Water Resources Plan.*

- *RECOMMENDATION 27-7.* Utilize updated county general plans, modified for consistency with *The Hawaii State Plan,* as local guidelines for implementation and future revision of the *Hawaii Water Resources Plan.*

Continuing Community Groups

Many federal, state, and county programs on a variety of subjects require citizen participation in the planning process. Public meetings and workshops are so scheduled that interested parties are bombarded with a variety of requirements in order to become informed and express their views. Coordination is needed among agencies holding such meetings.

Programs such as the Hawaii Water Resources Regional Study require a continuing dialogue between planners and citizens. The experience gained during the three-year span of the study in conducting a statewide public participation program indicates that both the government programs and the citizens might best be served through established and continuing community citizen groups organized by the respective counties, such as the neighborhood boards on Oahu.

- *RECOMMENDATION 27-8.* Coordinate public meetings and establish formal, continuing community citizen groups on all islands for orderly public participation in all government programs.

28. WATER RESOURCES INTERAGENCY COMMITTEE

In order to implement and update the *Hawaii Water Resources Plan* and effectively coordinate all water programs in Hawaii, those agencies having planning responsibility and implementation authority must be involved in an institutional arrangement. This chapter amplifies Recommendation 27-5.

Alternative Arrangements

Alternative institutional arrangements evaluated for suitability to the Hawaii Region are the river basin commission, interagency committee, and single coordinating agency.

Under Title II of the Water Resources Planning Act of 1965, the president may establish a river basin commission by executive order upon written request of the Water Resources Council, a state, or states. Six out of 21 planning regions designated by WRC are administered by river basin commissions. All six involve areas of more than one state.

The commission serves as the principal agency for the coordination of federal, state, local and private water development plans for the basin. It prepares and updates a comprehensive, coordinated plan which includes an evaluation of alternatives and recommendations for individual projects. It also establishes priorities for the collection and analysis of basic data and for investigation, planning, and construtcion of projects.

A river basin commission is served by an independent federal chairman and full-time staff. The chairman, appointed by the president, cannot be a member of any federal agency. All members of the commission except the chairman are delegates from and compensated by some other entity. Each state in the basin and each federal agency with a substantial interest is entitled to membership on the commission.

Agencies having substantial water programs in Hawaii include federal Departments of Army, Agriculture, Commerce, and the Environmental Protection Agency; state Departments of Health and Land and Natural Resources; and county Departments of Water Supply and Public Works.

An interagency committee under the aegis of the Water Resources Council is an alternative institutional arrangement for improved coordination of water and related land resources policies, programs, and activities. Although similar in function to a river basin commission, such a committee differs in organization, mode of operation, funding, and leadership responsibilities.

As a third alternative, under existing authorities a single federal, state, or county agency might carry out the responsibilities and functions necessary to insure a continuing coordinated program. A single agency might function with an advisory board made up of all other agencies concerned.

Advantages of Interagency Committee

Being one state and one region, Hawaii is geographically unsuited to the river basin commission structure, designed primarily for a region that includes portions of several states. On the other hand, the single agency arrangement would minimize opportunities for a fully comprehensive and coordinated approach to water resource planning.

Therefore, an interagency committee representing federal, state, county, and private interests concerned with water and related land resources programs appears to be most suitable for the Hawaii Region.

An institutional arrangement called the Hawaii Water Resources Interagency Committee (HWRIC) is proposed. The committee would be an outgrowth of the existing HWRRS Planning Board with some structural and functional modifications. Federal statutory authority for HWRIC is Title II, Sections 201 and 204, of PL 89-80. State authority is H.R.S., Chapter 176, Water Resources.

The proposed structure and functions of HWRIC are based upon the following considerations:

1. Use of existing programs and organizations, including intergovernmental funding arrangements between the U.S. Water Resources Council and the State of Hawaii.
2. A minimum of organizational layers, to expedite decisions.
3. Federal, state, county, and private participation in decisions.
4. Assignment of a single agency to provide administartive and technical staff support.
5. State government leadership because of Hawaii's one-state, one-region geography. The state has regionwide authority, an intermediary position in federal, state, and county relationships, and the principal jurisdiction for national programs.
6. County governments have primary implementation, operation, and maintenance functions.
7. Provision for linking the *Hawaii Water Resources Plan* to the national Water Assessment and Appraisal Program (WAAP), to state and county general plans, and to other functional plans in the Hawaii Region.

Those government and private agencies having substantial water resources programs in the Hawaii Region and their respective responsibilities related to water resources are listed in Table 48. It is suggested that the governor appoint the state and industry representatives, that the Water Resources Council appoint all federal representatives, and that the respective mayors appoint the county representatives.

TABLE 48
Agencies With Substantial Water Resources Programs

DEPARTMENT/AGENCY		RESPONSIBILITY
Federal:	Agriculture	Soil conservation, flood prevention
	Army	Harbors, flood control, shoreline erosion
	Commerce	Coastal zone management
	EPA	Water quality
	FPC	Hydroelectric power
	HUD	Water supply, sewage, drainage, flood insurance
	Interior	Water data, fish and wildlife, outdoor recreation
	Navy	Water development, coastal water use
	Transportation	Coastal water regulations
State:	DOA	Agricultural land use
	DOH	Water quality
	DLNR	Water supply, flood control, fish and wildlife, oudoor recreation, watershed management, soil and water conservation
	DPED	Coastal zone management
	DOT	Marine transportation, harbors
	UH	Water research, marine resources affairs
County:	BWS/DWS	Domestic water supply
	DPW	Sewage, drainage, flood control
	Parks	Outdoor recreation
Private:	HFBF	Diversified crop irrigation
	HSPA	Sugarcane irrigation, industrial water supply, water quality, drainage, soil erosion
	PRI	Pineapple irrigation, drainage, erosion

HWRIC General Functions

It is proposed that HWRIC meet quarterly in January, April, July, and October to conduct interagency activities, including the following:

1. Monitor implementation of the *Hawaii Water Resources Plan*.
2. Periodically revise and update the plan.
3. Coordinate programs of member agencies concerning: (a) basic data collection and analysis, (b) research, (c) special studies, and (d) projects.
4. Provide a forum for the discussion of issues and resolution of conflicts which might arise among member agencies; attempt to achieve a consensus of the membership on all issues.
5. Prepare and submit annually to the Water Resources Council federal program and budget priority reports.
6. Encourage complementary priority reports for state, county, and private programs and budgets.
7. Observe meetings of the Water Resources Council.
8. Coordinate within the region any federally funded programs under the aegis of the council.

HWRIC Operations

The state Department of Land and Natural Resources is the designated Hawaii regional sponsor for U.S. Water Resources Council activities. As such, the department should logically be the lead agency and provide the HWRIC chairman. It is suggested that the vice-chairman be selected from

among the federal members of the interagency committee.

Four subcommittees are proposed. It is suggested that a seven-man executive subcommittee include, in addition to the chairman and vice-chairman, a representative of the federal government, the state government, the City and County of Honolulu (Oahu), one Neighbor Island county, and private interests.

The executive subcommittee would meet monthly to handle administrative matters and to develop preliminary policies and procedures for consideration by the full committee at its quarterly meetings.

A planning subcommittee would revise and update the *Hawaii Water Resources Plan* by refining the analytical process and emphasizing application of the council's *Principles and Standards.*

A coordinating subcommittee would discuss issues, monitor agency programs and projects, and endeavor to resolve conflicts.

A priorities subcommittee would establish annual program and projects priority and prepare a priorities report for submittal to: (1) WRC through the governor for federal programs and projects, (2) the governor for state programs and projects, and (3) mayors for county programs and projects.

A full-time staff would provide administrative and technical support to HWRIC. The Department of Land and Natural Resources presently has a water resources planning staff.

Memoranda of Agreement

The organizational groundwork should be formalized by intergovernmental and interagency memoranda of agreement. The following basic agreements appear necessary to initiate the program:

1. Memorandum of Agreement between the U.S. Water Resources Council and the Governor of Hawaii. This agreement would commit the State of Hawaii to provide leadership to the HWRIC and insure participation by other state agencies. Also, financial support up to 25 percent of the total HWRIC operating costs should be supported by the state to achieve the optimum program level in FY 1979.
2. Memoranda of Agreement among the U.S. Water Resources Council, Governor of Hawaii, and the county mayors. These four agreements would insure participation in HWRIC activities by the Counties of Hawaii, Maui, and Kauai and the City and County of Honolulu.
3. Memoranda of Agreement among the HWRIC and the respective federal agencies, including the military. These agreements would insure federal participation.

Implementation

It is proposed that the state Department of Land and Natural Resources undertake to organize the Hawaii Water Resources Interagency Committee.

It is further proposed that HWRIC be established by a transitional process through FY 1979. This process would coincide with FY 1978 funding levels proposed by the U.S. Water Resources Council. Full funding would be targeted for FY 1980 with the federal budget call for FY 1980 funds.

Council funds are being budgeted to defray the costs of committee member travel and operating overhead of HWRIC during the transition period. During 1978, the council budgeted funds at a minimal level, based on national criteria for the allocation of federal funds. State or local matching funds will not be required.

During 1979, a somewhat higher level of funding is anticipated, with a 75/25 federal-state cost sharing arrangement. It is expected that, beginning in FY 1980, the council would fund HWRIC activities at an optimum level.

State Capitol, Honolulu.

Plan Implementation

All 105 recommendations presented under appropriate subject headings in prior sections of this plan are assembled in a full implementation schedule in Chapter 30.

Those 38 recommendations determined in the course of public review of preliminary drafts of this plan to be deserving of priority implementation have been extracted from the full schedule for emphasis in Chapter 29.

Implementation cost sharing of government entities involved is suggested in Chapter 31.

29. PRIORITY RECOMMENDATIONS

Prior chapters present 105 recommendations, assembled in Chapter 30. From among these recommendations, 38 selected as deserving priority implementation are presented in this chapter.

The selection has been influenced by U.S. Water Resources Council *Principles and Standards*, legislative expressions of public policy, state and county administrative goals, agency missions, and particularly by citizen response at public meetings held during the course of the study.

Also, the selection attempts to provide representative coverage of the broad spectrum of water and related land resources needs, problems, and opportunities, both from a functional viewpoint and a balanced economic/environmental perspective.

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
7-1	Express decisive public policy on rights to surface water use by legislative codification with due regard for: • General public welfare. • Vested private rights challenged by the Hanapepe decision. • Impact upon existing irrigation and domestic water systems dependent upon transfer of water from one watershed to another. • Impact upon agricultural production, urban requirements, and the economy. • Environmental impact, including effect on minimum streamflow requirements.	*Legislature DPED DLNR DOH DOA OEQC WRRC			
7-4	Enact legislation to codify rights to reasonable use of ground water resources.	*Legislature DLNR			
7-5	Establish rules and regulations for implementing the Ground Water Use Act (H.R.S., Chapter 177).	*DLNR			
7-6	Improve laws and regulations to reflect the substantial interrelation between ground water and surface water sources.	*Legislature DLNR			
7-7	Consider legislation to grant appropriate administrative authority for comprehensive and coordinated management of all surface and ground water resources on each island.	*Legislature DLNR DOH			
7-8	Consider legislation to grant express administrative authority to allocate water resources among competing uses.	*Legislature DLNR			
10-2	Develop alternative water sources to supply Oahu in addition to planned development from conventional ground water sources. • Restore dike storage. • Optimize development of Honolulu and Pearl Harbor aquifers. • Increase streamflow diversions compatibly with minimum streamflow requirements.	*BWS DLNR USGS WRRC DOH EPA	32,000	x	x

* Lead agency.

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Recycle wastewater and exchange for high quality irrigation water. • Blend potable water with brackish water for a usable domestic product. • Desalt brackish water supplies for domestic use.				
10-3	Intensify water conservation programs to improve efficiency of domestic water use. • Set water rates to discourage excessive use. • Institute rigorous water system leak control programs. • Amend plumbing codes to require the installation of water-saving fixtures and appliances. • Institute a continuous community awareness program to encourage wise water use. • Operate water systems on sequential use schedules to make optimum use of storage and pipeline capacities. • Discourage urban development in areas where overdraft of ground water supplies is threatened or already exists.	*BWS/DWS Military Private	6,500	x	x
10-5	Improve domestic water systems to insure that water quality meets minimum standards of the Safe Drinking Water Act of 1975. • Obtain federal and state assistance for construction. • Conduct research on the chemical and biological quality of surface water in watersheds. • Construct water treatment plants for systems utilizing surface water sources. • Where feasible, convert systems from surface water to ground water sources. • Prevent pollution of existing sources by controlling land use in watersheds, waste injection, and overdraft of basal sources. • Initiate water quality monitoring and control.	*BWS/DWS DOH EPA DLNR USGS Private	86,000	x	x
10-6	Improve rural domestic water systems to deliver a dependable supply in adequate quantities and at sufficient pressures for droughts and fire-fighting. • Provide county water departments with legal authority to acquire control of surface and ground water sources for each system. • Develop sources by stages to meet year 2000 demands. • Replace deteriorated pipelines and storage tanks and provide additional storage. • Design systems to meet average and peak demands at adequate pressures. • Include adequate fire-fighting capabilities in system design.	*BWS/DWS DLNR DOH EDA FmHA Private	20,000	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
11-1	Reuse treated sewage effluent water for beneficial purposes. • Locate new treatment plants near agricultural operations. • Encourage agricultural operations to locate near existing sewage treatment plants where feasible. • Use effluent water for industrial cooling or processing. • Apply treated effluent to forest watersheds where compatible. • Design waste treatment and reuse as part of a single system to irrigate golf courses, lawns, or other open space.	*DPW/BWS/DWS DOH DOA EPA DLNR Private	7,000	x	x
11-2	Consider integration of domestic water supply and wastewater management functions at both state and county levels.	*DLNR/DOH *BWS/DPW			
12-1	Reduce the loss of life and property damage caused by storm flooding. • Provide non-structural measures such as regulation of flood plain use, zoning, building codes, and flood insurance. • Provide structural measures such as dams, lined channels, and flood proofing where non-structural measures are inadequate. • Improve flood peak records, flood mapping, and damage surveys.	*CE SCS HUD SWCD DLNR DPW USGS	150,650	x	x
12-2	Reduce the loss of life and property damage caused by tsunami and high surf. • Provide non-structural measures such as regulation of flood plain use, zoning, building codes and flood insurance. • Control coastal development in areas most subject to tsunami and high surf.	*PD DPED CZM FA			
13-1	Improve access to public shoreline and inland recreation areas. • Acquire or lease public rights-of-way. • Provide adequate patrolling and litter control.	*PR DPW DLNR BOR	5,500	x	
14-1	Use more efficient irrigation methods. • Convert to drip or sprinkler irrigation where feasible. • Reduce storage and transmission losses.	*Private DOA DLNR SWCD SCS	16,000	x	x
14-2	Provide additional irrigation water. • Improve diversion, storage, and transmission systems. • Develop more surface and ground water, compatible with environmental and recreational needs. • Determine the level of treatment necessary to reuse domestic wastewater for sugarcane irrigation.	*DLNR WRRC DOA BWS DPW SCS Private	47,000	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Study the reuse of treated domestic wastewater for irrigating diversified crops and timber.				
	• Develop systems to reuse treated domestic wastewater as a new source of irrigation water supply.				
15-2	Increase commercial forest production from selected watersheds, at the same time preventing threat to native forests.	*DLNR DPED USFS Private	12,100	x	x
	• Complete inventory of timber and wildlife resources in watershed lands.				
	• Develop harvesting methods and equipment for Hawaiian conditions.				
	• Improve road networks and marketing systems.				
	• Develop markets for underutilized species and uses for waste products.				
	• Identify and locate unique ecosystems and wildlife resources to avoid incompatible commercial use.				
15-3	Reduce erosion of inland areas.	*SWCD SCS DLNR USGS Private	75,550	x	
	• Apply land treatment practices to cropland and pastures, such as contouring, improved vegetative cover, and strip cropping; and use structural measures such as terraces, drop structures, and check dams in gullies.				
	• Enforce erosion control ordinances on new construction.				
	• Enact and enforce ordinances to control feral game and introduced game species in areas of severe erosion.				
	• Improve programs for revegetating eroded areas such as road cuts, abandoned fields and pastures, and military practice areas.				
	• Study effectiveness of various erosion control measures.				
	• Gather data on erosion and sedimentation rates for various soils and land uses.				
	• Determine relationships between hydrologic properties of soils and storm drainage design.				
	• Determine relationships between soil erosion and sediment yield (delivery rates) for Hawaiian watersheds.				
16-3	Encourage aquaculture as an industry of potential major importance to Hawaii.	*DLNR DOA OMAC UH Private	28,000	x	x
	• Continue government support of aquaculture at a high level, including loans and tax incentives.				
	• Stock and protect selected streams, bays, and fishponds with fish and shellfish where compatible, giving preference to native species.				
	• Refurbish and utilize selected Hawaiian fishponds.				

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
16-4	Safeguard the commercial fishing potential of the Northwestern Hawaiian Islands. • Complete study to evaluate commercial fishing potential prior to designation as a wilderness area. • Provide the capability for additional wildlife protection and regulation.	*DLNR NOAA CG FWS	700	x	
16-5	Identify and develop opportunities for Hawaii's fishing industry within the 200-mile fishery conservation zone established under PL 94-265. • Assess the probable impact of the new law on the foreign and domestic fishing industries. • Implement an effective management program to maximize advantages to Hawaii's fishing industry.	*NOAA DLNR DPED DOT OMAC	100	x	
17-3	Establish an appropriate continuing role for Hawaii in the mining and processing of manganese deposits. • Assess the environmental and economic impact on Hawaii of participation at various levels. • Plan the allocation of resources to support an appropriate level of participation. • Continue technical and logistic support. • Pursue the establishment of archipelago status under international law.	*DPED OMAC DLNR DOT NOAA BLM Private	300	x	x
18-2	Improve inter-island marine transportation services. • Develop data on comparative demand for all marine transportation systems. • Continue to investigate methods of improving the surface transportation links between the islands for cargo, vehicles, and people. • Determine environmental and economic impacts of a marine highway system.	*DOT FMA FHWA Private	500	x	x
19-2	Develop geothermal energy as a major power source on Hawaii and investigate potential as a supplemental source on Maui and Oahu. • Accelerate geothermal source development on Hawaii. • Conduct geophysical surveys of potential geothermal areas on Maui and Oahu.	*HIG DLNR DPED DOE Private	20,000	x	
20-1	Control salt water intrusion into basal fresh water aquifers. • Design and space new wells and regulate pumping schedules of all wells to prevent excessive thinning of fresh water lenses. • Increase fresh water recharge to basal aquifers. • Determine long-term effects of periodic over-draft on ground water quality.	*DLNR DOH BWS/DWS WRRC USGS Private	10,500	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
20-2	Regulate subsurface injection of wastewater to prevent contamination of basal fresh water aquifers and wetlands. • Strengthen design, licensing, and monitoring requirements for effluent injection wells, including treatment of injected wastes. • Allow wastewater injection only into confined saline aquifers. • Compile data on location and extent of underground wastewater disposal. • Conduct research on effects of underground waste disposal on ground water quality and on wetlands.	*DOH EPA DPW DLNR BWS/DWS USGS WRRC	100	x	
20-5	Reduce non-point source pollution of streams and coastal waters. • Develop coordinated programs within each county to improve control over non-point source pollutants. • Minimize erosion and floods by limiting soil-disturbing activities in urban areas and watersheds. • Maintain sanitary conditions in streams and drains by litter controls, street sweeping, and control of open storage in industrial and commercial areas. • Implement improved soil conservation practices on croplands and grazing lands. • Reclaim severely eroded areas. • Increase controlled hunting of pigs and grazing animals in kapu watersheds to reduce pollution of surface water. • Gather date on pollutant loads in urban runoff.	*DOH DPW EPA SWCD SCS DLNR	161,600	x	x
21-4	Preserve and enhance wetlands, shorelines, and submerged lands. • Ensure adequate water circulation in bays, estuaries, and wetlands by careful maintenance of channels and adequate streamflow levels. • Protect wetlands and submerged lands from excessive sedimentation and erosion. • Identify and protect wetlands of prime value as wildlife habitat.	*DLNR PD DOH	58,000	x	x
22-1	Preserve rare and endangered animals and plants. • Refine endangered species lists. • Improve delineation of critical habitat areas. • Improve data on fish and game species and habitat characteristics. • Establish natural area reserves where rare and endangered plants and animals are a significant part of the ecosystem.	*DLNR NARC FWS	22,500	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Establish wildlife and plant sanctuaries in critical areas.				
	• Manage native forests to protect and preserve rare and endangered species.				
	• Create new habitat as part of water development and storage projects.				
22-2	Preserve unique coastal and terrestrial ecosystems.	*DLNR NARC DPED FWS DOH DPW	18,060	x	
	• Define and locate native ecosystems.				
	• Identify and protect unique natural ecosystems under the Natural Area Reserve or Marine Life Conservation District programs.				
	• Establish buffer zones around unique natural ecosystems to minimize potential harmful impacts.				
	• Study stream habitat changes and ecological affects of water control and development.				
	• Establish criteria for maintaining minimum flows in streams and preserving wetlands and nearshore areas.				
	• Maintain low flow in perennial streams where possible to protect relatively undisturbed ecosystems.				
	• Develop methodology for monitoring gradual adverse effects on coral reef ecosystems.				
	• Protect coastal ecosystems from excessive fresh water flood flows.				
	• Determine impacts of power generation on terrestrial and coastal water resources.				
24-3	Protect the beauty of waterfalls and other scenic water resources.	*LUC DLNR DGP OEQC	30	x	
	• Preserve visual access to scenic water resources.				
	• Acquire water rights to maintain adequate streamflow and water levels.				
	• Prevent unsightly and damaging encroachments on scenic water areas.				
	• Catalog pertinent on-site and off-site aesthetic values.				
	• Develop methods for quantifying relative values.				
25-4	Establish a central water resources data referral center to carry out the following functions:	*DLNR USGS DOH BWS/DWS Private			
	• Periodically publish an updated catalog of water related data sources.				
	• Identify gaps in the present water data base.				
	• Identify long-term basic data requirements to support water resources planning and decision making.				
	• Work with agencies concerned to make general data collection more useful for water resources planning and management.				

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Participate in national data exchange programs as soon as feasible.				
27-1	Accelerate implementation of the National Water Assessment and Appraisal Program to establish priorities for federal funding of water and related land resources programs and projects.	*WRC DLNR DPED			
27-2	Use the Hawaii Water Resources Plan to guide authorization and appropriation of federal funds for water related agency programs and projects undertaken in the Hawaii Region.	*WRC			
27-3	Extend application of U.S. Water Resources Council's Principles and Standards for Planning Water and Related Land Resources to all federal agencies having substantial water and related land resources programs.	*WRC			
27-5	Establish a permanent water planning committee with membership from federal, state, county, and private agencies having substantial water resources programs in Hawaii (see Chapter 28) to carry out the following functions: • Implement and update the Hawaii Water Resources Plan within existing authorities, agency capabilities, and funding arrangements. • Serve as a planning and coordination group. • Recommend Hawaii's priorities for national planning and appraisal programs in the light of changing circumstances.	*WRC Governor Mayors			
27-8	Coordinate public meetings and establish formal, continuing community citizen groups on all islands for orderly public participation in all government programs.	*HWRIC			

30. PLAN IMPLEMENTATION SCHEDULE

All recommendations and specific actions contained in the previous chapters are presented in the following schedule, together with implementation considerations.

It is desirable that one agency assume lead responsibility for implementing recommendations under specific authority. Therefore, the schedule suggests lead agencies from among those concerned. In addition, approximate gross program costs are given, where available, along with the suggested time frame for carrying out the actions.

Listed below are the abbreviations used in the following schedule.

Agency Abbreviations

BLM — U.S. Bureau of Land Management
BOR — U.S. Bureau of Outdoor Recreation
BWS — County Board of Water Supply
CE — U.S. Corps of Engineers
CG — U.S. Coast Guard
CZM — State Coastal Zone Management
DGP — County Department of General Planning
DLNR — State Department of Land and Natural Resources
DOA — State Department of Agriculture
DOH — State Department of Health
DOT — State Department of Transportation
DPED — State Department of Planning Economic Development
DPW — County Department of Public Works
DWS — County Department of Water Supply
EDA — U.S. Economic Development Administration
EPA — U.S. Environmental Protection Agency
ERDA — U.S. Energy Research and Development Administration
FmHA — U.S. Farmers Home Administration
FMA — U.S. Maritime Administration
FS — U.S. Forest Service
FWS — U.S. Fish and Wildlife Service
HUD — U.S. Department of Housing and Urban Development
LUC — State Land Use Commission
MAC — State Marine Affairs Coordinator
NARC — State Natural Area Reserve Commission
NOAA — National Oceanic and Atmospheric Administration
NPS — U.S. National Park Service
OEQC — State Office of Environmental Quality Control
PD — County Planning Department
PR — County Parks and Recreation Department
PUC — State Public Utilities Commission
SCS — U.S. Soil Conservation Service
SWCD — Soil and Water Conservation Districts
UH — University of Hawaii
USGS — U.S. Geological Survey
WRC — U.S. Water Resources Council
WRRC — Water Resources Research Center, University of Hawaii

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
7-1	Express decisive public policy on rights to surface water use by legislative codification, with due regard for: • General public welfare. • Vested private rights challenged by the Hanapepe decision. • Impact upon existing irrigation and domestic water systems dependent upon transfer of water from one watershed to another. • Impact upon agricultural production, urban requirements, and the economy. • Environmental impact, including effect on minimum streamflow requirements.	*Legislature DPED DLNR DOH DOA OEQC WRRC			
7-2	Augment programs for the collection, storage, and retrieval of the following data: • Ground water occurrence. • Chemical and biological quality of ground water, including the effects of cesspools. • Precipitation and evapotranspiration rates in recharge areas. • Dynamics of the transition zone of salt and fresh water in basal aquifers.	*USGS DLNR DOH WRRC BWS			
7-3	Pursue the following specific lines of research: • Methods of increasing ground water recharge. • Ground water exploration techniques. • Techniques for drilling in basaltic terrain. • Mechanics of ground water movement in basal lenses.	*WRRC USGS DLNR BWS			
7-4	Enact legislation to codify rights to reasonable use of ground water resources.	*Legislature DLNR			
7-5	Establish rules and regulations for implementing the Ground Water Use Act (H.R.S., Chapter 177).	*DLNR			
7-6	Improve laws and regulations to reflect the substantial interrelation between ground water and surface water sources.	*Legislature DLNR			
7-7	Consider legislation to grant appropriate administrative authority for comprehensive and coordinated management of all surface and ground water resources on each island.	*Legislature DLNR DOH			
7-8	Consider legislation to grant express administrative authority to allocate water resources among competing uses.	*Legislature DLNR			
7-9	Augment programs for the collection, storage, and retrieval of the following data: • Cost of water for various uses from various sources. • Per capita use of domestic water from all systems.	*DLNR BWS/DWS			

* Lead agency.

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
7-10	Pursue the following specific lines of research: • Identification and economic feasibility of alternative or supplementary water supplies for drought periods. • Uniform basis for projecting per capita demand. • Improved methods of water storage and distribution. • Potential application of desalting to Hawaii. • Engineering design of fog drip systems and catchments for isolated homesteads and ranches. • Methods of increasing rainfall through weather modification. • Methods of reducing evapotranspiration.	*WRRC DLNR BWS/DWS Private			
7-11	Investigate potential technological advances that might increase water supplies.	*WRRC BWS DLNR			
8-1	Enact legislation to apply the "archipelago doctrine" to the Hawaiian Islands, giving the United States the right to control the waters around the Islands, and delegating administration to the state.	*Congress WRC DPED DLNR			
8-2	Develop means of providing "one-stop service" to the public for permits from various government agencies regulating coastal activities. • Consolidate programs. • Execute interagency agreements. • Transfer funds as necessary.	*DOT CE DLNR DOH DPW			
9-1	Pursue the following specific lines of research: • Water consumption by plants in forested areas. • Soil characteristics and resource values in watersheds. • Wildlife values of watersheds.	*DLNR FS SCS			
10-1	Develop additional fresh water supplies to meet year 2000 needs statewide. • Hawaii: Develop ground water sources in Hilo, Kona, and South Kohala to meet the needs within those hydrographic areas (HGA). • Maui: Develop Lahaina and Wailuku ground water sources for use within the HGA; and develop surface and ground water in East Maui for Makawao HGA needs. • Oahu: Develop ground water islandwide, especially Schofield Plateau and Waialua areas. • Kauai: Develop Lihue and Koloa ground water sources to meet the needs within those HGA.	*BWS/DWS DLNR HUD EDA FmHA	40,800	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
10-2	Develop alternative water sources to supply Oahu in addition to planned development from conventional ground water sources. • Restore dike storage. • Optimize development of Honolulu and Pearl Harbor aquifers. • Increase streamflow diversions compatibly with minimum streamflow requirements. • Recycle wastewater and exchange for high quality irrigation water. • Blend potable water with brackish water for a usable domestic product. • Desalt brackish water supplies for domestic use.	*BWS DLNR USGS WRRC DOH EPA	32,000	x	x
10-3	Intensify water conservation programs to improve efficiency of domestic water use. • Set water rates to discourage excessive use. • Institute rigorous water system leak control programs. • Amend plumbing codes to require the installation of water-saving fixtures and appliances. • Institute a continuous community awareness program to encourage wise water use. • Operate water systems on sequential use schedules to make optimum use of storage and pipeline capacities. • Discourage urban development in areas where overdraft of ground water supplies is threatened or already exists.	*BWS/DWS Military Private	6,500	x	x
10-4	Encourage public and private water suppliers to establish drought plans for water allocation in periods of shortage.	*DLNR BWS/DWS Private Military	Administrative	x	
10-5	Improve domestic water systems to insure that water quality meets minimum standards of the Safe Drinking Water Act of 1975. • Obtain federal and state assistance for construction. • Conduct research on the chemical and biological quality of surface water in watersheds. • Construct water treatment plants for systems utilizing surface water sources. • Where feasible, convert systems from surface water to ground water sources. • Prevent pollution of existing sources by controlling land use in watersheds, waste injection, and overdraft of basal sources. • Initiate water quality monitoring and control.	*BWS/DWS DOH EPA DLNR USGS Private	86,000	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
10-6	Improve rural domestic water systems to deliver a dependable supply in adequate quantities and at sufficient pressures for droughts and fire-fighting. • Provide county water departments with legal authority to acquire control of surface and ground water sources for each system. • Develop sources by stages to meet year 2000 demands. • Replace deteriorated pipelines and storage tanks and provide additional storage. • Design systems to meet average and peak demands at adequate pressures. • Include adequate fire-fighting capabilities in system design.	*BWS/DWS DLNR DOH EDA FmHA Private	20,000	x	x
11-1	Reuse treated sewage effluent water for beneficial purposes. • Locate new treatment plants near agricultural operations. • Encourage agricultural operations to locate near existing sewage treatment plants where feasible. • Use effluent water for industrial cooling or processing. • Apply treated effluent to forest watersheds where compatible. • Design waste treatment and reuse as part of a single system to irrigate golf courses, lawns, or other open space.	*DPW/BWS/DWS DOH DOA EPA DLNR Private	7,000	x	x
11-2	Consider integration of domestic water supply and wastewater management functions at both state and county levels.	*DLNR/DOH *BWS/DPW			
11-3	Provide consolidated sewer systems for urban areas. • Expand existing systems and provide new interceptors and treatment facilities. • Dispose of wastewater by deep ocean outfalls or underground injection where reuse is infeasible.	*DPW DOH EPA	374,000	x	
11-4	Provide adequate treatment facilities for individual houses and towns located in rural areas. • Use package treatment systems or septic tanks. • Separate wastewater from various sources to reduce treatment needs. • Use waterless systems and on-site disposal of solid wastes.	*DPW DOH Private	25,000	x	x
12-1	Reduce the loss of life and property damage caused by storm flooding. • Provide non-structural measures such as regulation of flood plain use, zoning, building codes, and flood insurance.	*CE SCS HUD SWCD DLNR DPW USGS	150,650	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990-	TIME FRAME 1990-2000
	• Provide structural measures such as dams, lined channels, and flood proofing where non-structural measures are inadequate. • Improve flood peak records, flood mapping, and damage surveys.				
12-2	Reduce the loss of life and property damage caused by tsunami and high surf. • Provide non-structural measures such as regulation of flood plain use, zoning, building codes and flood insurance. • Control coastal development in areas most subject to tsunami and high surf.	*PD DPED CZM FA			
12-3	Enhance flood forecasting and warning systems. • Obtain most advanced radar systems for detecting storm conditions prior to flash flooding. • Develop methodology for flash flood forecasting in an island environment. • Develop adequate warning system for tsunami generated by local earthquakes. • Conduct education programs concerning warning systems and flood hazards.	*CD NOAA	3,000	x	
12-4	Ensure the safety of existing dams. • Fund and implement dam inspection provisions contained in PL 92-367. • Determine the safety of dams included in Corps of Engineers inventory by field inspection and analysis. • Inspect smaller dams not included in Corps of Engineers inventory at locations where failure would pose downstream hazards. • Take corrective action to remove hazards.	*CE SCS DLNR DPW Private	13,400	x	x
13-1	Improve access to public shoreline and inland recreation areas. • Acquire or lease public rights-of-way. • Provide adequate patrolling and litter control.	*PR DPW DLNR BOR	5,500	x	
13-2	Provide additional parks at beaches and in watershed areas. • Lease or acquire important shoreline areas. • Encourage multi-purpose use of watersheds. • Provide facilities for park use. • Maintain trails and appropriate facilities. • Increase controlled hunting in watershed areas. • Improve habitat and fish population in streams and reservoirs.	*DLNR PR BWS SCS BOR Military Private	26,500	x	x
13-3	Establish additional marine parks for public enjoyment and preservation of marine life.	*DLNR DOH PR BOR			

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
13-4	Protect surf sites. • Provide areas of non-conflicting recreational use. • Protect against damaging development, by conservation zoning and other regulatory measures. • Determine feasibility of developing artificial surfing reefs at suitable sites.	*PR DLNR DOT	6,000	x	x
13-5	Improve inshore fishing opportunities. • Provide access to shoreline areas with ample fish populations. • Harmonize land use policies and coordinate resource management.	*DLNR Private			
13-6	Include freshwater fishing and swimming as planned multiple uses in water storage projects.	*DLNR CE SCS			
13-7	Provide facilities for recreational boating. • Provide additional boat ramps and dry storage facilities. • Provide additional small boat harbors. • Develop specific facilities and programs to accommodate outrigger canoeing. • Provide additional buoys and other navigation aids for recreational boating safety.	*DOT DLNR DPW CE USCG Private	112,200	x	x
13-8	Enhance hiking opportunities. • Maintain trails to prevent landslides, soil erosion, and introduction of exotic plant species. • Rehabilitate overgrown, impassable, and unrecognizable trails. • Provide public access to trails through military and private lands.	*DLNR PR Military Private			
13-9	Investigate possibilities for increasing hunting opportunities in watersheds where compatible with the preservation of native ecosystems.	*DLNR BWS			
13-10	Provide for detailed recreational planning by a permanent staff within the implementing agency. • Determine participation rates for water related recreational activities. • Assemble use intensity data for existing recreational sites. • Develop criteria to determine the recreational value of water management alternatives. • Establish relationships between recreational opportunities, population densities, and the quality of life.	*DLNR BOR PR			

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
14-1	Use more efficient irrigation methods. • Convert to drip or sprinkler irrigation where feasible. • Reduce storage and transmission losses.	*Private DOA DLNR SWCD SCS	16,000	x	x
14-2	Provide additional irrigation water. • Improve diversion, storage, and transmission systems. • Develop more surface and ground water, compatible with environmental and recreational needs. • Determine the level of treatment necessary to reuse domestic wastewater for sugarcane irrigation. • Study the reuse of treated domestic wastewater for irrigating diversified crops and timber. • Develop systems to reuse treated domestic wastewater as a new source of irrigation water supply.	*DLNR WRRC DOA BWS DPW SCS Private	47,000	x	x
14-3	Improve distribution of livestock water for more efficient use of grazing land. • Increase number of stock watering ponds at high elevations. • Develop fog drip and rain catchments. • Develop springs and wells. • Expand pipeline and ditch systems.	*SWCD DLNR SCS Private	22,000	x	
14-4	Encourage in-plant recycling and the use of lower quality water to replace potable water used for industrial cooling. • Gather data on industrial water use, by quality categories and sources. • Compile statistics on reuse of wastewater for industry. • Continue to update industrial water use projections. • Determine potential for using municipal or agricultural wastewater for industrial cooling.	*BWS DLNR USGS	80	x	x
15-1	Reserve prime agricultural land for crop production. • Apply standard criteria for identification of prime agricultural land. • Establish specific restrictive zoning of prime agricultural land. • Acquire or lease prime land for agricultural parks. • Provide low-cost irrigation water and other government incentives to encourage crop production on prime agricultural land.	*DOA LUC PD SWCD SCS	50,000	x	

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
15-2	Increase commercial forest production from selected watersheds, at the same time preventing threat to native forests. • Complete inventory of timber and wildlife resources in watershed lands. • Develop harvesting methods and equipment for Hawaiian conditions. • Improve road networks and marketing systems. • Develop markets for underutilized species and uses for waste products. • Identify and locate unique ecosystems and wildlife resources to avoid incompatible commercial use.	*DLNR DPED USFS Private	12,100	x	x
15-3	Reduce erosion of inland areas. • Apply land treatment practices to cropland and pastures, such as contouring, improved vegetative cover, and strip cropping; and use structural measures such as terraces, drop structures, and check dams in gullies. • Enforce erosion control ordinances on new construction. • Enact and enforce ordinances to control feral game and introduced game species in areas of severe erosion. • Improve programs for revegetating eroded areas such as road cuts, abandoned fields and pastures, and military practice areas. • Study effectiveness of various erosion control measures. • Gather data on erosion and sedimentation rates for various soils and land uses. • Determine relationships between hydrologic properties of soils and storm drainage design. • Determine relationships between soil erosion and sediment yield (delivery rates) for Hawaiian watersheds.	*SWCD SCS DLNR USGS Private	75,550	x	
15-4	Reduce shoreline erosion. • Regulate shoreline use to prevent damaging development. • Provide structural measures such as sea walls, revetments, and beach nourishment to reduce critical shoreline erosion.	*DPW DLNR DOT CE	300	x	x
15-5	Reduce sedimentation of bays, estuaries, harbors, and coastal wetlands. • Implement upstream controls to reduce sediment loads, including control of feral mammals on private lands. • Revise and enforce more efficient grading ordinances. • Install debris and sediment traps. • Install levees and peripheral waterways.	*DPW DOH SWCD CE SCS	68,000	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Dredge and clear sediment deposits.				
	• Study effects of soil loss and sediment deposition in estuaries.				
16-1	Foster an increased catch of skipjack tuna (aku) by the Hawaii fishing fleet.	*DLNR FWS NOAA Private	9,000	x	x
	• Improve the supply of baitfish.				
	• Improve fishing and fish locating methods.				
	• Provide low-interest loans and tax incentives for improving fishing boats and equipment.				
	• Expand and improve harbor facilities.				
16-2	Increase inshore and offshore commercial fishing opportunities.	*DLNR NOAA FWS DOH DPW DOT	12,300	x	x
	• Protect and improve habitat for larval fish.				
	• Protect breeding population by establishing closed seasons or sanctuaries and size and bag limits.				
	• Use treated wastes to improve productivity.				
	• Improve access to underfished areas where compatible with conservation of other natural resources.				
	• Evaluate potential for improving yield by using nutrient-laden deep ocean water.				
	• Investigate possibilities for artificial propagation of fisheries resources.				
16-3	Encourage aquaculture as an industry of potential major importance to Hawaii.	*DLNR DOA OMAC UH Private	28,000	x	x
	• Continue government support of aquaculture at a high level, including loans and tax incentives.				
	• Stock and protect selected streams, bays, and fishponds with fish and shellfish where compatible, giving preference to native species.				
	• Refurbish and utilize selected Hawaiian fishponds.				
16-4	Safeguard the commercial fishing potential of the Northwestern Hawaiian Islands.	*DLNR NOAA CG FWS	700	x	
	• Complete study to evaluate commercial fishing potential prior to designation as a wilderness area.				
	• Provide the capability for additional wildlife protection and regulation.				
16-5	Identify and develop opportunities for Hawaii's fishing industry within the 200-mile fishery conservation zone established under PL 94-265.	*NOAA DLNR DPED DOT OMAC	100	x	
	• Assess the probable impact of the new law on the foreign and domestic fishing industries.				
	• Implement an effective management program to maximize advantages to Hawaii's fishing industry.				

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
17-1	Protect the precious coral industry. • Conduct an appraisal of precious coral resources. • Manage the precious coral harvest to assure a sustained yield of raw materials.	*DLNR	110	x	
17-2	Promote the mining of offshore sand deposits. • Continue to develop methods and technology. • Establish rules and regulations for resource management.	*DLNR OMAC BLM	500	x	
17-3	Establish an appropriate continuing role for Hawaii in the mining and processing of manganese deposits. • Assess the environmental and economic impact on Hawaii of participation at various levels. • Plan the allocation of resources to support an appropriate level of participation. • Continue technical and logistic support. • Pursue the establishment of archipelago status under international law.	*DPED OMAC DLNR DOT NOAA BLM Private	300	x	x
18-1	Improve harbor facilities for transocean shipping. • Improve navigability of existing harbors. • Increase cargo storage and handling facilities. • Provide additional deep-draft harbors as needed.	*DOT CE	93,000	x	x
18-2	Improve inter-island marine transportation services. • Develop data on comparative demand for all marine transportation systems. • Continue to investigate methods of improving the surface transportation links between the islands for cargo, vehicles, and people. • Determine environmental and economic impacts of a marine highway system.	*DOT FMA FHWA Private	500	x	x
18-3	Improve marine transit services to supplement land transit systems on the islands of Oahu and to link the islands of Maui County. • Expand and improve existing marine commuter services. • Conduct comparative studies of marine commuter systems.	*DOT DTS FMA UMTA Private	100,000	x	x
19-1	Investigate the potential for increasing hydroelectric power production. • Improve efficiency of existing hydroelectric plants. • Improve streamflow records at potential hydroelectric plant sites.	*DLNR CE DPED Private PUC	74,105	x	

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Study potential for hydroelectric power in Hawaii, including power generation from dike compartments.				
	• Assess the impacts of hydroelectric power development on fish and wildlife resources and recreational opportunities.				
	• Develop hydroelectric plants at suitable sites.				
	• Study use of geothermal and ocean thermal energy and surplus hydroelectric power to pump and store water to generate hydroelectric power for peak requirements.				
	• Investigate systems for storing and transporting surplus energy.				
19-2	Develop geothermal energy as a major power source on Hawaii and investigate potential as a supplemental source on Maui and Oahu.	*HIG DLNR DPED DOE Private	20,000	x	
	• Accelerate geothermal source development on Hawaii.				
	• Conduct geophysical surveys of potential geothermal areas on Maui and Oahu.				
19-3	Assess the potential of ocean thermal energy conversion.	*HIG DPED DLNR DOE	6,200	x	
	• Establish pilot project at Ke'ahole, Hawaii.				
	• Assess environmental effects of construction and operation.				
	• Consider additional sites on Oahu.				
	• Formulate ocean temperature profiles.				
	• Improve data on ocean currents.				
	• Conduct further research into the magnitude of the potential energy resource.				
20-1	Control salt water intrusion into basal fresh water aquifers.	*DLNR DOH BWS/DWS WRRC USGS Private	10,500	x	x
	• Design and space new wells and regulate pumping schedules of all wells to prevent excessive thinning of fresh water lenses.				
	• Increase fresh water recharge to basal aquifers.				
	• Determine long-term effects of periodic over-draft on ground water quality.				
20-2	Regulate subsurface injection of wastewater to prevent contamination of basal fresh water aquifers and wetlands.	*DOH EPA DPW DLNR BWS/DWS USGS WRRC	100	x	
	• Strengthen design, licensing, and monitoring requirements for effluent injection wells, including treatment of injected wastes.				
	• Allow wastewater injection only into confined saline aquifers.				

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Compile data on location and extent of underground wastewater disposal. • Conduct research on effects of underground waste disposal on ground water quality and on wetlands.				
20-3	Regulate the use of cesspools, seepage pits, and solid waste dumps to prevent contamination of fresh ground water supplies. • Replace cesspools as needed with sewers or other suitable systems. • Require treatment of wastewater disposed of in seepage pits. • Obtain data on contamination of ground water by leachates from land disposal systems. • Allow solid waste disposal only where leachates will not pose a hazard to ground water.	*DOH EPA DPW DLNR BWS/DWS USGS WRRC	15,050	x	
20-4	Conduct research on the effects of wastewater discharges, including the following: • Design criteria for deep ocean outfalls. • Effects of treated wastes on the ocean environment. • The fate and effect of nutrients and sediment on estuarine water quality and ecosystems. • Significance of fresh water coral kills in coastal ecosystems. • Mercury and toxic metal cycling in estuaries. • Level of health hazards from sewage-borne human pathogenic viruses in both marine and terrestrial ecosystems.	*WRRC DOH EPA	370	x	
20-5	Reduce non-point source pollution of streams and coastal waters. • Develop coordinated programs within each county to improve control over non-point source pollutants. • Minimize erosion and floods by limiting soil-disturbing activities in urban areas and watersheds. • Maintain sanitary conditions in streams and drains by litter controls, street sweeping, and control of open storage in industrial and commercial areas. • Implement improved soil conservation practices on croplands and grazing lands. • Reclaim severely eroded areas. • Increase controlled hunting of pigs and grazing animals in kapu watersheds to reduce pollution of surface water. • Gather data on pollutant loads in urban runoff.	*DOH DPW EPA SWCD SCS DLNR	161,600	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
20-6	Revise wastewater treatment and receiving water standards to suit Hawaii's conditions. • Lower the treatment level for disposal by deep ocean outfalls or by injection into confined saline aquifers. • Seek legislative or administrative relief where receiving water classes and effluent standards are determined to be unrealistic.	*DOH EPA OEQC DPW	114,000	x	
20-7	Reduce potential hazard to the environment from a major oil spill. • Enhance the readiness of men and equipment to enforce navigation and safety regulations in such event. • Develop contingency plans for protection and restoration of fish and wildlife resources.	*CG DOH DOT DLNR DOD	14,000	x	
21-1	Preserve and enhance the quality of forests and open land. • Prevent and control forest diseases, insect damage, fires, and the spread of noxious plants. • Control erosion by establishing and maintaining adequate vegetation, installation of structures, and control of grazing and roaming animal populations. • Improve fire fighting capability by development of program to assess fire hazard, limitation of conflicting use, and improved interagency coordination. • Identify and protect unique ecosystems and habitats for rare plants and animals.	*DLNR FS SCS UH SWCD	26,700	x	x
21-2	Preserve and enhance agricultural land quality. • Reduce erosion of cropland by applying appropriate conservation measures, and by ensuring cover on abandoned or inactive fields. • Increase strip cropping practices for sugar and pineapple to minimize soil loss and to improve the aesthetic values of agricultural landscapes. • Control grazing on pasture lands to ensure adequate cover conditions.	*SWCD SCS DOH DOA Private	201,200	x	x
21-3	Preserve and enhance the quality of urban land and highway corridors. • Enforce erosion controls ordinances on all new construction. • Establish and maintain vegetative cover on exposed road cuts and fills. • Use structural measures where they are needed.	*DPW *DOT SWCD SCS	Administrative	x	
21-4	Preserve and enhance wetlands, shorelines, and submerged lands. • Ensure adequate water circulation in bays, estuaries, and wetlands by careful maintenance of channels and adequate streamflow levels. • Protect wetlands and submerged lands from excessive sedimentation and erosion.	*DLNR PD DOH	58,000	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Identify and protect wetlands of prime value as wildlife habitat.				
22-1	Preserve rare and endangered animals and plants.	*DLNR NARC FWS	22,500	x	x
	• Refine endangered species lists.				
	• Improve delineation of critical habitat areas.				
	• Improve data on fish and game species and habitat characteristics.				
	• Establish natural area reserves where rare and endangered plants and animals are a significant part of the ecosystem.				
	• Establish wildlife and plant sanctuaries in critical areas.				
	• Manage native forests to protect and preserve rare and endangered species.				
	• Create new habitat as part of water development and storage projects.				
22-2	Preserve unique coastal and terrestrial ecosystems.	*DLNR NARC DPED FWS DOH DPW	18,060	x	
	• Define and locate native ecosystems.				
	• Identify and protect unique natural ecosystems under the Natural Area Reserve or Marine Life Conservation District programs.				
	• Establish buffer zones around unique natural ecosystems to minimize potential harmful impacts.				
	• Study stream habitat changes and ecological affects of water control and development.				
	• Establish criteria for maintaining minimum flows in streams and preserving wetlands and nearshore areas.				
	• Maintain low flow in perennial streams where possible to protect relatively undisturbed ecosystems.				
	• Develop methodology for monitoring gradual adverse effects on coral reef ecosystems.				
	• Protect coastal ecosystems from excessive fresh water flood flows.				
	• Determine impacts of power generation on terrestrial and coastal water resources.				
22-3	Protect fish and wildlife habitat.	*DLNR FWS	50	x	
	• Improve delineation of critical habitat areas for endangered and threatened species.				
	• Establish sanctuaries to protect seabird nesting sites, especially offshore islands.				
	• Minimize jurisdictional and management conflicts.				
	• Integrate fish and wildlife management into land use planning for state and federal lands.				

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
23-1	Restore and protect selected ancient Hawaiian fishponds. • Improve criteria for evaluating significance of fishponds. • Prevent destruction of all fishponds suitable for listing on National Register of Historic Places. • Manage tributary lands to minimize sediment and other pollutants. • Restore and manage selected ponds either in the ancient Hawaiian tradition or with modern aquaculture techniques.	*DLNR DPED DOA NPS FWS SCS SWCD	2,500	x	
23-2	Restore and protect selected ancient Hawaiian and historic irrigation systems. • Establish criteria for evaluating cultural significance of irrigation systems. • Locate, protect, and restore examples of ancient irrigation systems. • Locate, protect, and appropriately mark the pioneer water development systems of the sugarcane industry, including wells, shafts, tunnels, and irrigation ditches.	*DLNR NPS PD	1,050	x	x
23-3	Protect unique natural lakes and waterways from degradation or alteration. • Establish criteria for evaluating cultural significance of natural lakes and waterways. • Survey and select candidate sites for special protection status, based on their unique characteristics.	*DLNR NPS PD	280	x	
23-4	Protect and restore selected ancient and historic shoreline structures used for water transportation. • Establish criteria for evaluating cultural significance of water transportation structures. • Survey and select structures for protection and restoration.	*DLNR DOT NPS	30	x	
24-1	Protect and provide visual access to open spaces, including mountains and wilderness areas. • Provide and maintain access to viewing sites. • Control height and spacing of urban development to preserve mountain vistas. • Protect forest vegetation and restore vegetation to eroded areas. • Use lumbering and harvesting methods that protect the environment. • Develop and maintain a system of trails and facilities for on-site enjoyment where appropriate. • Catalog pertinent on-site and off-site aesthetic values.	*DLNR DPW PR FS OEQC	27,070	x	x

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
	• Develop methods for quantifying relative values.				
24-2	Protect physical and visual access to beaches, shorelines, offshore islands, and the ocean.	*LUC DP DLNR OEQC	22,020	x	x
	• Control density and height of buildings to seaward of coastal highways.				
	• Provide and maintain access to the shoreline.				
	• Reduce sediment and floating debris from streams and urban areas.				
	• Maintain desirable fresh water flows and water circulation in bays and estuaries.				
	• Maintain offshore islands in their natural condition.				
	• Catalog pertinent on-site and off-site aesthetic values.				
	• Develop methods for quantifying relative values.				
24-3	Protect the beauty of waterfalls and other scenic water resources.	*LUC DLNR DGP OEQC	30	x	
	• Preserve visual access to scenic water resources.				
	• Acquire water rights to maintain adequate streamflow and water levels.				
	• Prevent unsightly and damaging encroachments on scenic water areas.				
	• Catalog pertinent on-site and off-site aesthetic values.				
	• Develop methods for quantifying relative values.				
25-1	Improve programs and systems to collect data for the following purposes:	*USGS DLNR DOH WRRC BWS/DWS OEQC CE FA			
	• Interrelations among precipitation, ground water, streamflow, and water quality.				
	• Underground storage capacity and relationships with surface water systems.				
	• Determination of policy on flood damage reduction, water quality control, water costs, and water use.				
	• Environmental impact analyses.				
	• Measurement of program effectiveness.				
25-2	Include an assessment of the data base in all water resource planning reports and environmental impact statements, indicating which decisions or findings are most sensitive to data deficiencies.				
25-3	Make greater use of remote sensing (aircraft and space satellites) for data collection and transmission.	*USGS DLNR DPED			

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
25-4	Establish a central water resources data referral center to carry out the following functions: • Periodically publish an updated catalog of water related data sources. • Identify gaps in the present water data base. • Identify long-term basic data requirements to support water resources planning and decision making. • Work with agencies concerned to make general data collection more useful for water resources planning and management. • Participate in national data exchange programs as soon as feasible.	*DLNR USGS DOH BWS/DWS Private			
25-5	Integrate storage and retrieval systems for economic and environmental data.	*DPED DLNR USGS			
25-6	Design data systems to permit: • Feedback from monitoring. • Analysis of requests for data at data centers. • Analysis of the effects of planned actions on water and the environment.	*DLNR USGS OEQC			
25-7	Research and develop improved methods for water data synthesis and transfer.	*USGS DLNR			
25-8	Conduct studies before and after water project implementation to ascertain cause-and-effect relationships and the adequacy of basic data relied upon.	*USGS DLNR			
26-1	Include guidance to research agencies in water resource planning studies. • Assess research needed to support planning objectives. • Recommend research required to develop the scientific and technological base to cope with future management problems.	*WRRC USGS DLNR BWS/DWS			
26-2	Pursue those lines of research which will provide useful planning and/or management tools. • Develop systems to improve water management decisions. • Improve water resources planning models for insular environments. • Design a clearing house to simplify approval of water projects. • Recommend procedures for reconciling economic, environmental, and social issues in water management. • Project the long-term effects of the Hanapepe decision on the management and use of surface water in Hawaii.	*WRRC DLNR DPED			
26-3	Develop guidelines to reflect the impact of technological advances upon both short-range and long-range water resources planning.	*DLNR DPED BWS/DWS			

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
26-4	Maintain a current state-of-the-art assessment of new technology to assist planners and decision makers in developing and evaluating water management alternatives.	*WRRC			
26-5	Continue mission-oriented water research by government agencies, universities, industries, and private agencies.	*DLNR WRRC USGS			
26-6	Give priority to research in the following areas: • Economic, social, and environmental impacts of water resources development and management. • Costs and benefits of (a) various levels of wastewater treatment, and (b) changes in water use to achieve required levels of water quality. • Effects on water quality of non-point sources of pollution, including alternative means of control. • Relationships between energy production and water use, including the effects of heat and consumptive use on local water resources. • Means of more efficient and extensive use of existing water supplies. • New and developing water technology, including desalting, weather modification, wastewater reuse, and geothermal resources.	*DLNR WRRC BWS/DWS DPW DOH			
26-7	Review planning reports for an annual assessment of research priorities.	*WRRC			
27-1	Accelerate implementation of the National Water Assessment and Appraisal Program to establish priorities for federal funding of water and related land resources programs and projects.	*WRC DLNR DPED			
27-2	Use the Hawaii Water Resources Plan to guide authorization and appropriation of federal funds for water related agency programs and projects undertaken in the Hawaii Region.	*WRC			
27-3	Extend application of U.S. Water Resources Council's Principles and Standards for Planning Water and Related Land Resources to all federal agencies having substantial water and related land resources programs.	*WRC			
27-4	Establish integrated federal grant and loan application procedures for water data collection, research, construction, and planning in the Hawaii Region.	*WRC			
27-5	Establish a permanent water planning committee with membership from federal, state, county, and private agencies having substantial water resources programs in Hawaii (see Chapter 28) to carry out the following functions: • Implement and update the Hawaii Water Resources Plan within existing authorities, agency capabilities, and funding arrangements. • Serve as a planning and coordination group. • Recommend Hawaii's priorities for national planning and appraisal programs in the light of changing circumstances.	*WRC Governor Mayors			

REC. NO.	RECOMMENDATIONS & SPECIFIC ACTIONS	AGENCIES	ESTIMATED COST ($1,000)	TIME FRAME 1975-1990	TIME FRAME 1990-2000
27-6	Utilize the Hawaii State Plan's long-range social, economic, and environmental policies as general planning guides for implementation and future revision of the Hawaii Water Resources Plan.	HWRIC			
27-7	Utilize updated county general plans, modified for consistency with the Hawaii State Plan, as local guidelines for implementation and future revision of the Hawaii Water Resources Plan.	HWRIC			
27-8	Coordinate public meetings and establish formal, continuing community citizen groups on all islands for orderly public participation in all government programs.	HWRIC			

31. SUGGESTED COST SHARING

The preceding implementation schedule gives estimated costs of specific actions required to implement plan recommendations. Who will ultimately pay for the recommended actions is closely tied to cost allocations among plan purposes. This is because beneficiaries of resource development and responsibilities vary according to purpose.

Most of the impacts of the plan will be local and the actions carried out at the local level. Therefore, the non-federal cost share is much greater than the federal share. Since most of the recommended actions are subject to detailed analysis before they are implemented, cost sharing suggested in Table 49 is only tentative. Further analysis may result in different costs and cost-sharing arrangements.

Overall, the non-federal share is estimated to amount to 30 percent of investment costs and 80 percent of operation, maintenance, and replacement costs.

TABLE 49
Suggested Cost Sharing

PURPOSE	INVESTMENT COSTS		OPERATION, MAINTENANCE, AND REPLACEMENTS AT YEAR 2000	
	FEDERAL	NON-FEDERAL	FEDERAL	NON-FEDERAL
Water quality	35	65	10	90
Fish and wildlife	50	50	50	50
Forest conservation	30	70	20	80
Soil conservation	80	20	--	100
Recreation	55	45	65	35
Water supplies	--	100	--	100
Irrigation and drainage	65	35	--	100
Flood control	80	20	10	90
Navigation	90	10	90	10
Hydroelectric power	--	100	--	100
Other beneficial purposes	55	45	--	100

Summit of Mauna Kea above the clouds.

Appendices

The beneficial and adverse effects of recommended actions and the environmental impact of this water resources plan, as structured in the review draft of this report, are presented in Appendices A and B.

Response to the review draft is summarized in Appendix C. A glossary is presented in Appendix D, and bibliographic references are presented in Appendix E.

A. BALANCED PLAN AND EFFECT ANALYSIS

Following guidelines set forth in the U.S. Water Resources Council's *Principles and Standards,* the review draft of this report discussed economic development and environmental quality concerns associated with water planning in Hawaii. Major areas of concern were selected for further analysis in the "Level B" plan formulation process.

Where existing programs were deemed adequate, further "Level B" study was considered unnecessary, and that concern was eliminated from further analysis. The concerns remaining are those for which programs need extension or refinement in the 1990-2000 planning period or beyond.

In order to achieve a balanced, comprehensive, and integrated plan for water and related land resource management, alternative actions were first assembled into two plans in the review draft, one having economic emphasis and the other having environmental emphasis.

Water resources planning directed toward economic development objectives emphasizes an increased output of goods and services. These objectives might be achieved either by an additional commitment of resources or by more efficient use of available resources.

Water resources planning that stresses environmental quality is concerned with the maintenance and enhancement of the environment as a sources of present enjoyment and a heritage for future generations.

The respective plans were formulated by first stating a planning objective pertinent to each "Level B" concern and then suggesting alternative actions suitable for achieving the objective. The planning objectives and specific actions were based upon moderate growth (E-2) population projections shown in Figure 9 and upon water availability and demand rates depicted in Figures 27 to 32. Should any of these basic assumptions be altered greatly, the validity of some objectives and actions would require reexamination.

Those economic development and environmental quality actions deemed compatible were substantially integrated into a Balanced Plan. Trade-offs were made between competing and conflicting demands among various resource uses, in order to minimize conflict and foster coordination. Ownership, legal, budgetary, and manpower limitations were also considered to arrive at a workable plan.

Each of the three plans presented in the review draft was subjected to effect analysis, and full consideration was given to the four accounts of national economic development, environmental quality, regional development, and social well-being, as specified in *Principles and Standards.* Detailed analyses are contained in the *Plan Formulation Study Element Report.*

Only a brief summary of effects, derived from the review draft of this report, is presented here for the Balanced Plan. The substance of the Balanced Plan is reflected in the recommendations presented in the body of this final report.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
Domestic Water Supply Services		
• Accelerate major domestic developments to stay ahead of projected demands through the year 2000 for Oahu; Hilo and Kona HGA's on Hawaii; Lahaina, Wailuku and Makawao HGA's on Maui; and Lihue HGA on Kauai.		
* Hawaii: Develop basal ground water sources in Hilo and Kona hydrographic areas for respective local domestic needs.	Takes advantage of extensive basal water supplies of high quality.	Cost of development.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
* Maui: Develop basal ground water sources in Lahaina and Wailuku hydrographic areas for respective local needs; develop ground water sources and improve existing surface water source developments in the East Maui hydrographic area for transfer to Makawao HGA for domestic needs.	Assures continuing availability of ground water within Lahaina and Wailuku areas. Develops the most abundant water resources for use in East Maui.	Cost of development and transmission.
* Kauai: Develop ground water sources in Lihue and Koloa hydrographic areas for local domestic needs.	Takes advantage of undeveloped source of high quality water.	Cost of development.
* Oahu: Develop basal ground water island-wide and dike-confined ground water at Schofield.	Emphasizes high quality sources that can be developed with least environmental impact and treatment.	Cost of development and transmission.
• Intensify search for alternate potable water sources on Oahu for projected demands for the year 2000.		
* Bulkhead dikes in existing Koolau Mountain water development tunnels to restore about 30 mgd of high-level potable water.	Substantially increases wet-weather storage at low cost for dry-weather delivery.	
* Improve spacing of wells, control withdrawals, and centralize ground water management to increase yield of Honolulu and Pearl Harbor basal aquifers.	Could significantly increase available supplies, with minimum development costs.	Requires more government regulation and control.
* Blend water with high and low mineral content to increase supply of potable water.	A large volume of marginal quality water could be made suitable for domestic use at great savings.	Would reduce the overall quality of water delivered.
* Develop lower quality water (Pearl Harbor Springs, Waiawa and Waikele Streams, and effluent from Mililani and Honouliuli sewage treatment plants) and exchange for about 70 mgd of potable water presently used for sugarcane irrigation in the Ewa district.	Would make substantial quantities of potable water available for domestic use.	Transmission costs to deliver lower quality water to irrigation distribution system.
* Divert and impound streamflows island-wide, in particular about 30 mgd from Punaluu and Kahana Streams and Kalawao Springs.	Gravity flow from higher elevations minimizes energy expenditures for transmission and distribution.	May reduce downstream flows. Some treatment may be necessary.
• Intensify water conservation programs to improve efficiency of domestic water use.		
* Set water rates to discourage excessive use.	Conservation of resources; long-term savings to consumers.	Short-term increase in water cost. Possible reduction in operating revenues overall.
* Revise plumbing codes to require the installation of commercially available water-saving fixtures and appliances.	Savings in water and water delivery costs.	Cost of fixtures, installation.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
* Conduct aggressive public relations programs to encourage wise use.	Motivates voluntary conservation and resulting savings to consumers.	Cost of program.
* Operate water systems on sequential use schedules for optimum use of storage and pipeline capacities.	Allows storage and delivery of more water with the same facilities.	Initial cost of system programming.
* Institute effective program to control leaks from artesian wells and in transmission and distribution systems.	Prevents loss of ground water storage; reduces pumping and transmission costs.	Requires expenditures for additional inspection and maintenance personnel; also for replacement of marginal equipment.
• Improve rural domestic service to deliver adequate quantities of high quality water at sufficient pressure.		
* Improve source dependability by: (1) master planning and developing water sources by stages to meet incremental demands to year 2000; (2) obtainig legal control of surface and ground water sources; (3) converting systems from surface and ground water sources.	Improvement in service; long-term savings in delivery cost.	Cost of well development.
* Construct and operate water treatment plants to meet water quality standards and peak demands.	Increased safety.	Cost of plants.
* Improve distribution systems by: (1) replacing deteriorated storage, transmission, and distribution facilities; (2) integrating minor systems into larger systems where feasible; and (3) providing for fire fighting capability.	Increased service and safety.	None.
Domestic Wastewater Services		
• Reuse treated sewage effluent water of acceptable quality as a major new source of irrigation water.		
* Encourage new agricultural operations to locate near existing sewage treatment plants; and locate new plants near existing or suitable agricultural areas.	Great savings possible in source development and transmission systems.	None.
* Reuse treated effluent for other beneficial uses such as: (1) irrigating golf courses and parks; (2) industrial cooling; (3) recharge aquifers used for irrigation supply.	Conservation of water from other sources. Salvage of nutrient values.	Virtually none.
• Provide improved sewage disposal methods for rural communities located near fresh water supplies and along shorelines.		
* Require installation of "package" treatment systems or septic tanks or waterless systems.	Protects potable water sources; preserves the environment.	None.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Reduce sewage treatment costs by modification of standards.		
* Allow lower treatment level for deep ocean disposal or for underground injection into isolated saline aquifers.	Would allow treatment consistent with particular disposal conditions. Savings could be used to improve overall systems.	None.
Agricultural Production		
• Develop irrigation water supplies for projected water short areas of Makawao (Maui), Hoolehua (Molokai), and Koloa and Kekaha (Kauai).		
* Maui: Improve efficiency of existing surface water developments in the East Maui HGA for transfer to Makawao HGA.	Takes advantage of extensive transmission systems already in operation.	Cost of improvements.
* Molokai: Extend surface and ground water developments in the Pelekunu HGA for transfer to Hoolehua HGA.	Utilizes large supplies of high quality water presently undeveloped.	Cost of projects.
* Kauai: Improve efficiency of existing surface and ground water developments in Koloa and Kekaha HGA's.	Makes better use of existing systems.	Cost of improvements.
• Develop substantial irrigation water supply in the Hamakua (Hawaii), Lahaina (Maui), and Lihue (Kauai) HGA's.		
* Improve efficiency of existing surface and ground water source developments within the respective HGA's.	Emphasizes more efficient use of water to avoid new development.	None.
• Delineate and reserve prime agricultural land for crop production.		
* Establish a restricted agricultural subzone for prime agricultural land within the State's LUC agricultural district.	Avoids commitment of resources to other uses; would reduce speculation dependent upon upzoning.	Unavailability of some lands for urban or other uses.
* Provide low cost irrigation water for agricultural users.	Provides additional incentives for agricultural use.	Cost of providing water.
• Use more efficient methods for sugarcane irrigation and reduce transmission and storage losses.		
* Convert from furrow to drip or sprinkler irrigation where feasible.	Reduces loss of water to area between and below root zone. More productivity per acre. Water savings of 20-40 percent possible.	Costs of installing and operating systems, including special water treatment. Less infiltration recharge of ground water bodies.
* Reduce transmission losses and reservoir leakage.	Increases effective capacity of system.	Cost of maintenance.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Develop additional irrigation water up to the year 2000 to meet the needs of water-short hydrographic areas.		
* Increase yield of existing sources by: (1) more efficient stream diversions; and (2) optimized development of basal aquifers by new pump design, well spacing, and pumping schedules.	Allows cost advantages in developing more water from existing sources.	Improvement costs.
* Develop and use treated sewage effluent and slightly saline ground water.	Utilizes water and nutrients otherwise wasted. Improves quality of water discharged to environment.	Cost of delivery to point of use. Lack of uniform quality may make it unsuitable for certain crops.
* Divert additional streamflow where feasible.	Provides low-cost water at suitable elevations.	May have detrimental environmental effects downstream.
• Expand livestock water distribution systems for more productive use of grazing land.		
* Increase number and distribution of watering ponds on pasture lands at high elevations by: (1) developing water from rain catchments and fog drip; and (2) expanding distribution system.	Substantial increase in carrying capacity. Protection of cover on presently grazed land, by more uniform distribution of cattle.	Cost of systems development and maintenance.
Forest Production		
• Increase commercial forest production in selected watersheds.		
* Initiate detailed surveys of selected timber sites for long-range commercial production.	Opportunities for multiple use of watershed areas. Takes advantage of rapid growth and high demand for timber products.	Requires commitment of land to long-range production goals.
Commercial Fishing		
• Increase Hawaii's catch of skipjack tuna (aku) in the central and eastern Pacific Ocean.		
* Identify and protect primary baitfish (nehu) spawning grounds and continue research into development of a supplemental low cost and constant supply of baitfish.	Protection of nehu can also protect habitat for other species. Potential large increase of tuna catch.	None.
* Expand and improve harbor and support facilities.	Improved facilities can salvage more usable catch, increase fishing success.	Initial costs of program.
* Increase availability of low interest loans for vessel and equipment improvements.	Modernization and improvement of the tuna fleet.	Initial cost. Low interest long-term loans mean slow repayment to state.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Encourage development of aquaculture as a major industry.		
* Design and construct new fresh water ponds.	Economic growth. Potential use of water for agriculture.	Initial cost. Competition for water.
* Restore and use ancient Hawaiian fishponds for fish farming.	Multiple-use concepts possible; potential for accomplishing cultural and archaeological objectives.	Requires long-term commitment of resources.
* Stock and protect other suitable streams, bays, and estuaries.	Increased productivity of streams and bays.	Careful research and controls to preclude introduction of undesirable species.
* Provide technical and marketing support.	Establishes stable markets and technology for a growing industry.	Some net cost to taxpayers over increased revenues.
Industrial Output		
• Regulate the harvesting of precious coral resources to ensure sustained yield.		
* Manage the precious coral harvest to ensure a sustained yield.	Protects marine environment. Assures a continuing supply of raw materials.	Cost of regulation. High cost of equipment for harvesting by approved methods.
• Develop the potential for mining offshore sand deposits to supply the construction industry and replenish beaches.		
* Continue research in developing mining technology suitable for Hawaii conditions.	Technology may also have application to other marine resources.	Cost of research.
* Establish rules and regulations for offshore sand resource management.	Protects nearshore environment; decreases impact of land mining operations.	Cost of administering regulations.
• Maintain an aggressive role for Hawaii in developing the potential for mining and processing mid-Pacific ferromanganese deposits.		
* Formulate a long-range development plan specifying detailed economic and environmental impacts on Hawaii, shore support facilities, and water and land requirements.	Potential billion-dollar-a-year industry for Hawaii. Avoids depletion of land deposits and environmental impacts of land mining.	Potentially great demands on land and water resources. Impact on marine environment not quantified.
Energy Production		
• Develop hydroelectric power to provide a substantial portion of the energy needs of Kauai and Molokai and to supply small, isolated communities on Maui and Hawaii.		
* Improve efficiency of existing hydroelectric plants.	Allows increased production with little or no environmental impact.	Cost of improvements.
* Conduct feasibility studies of potential sites for development of new hydroelectric plants.	Takes advantage of a renewable source of energy. Multiple-use projects possible.	May require construction of dams and power plants; inundation of watershed areas.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Develop geothermal energy as a major power source on Hawaii and as a supplemental source on Oahu and Maui.		
* Continue geothermal exploration on Hawaii and expand to Oahu and Maui.	Important source of energy to reduce dependence on fossil fuels.	Cost of development; some minor environmental impacts such as noise and gas emissions.
• Assess the potential of ocean thermal energy conversion (OTEC).		
* Establish pilot project at Keahole, Hawaii.	Deep ocean waters near shore make conditions ideal for testing OTEC. Nutrient-laden cold waters could benefit fisheries or aquaculture operations.	Cost of pilot plant construction.
Flood-Free Lands		
• Reduce loss of life and property damage caused by storm flooding.		
* Provide protection to existing urban and rural communities from storm flood losses by structural measures such as dams, lined channels, and flood proofing. (See Figure 35 and Table 18.)	Only feasible alternative for protecting existing communities.	Cost of protection must be borne by taxpayers.
* Counties regulate use of flood hazard areas by land use zoning in urban, rural, and agricultural districts; State regulate use of conservation districts.	Decreases public cost of flood protection. Avoids commitment of flood plains.	May increase cost of housing and other developments.
* Provide flood insurance protection to households located in flood hazard areas.	Transfers cost from public to actual users of flood hazard areas.	Increases cost of housing.
* Accelerate detailed mapping of flood hazard areas to better implement structural measures, zoning, and flood insurance program.	Provides basic information to determine best means of flood protection.	Cost of data collection and interpretation.
• Reduce loss of life and property damage caused by tsunami and high surf.		
* Regulate coastal development in areas subject to tsunami and high surf flooding. (See Figure 35 and Tables 19 and 20.)	Most effective way of reducing life and property losses.	Limits land available for development; increases cost of available land.
* Provide structural measures where necessary.	Protects developed areas or particularly desirable coastal areas.	Cost of protective structures.
• Improve local flash flood forecasting and warning systems.		
* Use federal and state programs to obtain advanced equipment to forecast local storm conditions which may result in flash floods.	Protects lives and property in areas subject to flash flooding.	

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Evaluate the safety of dams with high or significant hazard potential as determined by federal criteria.		
* Evaluate the structural stability of potentially hazardous dams inventoried under federal guidelines. (See Figure 36 and Table 21.)	Protects lives and property downstream.	Cost of inspection and needed maintenance.
• Inventory and determine hazard potential of dams with a capacity less than federal criteria.		
* Inventory and evaluate structural stability of potentially hazardous smaller dams not considered under federal guidelines.	Identifies dams not covered under PL 92-367.	Cost of inventory.
* Develop a continuing inspection program under existing flood control and prevention programs.	Protects lives and property downstream.	Cost of program.
Stabilized Lands		
• Reduce erosion of cultivated land and unforested open land.		
* Enhance programs to control severe inland erosion occurring on all islands. (See Figure 43 and Table 34.)	Increases the value of land for beneficial use. Protects downstream areas from sediment pollution.	Cost of programs.
* Apply land treatment practices to sugar and pineapple croplands.	Reduces loss of topsoil. Protects streams and coastal waters.	Cost of programs. Possible loss of planting and harvesting efficiency.
• Reduce critical erosion along 31 miles of shoreline.		
* Restore by replenishing sand or protect by constructing sea walls and revetments. (See Figure 43 and Table 35.)	Protects valuable beaches and shoreline property.	Cost of program. Careful design necessary to avoid possible environmental impacts.
• Reduce sedimentation of major streams, bays, estuaries, harbors, and coastal wetlands at 13 locations throughout the state.		
* Enforce regulations to control: (1) agricultural land use practices; and (2) construction activities in urban areas.	Reduces cost of dredging. Preservation of environmental and aesthetic values; protection of wildlife.	Cost of installation and enforcement. Some possible loss of efficiency in operations.
* Construct sediment basins and bypass canals.	Sediment is deposited under controlled conditions for efficient dredging, or bypassed around critical areas.	Cost of construction and maintenance. Possible environmental effects.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
Marine Transportation		
• Improve navigability and harbor facilities for transocean shipping at Hilo, Kawaihae, Kahului, Honolulu, and Nawiliwili Harbors.		
* Improve navigability of Hilo, Kahului, Honolulu, and Nawiliwili harbors.	Improves efficiency and range of ships accommodated.	Cost of dredging and other improvements.
* Increase cargo storage and handling facilities at Hilo, Kahului, Kaunakakai, Honolulu, and Nawiliwili harbors.	Improves service between the major islands. Decreases shipping costs.	Cost of expansion. Impact on land use of adjacent areas.
* Develop second deep draft harbor on Oahu at Barbers Point.	Reduces congestion of Honolulu Harbor area; allows industrial expansion on Oahu.	Commitment of land and coastal area.
* Investigate feasibility of developing a deep draft harbor at Kaunakakai.	Improves opportunities for industry and agriculture on Molokai.	Cost of dredging and facilities. Possible environmental and cultural impacts.
• Improve inter-island marine commuter services linking six major islands.		
* Continue to investigate methods of improving surface transportation links between islands for cargo, vehicles, and people.	Increases options for inter-island transportation. Enhances economic, social, and cultural integration of the state.	Cost of providing new modes. Possible social disruption caused by freer movement of vehicles and people.
• Improve and expand marine commuter services to downtown Honolulu from Hawaii Kai, Pearl Harbor, Ewa Beach, Barbers Point, and Waianae.		
* Expand marine commuter services on Oahu to supplement overland systems.	Increases options for commuter services to Honolulu. Can complement other modes.	Cost of vessels and docking facilities.
Water Related Recreation		
• Improve access to shoreline and inland recreational areas.		
* Acquire in fee or lease public rights-of-way to recreational areas by: (1) conducting site surveys, including assessment of the cost of land and support facilities; and (2) providing personal safety and maintenance services over access routes. (See Figure 37 and Table 22.)	Makes large areas of public beaches and watersheds available for public use.	Cost of acquisition, patrolling, and maintenance. May conflict with other uses. Some danger of watershed degradation and abuse of private property rights.
• Reserve sufficient shoreline for future public use.		
* Acquire in fee or lease desirable shore areas for public use.	Assures future public use of desirable beaches and shore areas.	Cost of acquisition.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Provide additional marine parks.		
* Establish additional marine parks by: (1) designating areas; (2) developing support facilities; and (3) providing for adequate surveillance and maintenance services. (See Figure 38 and Table 25.)	Provides areas for observation of protected marine plants and animals.	Cost of establishing and maintaining parks.
• Reserve prime surf sites.		
* Designate by legal authority prime surf sites and provide support facilities and maintenance services. (See Figure 38 and Table 26.)	Assures continuing availability of sites for a sport originated in Hawaii.	Possible conflicts with other uses and abuse of private property rights.
• Provide adequate facilities for recreational boating.		
* Develop additional small boat harbors and support facilities. (See Figure 39 and Tables 27 and 29.)	Provides appropriate facilities and services for residents and visitors.	Commitment of both water and land areas for permanent facilities. Environmental impacts on coastal water.
* Develop additional boat launching ramps and support facilities. (See Figure 39 and Tables 28 and 30.)	Provides access for a large segment of the boat-owning public.	Requires land for packing and launching. Some alteration of reefs and channels.
• Provide additional parks and camp grounds in watershed areas.		
* Expand and develop additional parks by: (1) acquisition of property; and (2) formulating development plans. (See Figure 40.)	Increases the variety of recreational experience available.	Cost of program. Possible environmental impacts.
• Improve hiking opportunities in watershed areas.		
* Rehabilitate and maintain hiking trails and provide adequate access and support facilities. (See Figure 40.)	Improves access to inland areas; provides increased safety.	Cost of program. Possible environmental impacts.
• Enhance hunting opportunities in watershed areas.		
* Increase controlled hunting in selected watershed areas.	Provides additional recreational hunting. Reduces damage caused by overpopulation of animals.	Possible hazard to potable water supplies.
• Enhance fresh water recreational fishing and swimming opportunities.		
* Maintain minimum flows in selected streams and improve existing reservoirs to increase recreational fishing and swimming opportunities.	Provides additional recreational opportunities. Improves aquatic environment.	Reservation of water may affect other beneficial uses.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
Ground Water Quality		
• Prevent salt water intrusion into basal fresh water aquifers.		
* Design and space wells to prevent excessive drawdown and upconing.	Assures maximum safe yield of water. Minimizes degradation of quality.	Requires increased authority over withdrawals. Higher initial cost of wells and distribution systems.
* Regulate pumpage to minimize fluctuations and avoid thinning of the basal lens.	Protects water quality. Provides for maximum safe use of water.	Requires additional central authority over systems operation. Less water to users from existing wells.
* Increase infiltration of fresh water to recharge the basal lens.	Salvages water otherwise lost to the sea. Increases fresh water storage in the lens.	Hazard of water quality degradation if not carefully controlled. Ownership questions arise. Cost of energy for recharge facilities.
• Regulate subsurface injection of wastewater.		
* Strengthen licensing and monitoring of injection wells, including treatment of injected wastes.	Protects water quality. Might also increase hydrologic knowledge.	Cost of regulation and monitoring.
* Restrict wastewater injection to geologically isolated saline aquifers.	Protects water quality. May serve as an inexpensive method of wastewater disposal.	
• Regulate the use of cesspools, seepage pits and solid waste dumps which might contaminate ground water.		
* Replace cesspools with sewers or other suitable systems.	Reduces pollution hazard to ground water sources.	Cost of systems and maintenance.
* Require treatment of all water disposed of in seepage pits.	Reduces both surface and ground water pollution hazard. Increases effective life of pits.	Cost of treatment.
* Allow solid waste disposal only where leachates will not pose a hazard to ground water.	Reduces pollution hazard.	None.
Coastal Water Quality		
• Reduce non-point source discharges.		
* Improve control over such non-point sources as sediment, cesspool seepage, and urban storm drainage.	Reduces pollution of nearshore coastal water.	Cost of control systems.
• Reduce the potential hazard to the environment of a major oil spill.		
* Improve readiness of personnel and equipment to enforce navigation and safety regulations and to contain a major spill.	Protects marine habitats and recreation areas.	None.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Revise receiving water standards for Hawaii to assure realistic goals.		
* Determine on a case-by-case basis whether receiving water classes and water quality discharge standards are realistic.	Saves substantial sums of money and resources required for advanced treatment facilities.	Monitoring needed to assure no environmental degradation.
Surface Water Quality		
• Reduce non-point source discharges.		
* Control feral animal populations to minimize pollution to surface water and to improve vegetal cover in watershed areas.	Reduces non-point source pollution in streams.	None.
* Enforce sanitary conditions and good drainage in streams and canals.	Eliminates a major source of pollution to streams and coastal waters.	Cost of enforcing program.
Land Quality		
• Preserve and enhance the quality of forests and open lands.		
* Prevent and control forest diseases, insect damage, and the spread of noxious plants within watershed areas.	Improves quality and abundance of forest products. Ensures future quality of forests.	Cost of programs.
* Control erosion by establishing and maintaining adequate vegetation, installation of structures, and control of grazing and rooting animals.	Reduces sediment pollution of streams and coastal areas.	Cost of programs.
• Preserve and enhance agricultural land quality.		
* Reduce erosion of cropland by applying appropriate conservation measures, and by ensuring cover on abandoned or fallow fields.	Reduces sediment loads in streams. Improves aesthetic quality of land.	Cost of programs.
* Control grazing on pasture lands.	Improves long-term productivity. Protects aesthetic values.	None.
• Enhance the quality of urban land and ground transportation corridors.		
* Establish vegetative cover on exposed road cuts and fills; use structural measures where needed.	Preserves aesthetic quality along highways. Protects downstream areas from sedimentation.	Additional cost.
• Preserve and enhance wetlands, shorelines, and submerged lands.		
* Enforce erosion control ordinance on all new construction.	Protects downstream areas from accelerated sedimentation. Preserves quality of urban areas.	Cost of control measures.
* Ensure adequate water circulation in bays, estuaries, and wetlands by maintenance of channels and minimum streamflows.	Protects quality of wetlands and coastal water.	None.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
* Protect wetlands and submerged lands from excessive sedimentation and erosion.	Assures the continued survival of wetlands for wildlife and recreational values.	None.
<u>Biological, Cultural, and Geological Resources</u>		
• Preserve habitats for rare and endangered animals and plants.		
* Establish natural area reserves where rare and endangered plants and animals are a significant part of the ecosystem.	Assures maintenance of pristine state for continued survival of species.	Withdrawal of land from other possible uses.
* Establish wildlife and plant sanctuaries in critical areas.	Provides areas especially suitable for survival of species.	Cost of establishing or preserving proper conditions. Precludes other activities in areas.
* Manage native forests to protect and preserve rare and endangered species.	Provides large habitats for survival.	Limits other activities within forests.
* Create new habitat as part of water development and storage projects.	Expands the areas suitable for species survival. Serves multiple-purpose.	May add to the cost of projects.
• Preserve unique coastal and terrestrial ecosystems.		
* Identify unique natural ecosystems and protect as Natural Area Reserves or Marine Life Conservation Districts.	Preserves unique combinations of plants and animals and their environment. May combine with protection of rare and endangered species.	Requires withdrawal of land and water from other uses.
* Establish buffer zones around unique natural ecosystems to minimize potential harmful impacts.	Protects the ecosystem from damaging effects of outside influences.	Requires the commitment of larger land areas.
* Maintain low flow in perennial streams to protect relatively undisturbed ecosystems.	Preserves entire aquatic systems.	May preclude water development for other uses.
* Protect coastal ecosystems from excessive fresh water flood flows.	Preserves areas that may be lost because of man-induced changes.	Cost of flood protection measures.
* Protect seabird nesting sites, especially offshore islands.	Perpetuates seabird population.	Loss of other recreational uses.
* Increase forest fire prevention, detection, and suppression capabilities to protect forest habitats.	Assures continued survival of unique systems.	Cost of protective measures.
* Manage and protect coral reef ecosystems.	Protects living organisms, their habitat, and adjacent shorelines.	Restricts other activities.
* Protect and enhance stands of native trees and plants.	Assures continuing survival of native species on a meaningful scale.	Limits other land uses.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Protect and enhance fish and wildlife habitat.		
* Protect those values of water in perennial streams, lakes, and reservoirs essential to fish and game survival.	Assures low flows adequate to sustain aquatic associated fish and game.	May preclude use of water for other beneficial purposes.
* Improve hunter access to areas overpopulated by game animals.	Increases hunting opportunities; reduces damage to habitats.	Increases risk of pollution and introduction of undesirable plants.
• Restore and protect selected ancient Hawaiian fishponds.		
* Prevent destruction of all fishponds suitable for listing on National Register of Historic Places.	Assures opportunity for future preservation or rehabilitation of ponds.	Requires acquisition or protection from other uses.
* Manage tributary lands to minimize loads of sediment and other pollutants.	Reduces pollution problems at the source.	Cost of management programs.
* Restore selected ponds and operate either in the ancient Hawaiian manner or as a modern aquaculture operation.	Serves educational and cultural appreciation purposes. May also be economically feasible.	Initial cost of program.
• Restore and protect ancient and historic irrigation systems, including wells and tunnels.		
* Locate, protect, and restore examples of pre-Cook irrigation systems.	Preserves culturally important part of Hawaii's past.	Cost of program.
* Locate, protect, and appropriately mark pioneer water systems of the sugar industry, including various types of wells and shafts, tunnels, and ditches.	Assures preservation of historically significant sites for educational and industrial promotion purposes.	Cost of acquiring and preserving facilities.
• Protect unique natural lakes and waterways from degradation or alteration.		
* Survey and select candidates for special protection, based upon unique characteristics.	Assures appropriate attention and protection.	None.
* Reduce the quantity of sediment and floating debris from streams and urban areas.	Complements other land and water quality objectives.	None.
Aesthetic Values		
• Protect physical and visual access to beaches, shorelines, offshore islands, and the ocean.		
* Control density and height of buildings on seaward side of coastal highways.	Avoids degradation of visual values.	Limits the options for development along scenic coastlines.
* Protect offshore islands.	Preserves aesthetic and environmental values.	Limits economic uses of the islands.

• PLANNING OBJECTIVES & * SPECIFIC ACTIONS	EFFECTS OF SPECIFIC ACTIONS	
	BENEFICIAL	ADVERSE
• Protect and provide visual access to open spaces, including mountains and wilderness areas.		
* Protect forest vegetation, and restore vegetation to eroded areas.	Provides soil protection and preserves beauty and value of land and water.	Cost of programs.
* Provide and maintain access to viewing sites.	Provides for human enjoyment of scenic areas.	Cost of establishing and maintaining viewing sites.
* Develop and maintain a system of trails and facilities for on-site enjoyment where appropriate.	Provides recreation as well as protecting scenic and environmental values.	Some risk of degradation resulting from on-site use.
• Protect the beauty of waterfalls and scenic streams, rivers, lakes, and reservoirs.		
* Preserve visual access to scenic water areas.	Allows beneficial use.	None.
* Maintain flow or water levels to protect the beauty of water scenes.	Protects aesthetic and environmental values.	Loss of competing beneficial uses.
* Prevent unsightly and damaging encroachments on scenic water areas.	Protects aesthetic and environmental values.	None.

B. ENVIRONMENTAL IMPACT STATEMENT

Introduction

Responsible Agency. Hawaii Water Resources Regional Study, Honolulu, Hawaii.

Type of Action. Administrative.

The Action to Date. The Hawaii Water Resources Regional Study is hereby submitting to the U.S. Water Resources Council for transmittal to the President and by him to the Congress, a comprehensive *Hawaii Water Resources Plan* for the conservation, management, and use of water and water related land resources in the Hawaii Region. The region lies entirely within the State of Hawaii and, for hydrologic purposes, is divided into nine subregions. See Figure 4.

This Plan is based on comprehensive studies conducted by sixteen interagency teams. See Figure 1. Its emphasis is on coordination of the efforts of all public and private agencies having water resources interests in the Hawaii Region. Alternative actions were considerd and recommendations have been made for major concerns in the following areas:

A. National Economic Development
   1. Public services.
   2. Food and fiber production.
   3. Industrial output.
   4. Energy production.
   5. Land productivity.
   6. Transportation services.
   7. Recreational opportunities.

B. Environmental Quality
   1. Water quality.
   2. Land quality.
   3. Biological resources.
   4. Cultural resources.
   5. Aesthetic values.

Environmental Impact Analysis. The impacts of recommended actions on one or more of the environmental quality concerns were analyzed in the process of effects assessment. Both beneficial and adverse impacts were evaluated.

Review drafts of all study element reports were provided to state, federal, and county agencies, the governor, mayors, legislators, and county councils. Public meetings were conducted on three occasions throughout the state to review drafts of this plan and solicit comments. Summaries of these comments, included in the *Public Participation and Information Study Element Report,* were considered in preparing this final plan.

The Proposed Action. The proposed action is the implementation of this plan. The plan fully considers state and county land use plans and single-purpose water and wastewater plans. The impacts discussed in this assessment are those that can be attributed to specific recommendations contained in this report.

Net environmental impacts of the plan are strongly beneficial. Where adverse impacts were anticipated, the action recommended is that with the least adverse environmental impact.

Environmental Impacts of Plan Implementation

Domestic Water Supply. This plan includes water development to meet desired growth levels as expressed in state and county plans, with a minimum of adverse environmental effects.

Ground water is recommended as a preferred source of domestic water. Development of ground water requires a minimum of surface facilities. However, it does require a greater use of energy than surface water and thus has secondary impacts upon energy production. The general impact of ground wate management facilities is discussed in *Water Supply Study Element Report,* Appendix A-6.

When ground water occurs in a basal lens, its development causes no depletion of streamflow. Lateral flow to the ocean through the lens, which ranges from about 1 to 100 mgd per mile of shoreline, is depleted only to the extent of pumpage. Due to the large volume of ocean water mixing with fresh water and the relatively steep topography of the island mountain masses, development of basal ground water has no significant environmental effect upon coastal waters except for rare instances and in localized areas.

Development of ground water impounded in a dike system or perched on an impervious formation causes depletion of the streamflow through at least a portion of the downstream channel. Although percolation of streamflow to ground water is usually high, the effects are so variable that they cannot be generalized.

Surface water is usually developed in Hawaii by diverting streamflow rather than by major impoundments. Surface water supplies are likely to require a higher level of treatment than ground water and therefore larger treatment facilities.

Local on-site environmental effects of diversions are minimal. Downstream, the difference betwen high and low flows is magnified,

since a larger percent of low flows is diverted. See *Water Supply Study Element Report*, Appendix A-5.

It appears unlikely that any major impoundments principally for domestic water supply will ever be developed in Hawaii. However, domestic water supply would likely be a minor part of the few potential multi-purpose impoundments that tentatively appear feasible.

The reuse of treated wastewater would be environmentally beneficial because of reduced source development. The necessary additional treatment facilities would have local environmental impact.

Other techniques for augmenting domestic water supply include:

1. More efficient or restricted use of available supplies. More efficient use is desirable from all environmental viewpoints. Restricted use, when necessary, is likely to have undesirable environmental impacts such as the consequences of limitations upon watering of lawns.

2. Watershed management. Source supply and quality can be augmented by increasing, decreasing, or modifying the character of the vegetation in watersheds. Mechanical structures to catch fog and rain may have local application and impacts.

3. Diverting water from agricultural use to domestic use. Unless replaced by wastewater supplies, this would degrade environmental quality to the extent that it resulted in a loss of agricultural land as open space.

4. New technology for water transmission. Impacts must necessarily be considered on an individual basis.

5. Desalting brackish ground water. The principal impacts on the environment are the plant itself and the disposal of brine wastes. Desalting presently requires high energy consumption.

Domestic Wastewater. Centralized wastewater collection, treatment, and disposal facilities for urban areas have well recognized local impacts. Development of the collection system results in temporary impacts wherever sewers are installed. The impacts of treated wastewater disposal vary with the extent of reuse. Ultimate disposal of solid waste residues from the water eliminates the chance of pollutants percolating to ground water or later flow to surface streams or coastal waters.

Agricultural Production. Reservation of prime agricultural land for crop production maintains open space values. Sediment yield is greater from crop use than from uncultivated land with permanent cover. Burning of crop residue creates a temporary but locally significant air pollution problem.

The environmental impacts of water source development and transmission facilities are generally the same as for urban supplies. More efficient use of irrigation water will reduce the quantity of ground water recharge. Recreational use of agricultural water storage facilities creates fewer health hazards than with multiple use of domestic water storage facilities. Better distribution of stock water will encourage less intensive use of some areas now being overgrazed.

Commercial Fishing. An enlarged and more efficient fleet will have those impacts resulting from increased harbor capacity and processing facilities.

Fishing access to the waters of the Northwestern Hawaiian Islands might create hazards to the Hawaiian Islands National Wildlife Refuge. Improvements in the catch of shoreline fishermen will result in greater coastal activity.

Use of existing fishponds for aquaculture would maintain these valuable cultural and open space assets.

Forest Production. Management practices such as pruning and thinning have locally limited environmental impacts. The introduction of exotic species adds variety to the landscape but may replace species which are habitat for native wildlife. Increasing forest acreage will enhance aesthetic valus and reduce runoff and erosion.

Industrial Water Supply. Increased internal recycling of industrial water supplies will reduce the discharge of wastes and the need for new supplies. Integration of systems so that discharged water from one industry is of suitable quality to supply another industry will preserve fresh water sources. Maximum use of brackish water for industrial purposes will also preserve fresh water sources.

Deep Ocean Mining. The environmental impacts of deep ocean mining of ferromanganese nodules will depend on the role Hawaii plays. If Hawaii is a supply center, increased shipping and harbor facilities will be required. If refining and trans-shipment facilities should be established, industrial wastes must be disposed of without harm to the environment. Smelting would require more land and produce more wastes. Large amounts of electric power would be required for processing.

Energy Production. Modernizing existing hydroelectric plants will have negligible impact. Enlarging existing plants and developing new hydropower plants will have significant local and off-site impacts related to construction, reservoir land requirements, streamflow control, multi-purpose aspects, power transmission, and power use (compared to alternatives).

Facilities for the development of geother-

mal energy resources will have local on-site impacts but will lkely be more favorably located than facilities utilizing fossil fuel. Transmission lines will necessarly traverse from the source to urban centers.

The effects of ocean thermal energy conversion are unknown, since no power plant of this type has ever been built.

Flood Damage Reduction. The emphasis in this plan is on those actions which can be taken now to prevent future flood damage. Presently undevelopd flood plains can be retained as open space. Free flowing streams can be maintained with the attendant environmental benefits. Sediment which settles in the flood plain does not reach coastal waters. Watershed management practices upstream can reduce flood flows and the sediment they carry.

Protection of developed flood plains may take a variety of forms. Flood warning systems may prevent loss of life and reduce damage where flood proofing has been accomplished. Despite their environmental impact, structural measures are necessary to protect life and property in some instances.

Erosion Control. An aim of this plan is to reduce loss of coastal lands by shoreline erosion. Nonstructural controls, where applicable, have beneficial environmental effects. Required structural controls have visual impacts and disrupt the coastal ecosystem.

On agricultural and conservation land, the environmental impacts of land treatment practices are generally positive. Structures can usually be small and unobstrusive. Erosion control prevents off-site environmental damage by reducing sedimentation of bays, estuaries, harbors, and coastal wetlands.

Forest management to reduce erosion has largely positive impacts. Exotic species may be required in some instances to establish adequate erosion control.

The environmental benefits of protecting urban lands from erosion include reduced sedimentation of streams and coastal waters and beautification of the urban environment.

Sediment control structures, when necessary, will have local environmental impacts during and after construction.

Marine Transportation. Improvement of harbors and enlargement of cargo handling facilities will require use of coastal land.

A new harbor at Barbers Point will require a major commitment of coastal land and water. Necessary dredging will have a direct impact on coastal water ecosystems.

Recreational Opportunities. Coastal recreational facilities such as beach parks maintain open space and provide cultural values. Facilities such as small boat harbors and launching ramps require construction along the shoreline and a disruption of the coastal water ecosystems. Other park related facilities cause only a minor local impact.

Water related inland recreational facilities for daytime use will have only a minor impact. Facilities for intensive camping will have localized impacts depending on their size and nature. Hiking, fishing, and hunting have no significant environmental impacts.

Water Quality. Actions to prevent contamination of ground water from percolating contaminants such as cesspool seepage will result in impacts associated with construction and operation of collection and treatment facilities. Actions to prevent salt water intrusion should not have significant surface environmental effects.

Elimination of point source discharges into coastal water will also result in the environmental impacts associated with construction and operation of collection and treatment facilities. Disposal of treated wastes through deep ocean outfalls will affect ocean ecosystems at the outfall points. Land disposal of treated wastes may improve open space through irrigation of agricultural or forest crops and recreational areas such as parks and golf courses.

The reduction of non-point sources of pollution will have beneficial environmental effects. Structures needed to collect sediment-laden or other polluted storm waters will have local impacts. Land use controls and vegetation management will maintain the quality of open space.

Actions taken to protect coastal water quality will also improve the quality of streamflow and other surface water.

Land Quality. All actions taken to enhance land quality will have beneficial environmental impacts. Some minor adverse impacts will occasionally occur due to necessary management actions. Small structures may be required in some instances.

Biological Resources. Protection of habitat for rare and endangered species may require fencing and posting of signs and the consequential localized impacts. Management of surrounding areas may require vegetation modification for control of fire, insects, disease, or exotic plants. Restorative management, such as the removal of exotic plants, will have only minimal impacts. Restricted public access will be an adverse impact from the recreational perspective.

Management actions taken in plant and wildlife sanctuaries will likely be more intensive than habitat protection, since the focus will be on one or more species rather than a biological system.

Refuges for rare and endangered waterbird species require the greatest management care, due to the emphasis on one or more specific characteristics of the habitat. Facilities necessary for water level control such as water diversions, dikes, pumps, etc., will affect downstream flows. Specific food plants might be introduced and undesirable plants removed.

Too little is known about the ecosystems of fresh water streams to be specific about impacts. However, it is recognized that they are generally in dynamic balance with the flow regime of the stream. Any change in that regime, such as diversion of low flows or prevention of flood flows, will affect the ecosystems.

Cultural Resources. All actions taken to restore and protect fishponds, ancient Hawaiian irrigation systems, and historic water development facilities will have beneficial environmental impacts. Local adverse effects will occur where protective enclosures or facilities for public appreciation of the site are installed.

Aesthetic Values. All actions taken to protect open space are considered to have beneficial environmental impacts. Local adverse effects will be required for protection and management.

Alternatives to Proposed Actions

The basic theme of the more than 100 specific recommendations set forth in this plan is the coordination of water resources planning. The alternative is to continue the historic pattern of single-objective projects to fulfill immediate needs. The demonstrated inadequacy of this approach was one of the principal reasons for the Water Resources Planning Act of 1965.

The many alternatives within the proposed plan establish a flexible framework within which future needs and desires may be accommodated. In the process of selecting the recommendations, many other alternatives were considered. A brief summary of these follows.

Domestic Water Supply. The need for additional domestic water supplies could be reduced by closely controlling population growth or dispersing the population to underpopulated areas. Although these measures might have future application, it is presently unclear how the high degree of control needed to implement such a policy could be exercised within our free society. Encouraging population dispersion would tend to transfer the same problems to another area.

Desalting of seawater is an expensive technique for obtaining fresh water. It also requires high energy consumption and creates environmental problems of brine and salt disposal.

Agricultural Production. A basic assumption of this plan is that irrigated sugarcane production will continue at about the present level. Reduction in sugarcane acreage would make large quantities of water available for other uses, but at a high cost to the economy and the environment. Although the plan endorses expansion of diversified agriculture, no combination of crops could usefully employ all the land now devoted to sugarcane. Pressure would increase for urban and industrial use of idle lands.

Flood Damage Reduction. This plan emphasizes flood plain zoning and flood proofing as means of preventing future damages. In areas already developed, flood control projects represent the most desirable alternatives, especially concerning the environmental impact of relocation to flood-free lands.

Erosion Control. Non-structural controls are generally preferred to large structures because of the visual impacts, the nature of Hawaii soils, and high land values.

Marine Transportation. An alternative for deep water ports would be to reduce the number and limit direct calls primarily to four locations within the state. The environmental gains thus achieved would be more than offset by the consequently increased traffic and highway network.

Recreational Opportunities. Public acquisition of virtually all beachfront acreage and its preservation as open space was rejected as inordinately expensive and unrealistic.

The construction of small boat harbors to accommodate all boaters was considered. However, a combination of harbors and launching facilities requiring less commitment of shore area is recommended.

Watersheds would receive maximum environmental protection under a *kapu* system forbidding all human activity. This plan recommends controlled activity in these areas to reduce the damage caused by feral animals, provide access for better fire and disease protection, and to reduce the recreation pressure on adjacent areas.

Water Quality. An alternative plan for treating both urban storm runoff and sewage before release was rejected as being prohibitively expensive.

Land Quality. Reduction in erosion could be accomplished without structural measures by stringent application of land use controls to prohibit all soil-disturbing activities. Such a plan would virtually eliminate urban expansion and add greatly to the cost of agricultural operations; therefore, a combination of cover and structural measures is recommended.

Relationship Between Short-term Uses and Long-term Productivity

This plan stresses those actions which favor long-term productivity of the land and, through coordination of programs, would tend to discourage short-term commitments that might preclude other beneficial uses at a later time.

Emphasis in this plan is on maintenance of open space, reservation of prime agricultural lands, conservation of water and related land resources, and development of public lands for recreational purposes. Reclamation of wastewater for beneficial purposes will save on long-term investments for development of water sources, treatment plants, fertilizer, and additional electrical power.

Erosion control measures will help preserve the fertility of soils, as well as protect bays and wetlands from siltation.

The emphasis on preservation of rare and endangered species and the establishment of marine parks and sanctuaries assures the survival of genetically unique species for the enlightment of future generations.

Irreversible Commitments of Resources

Because this plan emphasizes the development of ground water for domestic use, irreversible commitments of resources are limited to a few areas where the use of building materials for the construction and fossil fuels for the operation of water development projects may be required.

C. RESPONSE TO REVIEW DRAFT

A series of 19 public meetings was held on the six major islands over a 90-day period to receive comments on the review draft of this report. Copies were also distributed to agencies at all levels of government and to private organizations concerned. Those agencies responding with written comments during the 90-day review period include the following.

Federal Agencies

Department of Agriculture
- Economic Research Service
- Farmers Home Administration
- Forest Service
- Soil Conservation Service

Department of Air Force
- Pacific Air Forces

Department of Army
- Corps of Engineers, Honolulu District

Department of Commerce
- Maritime Administration
- National Oceanic and Atmospheric Administration

Department of Health, Education, and Welfare

Department of Interior
- Bureau of Outdoor Recreation
- Bureau of Reclamation
- Fish and Wildlife Service
- Geological Survey

Department of Transportation
- Federal Highway Administration
- U.S. Coast Guard

Federal Power Commission

State Agencies

Governor, State of Hawaii

Department of Land and Natural Resources

Department of Planning and Economic Development

Department of Transportation

Office of Environmental Quality Control

University of Hawaii
- Water Resources Research Center

County Agencies

City and County of Honolulu
- Board of Water Supply
- Department of Public Works
- Department of Transportation Services

County of Maui
- Department of Economic Development
- Department of Planning

Private Organizations and Citizens

Amfac Communities-Hawaii, Honolulu, Hawaii

Hawaii Sugar Planters Association, Honolulu, Hawaii

Hawaiian Historical Society, Honolulu, Hawaii

Koele Company, Lanai City, Lanai

Lanihau Corporation, Honolulu, Hawaii

Frank E. Midkiff, Honolulu, Hawaii

Waipahu Community Association, Waipahu, Hawaii

Many favorable comments were received, generally endorsing the review draft as a commendable first attempt at a comprehensive water plan for Hawaii. Highlights of those comments suggesting improvements, which have been accommodated to the extent practicable in this final report, are summarized below.

1. *Study scope.* Site specific environmental and economic trade-offs were not adequately considered. Comprehensive treatment deemphasized major water supply issues. Fish and wildlife and energy demands were not sufficiently emphasized.

2. *Projections.* The State's growth management programs have generally lowered forecasts of the rate and total growth in population and economic activity levels for the mid-term period of 1990–2000 below those used for this plan.

3. *Plan formulation process.* The Balanced Plan represents a composite of two separate prior plans: the National Economic Development Plan and the Environmental Quality Plan. Another approach, better suited for project analysis, might have been used to resolve conflicts and demonstrate trade-offs.

4. *Report format.* Exposition of the planning process, although helpful in review of the plan, should be deemphasized in the final report.

5. *Relationship to Hawaii State Plan.* The timing of this plan is out of sequence with the Hawaii State Plan. The latter should provide policy directions. This plan should be considered the initial phase of the state functional plan on water resources development. Additional Level C projects should be included to meet the functional plan requirements.

6. *Composition of proposed HWRIC.* Suggested membership is to heavily government oriented. More private interests and water consumers should be represented.

D. GLOSSARY

Acre-foot — the quantity of water required to cover 1 acre to a depth of 1 foot; equal to 43,560 cubic feet, or 325,851 gallons.

Agricultural district — an area designated under the Land Act for agricultural use, the minimum size lot varying from one acre (Oahu) to five acres (Hawaii).

Ahupuaa — an ancient Hawaiian land division, often wedge-shaped and extending from the mountains to the sea, administerd by a chief.

Aku — skipjack tuna, a species of open-ocean schooling fish of commercial importance in the Pacific.

Alternative futures — a range of different future economic, social, and demographic patterns of development, each depending on a different set of assumptions with respect to public policies, lifestyles, patterns of consumption, etc., and any one of which might materialize. Contrasts with a single projection of future population, production, water requirements, etc.

Aquifer — a saturated underground body of rock or similar material capable of storing water and transmitting it to wells or springs.

Assimilative capacity — the ability of bodies of water to purify themselves after absorbing waste discharges or to render such wastes innocuous by dilution.

Atoll — a ring-shaped island formed by a fringing reef growing on a submerged mountain peak.

Benefit-cost ratio — comparison of the expected benefits of a project with its anticipated costs. Ordinarily, unless the computed benefits exceed the computed costs, the project is not considered feasible.

Biochemical oxygen demand — the oxygen requirement when organic matter decomposes in bodies of water. Oxygen-demanding wastes lower dissolved oxygen levels in water, which in turn can adversely affect aquatic life. Abbreviated "BOD."

Biota — the flora and fauna of an area.

Conservation district — an area limited to conservation use under the Land Use Act, administered by the state Department of Land and Natural Resources.

Consumptive use — water withdrawn and not returned directly to a surface or ground water supply; hence, water which is lost for immediate further use. Also called "consumption."

Cost allocation — the apportionment of the costs of a multipurpose water project among the various purposes served.

Cost effectiveness — comparison of alternative ways to achieve a given objective in order to identify the least-cost way.

Cost sharing — the assignment of the responsibility for paying the costs of a water project among two or more entities, as for example among the federal government, a state government, and individual users.

Depletion — water withdrawal from surface or ground water reservoirs at a rate greater than the rate of replenishment.

Desalting — the technical process of removing dissolved solids from brackish or sea water to convert to fresh water or other less saline condition. Also called "desalinization" and "desalination."

Dike-confined water — ground water which is impeded in its flow toward the ocean by curtain-like underground barriers of dense rock, or dikes, formed when molten rock was forced into volcanic rifts.

Discharge — the rate of flow of a spring, stream, canal, sewer, or conduit.

Diversified agriculture — in Hawaii, agriculture other than sugarcane and pineapple production.

Diversion — the removal of water from a natural watercourse.

Ecology — the study of the interrelationships of living organisms to one another and to their surroundings.

Ecosystem — relatively homogeneous recognizable units, including contained organisms, their environment, and all of the interactions among them.

Effluent — the outflow of used water from a sewer, holding tank, industrial process, agricultural activity, etc., either treated or untreated.

Estuary — the lower course of a river which flows to the sea and is influenced by the tides; an arm of the sea that extends inland to meet a river flowing to the sea; the reaches of a river into which sea water intrudes and mixes with fresh water from land drainage.

Evaluation — examination of a proposed project or program to determine feasibility.

Evaporation — conversion of liquid water into vapor; hence, the dissipation of water from water surfaces and the ground into the atmosphere.

Evapotranspiration — water dissipated to the atmosphere by evaporation from water surfaces and moist soil, and by plant transpiration.

Flood plain — the land bordering a stream or coastal area which is subject to flooding.

Geothermal energy — the energy available from the stored heat of the earth; usually, steam formed when ground water interacts with a hot body of volcanic rock.

Ground water — water that occurs beneath the land surface and completely fills all pore spaces of the rock material in which it occurs.

Hawaiian Archipelago — the collective name for the series of islands, reefs, and atolls which form a chain about 2,000 miles long from Kure Atoll in the north to the island of Hawaii in the south.

Headwaters — the place where a stream originates.

Hydrographic area — a geographic division of an island, generally defined by topographic features, from which water drains into a stream or streams. Also called "watershed," or drainage basin."

Hydrologic cycle — the circulation of water from the sea, through the atmosphere, to the land; and thence (with many delays) back to the sea by overland and subterranean routes, or directly back into the atmosphere by evaporation and transpiration.

Irrigable — land which is suited to and fertile under irrigation.

Instream use — use of water which does not require withdrawal or diversion from its natural watercourse. For example, the use of water for navigation, waste disposal, recreation, and support of fish and wildlife.

Interarea transfer — the physical transfer of water from one hydrographic area, or watershed, to another.

Kona storm — storm caused by the formation of low pressure areas southwest of Hawaii, whereby prevailing northeasterly tradewinds are replaced by southerly winds.

Leaching — removal of salts and alkali from soils by water which percolates through.

Level B Study, or Level B Plan — a reconnaisance level of planning intended to resolve complex and long-range problems of a regional nature. Level B studies fall between the broadest level of planning, which is regional problem assessment (Level A), and implementation studies for a particular project (Level C).

Major islands — generally, the eight southeasternmost islands of the Hawaiian Archipelago, commonly known as "the Hawaiian Islands." Reference to six major islands excludes Kahoolawe and Niihau.

Marine highway — a system whereby ferries would form a link between islands carrying vehicles, cargo, and people in an extension of the land highway system.

Mouth of a stream — the point where a stream empties into another stream, a river, or the sea.

Multiple use — development of a particular water resource to serve two or more purposes simultaneously.

Neighbor Islands — the seven major islands, other than Oahu.

Non-point source — a source of diffuse waste discharge into a water body, such as sediment and certain agricultural chemicals which cannot be located specifically.

Northwestern Hawaiian Islands — the chain of small islands, reefs, and atolls extending northwesterly from Niihau to Kure Atoll.

Pathogenic organisms — organisms capable of causing disease.

Perched water — ground water impounded at high level by an impervious layer of rock.

Point source — a specific source from which wastewater is discharged into a water body, such as effluent from a municipal sewage system, outflow from an industrial plant, or runoff from an animal feedlot.

Prime agricultural land — land with a combination of soil, slope, drainage, and location making it ideally suited for agricultural production. In this report, as defined by the Soil Conservation Service, the State Department of Agriculture, and the University of Hawaii.

Precipitation — any form of rain or snow falling to the earth's surface.

Recharge — that rainfall which infiltrates the earth and replenishes ground water bodies.

Recycling of water — the withdrawal of water for use and the subsequent reconditioning and reuse of that same water.

Reef — a barrier fringe around warmwater islands formed mainly of the skeletal structure of coral animals.

Reservoir — a pond, lake, aquifer, or basin, either natural or artificial, in which water is stored, regulated, or controlled.

Runoff — the part of precipitation that appears in surface streams.

Rural district — an area limited under the Land Use Act to a maximum density of a half acre per single-family dwelling.

Sediment — soil or mineral material transported by water and deposited in streams or other bodies of water.

Shelf — a flat area extending seaward from a land mass.

Shoal — a shallow water area.

Storage — the impoundment of water in surface reservoirs or accumulation in underground reservoirs for later use or release.

Streamflow — the discharge flowing in a surface stream course.

Sustained yield — the quantity of water which can be withdrawn annually from ground water aquifers, over a period of years, without depleting the available supply.

Taro — a root crop (arum) grown in paddies, from which poi is made.

Tradewinds — prevailing northeasterly winds which dominate the weather pattern in Hawaii.

Transpiration — the process whereby plant tissues give off water vapor to the atmosphere.

Tsunami — a long-period wave, often destructive, caused by earthquakes or other disturbances of the ocean floor or ocean rim. Often called a "tidal wave."

Urban district — an area designated under the Land Use Act for urban development.

Wai — Hawaiian for water.

Watershed — a geographic area which drains into a particular water body. (See hydrographic area.)

Water table — the upper level of an underground water body.

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