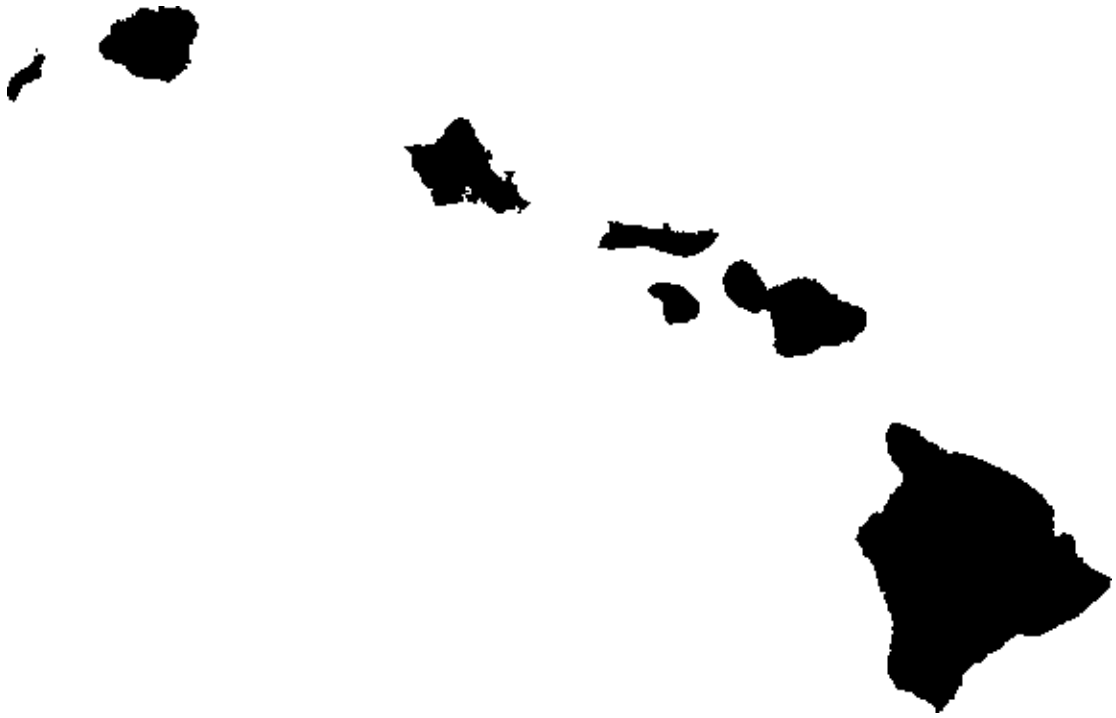
HAWAII WATER PLAN

WATER RESOURCES PROTECTION PLAN

Volumes I & II



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Commission on Water Resource Management
Department of Land and Natural Resources State of Hawaii

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JOHN WAIHEE
Governor

DEPARTMENT OF LAND AND NATURAL RESOURCES

COMMISSION ON WATER RESOURCE MANAGEMENT

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Preface

In 1987, the State Legislature passed the State Water Code (HRS Chapter 174C) to protect and manage Hawaii's surface and ground water resources. Part III of the State Water Code calls for the formulation of a Hawaii Water Plan, an integrated program for the protection, conservation, and management of the waters of the State. The **Water Resources Protection Plan** is one of seven subplans which collectively comprise the Hawaii Water Plan, and will serve as a continuing long-range guide for water resource management.

On June 27, 1990, the State Commission on Water Resource Management adopted the Water Resources Protection Plan for incorporation into the Hawaii Water Plan, with the following stipulations:

(1) The Commission staff will continue its investigations to acquire additional data to improve the information base on water resource use and availability. Information from current Water Source Registration and Water Use Declarations programs and the Hawaii Stream Assessment project will be incorporated in the Plan as such information becomes available.

(2) The Commission staff will further evaluate the adequacy of current and proposed future State programs in the areas of resource conservation and demand management, conjunctive use of ground and surface waters, saltwater intrusion, ground-water recharge, watershed enhancement, and instream uses.

(3) The Commission staff will review and revise, as necessary, the Water Resources Protection Plan by July 1, 1991. Thereafter, the Commission staff will review and make necessary revisions to the Water Resources Protection Plan every two years in concert with the updating and refinement of the Hawaii Water Plan.

VOLUME I

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I. EXECUTIVE SUMMARY AND RECOMMENDATIONS

EXECUTIVE SUMMARY

The Water Resources Protection Plan is one of the four major components of the Hawaii Water Plan authorized under the State Water Code. The others are the "Water Quality Plan", the "Water Use and Development Plan", and the State "Water Projects Plan". Briefly stated, the Protection Plan shall inventory the water resources of the State, determine their sustainable yields based on available data, and recommend means of conserving and augmenting such water resources.

The Protection Plan consists of two volumes. Volume I contains introductory and background material and discussion of water occurrence and behavior. It includes a description of the various government entities and private organizations involved in the development and use of water resources. It also includes text on inventory and assessment of resources (groundwater and surface water) such as the various hydrologic divisions and their characteristics, occurrence and location, sustainable yields, quality, and availability for development.

Another part of Volume I is a section on management, conservation and protection of our water resources, including preservation of instream values, flood control, and conjunctive use of surface and groundwaters.

Finally, a chapter is devoted to the various means and methods which may be utilized to augment our resources. Subjects such as waste water reuse, desalination, improved irrigation practices, weather modification, recharge, and surface water recovery are discussed.

Volume II is the Appendix and is composed of data bases and explanatory text as well as descriptions of the hydrological environments. It also contains all the maps of the hydrologic divisions discussed in the text.

The following are highlights in the major categories discussed in Volume 1:

A. Inventory and Assessment of Resources

1. The establishment of a basic system of aquifer classification is the cornerstone of the whole process of determining sustainable yields. Such classification is described in detail, beginning with an island as the largest component followed by sectors and systems.

2. Maps of the hydrologic divisions in the principal islands are included in the Appendix (Volume II).

3. The subject of sustainable yields is treated in detail with the caution that "The estimates of sustainable yields are not meant to be an exact number which could be used in final planning documents. The estimates should not be equated to developable groundwater." The limitations in the use of sustainable yield estimates are discussed in detail.

4. Aquifer system sustainable yields are described in great detail with reference to location of water sources, total quantities available, and reliability of estimates. The general geology and hydrology of all the principal islands are described in detail in the Appendix (Volume II).

5. Surface water is treated as a separate subject with discussions on stream classification, stream diversions (tunnels and ditches), flow records, and flow characteristics. Major stream diversion diagrams are included in the Appendix (Volume II).

6. Minimum Stream Flows and Instream Values are discussed, with emphasis on minimum stream flow characteristics. A flow parameter is suggested which could form the basis for the establishment of permanent instream standards.

B. Resource Management and Protection

1 Minimum areas of conservation lands for watersheds as protected infiltration areas should be set aside. Oahu has a long history of maintaining watershed areas and imposition of strict controls to assure maximum infiltration and protection against contamination and loss of recharge. This practice should be assiduously observed throughout the State.

2. Because of breakdowns in the watershed control efforts throughout the country, Hawaii faces the possibility of having to employ multiple barriers of treatment which includes filtration and disinfection.

3. Adoption of flood control measures is advantageous by putting flood waters to beneficial use such as storage for recharge, low-flow augmentation, support of fish and wildlife, irrigation, recreation and other forms of re-use.

4. The establishment of designation procedures and the setting up of a permit system to control use are important features of a water use regulatory program. However, the counties must be given every opportunity for self-control before resorting to action

by the State.

5. Short-and long-term water conservation programs are vital to the preservation of our water resources and the effectiveness of how we utilize our total water resources. The U.S. Water Resources Council is of the opinion that by the year 2000, more than 20% of the country will have serious water shortages.

   Several areas in the State of Hawaii may face similar shortages, and well-planned water conservation programs will help alleviate the pressures of water shortage. As part of a water conservation program, serious consideration should be given to the establishment of inclining and seasonal rate structures.

C. Augmentation of Resources

1. Augmentation, especially on the Neighbor Islands, does not appear to be urgent. The problem is more a matter of development and distribution rather than a scarcity of water. The need for augmentation applies more to the island of Oahu, but a timetable for implementation is difficult to establish.

2. The cost of desalting seawater is still high. Desalting of brackish water by the reverse osmosis or electrodialysis method bears greater promise but the cost is still high when compared with conventional water development methods. For this reason, desalination does not occupy a high priority at this time.

3. The adoption of drip irrigation by the sugar industry resulted in significant savings in water use. However, the reduction is closer to 20-25% rather than the 40% as initially expected.

4. Weather modification as a realistic and practical solution to the State's water problems is uncertain at the present time. Chemicals used in cloud seeding could produce environmental problems. However, research and experimentation should continue.

5. Artificial recharge as a direct means of replenishing the groundwater body is not practiced in Hawaii. However, as the water supply problem becomes more acute, especially in certain areas on Oahu and Maui, recharge may become a feasible alternative in the future. Field tests and research, supported by a well-planned monitoring program, should be considered for early implementation.

6. The recovery of surface water for potable purposes in Hawaii is minimal, although fairly large quantities are impounded and used for irrigation. The potential of impounding surface water at least for irrigation purposes, thereby releasing potable water now used for irrigation, presents a viable alternative.

   For example, the impounding of Waikele Stream water in West Loch of Pearl Harbor offers possibilities for use of the water for irrigation, recreation, bait fish propagation, and if necessary, for domestic purposes after treatment.

7. The reclamation of wastewater for irrigation is practiced in Hawaii on a limited basis, particularly for golf course irrigation. The prospects for wider use are promising. The feasibility of using treated wastewater for recharge purposes appears encouraging based on studies completed to date. Research on this proposal should be continued.

RECOMMENDATIONS

1. A periodic review of sustainable yields and all pertinent hydrologic data and water quality parameters should be done at least every five years or even more frequently if circumstances warrant.

2. A Statewide resource monitoring and data collection program should be implemented with equal emphasis on surface and groundwater.

   A. Groundwater

      (1) Each aquifer system in which substantial groundwater development is underway should have a deep monitoring test well which penetrates through the fresh water lens into underlying seawater. Salinity profiles should be taken on a minimum semi-annual basis.

      One profile should be taken in the last week of February, and the other in the first week of October in order to measure the behavior of the lens during the periods of highest and lowest heads.

      (2) In those aquifer systems in which intense groundwater development is underway, simultaneous head readings should be combined twice a year, once in late February and again in early October.

(3) Measurements of head at various sites should be related to a single benchmark to assure that accurate relative differences in head are obtained.

(4) The current program of measuring salinity, heads and temperature should be evaluated. A formal program for obtaining these data, especially in critical areas, should be designed and carried out.

B. Surface Water

(1) The current program of data gathering should be reviewed and evaluated. The number of continuous streamflow measuring sites has declined sharply in the last decade. A study should be made to determine whether the statistical data base needs reinforcement or is already adequate.

(2) Physical characteristics and parameters of stream flow need to be assessed, and a stream classification scheme based on these data should be created to serve as the framework for decisions made about in-stream values and allowable minimum stream flow. The classification should address the relationships between surface water and groundwater.

(3) An inventory must be made of all the stream diversion systems in the State.

(4) Initiate studies in the near future on in-stream values and various parameters leading to the establishment of permanent in-stream standards. The environmental impact of these standards must also be considered.

(5) Establish the relationship between surface and groundwater and determine guidelines on conjunctive use of groundwater and surface water.

(6) Develop irrigation water quality criteria for primary, secondary and tertiary effluents, and brackish water.

(7) Increase the confidence levels in the determination of sustainable yields. This may include more comprehensive monitoring work, refining the water balance equation, allowance for return irrigation water and interhydrologic unit transfers.

(8) Proceed vigorously on research and pilot studies on:

(a) Recharge
(b) Surface water recovery
(c) Waste water recovery

A second-line priority would be the improving of irrigation practices, and a third priority would be desalination and weather modification as means to augment our resources.

(9) Study legislative means to protect and preserve our watersheds against contamination and encroachment of intake areas.

(10) Conduct studies leading to a plan for orderly delineation of areas which should be zoned as conservation lands for infiltration purposes (watersheds).

(11) Develop strong and effective short-and long-term water conservation programs.

(12) Expand studies on the feasibility of bulkheading dikes to create greater storage capacities.

(13) Amend building and plumbing codes to require the installation of water-conserving devices and appliances including landscape irrigation control fixtures.

(14) Investigate the possibilities of using waste heat resulting from the use of nuclear energy in power generation and geothermal energy in the desalination process.

(15) Initiate and expand studies on the conjunctive use of surface and groundwater.

(16) Investigate technology and means of reducing evapotranspiration.

(17) Conduct research on the feasibility of inducing rainfall through weather modification.

(18) Study feasibility of combining water and wastewater functions under single management for maximum utilization of our water resources.

(19) Conduct more research and pilot studies on the desalinization of brackish water by both reverse osmosis and electrodialysis methods, with emphasis on cost reduction, particularly energy costs.

(20) Expand flood control and drainage programs to increase use of our water resources for irrigation, recreational, fish propagation, and recharge purposes.

(21) Plan for and initiate a comprehensive program of monitoring for water quality of both ground and surface water sources to identify types and concentrations of contaminants to comply with levels (MCL) specified by the State Department of Health. Monitoring should be conducted in such a manner so as to establish relationships between the sources of contamination and points of water withdrawal.

II. INTRODUCTION

It has been generally recognized that the water resources of the State are in need of judicious management and regulation as a means to assure continued availability and to control pollution. Moreover, there has been a great need to clarify the status of water rights throughout the State. In 1978, the State Constitutional Convention mandated the Legislature to formulate a statutory plan to address these concerns. Accordingly, the Fourteenth Legislature in 1987 implemented Article XI, Section 7, of the State Constitution by enacting a State Water Code to "protect, control, and regulate the use of Hawaii's water resources for the benefit of its people." It is codified for Chapt. 174C of the Hawaii Revised Statutes.

The general administration of the State Water Code rests with a six-member Commission on Water Resource Management established within the Department of Land and Natural Resources. The Commission has broad powers and exclusive jurisdiction and final authority in all matters regarding the administration of the water code. According to the code, a major responsibility of the Commission is to prepare a four-part Hawaii Water Plan.

One part of the plan is a "Water Quality Plan" prepared by the Department of Health. Another part is the "Water Use and Development Plan" prepared by each county. The third part is the State "Water Projects Plan" which includes specific State water projects. The fourth part is the "Water Resources Protection Plan" which is the main part of the Hawaii Water Plan. This part is developed by the Commission itself.

In preparing the Protection Plan, the mandate to the Commission is exceedingly broad. The scope of the Commission's responsibility under the law is quoted as follows: "The Commission shall: study and inventory the existing water resources of the State and the means and methods of conserving and augmenting such water resources; review existing and contemplated needs and uses of water including State and County land use plans and policies and study their effect on the environment, procreation of fish and wildlife, and water quality; study the quantity and quality of water needed for existing and contemplated uses, including irrigation, power development, geothermal power, and municipal uses; and study such other related matters as drainage, reclamation, flood hazards, flood plan zoning, dam safety, and selection of reservoir sites, as they relate to the protection, conservation, quantity and quality of water."

The law further provides that "The Water Resource Protection Plan shall include, but not be limited to:

(1) nature and occurrence of water resources in the State;

(2) hydrologic units and their characteristics, including the quantity and quality of available resource, requirements for beneficial instream uses and environmental protection, desirable uses worthy of preservation by

permit, and undesirable uses for which permits may be denied;

(3) existing and contemplated uses of water, as identified in the water use and development plans of the State and the counties, their impact on the resource, and their consistency with objectives and policies established in the water resource protection quality plan;

(4) programs to conserve, augment, and protect the water resource; and

(5) other elements necessary or desirable for inclusion in the plan.

Thereafter, the Commission, in coordination with the counties and the Department of Health, shall formulate an integrated, coordinated program for the protection, conservation and management of the waters in each county based on the above studies. This program, with such amendments, supplements, and additions as may be necessary, shall be known as the Water Resource Protection and Quality Plan.

Thereafter, each county shall prepare a water use and development plan and the appropriate State agency shall prepare the State Water Projects Plan."

The preparation of the Protection Plan is an enormous undertaking in itself since it encompasses all groundwater and surface water sources in the State. Much of the basic information and data necessary for this study are not known. In order to complete it by the December 31, 1989 deadline, the Commission will have to rely on incomplete information and estimates. For example, the Legislature probably realized the uncertainty of the situation when commenting on the crucial item of sustainable yields. The law provides that "The sustainable yield shall be determined by the Commission using the best information available and shall be reviewed periodically." The Legislature wisely provided the means for the Commission to further develop, review, adjust, and fine-tune sustainable yields based on experience and availability of additional data and findings.

The development of the various parts of the Hawaii Water Plan is under the responsibility of the Commission. The Plan itself, with the exception of the Water Quality Plan, shall be adopted by the Commission. The Water Quality Plan shall be received by the Commission and incorporated into the Hawaii Water Plan. In summary, the intent of the Legislature is that the Commission shall integrate all the components called for into a single document called the Hawaii Water Plan.

III. OVERVIEW

STATE OF HAWAII

A. AREA

The Hawaiian Island chain stretches 1,523 miles southeast to northwest from Cape Kumukahi, the easternmost point of the Island of Hawaii, to tiny Kure Atoll to the north. The State consists of eight major islands and 124 minor islands. Total land area of the State is 6,427 square miles, or about 4,112,122 acres, which ranks Hawaii 47th of the 50 States in the country in size, ahead of Connecticut, Delaware and Rhode Island (Fig. 1 is a general map of the principal Hawaiian Islands).

B. GEOGRAPHY

The oldest islands are those in the northwestern portion of the chain (Kauai, Oahu); the youngest are those in the southwestern portion (Hawaii). The island of Hawaii is known for its active volcanoes, and the mountains of Mauna Loa and Mauna Kea, the highest peaks in the State (elev. 13,679 feet and 13,796 feet above sea level, respectively). Maui is famous for its Haleakala Crater, while Oahu is the site of Diamond Head Crater, Kaukonahua Stream, the longest stream in the State, and Kawainui Marsh, the largest lake in the State.

Kauai, the oldest of the major islands, is the home of Waimea Canyon and Mount Waialeale. Kahiwa Waterfall, with a cascade of 1,750 feet, is the State's highest waterfall and is located on the island of Molokai.

C. CLIMATE AND ENVIRONMENT

Hawaii's weather, with its generally clear, blue skies, warm temperatures and cool breezes is considered to be among the best in the world. The climate of the Hawaiian Islands in fact varies little throughout the year with temperatures most often in the 70 to 80-degree Fahrenheit range. During the summer months, temperatures can reach 90°F or even higher in some areas. This has become apparent especially in recent years. During the winter months, temperatures can drop to the mid-50's or even lower in high-altitude areas of Maui and Hawaii such as Haleakala, Kula, Mauna Loa and Mauna Kea.

Rainfall within the State, on the other hand, varies considerably, with precipitation generally highest in the mountain and windward areas, and lowest in the coastal and leeward areas. Waialeale on Kauai continues to be the wettest spot in the State and one of the wettest in the world with an average rainfall of almost 450 inches per year. In contrast, Puako on the Big Island is the driest spot in the State with an average annual rainfall of only about 10 inches.

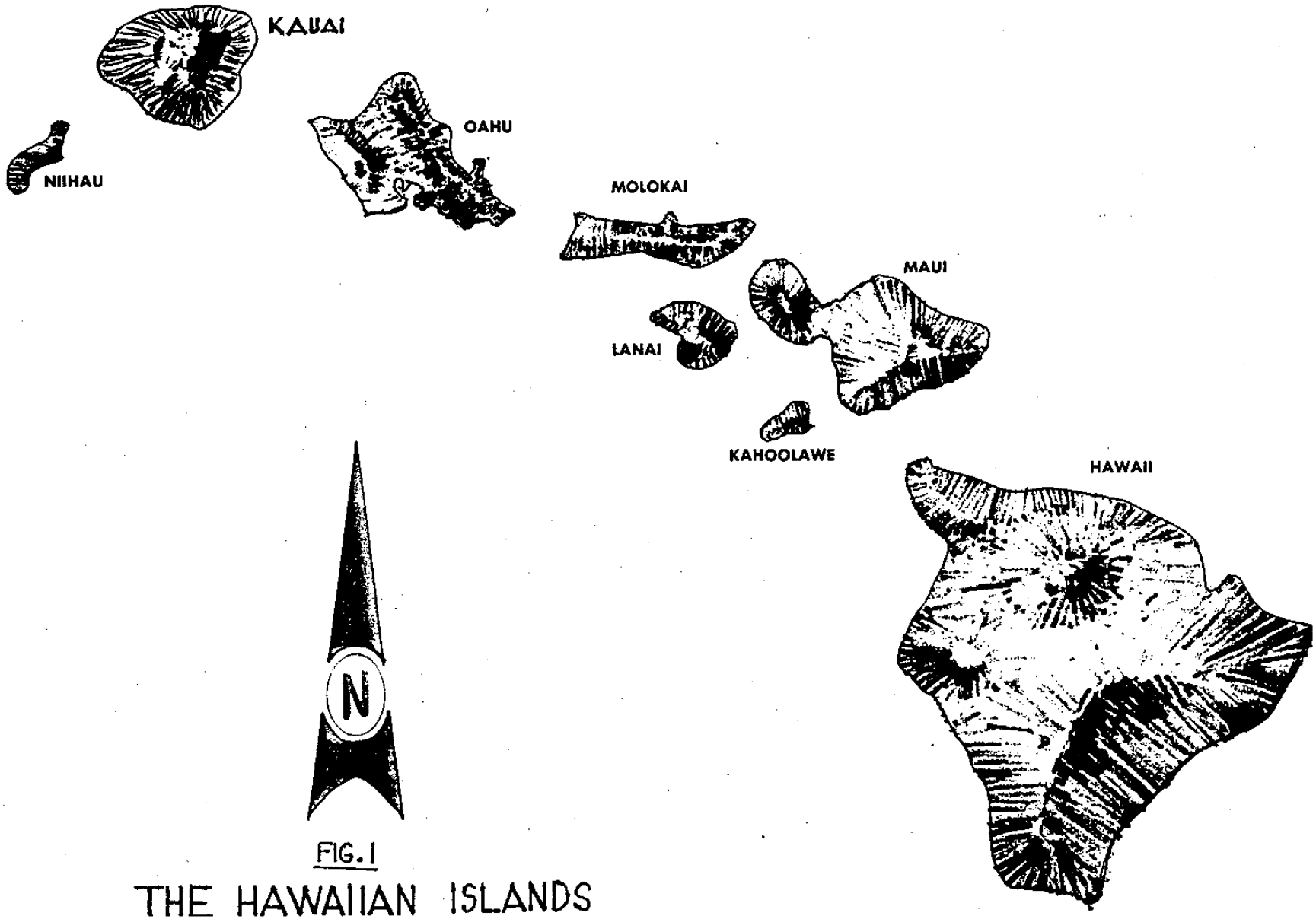


FIG. 1

THE HAWAIIAN ISLANDS

While on the whole lack of rainfall has yet to be a serious problem for the state of Hawaii, some areas in recent years, notably on Maui and Hawaii, have experienced mild droughts.

Relative humidity throughout the State is usually on the high side. Average relative humidity is about 75% during the day and drops to about 60% in the evening. In the summer, or in the absence of tradewinds, humidity can rise to 80% or even to more than 90%.

The quality of air in Hawaii is excellent. Measurements of air pollution indicate that Honolulu has in fact some of the cleanest air in the country. Air quality (tested for particulates and sulphur dioxide) of Oahu, Maui and Kauai is well within the Environmental Protection Agency's standards. Most of the air pollution that is present, as can be expected, comes from automobile exhaust, and industrial and agricultural fuel combustion.

Occasionally, volcanic haze from the Big Island travels north over the Hawaiian Chain. If the tradewinds which normally blow the haze away are absent, the haze can hover over the islands for several days. The stagnant haze is regarded more as a nuisance than as a harmful occurrence.

The flora and fauna of Hawaii were largely influenced by the arrival of inhabitants predominantly from Polynesia earlier than 900 A.D. and later in-migration from other Pacific islands and countries from the Far East. The drilling of the first artesian well on Oahu circa 1759 made possible large-scale sugar and pineapple cultivation, resulting in a lasting effect on the economy and environment of the Hawaiian Islands.

The Hawaii Water Resources Protection Plan of 1979 stated, "As 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". The observance of this policy will be dependent on what is done to protect our water resources against depletion and pollution. The maintenance of a safe and adequate water supply for all purposes is the cornerstone of this policy.

D. POPULATION

As of July 1, 1988, the resident population of the State of Hawaii, including enlisted military and their families, was 1,098,200, which ranks Hawaii 39th of the 50 states in the Union. Since 1970, the population has increased 25%, and since 1980, the increase was almost 14% making Hawaii one of the fastest growing States in the country. Table 1 shows the State population projections from 1985 to 2010.

TABLE 1

STATE POPULATION AND ECONOMIC PROJECTIONS: 1985 TO 2010

[In thousands]

Subject	1985	1990	1995	2000	2005	2010
Resident population	1,051.5	1,137.2	1,225.2	1,285.1	1,350.8	1,435.5
De facto populaton	1,149.6	1,269.1	1,382.3	1,468.6	1,560.3	1,674.2
Total labor force	537.4	602.2	657..5	704.9	741.9	780.2
Civilian labor force	479.0	543.8	599.1	646.5	683.4	721.7
Civilian persons employed	452.0	516.7	568.6	614.0	649.5	686.3
Total Jobs	541.5	611.0	665.5	713.1	750.4	789.1
Military jobs	68.4	68.4	68.4	68.4	68.4	68.4
Civilian jobs	473.1	542.6	597.0	644.7	682.0	720.6
Self-employed	36.9	42.3	46.6	50.3	53.2	56.2
Wage and salary jobs	436.2	500.2	550.5	594.4	628.8	664.6
Sugarcane - field	4.1	3.6	3.2	2.8	2.5	2.2
Pineapple - field	2.0	1.9	1.9	1.8	1.7	1.7
Other agriculture	4.4	5.4	6.3	7.1	7.8	8.6
Sugarcane processing	3.5	3.1	2.7	2.4	2.1	1.8
Pineapple canning	1.9	1.7	1.6	1.4	1.3	1.2
Other food processing	4.7	5.2	5.6	5.9	6.0	6.1
Misc manufacturing	11.9	12.7	13.3	13.9	14.5	15.0
Construction	17.2	21.2	23.3	25.0	26.1	27.1
Transp, warehousing	23.4	26.2	28.3	29.8	30.9	31.9
Communication	7.4	8.5	9.1	9.7	10.0	10.3
Utilities	2.5	2.7	2.8	2.9	3.0	3.0
Wholesale trade	19.6	22.5	24.5	26.3	27.4	28.3
Retail trade	56.0	65.9	73.3	80.0	85.6	91.6
Eating & drnk places	40.1	48.1	52.7	57.3	61.4	65.9
Banking & finance	31.9	35.4	39.2	41.6	42.9	44.5
Hotels	29.0	34.5	38.1	41.3	43.7	46.3
Healt, prof services	34.4	42.4	49.7	55.8	61.0	66.6
Other services	49.2	61.1	71.5	80.7	88.4	96.7
State-local gov	60.9	65.8	70.7	75.3	78.8	81.4
Federal gov	32.4	32.5	32.9	33.3	33.7	34.1
Personal income (millions of 1982 dollars)	13,045	15,509	17,994	20,094	21,920	24,122
Per capita income (thousands of 1982 dollars)	12.4	13.6	14.7	15.6	16.2	16.8
Disposable personal incomes (millions of 1982 dollars)	11,297	13,311	15,441	17,241	18,806	20,694
Gross State Product (millions of 1982 dollars)	15,132	18,345	21,670	24.720	27,469	30,418

Source: Population and Economic Projections for the State of Hawaii to 2010 (Series M-K), Department of Business and Economic Development, Research and Economic Analysis Division, State of Hawaii, November 1988.

About 80% of the State's population resides on Oahu. On a percentage basis Oahu has shown only slight increases. The population of the Neighbor Islands, on the other hand, has increased at a much faster rate.

Much of this growth is due to the notable increase in the number of immigrants coming to Hawaii primarily from the Philippines but also from South East Asia, Korea and the South Pacific.

The approximate ethnic composition of the State (1987) is as follows:

Caucasian	23%
Japanese	23%
Mixed (Part Hawaiian)	31%
Filipino	11%
Chinese	5%
Other	7%

The average life (1986) of a male residing in Hawaii is 75.4 years, while a female can be expected to live 80.9 years. The combined average life is 77.8 years, thus making Hawaii the State with the longest-living residents. Hawaii's population is rather young; the median age (1987) is 31.5 years. The birth rate in Hawaii has decreased consistently over the last 20 years. In 1987, the birth rate was 17.1 per 1,000, well below the birth rate of 21.2 per 1,000 in 1970.

E. ECONOMY

Tourism remains the State's premier industry, with 5.8 million visitors staying in the islands one night or longer (1987). People from Japan, Canada, the mainland United States (especially the West Coast), Australia and Western Europe comprise the bulk of the State's visitors.

The tourist industry is also the largest employer of the State. In 1986 there were some 196,000 tourist-related jobs in the Islands.

Another major industry of Hawaii is the military industry. As of July 1, 1988, there were 64,053 military personnel in the State, stationed almost entirely on Oahu, representing an increase of about 4,000 since the same date a year earlier. Military personnel and their families totaled 133,958, or about 11% of the State's population.

The military industry is a vital economic force in the Islands. Civilian employment in the military industry accounted for 20,050 jobs in 1987, representing only a slight decrease from 20,400 jobs in 1986. The military industry also awarded contracts totaling about $ 460.5 million in 1987. On the whole, the U.S. Department of Defense spent an estimated $ 2.0 billion on military and civilian payrolls, and on goods and services.

Other important industries in Hawaii are sugar and pineapple cultivation, diversified agriculture such as produce, coffee, macadamia nuts, com and cocoa, aquaculture such as shrimp, lobster and salmon, cattle and livestock, and flowers and nursery plants.

Hawaii also manufactures clothing and textiles, artwork and crafts, and a variety of foods such as cookies, jellies, breads and candies. Many of these products are exported to destinations around the world. Other manufactured goods include petroleum, furniture, hardware and building materials.

The entertainment industry, which includes film, music and dance, is another prosperous industry in the State. The entertainment industry not only promotes the islands but also provides jobs to the community.

Hawaii continues to play an important role in the world of science and technology. There are numerous State- and Federally-funded technological projects which are now underway. Alternate energy projects such as solar, hydroelectric, wind, geothermal, biomass and ocean thermal energy conversion have met with generally positive results. Space programs such as satellite tracking, space communications, and observatories are also established projects. Oceanographic research is another area in which Hawaii is well-suited for.

The labor force of the State is generally healthy. Unemployment for the month of December 1989 alone was 2.6%, while unemployment from January through November of 1989 was 2.9%. This figure is one of the lowest in the United States. Average per capita income in 1987 was $15,679.00. Average household income that same year was $34,398.00.

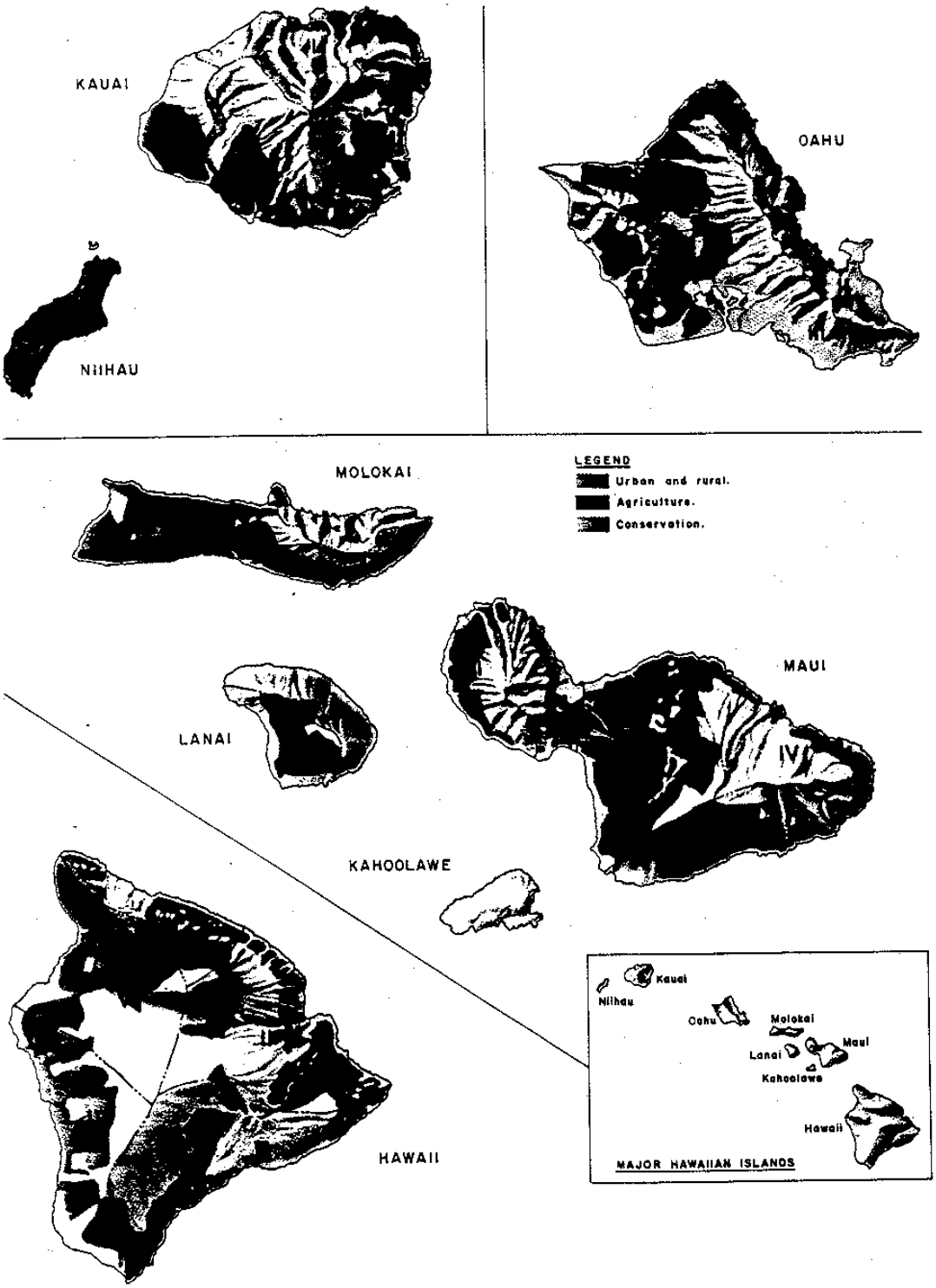
Major employers in the State are government (State, County and Federal, including military), manufacturing, service, healthcare, business (banking, real estate and insurance), agriculture, communications, and wholesale and retail trade. Table 1 shows the State economic projections from 1985 to 2010.

F. LAND OWNERSHIP AND CLASSIFICATION

About 62 percent of the 4,112,122 acres of the State of Hawaii is privately-owned land. The State and counties own about30 percent of the land, and the remainder, about eight percent, is owned by the Federal government. Privately-owned land includes residential parcels, corporation-and business-owned land and privately-owned agricultural land. State and County land includes land for State and County buildings, historical sites and landmarks, parks, streams, beaches and agricultural operations. Federal land includes land for Federal buildings and departments, national parks and wildlife sites, and military land. Fig. 2 shows land use patterns for the State of Hawaii.

The State Land Use Commission zoned 166,000 acres (about 4%) as urban

FIG 2
LAND USE PATTERNS FOR THE STATE OF HAWAII



Source: Hawaii Water Resources Plan, Hawaii Water Resources Regional Study, Department of Land and Natural Resources, State of Hawaii, Honolulu, Hawaii, 1979.

land, 1,967,000 acres (about 47.5%) as conservation land, 1,969,000 acres (about 47.5%) as agricultural land and 10,000 acres (about 1%) as rural land.

Across the State, 333,000 acres (about 8%) are in cropland, 974,000 (about 24%) acres are in pastureland, 1,473,000 acres (about 36%) are in forestland, 126,000 acres (about 3%) are in urban land, 341,000 acres (about 8%) are in Federal land, and 852,000 (about 21%) acres are in miscellaneous nonfarm land.

KAUAI COUNTY

A. AREA

Kauai County is the third largest in size of the four counties of the State of Hawaii. The islands of Kauai, Niihau, Kaula and Lehua, which comprise the County, have a total area of just under 620 square miles (Kauai alone has an area of 549.4 square miles while the remaining islands have a combined area of 70 square miles).

B. GEOGRAPHY

Kauai is famous for its lush valleys, majestic mountains, sprawling beaches and picturesque coastlines. Its precise location on the map is 21°59' north latitude and 159°21' west longitude. The island is the northernmost of the major Hawaiian islands and is geologically the oldest major island of the State. The highest mountains on Kauai are Kawaikini (elev. 5,243 feet) and Waialeale (elev. 5,148 feet). Only Hawaii and Maui have mountains which are higher.

Kauai is also home to the famous Waimea Canyon, located on the western side of the island. Major streams of the island are the Hanalei and Wailua rivers. The Waita Dam, located on Koloa, Kauai, is the second longest in the State (3,250 feet).

C. CLIMATE

The climate of Kauai is considered ideal, with average temperatures of 71°F in February/March and 79°F in August/September. In the mountain areas such as Kokee, it is not uncommon to see temperatures drop to the mid-50's or even to the mid-30's in the evenings. Temperatures rarely exceed 90°F, although the mercury level does sometimes surpass this temperature in coastal areas such as Poipu.

Like the rest of the State, rainfall varies widely throughout the island of Kauai. For example, in Kekaha, average annual precipitation (April, 1975) was 20 inches. However, as of September 3, 1988, annual precipitation at the Lihue Airport averaged 44 inches, in Kokee the average was 70 inches, and in Princeville the average was 95 inches.

Waialeale is the wettest spot on the island (and in the world). As of September 3, 1988, average annual precipitation there was 444 inches. On the whole, annual rainfall on the island of Kauai tends to be greater then that of the rest of the major Hawaiian Islands.

Another weather phenomenon which seems to affect Kauai more than the other islands is hurricanes. Four of the six major hurricanes to hit the Hawaiian archipelago since 1950 struck directly on Kauai. The most recent, Hurricane Iwa (1982), resulted in major damage estimated as close to $ 200 million.

D. POPULATION

The population of Kauai County continues to grow steadily. As of July 1, 1988, the County population was 49,300, representing an increase of 26.1% since 1980 (the statewide population increased only 13.8% during this same time period). However, Kauai County accounts for only about 5.0% of the State's total population, making it the least populous of the four counties.

The island of Kauai accounts for almost all of the County's population, with a total of 49,100 residents. Niihau's population remains at about 200, while Lehua and Kaula remain uninhabited.

As can be expected, most of the population growth has occurred in the larger towns while the smaller towns have shown little increase. The one exception is Hanalei, whose population grew to 5,300 by July 1, 1988, representing an increase of 99.3% since 1980.

Larger districts showing strong growth during this time were Koloa (population: 11,600, +33.2%), Kawaihau (population: 13,700, +30.8%) and Lihue (population: 10,000, +16.8%).

While there is no distinct ethnic majority, the ethnic group with the largest population in the County (as of July 1, 1987) is the Filipino population, with 10,464 residents. This is about 23% of the County's population, considerably higher than the Statewide figure of about 11%.

Other ethnic groups on Kauai which comprise the bulk of the County's population are: Japanese - 10,226 (about 22%), Part-Hawaiian - 10,206 (about 22%), and Caucasian - 8,579 (about 19%).

E. ECONOMY

Tourism has grown to become the County's premier industry. This industry had shown rapid growth, especially during the late 1970's and early 1980's, only to witness a sharp decline at the end of 1982 and through 1983, the period following

Hurricane Iwa, which devastated the island. However, after much rebuilding and redevelopment, the tourist industry now once again appears to be strong. In 1987, 1,032,840 tourists visited Kauai, the highest number ever. As a reflection of this increase, Kauai has been witnessing a rapid growth in the number of hotels being built (most targeting the upper-class visitor), as well as shopping malls, restaurants and other visitor attractions.

Visitors to Kauai are captivated by the island's beautiful scenery, quiet beaches, and county charm. Popular resort areas include Poipu, Princeville, and Waimea where there are several luxury hotels, golf courses and country clubs.

in addition to tourism, sugar is another major industry of Kauai. Although the amount of unprocessed sugar and molasses has gradually decreased throughout the years, on Kauai and all the Hawaiian Islands, the sugar industry on the island remains a vital economic force.

Other crops which Kauai regularly harvests are fresh fruits (primarily papayas, guavas, and bananas), vegetables, taro, and flower and nursery foliage. In addition to these crops, there are several food products which are unique to Kauai. They include ice cream, cookies, sausage, taro chips and poi, dried fruit, salad dressings, bread and honey.

Industries in their infancy include corn, soybeans and sunflower seeds. The climate of Kauai is ideal for these crops so their future looks promising. The future also looks bright for Kauai's aquaculture industry. A number of farms have successfully raised freshwater prawns, and other aquaculture experiments are currently underway.

The County of Kauai actively promotes its thriving film industry. Several major films and many television commercials, both national and international, have been shot using Kauai's scenery as backdrops.

The United States military, primarily the Navy at its Pacific Missile Range Facility at Barking Sands, sees Kauai as an important site for battle group training, new weapons development, and a new airstrip and hangar.

Major sources of employment for Kauai's residents include tourism, business, real estate and insurance, while other sources such as wholesale and retail trading, government, agriculture and manufacturing provide many jobs to Kauai's people as well.

F. LAND OWNERSHIP AND CLASSIFICATION

About 60 percent of all land of Kauai is privately-owned. This includes hotels, farms, businesses, single-family dwellings and the entire island of Niihau which is owned by the Robinson family.

The Federal government owns slightly under 0.9 percent of Kauai County's lands, which is considerably less than the statewide average of 8.4 percent. Most of this government land is used by the military. The Federal government also owns 50 percent of the islands of Lehua and Kaula.

The State of Hawaii owns almost 40 percent of Kauai County. This figure is much higher than the statewide average of only 29 percent. Included in this category are State parks and Waimea Canyon, government buildings and Kauai Community College, historic sites, beaches, State Department of Hawaiian Home Lands, and 50 percent of Lehua and Kaula.

The County of Kauai owns only about 0.17 percent of the island of Kauai, which is much less than the statewide average of 0.4 percent for county ownership. There are about 400,000 acres in all of Kauai County. Of this total, 91 percent is zoned ad non-Federal rural land. Of this non-Federal rural land, about 60 percent is classified as forestland, 22 percent as cropland, and only 13 percent as pastureland (the lowest percentage of the State's counties). The remaining lands are classified as: Minor land cover (about 5%), Urban land (about 3%), and Small water areas (about 1%).

As of June, 1988, slightly more than half (51 percent) of the land of Kauai County was zoned as agricultural land. About 46% was zoned as conservation, while the remaining 3% was zoned as residential, commercial, resort and industrial land combined.

CITY AND COUNTY OF HONOLULU

A. AREA

The City and County of Honolulu, which includes Oahu and the Northern Hawaiian Islands up to Kure Atoll almost 1400 miles from Honolulu, has an area of approximately 600 square miles. For most purposes, however, the City and County of Honolulu technically is defined as only the island of Oahu. This county is the smallest in total area of the four counties which comprise the State of Hawaii.

B. GEOGRAPHY

The island of Oahu can be located at 21°20' north latitude and 157°55' west longitude on the map. The island consists primarily of the Waianae Mountain Range, forming the western portion of the island, and the longer Koolau Mountain Range, forming the eastern portion. Kaala is Oahu's tallest mountain with an elevation of 4,017 feet. Other principal summits include Puu Kalena (elev. 3,504 feet) and Konahuanui (elev. 3,150 feet). Diamond Head, the State's most famous landmark, has an elevation of 760 feet.

Oahu is home to Pearl Harbor, located in Central Oahu, Wahiawa Dam, the most productive dam in the State, and Sacred Falls, one of the most cascading falls in the State.

C. CLIMATE

The climate on Oahu generally varies little throughout the island and there is also little seasonal variation. Hottest temperatures usually occur along the coasts while the coolest temperatures occur inland and in the mountains. During the summer months, temperatures sometime exceed 90°F, while during the winter months temperatures can dip to the upper- or even mid-50's.

Rainfall varies throughout the island, but like the other islands of the Hawaiian chain, rainfall is most abundant in the mountain areas, and most sparse along the coasts. Areas with plentiful rainfall include Nuuanu Valley and Manoa Valley with average annual precipitation levels of about 130 inches and about 160 inches, respectively, while coastal areas such as Waianae and Waikiki record only about 20 inches and 25 inches annually, respectively. Occasionally during the summer months groundwater will dip to low levels and voluntary water conservation is encouraged.

D. POPULATION

Although the City and County of Honolulu is the smallest county in the State in area, it is home to almost 80% percent of Hawaii's population, thereby making this county by far its most dense. With a total resident population of about 838,500 as of July 1, 1988, and with a total area of just under 600 square miles, there is an estimated density of almost 1500 residents per square mile (as a comparison, the county with the second highest population density, Maui County, has an estimated density of only about 155 residents per square mile).

The resident population of the City and County of Honolulu has increased by more than 200,000 between July 1, 1970 and July 1, 1988. Although this county has the most residents, its rate of growth is much slower than the other counties. For example, the percent growth in Maui County between 1980 and 1988 was 31.0, Hawaii County was 27.6 and Kauai County was 26.1. The City and County of Honolulu's percent growth during this same period, on the other hand, was only 10.0.

The largest districts on Oahu as of July 1, 1988 are: Honolulu - (379,300 or 46% of the County's population), Koolaupoko - (117,900, or 14%), and Ewa - (232,500, or 28%). Central and West Oahu, the sites of numerous new housing and business developments, continue to grow at the fastest rates, whereas Honolulu itself has seen little increase in growth rates, whereas Honolulu itself has seen little increase in growth rate. This trend is expected to continue well into the twenty-first century.

Oahu's ethnic mix is similar to that of the other islands, namely, there is no ethnic majority but there are a few ethnic groups which represent a significant majority of the population. Five ethnic populations comprise almost 90% of the total County population. They are: Caucasian (about 24%), Japanese (about 24%), Part-Hawaiian/Hawaiian (about 19%), and Filipino (about 11%).

The Chinese population, which represents only about 5% of the entire State's population, is chiefly rooted on Oahu. Ninety-six percent, or 46,680 of the 48,832 people of Chinese ancestry in the State of Hawaii live on Oahu.

The population of minorities on Oahu has seen a dramatic increase both in total number and type. Since 1980, there have been notable increases in Samoan as well as Vietnamese, Cambodian, Laotian and other Southeast Asian populations.

E. ECONOMY

Tourism continues to be the dominant industry of Oahu, with more and more visitors coming to the island each year. In 1987, three-fourths of the westbound visitors coming to the State, 3,078,500 of the State's 4,204,010 visitors, stayed in Honolulu. Honolulu has also seen a dramatic increase in foreign visitors, including those from Canada, Australia, Europe, and especially Japan. In 1986, there were more than 38,000 hotel and apartment-hotel units, and this figure has undoubtedly increased significantly since then.

Needless to say, Honolulu has grown increasingly dependent on tourism for livelihood. Some critics say that Honolulu may in fact be too dependent on tourism and thus encourage vigorous development of additional industries to provide for a more diverse economic environment.

Some of these industries include diversified agriculture such as milk and dairy products, cattle and livestock, vegetables, fruit (excluding pineapple). Exploratory industries include corn seed, coffee, cocoa, salmon, alfalfa and potatoes. Other established and flourishing crops are flowers and potted plants. Aquaculture farms, while relatively young, have proven to be successful and are becoming increasingly important contributors to the County's economy.

Sugar and pineapple are still the major economic agricultural staples, although their production has decreased steadily in recent years.

Honolulu also has profitable interests in the film industry, petroleum products, clothing and textiles, jewelry, printing and publishing, stone, clay and glass products, handcrafted items, packaged foods, and music and entertainment.

One of the major economic forces on Oahu is the military, which comprises some 15 percent (including family and dependents) of the population of Oahu. In addition to those transferred to Oahu from the mainland, the military is an important

employer for many of Oahu's residents.

Major military installations include the Pearl Harbor Shipyard, Tripler Army Medical Center, Hickam. Air Force Base, Kaneohe Marine Corps Air Station, the U.S. Army's Fort Shafter and Schofield Barracks, and the Unified Military Command for the Pacific located at Camp Smith in Aiea.

Research and development (R&D) activity has grown substantially during the past few years on Oahu, especially in the areas of oceanography, geophysics, astrophysics, hydrology and biomedicine. Research facilities include the University of Hawaii (home of the Hawaii Institute of Geophysics, Pacific Biomedical Research Center, Hawaii Institute of Marine Biology, Look Laboratory of Oceanographic Engineering and the Water Resources Research Center), and the State's High Technology Development Corporation which is responsible for the development of industrial parks for high technology use.

The Federal government oversees such R&D agencies as the National Marine Fisheries Service, the Institute of Pacific Islands Forestry, the Environmental Science Services Administration, and the Hawaii Natural Energy Institute.

Private R&D agencies include the Bishop Museum, the Oceanic Institute, and the Hawaii Sugar Planters' Association Experiment Station.

During the period between January 1, 1989 through September 30, 1989, Oahu had an unemployment rate of only 2.6%, the lowest unemployment rate of the major cities in the United States. Major sources of employment include finance, insurance, real estate, wholesale and retail trade, government, agriculture and manufacturing.

F. LAND USE AND CLASSIFICATION

Of the more than 397,000 acres which comprise the island of Oahu, about 63.0%, or 220,550 acres is privately-owned (this is on par with the Statewide average of 61.8%). More than 13% of the land of Oahu (about 48,800 acres) is owned by the Federal government, which is substantially higher than the State average of only 8.1%. The State of Hawaii owns almost 20%, or about 69,100 acres, of the land of Oahu. This figure is less than the Statewide average of 29.4%. The City & County of Honolulu owns about 3.3% of Oahu's land, which is just slightly under the Statewide average of 4%.

Federally-owned land on Oahu includes extensive military holdings (military bases, Tripler Army Medical Center and Pearl Harbor), as well as Federal office buildings, and other Federal buildings. State-owned land includes beaches, historic sites and monuments, government buildings (including the State Capitol), Leahi Hospital in Honolulu and the State Hospital in Kaneohe, the University of Hawaii at Manoa, the Community Colleges, and Department of Hawaiian Home Lands. County-owned lands include county buildings, parks and other County operations

structures.

As mentioned above, 13.9% of the island of Oahu, or more than S1,000 acres, is owned by the Federal government. The remainder of the non-Federal land, some 86%, or 331,000 acres, can be classified as rural land, urban land, rural transportation land and water areas. Rural land accounts for about 81% of the non-Federal land.

Rural land is divided into cropland, which makes up about 28% of the rural land, forest land, which accounts for 39% of this land, and minor land cover, which contributes 5% to the total.

Urban land, as can be expected, accounts for a much larger percentage of the island's land than the other Hawaiian Islands (about 18% of the non-Federal land). Rural transportation lands accounts for about 2% of the non-Federal land, while water bodies account for about 5% of this land.

The largest sector of land on Oahu (about 35% is classified as conservation land, while land classified as agricultural land comprises about 32%, and residential land comprises about 30% of the island. The remainder of Oahu is classified as industrial (about 3%), commercial (less than 1%), and hotel/resort (less than 1%).

MAUI COUNTY

A. AREA

The county of Maui consists of the islands of Maui, Molokai, Lanai and Kahoolawe (Kalawao County, a State hospital settlement on Molokai, is not considered part of the County). Maui County is the second largest county of the State of Hawaii in area, measuring some 1,175 square miles. The island of Maui alone accounts for about three quarters of the County's total area, measuring 728.6 square miles. Molokai's area is 260.9 square miles, Lanai's area is 140.4 square miles, and Kahoolawe's total area is about 45 square miles.

B. GEOGRAPHY

The islands of Maui County are geographically diverse, each island with its own unique beaches, valleys, shorelines, streams, lakes and mountains. Molokai is plotted on the map as 21°05' north latitude and 157°02' west longitude. Molokai has several mountain peaks, most notably Kamamoku (elev. 4,961 feet), Oluki (elev. 4,606 feet), and Kaunuohua (elev. 4,535 feet).

Lanai, located at 20°48' north latitude and 156°57' west longitude on the map, has one major summit, Lanaihale (elev. 3,370 feet), which is found at the southeastern comer of the island.

Kahoolawe, which is found at 20°34' north latitude and 156°34' on the world map, has only two small mountain peaks, Puu Moaulanui (elev. 1,483 feet) and Puu Moaulaiki (elev. 1,434 feet).

The island of Maui stands out among the other islands of the County as having by far the tallest summits and thus the most extreme climate variations. Located at 20°54' north latitude and 156°26' west longitude, Maui is home to Haleakala, a large volcano which has been dormant since 1790. Haleakala, whose elevation is 10,023 feet (Red Hill) and 8,201 (Kaupo Gap), is also sometimes the site of snow and hail. Other major summits include Puu Kukui (elev. 5,788 feet) and the famous Iao Needle (elev. 2,250 feet).

C. CLIMATE

The climate of Maui County is generally mild, with mostly clear and sunny days, tradewinds, and occasional rainfall. As is typical of the Hawaiian Islands, rainfall in Maui County usually is heaviest in the mountain areas, while the beaches and coasts are the driest areas.

Molokai and Lanai temperatures are basically consistent throughout the year, with average temperatures in the mid-70's. Maui temperatures, on the other hand, vary considerably throughout the island. The areas around the beaches (Kihei, Lahaina) can get warm in the summer months, with high temperatures sometimes exceeding 90°F. In contrast, the mountain areas (Kula, Haleakala) can be very cool, with low temperatures reaching 40°F and even falling below that to freezing levels.

Precipitation levels of Maui County are on the whole somewhat low, occasionally resulting in mild droughts in some areas during the summer months. The wettest area in the county is the Hana. area on the island of Maui, with an average annual precipitation of greater than 150 inches.

D. POPULATION

Maui's ethnic mix has no real majority in any group. However, four ethnic populations comprise some 85% of the County's total population. They are: Caucasian (about 26%), Hawaiian/Part Hawaiian (about 25%), Japanese (about 20%), and Filipino (about 16%).

E. ECONOMY

Much of Maui's population boom can be attributed to the County's growth in industry, especially tourism and agriculture, which in turn provide an array of jobs for the County's people.

Tourism has become Maui County's number one industry within the last decade, surpassing long-time chief industries sugar and pineapple. The visitor count increased from 1,111,000 in 1976 to 1,908,780 in 1987, or a growth of about 72 percent.

As a reflection of this growth, the number of hotel rooms has increased tremendously. In February of 1986, there were 13,264 hotel and apartment-hotel units on Maui alone. Even this figure has no doubt increased since then. Molokai and Lanai have far fewer units (575 and 10, respectively), but extensive plans are in the works for major hotel complexes on both islands, so we should expect increases in hotel units as well as visitor-related establishments (restaurants, shops, etc.) in the very near future.

Tourism has become such an important part of the County's economy that, in fact, visitor expenditures are second only to the City and County of Honolulu, more than double the expenditures of Kauai County and quadruple those of Hawaii County. Most visitors are attracted to Lahaina and its resort neighbor, Kaanapali, while country areas such as Hana and Haleakala are also popular spots.

Of course, tourism isn't the only industry of the County. There are a number of industries vital to the County's economy. As mentioned above, sugar and pineapple, though not as active as they once were, remain major industries of the County, especially on Molokai and Lanai.

In addition to these crops, other profitable industries include dairy, beef and other livestock, and produce such as cabbage, lettuce, broccoli, ginger, cauliflower, watermelon, sweet potato, beans, peppers, and corn. The County is also the home of a winery, protea nurseries, a potato chip factory, and a fast-growing aquaculture operation primarily cultivating marine shrimp.

New agricultural industries are also emerging. Presently, the development of cocoa and coffee cultivation is moving along and both industries show promising futures.

Scientific research is another important segment of the County's economy. Public and private funds are being used to develop Kihei Research and Technology Park. The State government has also funded Agritech Industry Maui, an operation formed to market new scientific technologies to help farmers in developing countries.

Haleakala Crater is the site for extensive research on the skies and universe. Several universities throughout the country operate telescopes at the summits observatories. The Federal government also does monitoring at its facilities within the Crater.

While tourism provides many jobs for residents, other major sources of employment include government and related jobs, business and finance, wholesale and retail trade, agriculture, and manufacturing.

F. LAND OWNERSHIP AND CLASSIFICATION

Private landowners account for about 70 percent of all the lands of Maui County. Such lands include hotels and resorts, farms, and businesses (the island of Lanai is almost entirely privately-owned by sugar and pineapple interests).

The State of Hawaii owns about 21 percent of the County's lands, which include the State Department of Hawaiian Home Lands, government buildings and Maui Community College, some historic sites, beaches, and State parks (Kalawao County on Molokai, not considered part of Maui County, is also State-owned).

The Federal government owns about eight percent of County lands (on par with the State average of 8.4 percent). Included in this category are the islands of Kahoolawe and Molokini, Haleakala National Park, and various wildlife, park and military lands.

The County of Maui itself owns the remainder of the County land, which comes to only about 0.2 percent of all land.

Of the approximately 760,000 acres of all lands of Maui County, some 89 percent are zoned as non-Federal rural land. Of this land, about one-third is forestland, and 30 percent is pastureland. The remainder includes cropland, minor land cover uses, urban and built-up land, water bodies, and rural transportation land.

As of June, 1988, more than half (approximately 56 percent) of Maui County land was classified as agricultural, and about 42 percent was classified as conservation lands. The remaining eight percent of County lands were comprised of residential lands (about three percent), industrial lands (about one percent), resort lands (about one percent), and commercial lands (about one percent).

HAWAII COUNTY

A. AREA

The Big Island of Hawaii, which comprises Hawaii County, has an area of 4,034 square miles, making this county by far the largest of the four counties of the State. In fact, the Big Island is almost twice the area of all the other islands of the State combined.

B. GEOGRAPHY

The Big Island of Hawaii is geologically the youngest island in the Hawaiian chain and measures 93 by 76 miles. Its location on the map (Hilo) is 19°43' north latitude and 155°04' west longitude. Ka Lae Point marks the southernmost point of

the United States.

The Big Island was formed by five large volcanoes. Two of these volcanoes, Kilauea and Mauna Loa, plus several smaller ones along the Chain of Craters, are still active today. The tallest summits on the island of Hawaii are Mauna Kea (elev. 13,796 feet), Mauna Loa (elev. 13,679 feet) Hualalai (elev. 8,271 feet), Kaumu o Kaleihoohie (elev. 4,093 feet), Kilauea (Uwekahauna at elev. 4,093 feet, and Halemaumau Rim at elev. 3,660 feet).

Because Hawaii still has active volcanoes, it is not surprising, therefore, that this island has experienced the most earthquakes on record, in number and in magnitude, of all the major Hawaiian Islands. Between 1980 and August 9, 1988, nine of 14 earthquakes (with a magnitude of 5.0 or greater on the Richter scale), which occurred in the State of Hawaii, occurred on the Big Island.

C. CLIMATE

Climate varies widely on the Big Island due to extreme ranges of altitude throughout the island. Both the hottest and coldest temperatures on record in the state of Hawaii occurred on the Big Island.

In some coastal areas such as Kailua-Kona, temperatures sometimes exceed 90°F, while inland (in areas such as Kamuela) temperatures are often much cooler, ranging from 50° to 60°F. In the mountain areas, temperatures dip even further; it is not uncommon to see snow on the 14,000-foot peaks of Mauna Loa and Mauna Kea. Rainfall also varies widely throughout the Big Island. In Hilo, one of the wettest and cloudiest spots in the State, average annual precipitation is 129 inches, whereas in Puako and Kawaiahae, on the northwest comer of the island (at about sea level), average annual precipitation is only about 10 inches and six inches, respectively.

D. POPULATION

As of July 1, 1988, the estimated resident population of the Big Island was 117,500, up from 114,400 (representing an increase of about 2.3 percent) from the previous year. Between 1970 and 1988, the Big Island witnessed a rapid population surge, increasing almost 28 percent, well above the State average increase of 13.8 percent during this same time period. Hawaii County is the least dense in population, with an average density of only about 30 people per square mile.

Districts with the largest increase in population (between July 1, 1980 and July 1, 1988) are: South Kohala - 7,900 (+71.1%), Puna - 19,800 (+68.6%), and North Kona - 21,600 (+56.8%). South Hilo, the Big Island's largest district in population with 45,400 (about 40% of the island's entire population), had an increase of only 7.3%.

While there is no ethnic majority among the population of the Big Island, there are several ethnic groups which comprise the majority of the County's population. As of July 1, 1987, those who identify themselves as Hawaiian or Part-Hawaiian constitute the largest ethnic group of the County, with 33,405 in population, or about 31 percent of the County's population. The Caucasian population represents the second largest group, with 26,174 people, or about 24 percent of the County's total population. The third largest ethnic group is the Japanese population, with 22,473 people. This represents about 21 percent of the County's total. Other ethnic groups which are present include: Filipino (about 9%), and Chinese (about 2%).

E. ECONOMY

Some of the major industries on the Big island are cattle ranching and dairy operations, agriculture and farming, and scientific research and development. The Parker Ranch, located in Kamuela, is one of the largest cattle ranches in the country. This ranch, along with many small, family-owned ranches throughout the island, accounts for about 61 percent of all cattle and livestock production in the entire State. Agriculture and farming is another major industry in the County. Crops include sugar, taro, fruits (bananas, papayas, guavas, and tangerines), and vegetables (cabbage, tomatoes, cucumbers, and ginger). Because of the Big Island's unique climate, several crops are cultivated solely on this island. They are macadamia nuts, coffee (the only site in the country), oranges, and flowers such as anthuriums orchids and roses. The Big Island is also the only island in the State that has never grown pineapple. However, efforts are presently underway to cultivate this crop, thus establishing another viable industry for the County.

Products which are manufactured on the Big island include macadamia nut candies, jellies and syrups, beverages, Hawaiian sportswear, concrete products, and heavy equipment.

Scientific research and development also plays a significant role in the island's economy. The summit of Mauna Kea is regarded by many as the best site in the world to study the universe. Mainland universities (Cal-Tech, University of California), the University of Hawaii, and foreign countries (Canada, France, United Kingdom and the Netherlands) operate telescopes on the summit.

Hawaii County is also quickly becoming a world leader in alternate energy development, successfully undertaking geothermal electricity generation, biomass, wind farm and other alternate energy projects.

Tourism is an important industry of the County, but unlike the other counties, it is not its leading industry. In 1987, there were 782,550 visitors to the island, a decrease from the previous year of 786,930. Still, the future of tourism on the Big Island looks very good, as several major super luxury hotels have recently been completed, and plans are in the works for several more. Favorite attractions include Kona, Hawaii Volcanoes National Park, Mauna Kea summit, and various cultural and

sports events.

There are also a number of industries in their infant stages. Among them are timber, high-tech industrial parks, and aquaculture (including abalone and lobster propagation).

Major sources of employment in Hawaii County include business and finance, hotels and service industries, government, wholesale and retail trade, agriculture, and manufacturing.

F. LAND OWNERSHIP AND CLASSIFICATION

Of the 2,497,055 total acres comprising the Big Island, slightly more than half (1,448,537 acres or 58%) is privately-owned. Most of this land is farmland (including the Parker Ranch which makes up 16% of this total) as well as single-family home parcels and commercial land. The remainder of the island is made up of Federal land (229,848 acres, or about 10%, higher than the Statewide average of 8.1%), State land (one-third of the total, or 817,391 acres, higher than the Statewide average of 29.4%), and County land (less than 1%, or 1,278 acres, lower than the Statewide average of 4%).

Federal land includes land used for military training and education, NASA's pre-spaceflight exercises and maneuvering, National Parks and landmarks, and scientific research and development. State land includes beaches, historic sites, buildings, Hilo State Hospital, University of Hawaii at Hilo, parks, and Department of Hawaiian Home Lands. County lands include buildings, parks and County operations. Of the almost 2,500,00 acres comprising the Big island, about 10 percent is Federal land. The remainder of the non-Federal land can be classified as rural land, urban land, rural transportation land and water areas.

Rural land, which makes up almost all of this non-Federal land (about 98%), is divided into forest land (about 39%), minor land cover (about 31%), pastureland (about 28%), and cropland (about 4%).

Urban land accounts for about two percent of the non-Federal land, rural transportation land accounts for less than one percent, and water bodies also account for less than one percent.

Land classified as conservation land accounts for slightly more than half of the island (about 51%), while land classified as agricultural land accounts for slightly less than half of the island (about 48%). The remainder of the island can be classified as residential (about 2%), commercial (less than 1%), industrial (less than 1%) and hotel/resort (less than 1%).

Note: The figures from this section were obtained from the Hawaii Data Book, 1988 c. State of Hawaii, Department of Business and Economic Development, November, 1988. Land use classification statistics vary considerably among sources.

IV. WATER SYSTEM AND ORGANIZATION

STATE OF HAWAII WATER SYSTEMS

Water systems which are State-owned and operated fall under various State department jurisdictions. The following is a list of these departments which oversee the State water systems:

1. Department of Land and Natural Resources
2. Department of Agriculture
3. Department of Health
4. Department of Hawaiian Home Lands
5. Department of Corrections
6. Department of Social Services
7. Department of Transportation
8. Department of Education

The Department of Land and Natural Resources operates 25 water systems, supplying surface and groundwater for recreational and residential use, on the major Hawaiian Islands. These include Kaumahina (Maui), Kokee (Kauai), Waialala (Maui), Kahana (Oahu), Polihale (Kauai) and Maunakea (Hawaii).

Three private farms obtain water through water systems under the control of the Department of Agriculture. The Department sells water to the farmers at nominal rates. The farms are:

1. Waimanalo irrigation - uses groundwater and surface water from five streams, and services about 75 farmers

2. Molokai Irrigation - uses both surface and groundwater and services about 180 farmers

3. Waimea Irrigation (Big Island) - uses groundwater and surface water from streams in Waipio Valley and services three areas, two at Pukapu Homestead and one at Lalamilo Farm Lots, and services about 100 farmers

4. Kahuku Agricultural Park (probably open in 1990) - Will service about 100 farmers, and will use groundwater from a well owned by the Estate of James Campbell

The Department provides only irrigation water to these farm lots. Water required for domestic use is obtained from County water systems.

The State also operates water systems for:

1. Hawaii State Hospital and Waimano Home on Oahu under the Department of Health (serving more than 2,200 people)

2. Waiawa Correctional Facility on Oahu under the Department of Corrections (serving more than 200 people)

3. Kulani Correctional Center on Big Island under the Department of Social Services (serving about 200 people)

4. Anahola Farm Lots on Kauai and Hoolehua Farm Lots on Maui under the Department of Hawaiian Home Lands (serving more than 1,700 people)

5. Mokuleia Beach Park (site of handgliding) on Oahu under the Department of Transportation (serving about 1,800 people)

6. Lahainaluna High School on Maui under the Department of Education (serving about 800 people)

Each State department is managed by a department head appointed by the Governor. Deputies appointed by the department head assist in department operations, and other personnel such as engineers, administrators, planners, branch and division supervisors, and support staff round out the department structure.

Presently, the State Department of Health (DOH) collects and analyzes all bacterial and chemical samples. However, the DOH is planning in the near future to have the individual State agencies collect their own water samples and submit them to the DOH for analysis.

Operating funds are obtained through each department's annual budget determined by the State Legislature and approved by the Governor, and through any revenues obtained from water sales.

COUNTY WATER SYSTEMS

1. KAUAI COUNTY WATER SYSTEM

The Kauai County Department of Water was established by the County Charter in 1968 and became effective on January 2, 1969. During the next 15 years, there were numerous amendments to the Charter; the latest mandatory charter review was completed in 1984.

The Department consists of a board of water supply, manager and chief engineer, and staff. The seven-member board consists of five members appointed by

the mayor with the approval of the County Council. The remaining members are the State district engineer of the Department of Transportation, and the County Engineer.

The Kauai County board manages, controls, and operates the waterworks of the county and its properties. The board is also responsible for collecting, receiving, expending and accounting of monies derived from the sale of water and other operations. A financial account of all management and operational activities is submitted in a quarterly report to the mayor and the City Council.

Rates and charges are determined by the board. The board also makes and amends rules and regulations relating to management, control, operation, preservation and protection of the waterworks.

The board has the power to appoint a manager and chief engineer. The engineer's duties and powers are determined by the board.

2. HAWAII COUNTY WATER SYSTEM

The Board of Water Supply of the County of Hawaii was created by the Territorial Legislature in 1949 as a semi-autonomous board to manage the County's waterworks. On January 1, 1950, the properties and functions of the bureau were transferred to the new Board of Water Supply.

In January of 1969, the first County Charter was adopted, and the Board of Water Supply was renamed the Department of Water Supply of the County of Hawaii. Few administrative changes were made, and to this day, the Department has retained its semi-autonomous status.

The Department of Water Supply of the County of Hawaii operates under a Water Commission, a nine-member commission whose duty is to manage, control, and operate the Department and its properties. The Commission, which includes members representative of the geographical areas of the County, also includes the Departments manager, planning director and chief engineer who possess no voting powers.

In most aspects, the Department is independent of the County government although its employees are in the same employee bargaining unit and go through county civil service procedures in personnel administration. In addition, the County Corporation Counsel represents and advises the Department.

The Department has three major divisions: Finance, Engineering and Operations. It operates 22 separate water systems throughout the County and is financially independent.

3. MAUI COUNTY WATER SYSTEM

Prior to January 1, 1989, the Maui County Department of Water Supply was under the complete jurisdiction of the County Mayor and City Council.

Under Chapter 11 of the Revised Charter of the County of Maui (1983), the status of the Maui County Department of Water Supply was changed to provide for management of the department under a nine-member board of water supply appointed by the mayor, with the approval of the City Council (these Amendments to the Revised Charter of the County of Maui were approved by a majority of the voters at the General Election on November 8, 1988). Also on the board is the Planning Director and the Director of the Department of Public Works. They are non-voting, ex-officio members.

In addition to the board of water supply, the Department of Water Supply consists of a director, a deputy director and staff.

The primary function of the board is to adopt rules and regulations to the management, control, operation, preservation and protection of the waterworks. The adoption, amendment and repeal of such rules and regulations, however, are subject to the approval of the Mayor and the City Council. The County Council has the power to overrule any recommendation by a two-thirds vote of its entire membership.

The board also establishes rates and charges for furnishing water, establishes an annual operating budget, and appoints a director.

4. CITY AND COUNTY OF HONOLULU WATER SYSTEM

All water functions in the City and County of Honolulu were under the Honolulu Water Works, under the administration of the Territory, until 1914 when it was transferred from the Territory to the City and County by legislative act. In 1925, in response to the growing problem of adequacy of sewer and water service, the Territory created the now defunct Sewer and Water Commission, thus morally assuming the responsibility of solving the water and sewerage problems of the City and County.

In 1929, upon the recommendation of the Sewer and Water Commission, the Legislature created the Honolulu Board of Water Supply and conferred upon it the responsibility and authority to meet the then growing problems of water supply adequacy and threatened sea water encroachment and to plan for the future growth of Honolulu.

The Board of Water Supply thus established became a semi-autonomous board with executive powers to set water rates, sell bonds for its capital improvements program, promulgate rules and regulations having the force and effect of law, and appoint a chief executive officer (Manager and Chief Engineer) with the authority to

hire and fire employees.

The Board consists of five members appointed by the Mayor for staggered five-year terms and two ex-official members, the Director of Public Works of the City and County of Honolulu, and the State Director of Transportation.

The employees of the Water Department operate under the civil service rules of the City and County and the department is subject to performance audits by the City Council. The broad powers of the Board are generally in effect under the Honolulu City Charter.

FEDERAL WATER SYSTEMS

In the state of Hawaii, the Federal government supplies water to its national parks on the islands of Maui (National Parks Service) and Hawaii (U.S. Department of the Interior). These systems are relatively small, affecting few people.

By far the largest Federal water system operation is by the United States Department of Defense. This water system, which serves a total of more than 125,000 people, is operated by two armed services, the United States Army and the United States Navy.

The United States Army serves more than 40,000 people in the Schofield Barracks, Fort Shafter and Tripler Army Medical Center areas. The United States Navy serves more than 85,000 people. The Navy pumps groundwater from the Waiawa Shaft, Halawa Shaft, Red Hill Shaft and Barber's Point Shaft. In addition, the Navy sells water to the United States Air Force for the Hickarn Air Force Base. The Kaneohe Marine Corps Air Station buys its water from the City and County of Honolulu's Board of Water Supply.

Wells are monitored by the State of Hawaii and the Environmental Protection Agency as well as the Public Works Center on daily, weekly, quarterly and semi-annual bases, depending on the type of monitoring done.

The water systems are funded through operating budgets overseen in Washington, D.C. Charges for water are negotiated at higher levels. The systems have their own pumps and the water is provided privately to the military only; they are responsible for maintenance and for distribution to their customers.

QUASI-PUBLIC WATER SYSTEMS

The Public Utilities Commission (PUC) of the State of Hawaii is the agency responsible for overseeing the operations of eight private water systems located on Maui, Kauai, Hawaii, Molokai and Lanai. They are the Kaanapali Water Company (Maui), Kilauea Irrigation (Hawaii), Kohala Ranch Water Company (Hawaii), Lanai

Water Company (Lanai), Miller and Lieb Water Company (Hawaii), Molokai Public Utilities (Molokai), Princeville Water System (Kauai), and Waikoloa Water Company (Hawaii). These operations offer water and sewage services for residential, commercial, hotel, condominium, single-family, agricultural and irrigation use. Kaanapali Water Company, Waikoloa Water Company and the Princeville Water System also provide water for resort golf courses.

Any establishment which is selling water to the public must be regulated by the PUC. There are about 50 other private water operations which are not regulated by the PUC because no sale of water to the public is involved.

The PUC is managed by three commissioners appointed by the Governor. These commissioners serve six-year terms and determine each company's rates, and establishes each company's own unique set of rules and regulations for operations.

in order for a private company to be recognized by the PUC, it must first get a Certificate of Public Convenience and Necessities, and then file an application declaring area to be served, number of people affected, cost to operate the system, and how much capital has been invested into the system to date.

Rates are based on the type of consumer served: residential, commercial, single-home, condominium, and agricultural. Prior to the adoption of rates, a public hearing is held by the PUC and the Consumer Advocates Office (CAO). The PUC and the CAO have the right to call hearings to evaluate operations periodically, and to determine any changes (increase or decrease) in rates to be charged to the consumer.

PRIVATE WATER SYSTEMS

There are about 50 private water systems in the state of Hawaii which are not regulated by the Public Utilities Commission. At present, the State Department of Health (DOH) collects and tests all of these water systems periodically. However, in the near future, the establishments themselves will collect the samples and turn them over to the DOH for analysis.

Listed below is brief information on 10 of the major private water systems in Hawaii. All are located on Oahu.

1. Waialua Sugar Company
   Population Served: 350
   Source: Groundwater

   The Waialua Sugar Company's water system is operated by the Waialua Sugar Company's Electrical Department. The water is provided to the employees free of charge. The President-Manager of the system reports to the Board of Castle & Cooke, the owner of Waialua Sugar.

The system is funded through Castle & Cooke's annual budget. The State DOH makes periodic checks of the water.

2. Del Monte Corporation
Population Served: 750
Source: Groundwater

Del Monte Corporation (DMC) uses potable, processing and irrigation water in its operations. Also, DMC sells water to farmers and cattle raisers, the cost of which is included in their leases.

Although a manager is responsible for the overall system operation, the corporation's Housing Department is in charge of such day-to-day operations as chlorination and maintenance.

The State tests the water supply monthly. The system is funded through DMC's general operations budget.

3. Punahou School
Population Served: 4,000
Source: Groundwater

Punahou School provides water free of charge to its campus, including faculty housing and dormitories. The water system, operated by the school Physical Plants Department, is funded through Punahou's annual operations budget. The water quality is checked weekly by the State DOH.

4. Zion Securities
Population Served: 7,000
Source: Groundwater

Zion Securities, a business firm headquartered in Salt Lake City, Utah, provides water and sewage services to the town of Laie on Oahu's North Shore. Zion also owns most of the land in Laie. Zion previously serviced the nearby town of Hauula as well, but has since turned that operation over to the City & County of Honolulu Board of Water Supply (BWS).

A local manager and business staff run the operation. Rates and charges to its customers are similar to those charged by the BWS. It is speculated that by 1995, the BWS will take over the operation entirely.

The State DOH checks the water quality twice each week.

5. Kamehameha Schools
Population Served: 3,700
Source: Groundwater

The Kamehameha School's water system, run by the school's Physical Plants Department and operated by the school Board of Trustees, is funded by the Bishop Estate. The Kamehameha School provides free water to various campus entities such as the swimming pool, irrigation, dormitories, faculty housing and, and cafeteria. The State DOW checks the water monthly.

6. Dole Cannery
Population Served: >1,200
Source: Groundwater

The Dole Cannery water system provides water to its employees for cannery processing needs, and for domestic use (restrooms, cafeteria, drinking, etc.). There is no charge for the water.

The system, which has been in operation prior to 1930, is run by Dole's Mechanical Utilities Division, part of the company's Shops and Services department. The Department is managed by a planning engineer. Dole's parent company is Castle & Cooke Foods.

An estimate of operating costs for the system, which includes maintenance, distribution and pumping, is submitted, along with other utility costs (air conditioning, electricity, etc.) to Dole Packaged Foods division in California, subject to revision.

The State DOH checks the water more than once a month for coliform, bacteria and chlorine levels (Dole applies 0.2 mg/I chlorine in all its water).

The Dole Cannery Tour, where visitors stop to sample the pineapple and to visit the plantation, is operated by Oceanic Properties, another Castle & Cooke subsidiary. Its water system is run by the BWS.

7. Queens Medical Center
Population Served: 1,200
Source: Groundwater

The Queens Medical Center Gets its water from a private water system owned and operated by the Queens Health System. The water system also serves the Queens Physicians' Office Building (QPOB), but not the Mabel Smyth Auditorium, which is served by the BWS.

The Facilities and Building Services Department operates and maintains

the water system, while the Fiscal Office oversees all operating costs. The water is provided free of charge to the Hospital building and campus. Tenants of the QPOB are charged for this water.

The State DOH checks the water periodically.

8. Sheraton Hotels
Population Served: 2,830
Source: Groundwater

Sheraton Hotels Hawaii provides potable water for three of its hotels--the Princess Kaiulani, Royal Hawaiian and Moana. Water is used for guest accommodations, cooking, housekeeping, landscaping and general maintenance.

The well, located on the grounds of the Princess Kaiulani Hotel, is owned by Sheraton Hotels Hawaii's parent company, Kyo-Ya Company, Ltd.

Operating funds for the water system are derived from Kyo-Ya's general budget. The system is operated by the company's Engineering Division and is managed by a Chief Engineer.

The State DOH checks the well periodically.

9. Oahu Sugar Company
Population Served: 1,356
Source: Groundwater

Oahu Sugar Company is owned and operated by American Factors (AMFAC). The company provides potable water (for employee housing) and non-potable water (for irrigation and processing) for operations. Water is provided to employees free of charge or for a nominal fee. This charge is not adequate to operate the water system on a self-sustaining basis.

The water system is operated by Oahu Sugar's Engineering Division under the supervision of the Division Manager. The Manager reports to AMFAC's board of directors. Oahu Sugar Company's water system operation is funded by the plantation's general fund and budget. The system is checked periodically by the State DOH.

10. Hawaii Country Club
Population Served: 800 patrons daily, 40 employees
Source: Groundwater

The Hawaii Country Club (HCC) owns and operates a well for its golf course maintenance and course facilities. It has been operating since the early 1960's. The HCC employs a private contractor to oversee the general operation of the well.

The water is chlorinated once each month and is tested every two to three days by the HCC's manager of maintenance. In addition, the State DOH tests the well periodically.

V. INVENTORY AND ASSESSMENT OF RESOURCES

AQUIFER CLASSIFICATION

In the Hawaiian Islands, the occurrence of groundwater resources is highly variable in extent and type. Aquifers range from being quite limited in size to being very extensive, and from being isolated to being connected with other aquifers. The variety of aquifer types is great in which groundwater ranges from unconfined in sedimentary deposits to confined in basal lenses resting on seawater. This array of aquifer types and groundwater occurrences cannot be sensibly incorporated into hydrographic divisions based on topography or political boundaries. Because groundwater is the premium water resource in the State, classification based on aquifer and groundwater parameters is desirable.

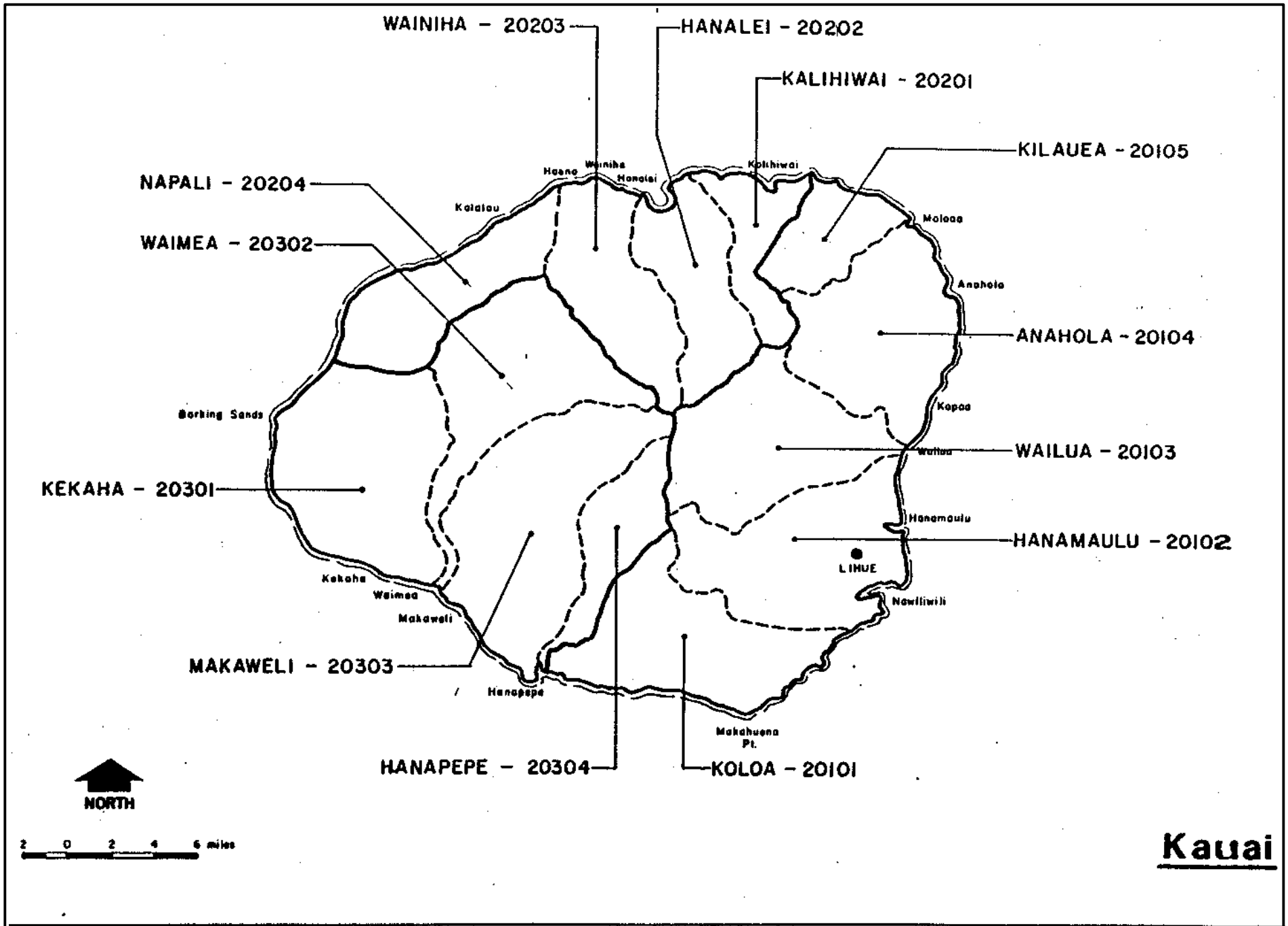
A consistent scheme of classification and nomenclature for the aquifers of the State of Hawaii has been created to assist in planning studies. The effort was initiated several years ago by the State Department of Health in response to U.S. Environmental Protection Agency directives and is being formulated by the Water Resources Research Center of the University of Hawaii.

Aquifer classification starts with an island as the largest component in the hierarchy, following by Aquifer Sectors and Aquifer Systems. Eventually Aquifer Types and Aquifer Units will be identified, but for general planning purposes, the Sector-System categories are sufficient.

Each island is divided into Aquifer Sectors which reflect broad hydrogeological similarities yet maintain traditional hydrographic, topographic and historical boundaries where possible. Aquifer Systems are more specifically defined by hydraulic continuity among aquifers in the System.

Each island is identified by its USGS number (1=Niihau, 2=Kauai, 3=Oahu, 4=Molokai, S=Lanai, 6=Maui, 7=Kahoolawe, and 8=Hawaii) as the first digit in the Aquifer Code, followed by two digits for an Aquifer Sector, followed by two more digits for an Aquifer System. Sectors and Systems are also assigned names. Hawaiian place names are preferred, but for some Sectors geographic orientation such as North, East, South, West, Central and Windward are required for clarity. All Aquifer Systems have Hawaiian names.

Simplified maps of Aquifer Sectors and Systems in the principal Hawaiian Islands are shown on the following pages. Detailed maps are included in the Appendix.



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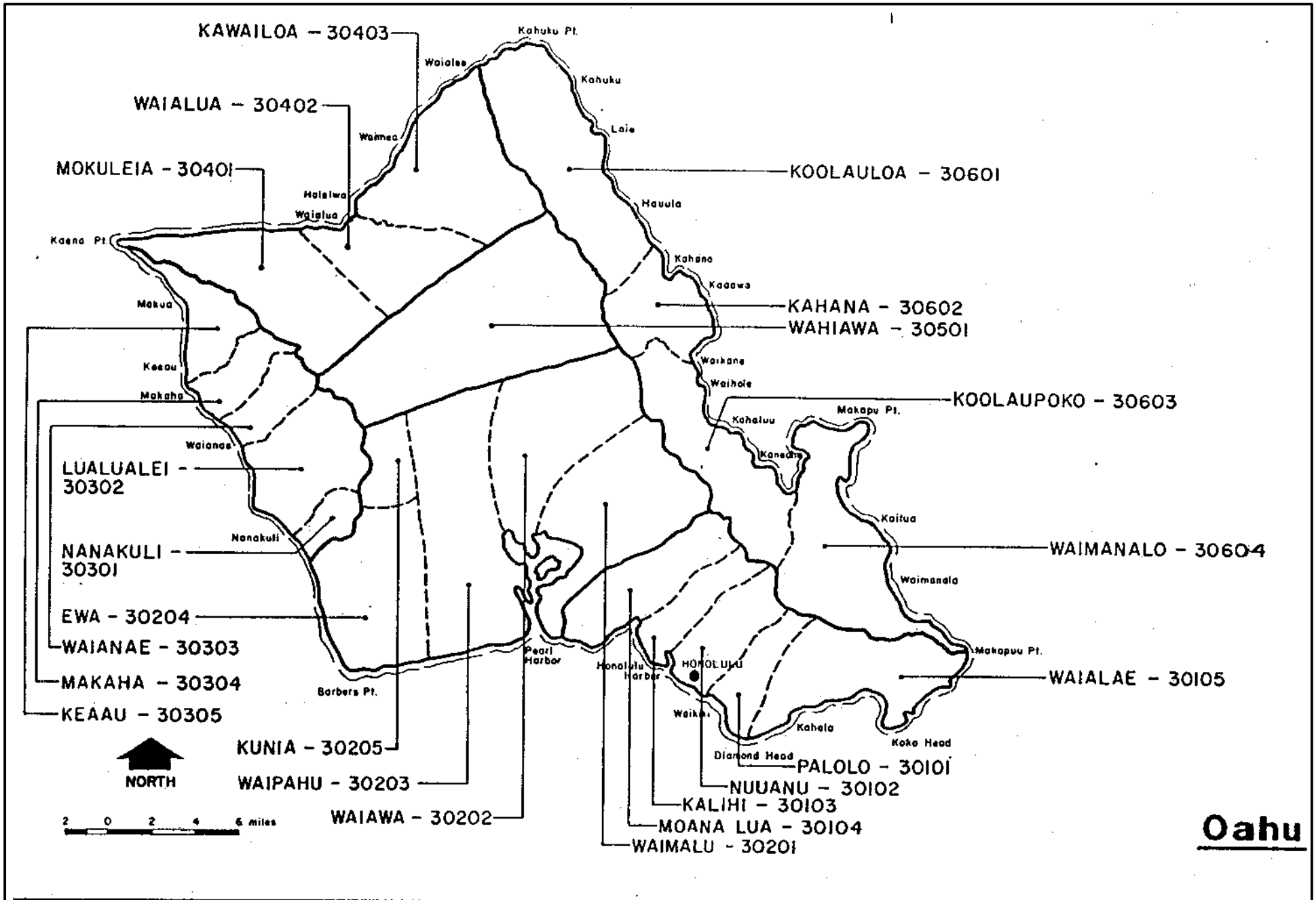

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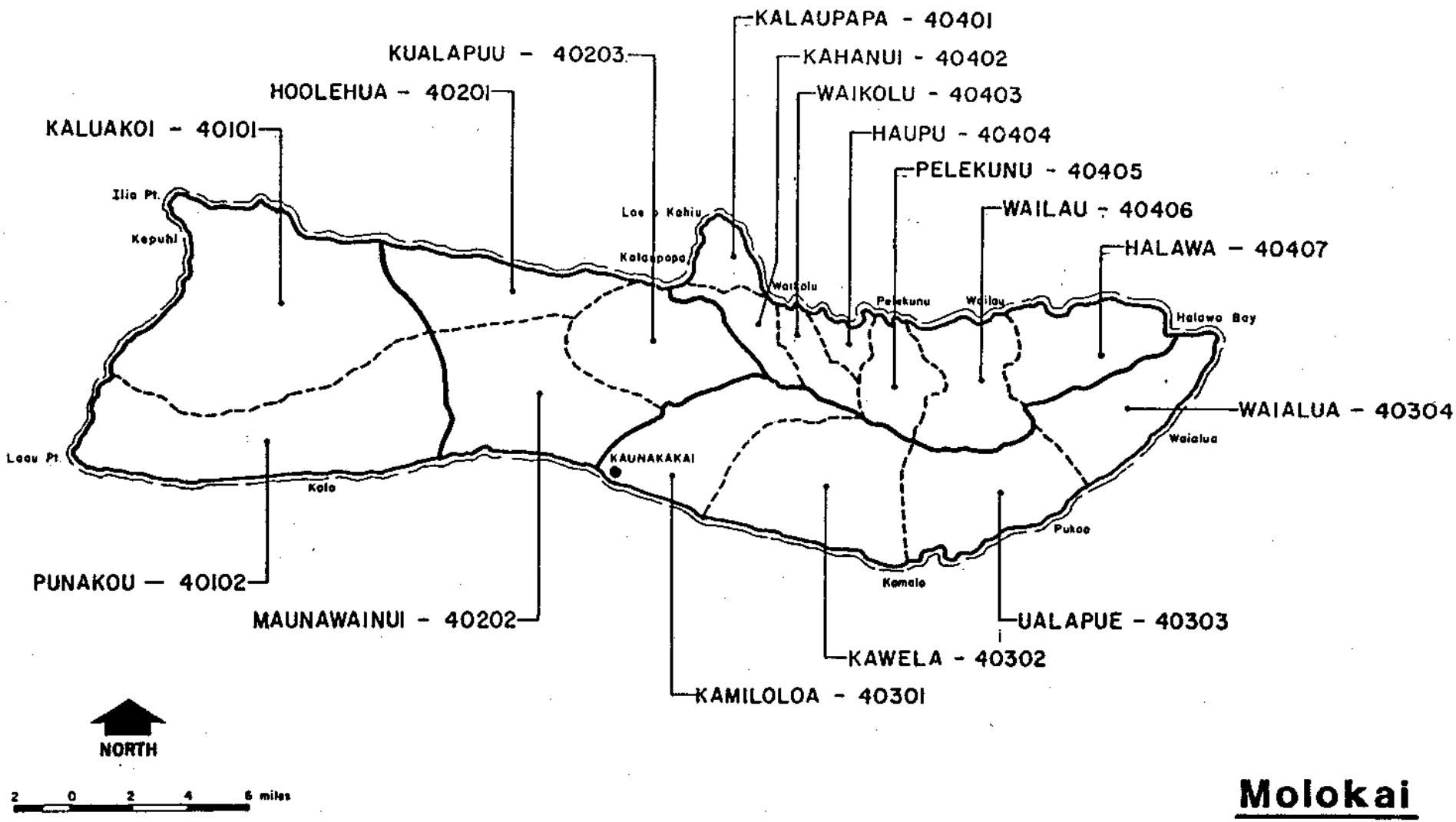

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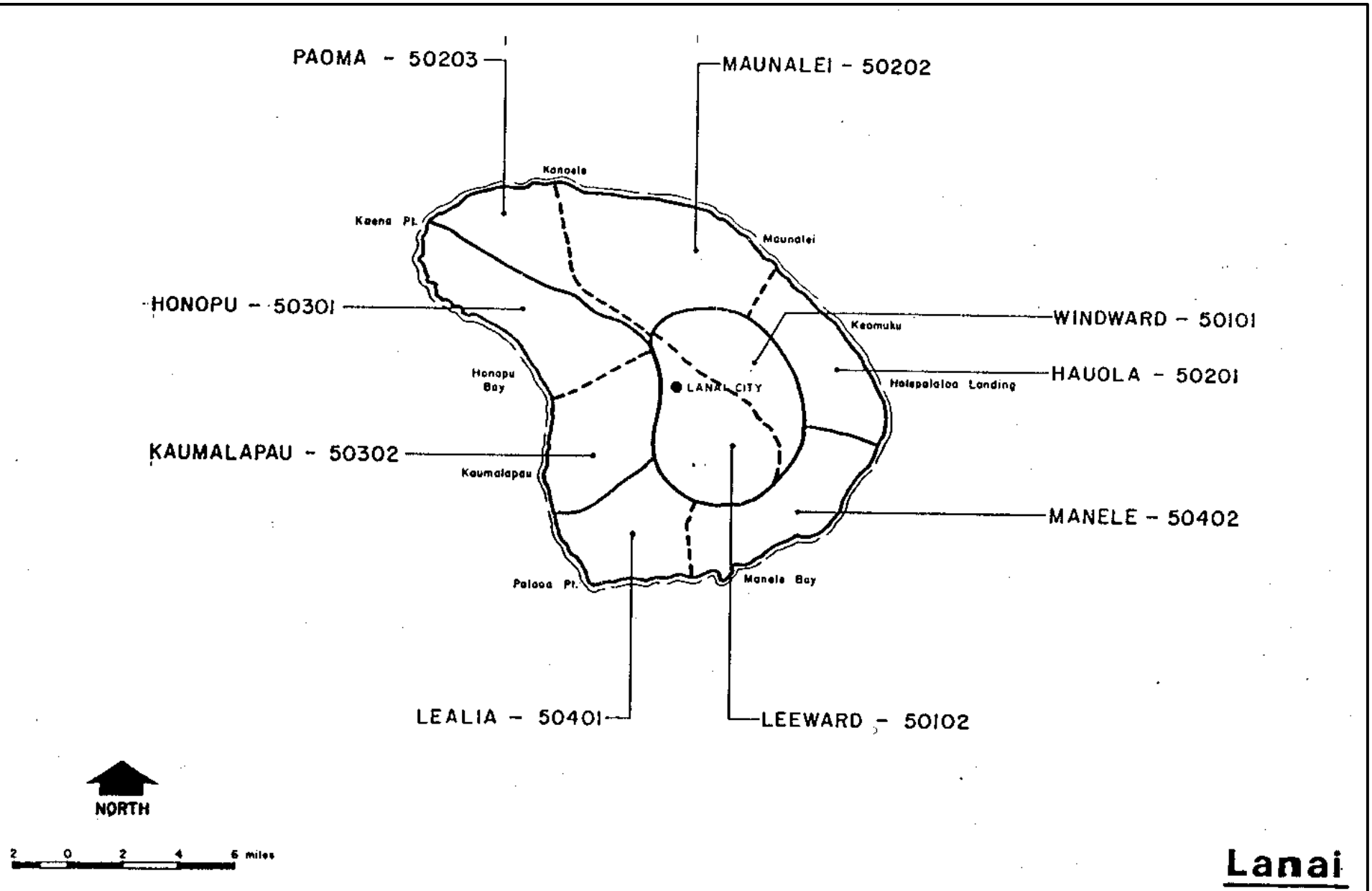
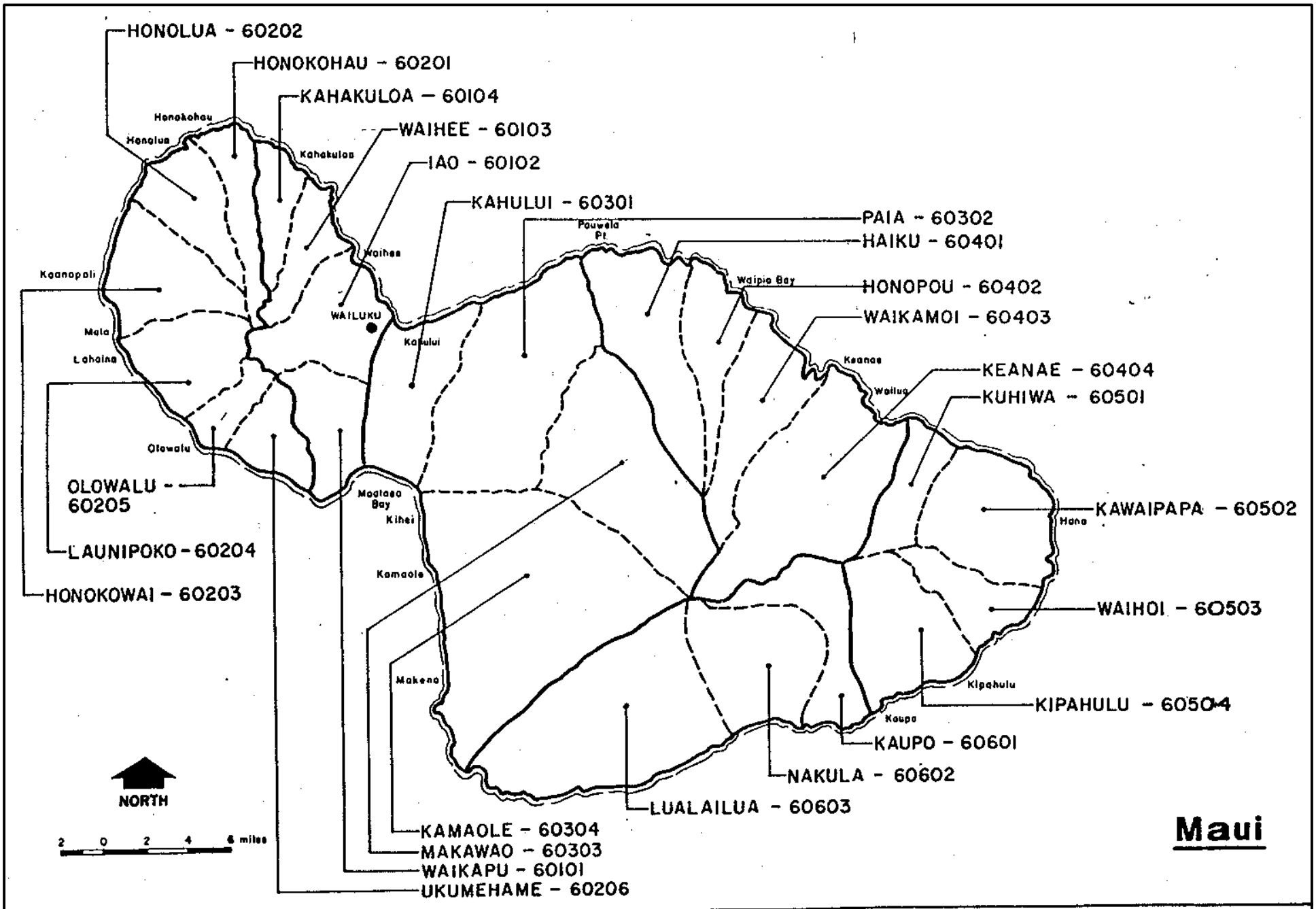
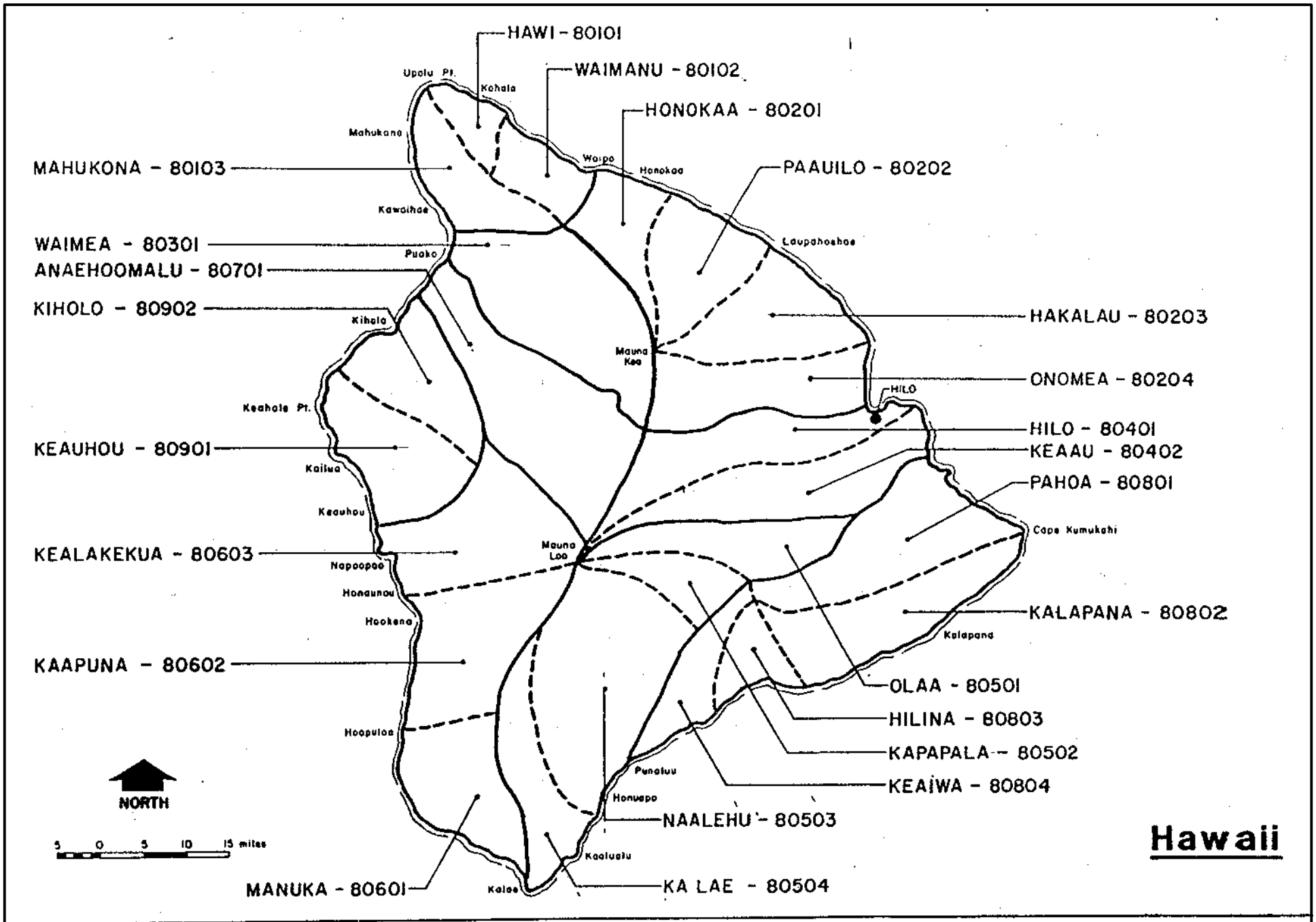


HYDROLOGIC UNITS - ISLAND OF LANAI



HYDROLOGIC UNITS - ISLAND OF MAUI



HYDROLOGIC UNITS - ISLAND OF HAWAII

SUSTAINABLE YIELD

Sustainable yield refers to the forced withdrawal rate of groundwater that could be sustained indefinitely without affecting either the quality of the pumped water or the volume rate of pumping. It depends upon the head selected as the minimum allowable during continuous pumping. Head is the elevation of the unconfined water table above sea level. There is not a unique value for sustainable yield; the value depends on the head that will preserve the integrity of the groundwater resource at the level decided upon by the manager.

Sustainable yield is equal to a fraction of the recharge. In a basal lens the fraction is usually more than half and sometimes greater than three fourths where initial heads are high. In high level aquifers about three fourths of the recharge can be taken as sustainable yield.

The simplest way to understand the behavior of a groundwater system from the management point of view is to treat the system as a single unit exhibiting global rather than local response behavior. At the equilibrium state, global sustainable yield depends on the initial head, the rate of recharge and the selected equilibrium head. A sustainable yield exists for each value of an equilibrium head between the limits of head greater than zero (0) and less than the initial head. Sustainable yield is always less than recharge. If it were to equal or exceed recharge, head would eventually go to zero because outflow from the aquifer is a combination of natural leakage and draft. For a sustainable yield to exist, a balance must be established among leakage, which is controlled by head, draft and recharge.

Sustainable Yield Estimates

Good estimates of sustainable yield need a reliable data base. In most of the State not enough is known about the extent and behavior of groundwater to allow more than a weak estimate of sustainable yields. Only in Southern Oahu, Lanai and West Maui, where many years of investigation have been devoted to unraveling the complexities of groundwater occurrence, can the sustainable yields be accepted with confidence.

The sustainable yield estimated for each Aquifer System in the State is based on a simple pre-development water balance equation. The output components of runoff, evapotranspiration and infiltration are equated to rainfall as follows:

$$P = ET + RO + I$$

in which P is average rainfall, ET is average evapotranspiration, RO is average runoff and I is average infiltration (recharge). The balance was computed for each Aquifer System using averages based on the data record. The averages incorporate high level and basal aquifer regions but exclude caprock areas.

The estimates were limited to basal aquifer conditions except where high level groundwater is dominant or reaches to the coast. The typical sequence of aquifers in

the Hawaiian Islands is from a zone of high level water in mountainous regions to a basal aquifer terminating either at the coast or beneath caprock some distance off the coast. Groundwater in the high level aquifers passes into basal aquifers. Where groundwater is removed directly from a high level source, the sustainable yield calculated for the basal aquifer must be reduced.

The estimates of sustainable yield are not meant to be an exact number which could be used in final planning documents. The estimates are constrained not only by the scanty data base but also by the fact that they do not consider the feasibility of developing the groundwater. The estimates should not be equated to developable groundwater. In many regions, taking advantage of a high estimate would not be economically feasible.

Considerations restricting the unqualified use of the sustainable yield estimates are as follows:

1. The estimate is computed by the water balance method for pre-development conditions. This means that transfer of water from one Aquifer System to another for irrigation is not taken into account in the System affected by recharge from surplus irrigation.

2. The sustainable yield is correlated with an equilibrium head chosen on the basis of experience in the islands. The experience may not be relevant to a given aquifer, however. An equilibrium head higher than the one selected would result in a lower sustainable yield, and the converse would be true for a smaller equilibrium head.

3. Assumptions about the state of an aquifer may be faulty, in particular a value for the initial head.

4. Sustainable yield is calculated as the total supply developable. In most cases the estimate would be potable where optimal extraction techniques were employed, but in some instances none of the estimate would be potable.

S. The sustainable yield estimate should not be equated to feasibly developable water, either technically or economically.

In view of the above limitations, the sustainable yield estimates should be used as a guide in planning rather than an inflexible constraint.

A discussion of sustainable yields for each Aquifer Sector and System in all islands except Niihau and Kahoolawe follows. An appendix includes tables of basic data and a discussion of the method employed in determining the estimates.

KAUAI - AQUIFER SYSTEM SUSTAINABLE YIELDS

The sustainable yields of groundwater for the Aquifer Systems of Kauai are diff[cult to estimate because of the complex relationships among the various types of groundwater and between groundwater and surface water. Wherever the Koloa volcanics are the dominant rock type, perched groundwater is widespread in discontinuous aquifers and masks the presence of basal water. Beneath the aquifers in the Koloa formation, high level and basal groundwater may exist in the basement rock of the Napali volcanics. Adding to the uncertainties of water provenance are numerous large perennial streams which drain high level and perched aquifers.

The Koloa formation dominates all of the Aquifer Systems of the Lihue Aquifer Sector. It is also hydrogeologically important in the Hanapepe and Makaweli Systems of the Waimea Aquifer Sector. In the Lihue Sector the estimated sustainable yields are derived on the assumption that exploitable basal lenses exist. However, nowhere has an extensive lens been discovered.

The major streams and most minor ones are sustained in large measure by groundwater drainage. The streams of the western half of the island receive high level dike-impounded water, while those in the east are fed by high level dike aquifers in the interior and perched aquifers in the lower lands. As much as 75 percent of the rainfall completes its path in the hydrologic cycle as stream flow in the region dominated by Koloa rocks; about 50 percent flows away where streams cut the rift zone of the Waimea Canyon volcanic series in the western part of the island.

Although a large fraction of stream outflow is derived from groundwater, this fraction is included in total groundwater flux in the computation of estimated sustainable yields. If the sustainable yields were realizable, stream flows would decrease in some proportion.

Aquifer Sector: Lihue

Aquifer System: Koloa [20101]

Groundwater occurrence and behavior is controlled by the Koloa formation which covers the System except for isolated ridges of the Napali volcanics located inland. Perched and basal groundwaters occur in the Koloa, and high level and basal groundwaters probably exist in the Napali formation below its contact with the Koloa. The coast is not rimmed with sediments.

The estimated sustainable yield of 30 mgd assumes capture of infiltration before it drains into streams. The estimate is speculative.

Aquifer System: Hanamaulu [20102]

Virtually the entire System is mantled with the Koloa formation. The major stream valleys contain tongues of alluvium which are not effective as caprock. Perched water in the Koloa is the most common type of groundwater, but basal water occurs near the coast.

As in the Koloa System the estimated sustainable yield of 40 mgd includes stream flow that once was groundwater. It is not a reliable estimate.

Aquifer System: Wailua [20103]

The drainage basin of the Wailua River comprises the System. Drainage is chiefly from the Koloa volcanics, but important input of high level dike water from Napali rocks in the interior contributes to stream flow. The perched and dike water are responsible for a large base flow in the river. Basal groundwater occurs near the coast.

The estimated sustainable yield of 60 mgd includes groundwater which eventually leaves the System as streamflow. The estimate is not reliable.

Aquifer System: Anahola [20104]

The System includes a segment of Napali volcanics in the Makaleha Mountains but chiefly consists of Koloa rocks. Large patches of sediments also occur but do not behave as caprock. High level dike groundwater exists in the Makaleha Mountains, while perched aquifers are common in the Koloa formation. A basal lens in the Koloa lies near the coast.

The sustainable yield was computed as if exploitable basal water were in the Koloa formation. The estimate of 36 mgd is not reliable.

Aquifer System: Kilauea [20105]

Numerous small streams and the larger Kilauea Stream drain the System. The Koloa formation is dominant; segments of Napali rocks are exposed in the interior. A small quantity of sediments occurs, but none form a caprock.

Perched and basal aquifers occur in the Koloa. The speculative estimated sustainable yield of 17 mgd refers to basal conditions.

Aquifer Sector: Hanalei

Aquifer System: Kalihiwai [20201]

The drainage basin of Kalihiwai Stream constitutes most of the System. The Koloa formation covers almost the entire basin. Basal water occurs near the coast and perched aquifers inland.

The sustainable yield of 16 mgd is an estimate based on the assumption that all groundwater becomes basal before discharging at the coast. The estimate is not reliable.

Aquifer System: Hanalei [20202]

Except for isolated patches of the Koloa series, the System is covered by the Olokele formation and the Napali member of the Waimea Canyon volcanic series. Alluvium covers major valley floors and forms a coastal plain at the mouth of Hanalei River, but it is not an effective caprock. High level dike water drains to Hanalei. Toward the coast dikes occur, but the groundwater becomes basal.

The estimated sustainable yield of 35 mgd depends on movement of an groundwater to the basal zone. Hanalei River, however, captures much groundwater drainage. The estimate is not reliable.

Aquifer System: Wainiha [20203]

Two major rivers, Lumahai and Wainiha, drain a terrain almost exclusively composed of formations in the Waimea Canyon volcanic series. In the interior high level water drains from the Olokele member, while toward the coast a rift zone of the Napali member is cut by streams. The deep valleys contain old and recent alluvium, but these sediments do not act as a caprock.

The sustainable yield estimate of 24 mgd assumes exploitation of basal conditions in the rift zone toward the coast. If groundwater were to be developed, it would be preferable to seek high level dike water. The estimate is poor.

Aquifer System: Napali [20204]

Only. the Napali is exposed as basement rock. The region, on the edge of the caldera of the principal volcano, is part of the dike complex of the rift zone. Sediments occur in Kalalau and smaller valleys but do not behave as caprock.

The estimated sustainable yield of 20 mgd is conjectural. The mode of

occurrence of groundwater in the System has not been explored.

Aquifer Sector: Waimea

Aquifer System: Kekaha [20301]

Kekaha is the only System in all of Kauai having a clearly defined basal lens protected by a thick sedimentary caprock at the coast. The basement rock, which is exposed above an elevation of about 100 feet, is the Napali basalt member of the Waimea Canyon volcanic series. A weak rift zone strikes from the caldera area at the head of the Waimea River drainage.

A basal lens underlies the caprock and extends an unknown distance inland. The estimated sustainable yield of 12 mgd refers to basal water. The entire sustainable yield is developed primarily for sugar cane irrigation and partly for domestic use. Much of the water pumped for irrigation is not potable. The estimate is fair.

Aquifer System: Waimea [20302]

The drainage basin of the Waimea River comprises the System. The origin of the river is in the caldera of the main volcano which is covered by the Olokele member of the Waimea Canyon volcanic series. The lower two thirds of the river flows through the Waimea Canyon in which Napali rocks are exposed. Dikes intrude the volcanic formations throughout the System.

The estimated sustainable yield of 42 mgd assumes groundwater development from a basal lens. Much high level groundwater occurs in the interior, but the extent of basal conditions is uncertain. The estimate is speculative.

Aquifer System: Makaweli [20303]

The drainage between the Waimea and Hanapepe Rivers is included in the Makaweli System. The Makaweli and its principal tributary, Olokele, drain most of the region. The Makaweli joins the Waimea River one mile from the coast.

The most extensive formation is the Makaweli member of the Waimea Canyon volcanic series. The headwaters of the Makaweli River reach into both the Napali and Olokele members of the same series. The coastal area is covered by the Koloa volcanic series, which reaches as far as five miles inland. Sediments form the floors of the larger valleys but do not behave as caprock.

The sustainable yield of 30 mgd refers to basal groundwater. The estimate is poor.

Aquifer System: Hanapepe [203041

The drainage basin of the Hanapepe River comprises the System. The interior two thirds of the drainage is covered by the Napali member that probably carries high level dike water. The lower third drains a Koloa terrain. A tongue of alluvium in the valley extends about five miles inland but is not a caprock.

The estimated sustainable yield of 26 mgd assumes development of basal water. It is not reliable.

OAHU - AQUIFER SYSTEM SUSTAINABLE YIELDS

The groundwater resources of Oahu have been more thoroughly studied than those of any other island. Southern Oahu, which encompasses the Honolulu and Pearl Harbor Aquifer Sectors, has undergone the closest scrutiny, and its water resources are better understood than anywhere else.

The Aquifer Systems in the Honolulu Sector have been efficiently exploited for nearly a century. An equilibrium now exists between natural recharge and current removals of groundwater. In the Pearl Harbor Sector changes in areal distribution and rates of application of irrigation have been taking place over the last three decades after nearly half a century of stability. The present arrangement of pumpage for domestic and irrigation demands, and the method and extent of irrigation are in a quasi-steady state as a consequence of the allocation of the resource by the State.

In the remainder of the island the need to control groundwater development has not been as pressing as in Southern Oahu. Nevertheless, the growth of population and increase in economic activity will eventually require the movement of water resources from Windward and Northern Oahu to supply the congested south.

The estimated sustainable yields of the Aquifer Systems is a guide to the developable quantity of potable water under pre-agricultural and pre-urbanization conditions. They are not adjusted for the effects on water balances due to return irrigation, nor do they take into consideration reductions in stream flow where groundwater accounts for the base flow of streams.

Aquifer Sector: Honolulu

The estimated sustainable yield in each Aquifer System is for a large basal aquifer in Koolau volcanics. High level dike and perched groundwaters drain

into the basal lenses from small aquifers in the mountainous regions. A wide coastal plain is the surface of a thick, effective sedimentary caprock which forced the original groundwater head to rise to 42 feet above sea level before balance was attained between inflow and outflow.

Estimated sustainable yields are derived from water balances in conjunction with pumping data from the long history of operation. The estimates for the Palolo System (5 mgd), Nuuanu System (15 mgd), Kalihi System (9 mgd) and the Moanalua System (18 mgd) are among the best in the State. The estimate for the Waialae System (3 mgd) is fair.

Aquifer Sector: Pearl Harbor

The Sector is divided into five Systems of which three - Waimalu, Waiawa and Waipahu - can be combined into one large System because the great basal lens of central and southern Oahu extends in unbroken continuity beneath them. The boundary between Waimalu and Waiawa, and between Waiawa and Waipahu are "synthetic" because they are not strong hydrogeological. divisions. The Ewa and Kunia Systems, on the other hand, are separated from the Waipahu System by the unconformity between the underlying Waianae and the overlying Koolau volcanos. However, the boundary between the Ewa and Kunia Systems also is synthetic and was drawn to separate the region (Kunia System) which is irrigated with water from the Waiahole Ditch from the region (Ewa System) mainly irrigated with well water.

The Waimalu, Waiawa and Waipahu Systems contain a basal lens in the Koolau volcanic series. in the Ewa and Kunia Systems the basal lens is in the Waianae volcanic series. A deep, effective caprock of sediments causes high groundwater heads in all Systems.

Estimated sustainable yields, along with those of the Honolulu Sector, are the most accurately calculated in the State and are highly reliable. They are for pre-development conditions, however. Water balances in the Waipahu, Ewa and Kunia Systems are complicated by recycling of irrigation water, including the transfer of water from the windward side of the island by way of Waiahole Ditch. The pre-development and post-development sustainable yields are discussed on page 82 of the Pearl Harbor Report (George A.L. Yuen and Associates, 1988). The discussion is summarized in the following table.

Aq. System	Pre-Dev. SY mgd	Current SY mgd	Comments
Waimalu	45	45	No irrigation
Waiawa	52	52	No irrigation
Waipahu	50	67	Irrigation
Ewa -Kunia	11	17	Irrigation

The sustainable yields are for an equilibrium head of 18 feet, about half the

original head.

The sustainable yield takes into account spillover from the Wahiawa Aquifer System. In the Pearl Harbor Report the spillover is calculated as 62 mgd to the Waipahu Aquifer System and 14 mgd to the Kunia Aquifer System. Groundwater of the Kunia System flows into the Ewa System.

Aquifer Sector: Waianae

The Sector includes the valleys of Nanakuli, Lualualei, Waianae and Makaha as separate Systems, and Keaau as the System extending beyond Makaha to Kaena Point. Geology is dominated by the caldera and rift zones of the Waianae volcano, and deep sedimentary fill in the valleys.

The Waianae basalt is intruded by dikes all the way to the coast. For some distance inland a brackish to fresh basal lens exists in the dike compartments. Caprock, although thick and extensive, does not play an important role in supporting a fresh water lens. The sustainable yields in each of the Systems refer to high level and basal groundwater in dike aquifers. The estimates are fair.

Aquifer Sector: North

The North Sector includes a System (Mokuleia) in the Waianae formation and two (Waialua and Kawailoa) in the Koolau formation. A deep wedge of sedimentary caprock causes thick basal lenses to exist in the Mokuleia and Waialua Systems. The Kawailoa System, extending from the Anahulu River to Sunset Beach, lacks an effective caprock.

Estimates of sustainable yields are based on water balances computed within System boundaries. The estimate of 9 mgd for Mokuleia is fair, while that of Waialua is understated because spillage from the Wahiawa High Level System is not included. Assuming all of the Wahiawa water moves either north into Waialua or south into Pearl Harbor, the recharge to the north may be as much as 52 mgd.

Spillover is not factored into the sustainable yields of the North Sector. By using the same coefficient employed for determining natural sustainable yield, a total of 37 mgd could be added to the sustainable yield of the North Sector as a result of spillover from Wahiawa.

Aquifer Sector: Central

Only high level groundwater occurs in the Sector. The resource is continuous from the wet Koolau to the drier Waianae mountains. The geologic structure

responsible for the accumulation of groundwater far above sea level (water table about 280 feet) has yet to be identified.

Leakage from the high level aquifer helps sustain the large basal lenses in the Pearl Harbor Sector and the smaller ones in the North Sector. The sustainable yield estimate of 104 mgd assumes that all of it would be withdrawn from within the System. If this were to be the case, then the sustainable yields of the Pearl Harbor and the North Sectors would decrease in some proportion. The estimated sustainable yield of the Pearl Harbor Sector requires a total spillage from Wahiawa of 76 mgd. The Waipahu and Kunia - Ewa Aquifer Systems would be devastated if this spillage were substantially reduced by development of the estimated sustainable yield in Wahiawa.

Aquifer Sector: Windward

The Sector includes a System (Koolaualoa) having a thick basal lens, one dominated by a large stream which is the sink for groundwater (Kahana), another (Koolaupoko) in which high level dike water reaches to the coast, and a fourth (Waimanalo) which is dominated by the caldera complex of the original Koolau volcano.

The basal groundwater resources of the Koolauloa System have been studied in some detail. High level dike water in the interior leaks to the basal lens which is protected at the coast by a deep wedge of sedimentary caprock. The sustainable yield estimate of 42 mgd refers to potable water in the basal lens. However, a more conservative estimate of 35 mgd is being used in planning. The lower value assumes maintenance of a higher equilibrium head.

In the Koolaupoko Aquifer System the estimated sustainable yield of 30 mgd refers to high level water exclusive of that removed by the Waiahole Tunnel for diversion to southern Oahu. This value was computed by the water balance method. Because all groundwater becomes surface or wetland water before escaping to the sea, removal of water for domestic and other uses will decrease surface flows in the same proportion. The given sustainable yield estimate ignores environmental consequences of its development.

The estimated sustainable yield of 15 mgd for the Kahana System includes groundwater which drains to streams. Withdrawal of the sustainable yield will eventually decrease flow in Kahana Stream.

Groundwater in the volcanics of the Waimanalo System is also inseparable from the base flow of streams. Development of the estimated sustainable yield of 13 mgd would deplete stream flow. It would also be extremely difficult to accomplish because of the unfavorable hydrogeological conditions in the System.

MOLOKAI - AQUIFER SYSTEM SUSTAINABLE YIELDS

Aquifer Sector: West

Aquifer System: Kaluakoi [40101]

The System covers the northern two thirds of the extreme western portion of the island. All of the rocks except for hydrogeologically unimportant patches of sediments belong to the West Molokai volcanic series. Groundwater is predominantly basal and occurs in both the flank lavas and the rift zones where dikes control aquifer behavior. The System is large, but to date no fresh groundwater has been discovered and it is improbable that domestic quality water is developable. Brackish groundwater permeates the entire region, most of it having salinity in excess of 1000 mg/l chloride. It is suitable only for salt tolerant plants and crops and for specialty purposes such as aquaculture. The estimated sustainable yield of useable water is on the order of 2 mgd. All potable water and much irrigation water must be imported from further east.

Aquifer System: Punakou [40102]

The weak southwest rift zone of the West Molokai volcano constitutes the System. A narrow rim of sediments lines the coast but not as caprock. Basal groundwater is dominant, but none is potable. The estimated sustainable yield of 2 mgd is brackish.

Aquifer Sector: Central

Aquifer System: Hoolehua [40201]

The System extends northward from the long axis of the island to the coast and east along the axis to Kualapuu. The basement rock is the basaltic lower member of the East Molokai volcanic series. Much of the region is covered by the andesitic upper member. There is not a sedimentary caprock rim at the coast.

The System is underlain by moderately brackish water in a basal lens. Its quality is good for most agriculture but cost of development would be high. The estimated sustainable yield of 2 mgd is good.

Aquifer System: Maunawainui [40202]

The southern portion of the Hoolehua Plain is the Maunawainui System. Like the Hoolehua System to the north, it includes the upper and lower members of the East Molokai volcanic series and is underlain by

moderately brackish basal water. A coastal plain of sediments is a partially effective caprock.

The estimated sustainable yield of 2 mgd is useful for irrigation.

Aquifer System: Kualapuu [40203]

The System is the furthest extension westward from the wet northeast of groundwater meeting potability standards. The lower member of the East Molokai series is exposed in valleys but the upper andesitic member covers the interfluves. The aquifer is basal but groundwater occurrence is controlled by dikes extending westward from a major rift zone in the northeast. Heads are too high, in the range 10 to 15 feet, to be attributable to basal water in an uninterrupted flank lava aquifer.

Sustainable yield of potable water is estimated as 7 mgd. The estimate is good.

Aquifer Sector: Southeast

Aquifer System: Kamiloloa [40301]

The System falls between Kaunakakai and Onini Gulches. Aquifer rock belongs to the lower member of the East Molokai series, but much of the surface is covered by the upper member. Over about two miles in from the coast a brackish to fresh basal lens exists. A small area of high level dike water occurs near the crest of the mountains. The estimated sustainable yield of 3 mgd potable water is poor.

Aquifer System: Kawela [40302]

Between Onini and Kamalo Gulches the System embraces about 19 square miles of basal and several square miles of high level dike waters in the lower member of the East Molokai series. Much of the surface is covered by the upper member. A narrow coastal plain of sediments behaves as weak caprock. The estimated sustainable yield of 5 mgd is reasonable provided all wells were placed far inland.

Aquifer System: Ualapue [40303]

Like the Kawela System, Ualapue includes mostly basal water and a few square miles of high level water in the lower member of the volcanic series. Much of the ground surface consists of the upper member. Good quality basal water discharges near the coast behind a rampart of weak caprock, suggesting that careful development could extract most of the estimated sustainable yield of 8 mgd as potable water. The estimate is

reasonable.

Aquifer System: Waialua [40304]

This most easterly System in the Sector is underlain mostly with basal water but contains a few square miles of high level water. The aquifer is the lower member of the volcanic series. An effective caprock does not exist. No deep wells have been drilled, but numerous basal springs and dug wells provide fresh to somewhat brackish water. The estimated sustainable yield of 8 mgd can be developed as potable water. The estimate is speculative but probably good.

Aquifer Sector: Northeast

Aquifer System: Kalaupapa [40401]

The System embraces Waihanau and Waialeia Valleys and Kalaupapa Peninsula. The underlying geology consists of Kalaupapa volcanics which erupted after erosion of the original East Molokai volcano had taken place, and of the lower member of the main volcano. Colluviurn covers much of the older formation.

The estimated sustainable yield of 2 mgd refers to high level dike water in the two valleys. The estimate is reasonably good.

Aquifer System: Kahanui [40402]

The System contains high level water in the rift zone of the East Molokai volcano. The estimated sustainable yield refers to high level water and is conjectural.

Aquifer System: Waikolu [40403]

The System is restricted to the drainage limits of Waikolu Valley, which is in the rift zone consisting of the lower member intruded by numerous dikes. The estimated sustainable yield of 5 mgd high level water is reasonable because of the many investigations made in the valley. Currently an average of about 3.5 mgd is exported to central Molokai by way of the Waikolu Tunnel. Included in the average are seepages in the tunnel, diverted stream flow and pumpage from several wells.

Aquifer System: Haupu [40404]

Waihookalo and nearby small valleys draining to Haupu Bay comprise the System. The region is part of the East Molokai rift zone. The estimated sustainable yield of 2 mgd refers to high level water and is

conjectural.

Aquifer System: Pelekunu [40405]

The System consists of the drainage basin of Pelekunu in the mid portion of the Sector. Pelekunu drains the caldera of the east Molokai volcano and its associated dike complex. All groundwater is high level except for a minor volume of basal water near the coast. The coastal tongue of sediments plays no role as caprock.

Total estimated sustainable yield is 9 mgd, much of which would have to be taken from the lower third of the valley. The estimate is good.

Aquifer System: Wailau [40406]

The next drainage basin east of Pelekunu constitutes the System. It is larger than Pelekunu but somewhat smaller than Halawa which adjoins it to the east. Wailau drains part of the caldera and much of the rift zone. Its estimated sustainable yield of 15 mgd, all high level water, is the largest of any System in the island. The small sedimentary coastal plain does not behave as caprock.

Aquifer System: Halawa [40407]

This System completes the Northeast Sector. Groundwater occurs in a complex geological framework starting with perched water in and on the upper member of the East Molokai volcanic series, then high level dike water in the lower member, and finally basal water in dike aquifers for a considerable distance inland. Sediments are not hydrogeologically important.

Sustainable yield is estimated as 8 mgd, most in high level aquifers. The dike basal portion may be compromised by sea water intrusion. The estimate is good.

LANAI - AQUIFER SYSTEM SUSTAINABLE YIELD

Lanai is a single Aquifer Sector comprising four Aquifer Systems. In only one System, however, does potable groundwater occur. In the other three, which account for five sixths of the island, all groundwater is brackish in basal lenses. The potable groundwater in the Central System is impounded in high level dike compartments.

Aquifer System: Central [50101]

High level groundwater underlies a total area of about 24 square miles in east central Lanai. In approximately 14 square miles the water table

lies higher than 600 feet above sea level; in the other ten square miles it is lower and drops to about ten feet above sea level at the periphery of the System. Except in Palawai Basin the water is potable.

The high level aquifers occur in the rift zones and at the margin of the caldera of the Lanai volcano. Dikes and other poorly permeable rocks impede the movement and escape of groundwater. Although the high level resource consists of many small aquifers, the composite of these aquifers behaves as a regional aquifer because of hydraulic connection between adjacent units.

The estimated sustainable yield of 6 mgd is the ultimate quantity which can be safely withdrawn. To achieve production of 6 mgd, the techniques of development and means of operation will have to be optimal. Under current conditions of development and operation the realizable sustainable yield is 4 to 5 mgd.

The estimates are good because they are the conclusions of careful water budget studies and analyses of historical trends.

MAUI - AQUIFER SYSTEM SUSTAINABLE YIELDS

Aquifer Sector: Wailuku

Aquifer System: Waikapu [60101]

High level dike impounded groundwater occurs in Waikapu Valley above an elevation of about 1000 feet and basal groundwater at lower elevations throughout the System. The Wailuku volcanic series is the basement formation and is exposed over most of the region, but Honolua andesitic lavas cover the surface as thin layers near Pohakea. The sustainable yield is based on developability of the basal lens as the source of supply. The lens is not protected by caprock at the southern coast of the island, but toward the Isthmus a thick wedge of alluvial cover controls groundwater movement in the volcanic rock.

A well and a test hole have been drilled in the basal lens, but in neither case was potable water found. The estimated yield of 2 mgd refers to groundwater suitable for irrigation but not for drinking. Potable groundwater is limited to the high level portion of the System.

Aquifer System: Iao [60102]

The base perennial flows in Iao and Waiehu (North and South) valleys originate as groundwater seepage from high level aquifers in the caldera and dike complex of the West Maui volcano. However, the principal

exploited groundwater resource is the basal lens in the Wailuku series extending between Waikapu and Waihee valleys below an elevation of about 800 feet. Thick caprock constrains discharge from the lens, which before the start of exploitation had an initial head of approximately 25 feet.

Considerable attention has been given to the size and yield of the basal lens. The sustainable yield of 20 mgd is a reasonably good estimate and has been accepted by the State, County and private water landowners and water developers.

Aquifer System: Waihee [60103]

Between Waihee and Kahakuloa valleys high level groundwater occurs not only in dike compartments of the Wailuku basalt but on perching members in the Honolua formation as well. The perched water forms marshes in places. The base flows of Waihee and Kahakuloa consist predominantly of dike impounded groundwater, but that of Makamakaole is entirely perched water. The thick caprock wedge of the Iao System is truncated by Waihee valley and has no bearing on the basal groundwater of the Waihee System.

A basal lens in the Wailuku basalt, protected along some stretches of the coast by lavas of the Honolua series acting as caprock, may extend inland to about the Forest Reserve line. The testing of two wells drilled on the north bank of Waihee Stream have proved the existence of a sizeable groundwater resource that is assumed to be basal.

The sustainable yield of 8 mgd for the System is based on results of pumping tests and information from an exploratory well in Wailena. The estimate is reliable.

Aquifer System: Kahakuloa [60104]

The entire Kahakuloa System is probably in a rift zone, but near the coast groundwater is basal, even if impounded in dike compartments.

High level dike water in the Wailuku formation is known to occur one and a half miles upstream of the coast and to extend inland to the boundary of the System at Puu Eke. In the upper reaches of the valley marshes sustained by perched water in the Honolua formation add perennial flow to the main stream. Caprock does not rim the coast.

The estimated sustainable yield of 8 mgd refers to potable quality water. The estimate is moderately good because it is based on a study of the valley completed in the last ten years.

Aquifer Sector: Lahaina

Aquifer System: Honokohau [60201]

A rift zone extends all the way to the sea, but within a mile or so of the coast basal groundwater occurs in Wailuku basalt dike compartments. The perennial flow of Honokohau Stream is sustained chiefly by high level dike water; perched water seeping from the Honolua series also contributes to the stream's low flow.

Most of the stream water is diverted by Honokohau Ditch for use further south in the Lahaina Sector. Basal groundwater has not been developed. in the lower reaches of the valley alluvial fill behaves as a weak caprock.

The Honokohau System is included in Area A of previous studies. The estimated sustainable yield of 10 mgd refers to potable basal groundwater under pre-Honokohau Ditch conditions. The estimate is poor to fair.

Aquifer System: Honolua [60202]

A free basal lens in Wailuku basalt occurs for at least two miles inland of the coast, followed by high level dike water which extends to the boundary of the System. Honolua lavas cover a part of the System but are not hydrologically important. Stream flow is diverted to the Honokohau Ditch.

All high level water is impounded in dike compartments. The basal lens saturates flank lava flows, but widely spaced dikes may reach to the coast. Outflow of the basal lens is not impeded by caprock.

The sustainable yield of 8 mgd refers to basal groundwater. In previous investigations the System was included in Area A, along with the Honokohau System, because its hydrology was not influenced by return irrigation flows. The sustainable yield estimate is good because water balances for Area A have been computed. The yield is developable as potable water.

Aquifer System: Honokowai [60203]

That part of the System within three miles of the coast has a basal lens; the remaining mountainous portion contains high level dike water. The Wailuku basalt is the only important water formation, but local hydrogeology is complicated by the Lahaina series in the southern part of the System.

Perennial flow of streams consists of high level groundwater seepage, all of which is either diverted or infiltrates to the basal lens before reaching the coast. Basal groundwater saturates flank lavas. At the coast a narrow zone of sediments is ineffective as caprock.

Return irrigation water plays an important role in the water balance of the System. Much of the irrigation supply is transported into the System from the Honolua and Honokohau Systems by way of Honokohau Ditch. The sustainable yield was computed for the pre-development situation.

The Honokowai System is included in Area B of former studies. The sustainable yield of 8 mgd is a good estimate of original conditions and refers to potable water.

Aquifer System: Launiupoko [60204]

About two miles of basal groundwater in Wailuku basalt extends inland from the coast, beyond which is high level dike water, also in Wailuku basalt. The System is part of Area B of previous studies.

The basal groundwater occurs in flank lavas which are covered at the coast by a narrow shelf of sediments. These sediments are ineffective as caprock.

The sustainable yield was calculated for pre-irrigation conditions. The estimate of 8 mgd potable water is fair.

Aquifer System: Olowalu [60205]

In the seaward two miles of the System is a basal lens in Wailuku basalt. The remaining 2.5 miles is part of a rift zone containing high level groundwater, also in Wailuku basalt. A coastal plain of sediments having a maximum width of one mile behaves as a weak caprock. The hydrogeology of the high level water is complicated by intrusions of the Honolua series.

The System is part of Area C of previous studies. The estimated sustainable yield of 3 mgd refers to potable groundwater taken from the basal lens.

Aquifer System: Ukumehame [60206]

High level groundwater starts about two miles inland and is found chiefly in dike aquifers. The escape of basal groundwater at the coast is somewhat impeded by a sedimentary caprock wedge about half a mile wide. All of the exploitable groundwater saturates Wailuku basalt.

Along with the Olowalu System, Ukumehame was included in Area C of previous reports. The estimated sustainable yield of 3 mgd is fairly reliable and refers to potable water.

Aquifer Sector: Central

Aquifer System: Kahului [60301]

All of the groundwater is basal and occurs in a complicated arrangement of sediments and volcanics from West and East Maui. The developable groundwater is taken from East Maui volcanics underlying the sedimentary cover of sand and alluvium. Kahului Bay is the northern and Malaaea Bay the southern boundary of the System. A moderately effective sedimentary caprock impedes discharge of the lens at either coast.

The estimated sustainable yield of 2 mgd refers to pre-irrigation conditions. Return irrigation flows are responsible for complex modem water balances. Ditch flows from the Koolau Aquifer Sector of East Maui and from streams of West Maui contribute enormously to recharge. The groundwater is not potable.

Aquifer System: Paia [60302]

The entire System is underlain with basalt of the Honomanu volcanic series covered by andesitic rocks of the Kula volcanic series. Basal groundwater occurs in both formations. An effective sedimentary caprock is absent.

The sustainable yield estimate of 8 mgd was derived for pre-irrigation times. A very large volume of Koolau Sector surface runoff is transported to the System by ditches for irrigation. Before the start of irrigation the sustainable yield would have been potable; now only the reach between Hamakuapoko and Maliko contains potable basal water. The estimate of sustainable yield as recoverable potable water is about 4 mgd.

Aquifer System: Makawao [60303]

Very little is known about the occurrence and distribution of groundwater in the System. The entire region is covered by Kula lava, and nowhere does the System border along a coastline. Basal groundwater in Wailuku basalt underlies about three fourths of the total area. Where high level water occurs, it lies far below the surface in the Wailuku basalt.

Minimum elevation in the System is approximately 1000 feet. Drilling of deep wells would be very costly, and operating costs expensive. The estimated sustainable yield of 15 mgd was computed for pre-development conditions but is applicable to current conditions also because the extent of irrigation is small. The estimate refers to potable basal groundwater and is speculative because virtually no subsurface exploration has been done in the region.

Aquifer System: Kamaole [60304]

About three to five miles of basal groundwater extend inland from the coast. The dominant rock is Kula volcanics, but the Hana series covers the Kula formation in the south part of the System. The region beyond the basal sector contains deep high level water in Honomanu volcanics associated with an original rift zone of Haleakala. Spotty accumulations of sediments along the coast do not act as a caprock.

The sustainable yield of 11 mgd is based on total natural input to the basal water portion. It refers to potable water, providing extraction is by means of small capacity wells at considerable distance inland. The estimate is speculative; no exploration has taken place beyond a mile or so from the coast.

Aquifer Sector: Koolau

Aquifer System: Haiku [60401]

Basal, high level dike and high level perched groundwater occurs in the System. The whole of the region is covered by Kula volcanics. The principal developable groundwater in the seaward three to four miles is basal, mostly restricted to the Honomanu basalt. Substantial perched water occurs in the Kula formation. Much of this water is captured by the ditch system of the East Maui irrigation Company. High level dike groundwater lies far below the ground surface in the Honomanu volcanics.

The estimated sustainable yield of 31 mgd (note: the estimate of 40 mgd in the original table is incorrect because of an arithmetical error) is based on original hydrological conditions before the capture of perched water by the ditch system. A more conservative estimate of 15 mgd is preferred until a better water balance is derived. All of this sustainable yield is potable and developable from the basal groundwater. The estimate is poor in spite of the fact that several wells have been drilled in the System.

Although a sedimentary caprock does not rim the coast, the Kula series

locally behaves as variably effective caprock that retards discharge from the basal lens in the underlying Honomanu volcanics.

Aquifer System: Honopou [60402]

Only surface water resources are understood to some degree because of the collection ditches that transfer water to central Maui. No exploration has yet been done for basal groundwater. The region is covered by the Kula volcanics. However, for about a mile inland basal water is likely to saturate underlying Honomanu basalt. Sedimentary caprock is absent at the coast, but the Kula may behave as a weak caprock in places.

Perched groundwater in Kula volcanics drains to streams, which are diverted to the ditch system. High level dike water occurs far inland in the Honomanu basalt but at great depth.

For original pre-ditch conditions, estimated sustainable yield of potable basal groundwater is 29 mgd. The estimate is highly speculative.

Aquifer System: Waikamoi [60403]

Perched high level groundwater in the Kula series, which mantles the System, extends all the way to the coast. Basal groundwater in the basement of Honomanu basalt probably occurs in a zone several miles wide, followed by high level dike water, also in the Honomanu but at great depth.

Little is known about the groundwater resources of the System. Much of the perched water is collected by East Maui Irrigation Company ditches. No sedimentary caprock covers the coast.

The pre-development estimated sustainable yield of 46 mgd is for potable water, but the estimate is poor.

Aquifer System: Keanae [60404]

Relationships among high level perched, high level dike and basal groundwaters are extremely complex. Three volcanic series - Honomanu, Kula and Hana - serve as aquifers and control groundwater accumulation and movement. Perched water extends to the coast. Basal water saturates the basement of Honomanu basalt and may occur in the Hana series at the mouth of Keanae Valley. Far inland, high level dike water in the Honomanu series lies deep below the surface. A coastal caprock of sediments is absent.

The estimated sustainable yield of 96 mgd is large, but the System is

extensive (56 sq.mi.) and receives an average of 185 inches rain annually. The estimate is poor, but there is no doubt that a considerable sustainable yield is developable.

Aquifer Sector: Hana

Aquifer System: Kuhiwa [60501]

Basal groundwater flows in both the Hana and Honomanu volcanic series. The System is covered by the Hana series, which masks any perched high level groundwater in the Kula volcanics. High level dike water in the Honomanu lies deep below the surface in the interior of the System.

The estimated sustainable yield of 16 mgd refers to potable water in the basal lens. Its reliability is low.

Aquifer System: Kawaipapa [60502]

Basal groundwater reaches to at least two miles inland, in the Hana series to some extent but chiefly in the Honomanu series. It is not protected at the coast by caprock. Inland, high level dike water in Honomanu basalt lies far below the surface.

The estimated sustainable yield of 48 mgd reflects high rainfall in the System. Several wells develop potable water from the basal lens. The reliability of the estimate is fair.

Aquifer System: Waihoi [60503]

Young Hana lavas overlie the Kula series which in turn cover the basement of Honomanu basalt. Groundwater relationships are complicated, as they are wherever this vertical sequence exists. Basal groundwater extends at least a mile inland of the coast, and its outflow is not impeded by caprock. High level dike water occurs in the Honomanu basement at considerable depth below the surface. High level perched water in the Kula series is masked by the cover of Hana lavas.

The estimated sustainable yield of 20 mgd applies to basal water. Its reliability is fair to poor. Development of the resource has not been attempted.

Aquifer System: Kipahulu [60504]

All three of the major volcanic series in East Maui have been identified.

Basal, high level perched and high level dike groundwaters occur. A complicated relationship between high level perched and basal waters exists in the lower portion of the System. High level dike water in Honomanu basalt lies deep below the surface farther inland. The Kula series is exposed at the coast where it may act as a weak caprock.

The estimated sustainable yield of 49 mgd is poor, but nevertheless a large quantity of potable groundwater is developable. A single, small well has been drilled in the System.

Aquifer Sector: Kahikinui

Aquifer System: Kaupo [60601]

The Hana volcanic series covers the entire System. Some areas may be underlain by Kula rocks, but everywhere the basement is the Honomanu series. Virtually nothing is known about groundwater occurrence. Basal groundwater probably exists in the Hana series at the coast and for some distance inland. It is not protected by caprock. in the interior high level dike water in Honomanu volcanics lies deep below the ground.

The estimate of sustainable yield (18 mgd) is weak. To assure potable water, wells would have to be drilled far inland.

Aquifer System: Nakula [60602]

Virtually the entire area is covered by the Kula series. Near the coast basal groundwater occurs in the Kula as well as the underlying Honomanu series. The coast is rimmed with Kula rocks. Far inland high level dike water may occur in the Honomanu at great depth. Groundwater exploration has yet to be attempted in the System.

The estimated sustainable yield of 7 mgd is not reliable. To obtain potable water, wells would have to be located at a considerable distance inland.

Aquifer System: Lualailua [60603]

Except for a few outliers of Kula lavas, the System is covered by the Hana series. Basal groundwater occurs in Hana rocks near the coast and in the Honomanu series inland. The coast is rocky and has no caprock. Most of the System may be underlain by basal groundwater; high level dike water is restricted to the farthest interior.

No exploratory work relating to groundwater has been done. The

estimated sustainable yield of 11 mgd refers to basal groundwater obtained several miles inland to assure its potability. The estimate is not reliable.

HAWAII - AQUIFER SYSTEM SUSTAINABLE YIELDS

Aquifer Sector: Kohala

Aquifer System: Hawi [80101]

Most of the region contains basal groundwater in the basement rock of the Pololu volcanic series. The coast is rocky and is not rimmed with a sedimentary caprock. High level dike water extends in a band about two miles wide reaching toward the coast from the crest of the Kohala Mountains. Perched high level groundwater occurs in the andesitic rocks of the Hawi volcanics which mantle the Pololu inland.

The estimated sustainable yield of 27 mgd refers to the basal lens and is fairly reliable. Groundwater exploration is underway in the System.

Aquifer System: Waimanu [80102]

The System embraces the canyons and gulches which cut deeply into the Pololu series to drain high level water from the rift zone of the Kohala Mountains. Most of the high level water is impounded between dikes; some drains from perching members in the Hawi volcanics. Basal groundwater in the Pololu series reaches a mile or two inland of the coast. its flow is not impeded by caprock.

The estimated sustainable yield of 110 mgd assumes that none of the groundwater drains to streams and all is developable. Much of the estimate is already diverted by the Upper and Lower Hamakua Ditches, and the Kohala Ditch system. The estimate is speculative, but undoubtedly a very large quantity of groundwater is developable.

Aquifer System: Mahukona [80103]

Basal and high level dike water occurs in the Pololu basalt along with a small amount of perched water in the overlying Hawi volcanics. High level water may reach as far as two miles seaward of the Kohala Mountains crest in the mid section of the System. Basal groundwater may be potable two or more miles inland but brackish toward the coast. Groundwater discharges freely at the coast because no caprock is present.

The estimated sustainable yield of 17 mgd assumes that groundwater

is taken far enough inland to be potable. The estimate is poor to fair.

Aquifer Sector: East Mauna Kea

Aquifer System: Honokaa [80201]

Basal groundwater in the Hamakua basaltic formation of Mauna Kea volcano may extend five to seven miles inland of the coast. The Laupahoehoe series of the same volcano blankets portions of the Hamakua formation and contains high level perched water. High level dike water is likely to be found in Hamakua rocks at great depth along the northwest rift of Mauna Kea. A sedimentary caprock does not exist at the coast, but the Laupahoehoe series may act as caprock where it reaches the sea.

The estimated sustainable yield of 31 mgd is reasonably good. Several successful basal water wells have been drilled and yield potable water.

Aquifer System: Paauilo [80202]

Paauilo resembles the Honokaa System but is larger and enjoys somewhat more rainfall. The area of Laupahoehoe lava covering the Hamakua formation is relatively small except near the inland margin of the System. The Hamakua contains basal aquifers while perched water drains from the Laupahoehoe series. High level dike water lies far below the surface in the rift zone section of Mauna Kea. Sedimentary caprock is absent.

The estimated sustainable yield of 60 mgd refers to potable groundwater in the basal lens. The estimate is reasonably good.

Aquifer System: Hakalau [80203]

A large part of the System is covered by the Laupahoehoe series blanketing the Hamakua basement. Basal water in the Hamakua extends more than five miles inland. Toward the Mauna Kea Rift zone high level dike water occurs at great depth. The Laupahoehoe carries perched water. At the coast no sediments are found, but the Laupahoehoe formation serves as a partial caprock for basal water in the Hamakua lavas.

The estimated sustainable yield of 150 mgd reflects the size of the System and its high rainfall. The estimate is fair. No doubt a great deal of potable basal groundwater can be developed.

Aquifer System: Onomea [80204]

The Hamakua series, covered in places by Laupahoehoe lavas, constitute the System. The southern boundary, which is nearly coincident with the Wailuku River, separates formations of the Mauna Kea volcano from those of Mauna Loa.

Basal groundwater reaches many miles inland. High level dike water may occur toward the summit of Mauna Kea. High level perched water is common in the Laupahoehoe series. Outflow of the basal lens is not impeded by caprock.

About 147 mgd is estimated as sustainable yield. The estimate is reasonable.

Aquifer Sector: West Mauna Kea

Aquifer System: Waimea [80301]

A basal aquifer in the Hamakua formation contains brackish groundwater over a distance of four to five miles inland of the coast. Further inland the basal groundwater continues but with a head sufficiently high to allow withdrawal of potable water. Toward the crest of Mauna Kea high level dike water occurs at great depth in the Hamakua formation. Sedimentary caprock doesn't rim the coast.

The estimated sustainable yield of 24 mgd assumes that all water is extracted from the high head portion of the basal aquifer more than five miles inland. The estimate is poor.

Aquifer Sector: Northeast Mauna Loa

Aquifer System: Hilo [80401]

A complex suite of groundwater resources underlies the System. The Kau volcanic series of Mauna Loa volcano reaches from the coast to the inland boundary at the crest of Mauna Loa. Basal groundwater extends several miles inland from Hilo Bay, followed by high level dike and perched water. The coast is free of a sedimentary caprock.

The estimated sustainable yield of 347 mgd reflects the size of and the high annual rainfall in the System. The estimate is fair and is based on several water budget studies. A very large volume of basal groundwater discharges into Hilo Bay.

Aquifer System: Keaau [80402]

Like the Hilo System, Keaau is entirely in the Kau series except for a small exposure of Kahuku lavas, an earlier basalt formation from Mauna Loa. Basal groundwater occurs for several miles inland, followed by high level perched and dike groundwater. Sediments are sparse and none line the coast as caprock.

The volume of groundwater moving through the System is enormous because of high rainfall and infiltrability of surface rocks. The estimated sustainable yield of 393 mgd is speculative, but without a doubt a great volume of groundwater can be developed.

Aquifer Sector: Southeast Mauna Loa

Aquifer System: Olaa [80501]

Basal groundwater probably does not occur because the System lies about ten miles inland of the coast. The Kau volcanic series is dominant, but a few areas of Kahuku lavas have been mapped. High level perched and dike water lie at great depth below the surface.

The estimated sustainable yield of 124 mgd reflects high rainfall and permeable rocks in the System. The boundary to the south is the Kilauea rift zone, which causes groundwater to move northeast. The estimate is speculative, but as in the Hilo and Keaau Systems there is no doubt that a large supply of groundwater exists.

Aquifer System: Kapapala [80502]

The System is composed of Kau volcanics on the flank of Mauna Loa and has no coastal boundary. High level perched and dike water lie deep below the surface but basal water is not likely to be a resource.

The estimated sustainable yield of 19 mgd reflects the dry nature of the southeast slope of Mauna Loa. Groundwater would be extremely expensive to develop because of the depth required to reach it.

Aquifer System: Naalehu [80503]

The most areally extensive formation is the Kau volcanics, but significant and hydrogeologically important exposures of the Kahuku and Ninole series of Mauna Loa occur in the southern part of the System. Basal groundwater extends several miles inland between Punaluu, and Naalehu. Further inland perched water is associated with ash beds in the Kahuku and Ninole series. High level dike water underlies the region inland of the basal groundwater. No caprock impedes the escape of groundwater

from the basal lens at the coast.

The estimated sustainable yield of 117 mgd was derived for the entire area bounded on the east and south by the Kilauea rift and on the west and north by the Mauna Loa southeast rift. It is speculative but is indicative of a large flow of groundwater.

Aquifer System: Ka Lae [80504]

The System is bounded by the ridge line of the southwest rift of Mauna Loa on the west and the Naalehu System on the east. Except for a few small areas of Kahuku series rocks, the visible geology consists of Kau series, including some historical flows. Basal groundwater extends several miles inland, but toward the coast is brackish. A caprock does not exist to impede outflow to the sea.

The estimated sustainable yield of 31 mgd assumes exploitation of the basal lens three or more miles from the coast. A portion of the sustainable yield is likely to be brackish. The estimate is poor.

Aquifer Sector: Southwest Mauna Loa

Aquifer System: Manuka [80601]

Highly permeable basalt of the Kau series carries basal water over a distance at least six miles inland. The lens is thin and difficult to develop for potable water. It is not protected by caprock at the coast. Far inland high level dike water lies at great depth.

Exploratory drilling has demonstrated that the basal lens is brackish inland to the belt highway. The estimated sustainable yield of 42 mgd includes brackish and potable water. it is not a reliable estimate.

Aquifer System: Kaapuna [80602]

Permeable Kau volcanics cover the entire System. Basal groundwater extends at least six miles inland. It is not protected by caprock. High level water may be found at great depth toward the boundary of the System along the southwest rift of Mauna Loa.

The basal lens is thin and difficult to exploit because of the high permeability of the Kau basalts. The estimated sustainable yield of 50 mgd refers to extractions made more than several miles inland. It is not a good estimate and includes brackish water.

Aquifer System: Kealakekua [80603]

As in the Manuka and Kaapuna Systems, the Kau volcanic series covers the whole region. its extremely high permeability coupled with the absence of coastal caprock prevents the buildup of a thick basal lens. High level groundwater may occur far inland.

The estimated sustainable yield of 38 mgd would be difficult to develop entirely as potable water. The estimate is poor, but unquestionably a considerable volume of potable groundwater is developable.

Aquifer Sector: Northwest Mauna Loa

Aquifer System: Anaehoomalu [80701]

The surface is covered by Kau volcanics, but these Mauna Loa lava flows cover Hualalai volcanics to the south and Mauna Kea volcanics to the north. Basal groundwater occurs in highly permeable aquifers for at least five miles inland. At approximately ten or more miles from the coast high level water may occur at great depth. Lack of caprock at the coast prevents the buildup of a thick lens.

It is not possible to develop potable water where the lens is thin, as it is in most accessible places. About five miles inland a discontinuity disrupts the smooth curve of the water table, causing head to rise several feet higher than expected. The estimated sustainable yield of 30 mgd assumes that all recharge taking place in the System discharges at the coast between Anaehoomalu and Puako. This may not be so. A significant portion of estimated sustainable yield is probably brackish. The estimate is not reliable.

Aquifer Sector: Kilauea

Aquifer System: Pahoa [80801]

The Puna volcanic series of Kilauea volcano cover the region. Because of the continuing activity of Kilauea and the youth of the local geology, groundwater occurrences and relationships are complex. A large volume of high level groundwater in the vicinity of the Kilauea rift and basal water on the flank moves through the System. The high level component includes dike and perched water. No caprock exists along the coast. In the rift zone geothermal fluids are being developed.

The estimated sustainable yield of 435 mgd reflects the large area of and high rainfall in the System. The estimate is weak and much of it may not be developable as potable water because of the high permeability of

the aquifers and the complicated arrangement of the geology.

Aquifer System: Kalapana [80802]

The principal east rift and the southern flank of Kilauea constitute the System. Basal water aquifers exist along the coast and extend several miles inland. High level groundwater is associated with the rift zone. Geological and hydrogeological relationships are complicated. Fresh, brackish and saline geothermal groundwaters occur.

The estimated sustainable yield of 157 mgd assumes normal drainage from high level to basal groundwater. To develop this yield as potable water, wells would have to be located far inland. The estimate is poor.

Aquifer System: Hilina [80803]

Basal groundwater probably occurs seaward of Hilina Pali and high level water toward the southwest rift of Kilauea. The terrain is young and has no caprock at the coast. The region is included in the Kau desert and is very dry.

Potable groundwater would be difficult to develop. The estimated sustainable yield of 9 mgd is not reliable.

Aquifer System: Keaiwa [80804]

Most of the region may be underlain with high level groundwater in the southwest rift of Kilauea. Along the coast basal water saturates highly permeable Puna volcanics. The hydrogeological. framework is virtually unknown.

The estimated sustainable yield of 17 mgd is based on a simple water budget. Groundwater in the basal lens is likely to be brackish. The estimate is poor.

Aquifer Sector: Hualalai

Aquifer System: Keauhou [80901]

Basal groundwater in aquifers of Hualalai volcanics is known to extend at least four miles inland to Mamalahoa Highway. Beyond about five miles high level groundwater may exist in one of the Hualalai rift zones.

The sustainable yield of 38 mgd is not developable only as potable water. The estimate is poor.

Aquifer System: Kiholo [80902]

Basal groundwater occurs in Hualalai volcanics for at least five miles inland. At about four miles inland a hydrologic discontinuity apparently causes the head to rise several feet more than expected. The lens is not protected by caprock at the coast. This is the condition throughout the young island of Hawaii. High level groundwater lies at considerable depth in the rift zones, including the Puu Waa Waa rift.

The estimated sustainable yield of 18 mgd would be potable if all of it were developed more than five miles inland where elevations normally exceed 1500 feet. The estimate is fair.

SURFACE WATER

Introduction

The primary hydrologic unit for describing stream flow is the drainage basin, whereas the principal division for groundwater is the Aquifer System. The boundaries of drainage basins and Aquifer Systems do not necessarily coincide because groundwater flow is governed by subsurface geological continuity rather than by topographic controls. However, where reasonable, Aquifer System boundaries have been drawn along drainage basin divides, but where known boundaries are not coincident with topographic divides, aquifer continuity determines the limits of the Aquifer System.

In Oahu, where the extent of aquifers is known with a good degree of certainty, drainage basin divides are not usually the same as Aquifer System boundaries. To a lesser extent the same is true in West Maui. Elsewhere, however, because much less is known about aquifer boundaries, drainage divides and Aquifer System limits are often made to coincide to allow for simplicity in hydrologic budgeting.

Natural Stream Flow

Stream flow may be defined as all waters which accumulate and travel in a stream channel. It includes direct surface runoff, groundwater seepage and bank storage. Direct surface runoff is the component of rainfall that moves overland on the surface and through a shallow layer of soil and debris before joining a stream. Groundwater is infiltration which accumulates in a saturated aquifer after passing through the unsaturated (vadose) zone. Bank storage is the infiltration which remains near the surface above the unsaturated zone and drains by gravity to a stream.

Direct surface runoff accompanies rainfall, and its volume depends on the intensity and persistence of the rain, and the size, geology and morphology of the

drainage basin. In Hawaii the direct surface runoff associated with a particular rainfall lasts for a short time, no more than a few days even in the largest drainage basins. Groundwater seepage originates as overflow and underflow from dike and perched aquifers, and as outflow from basal aquifers at the inland margins of coastal plains. Bank storage drains slowly but requires frequent rainfall for replenishment because the storage volume is small.

In the Hawaiian Islands volcanic rocks and the accompanying overburden are an efficient infiltration medium that permits a large fraction of rainfall to percolate to deep groundwater bodies. Once in the zone of saturation, groundwater moves seaward unless it is interrupted by a stream channel acting as a drain. In rift zones streams incise dike compartments to allow drainage, while in regions where less permeable flank lavas, usually consisting of andesitic-trachytic rocks, cover the primary basalts, perched aquifers are a source of seepage. The great basal aquifers contribute water to streams only at low elevations, usually below an elevation of about 25 feet above sea level.

The volume of groundwater lost to streams is far less than the volume which remains in the ground to eventually discharge into the sea, but the groundwater component of stream flow sustains the ecology dependent on running water, and in many regions is a vital source of irrigation supply. Most wetlands also survive because of groundwater seepage.

Stream flow is highly variable and the statistics of flow are dominated by direct runoff from rainfall. The average flow of a stream which is perennial because of groundwater seepage is about two to three times the base flow. Flow duration curves of natural streams show a stronger resemblance to a log normal distribution than to the standard normal distribution. In most instances the average base flow is taken as the flow at the 90 percentile exceedance. This means that 90 percent of the time flows are equal to or greater than the exceedance flow.

Only those streams which carry water, no matter how little, at all times are considered perennial. Streams that traverse rift zones containing high level aquifers from headwaters to the sea are perennial throughout their length. In many cases, reaches of streams are perennial in high level groundwater zones but non-perennial where channels pass over permeable flank lavas. In very high rainfall areas streams are perennial because of constant seepage from bank storage even where high level aquifers don't exist. Streams sustained by basal groundwater outflow occur only where the basal lens is thick and head is high as a result of caprock impeding escape of groundwater.

Stream Classification

Various classification schemes that address particulars of stream behavior, especially in terms of ecology, have been proposed but none have become a standard. A simple classification should be based on physical attributes of the stream and its

drainage basin. Once the physical framework is established, ecological and other environmental considerations could be woven into the classification.

The simplest classification should refer to general stream behavior, geology of the drainage basin, and provenance of perennial flow. Once these features are established, ancillary characteristics naturally follow. The scheme suggested below accounts for basic stream attributes.

General Behavior

1. Perennial
2. Non-perennial
3. Ditch (man-made diversion)

Basin Geology (upstream of a stated point)

1. Rift zone
2. Flank lavas
3. Rift and flank
4. Sediments
5. Rift and sediments
6. Flank and sediments
7. Rift and flank and sediments

Perennial Flow Provenance

0. Not applicable (non perennial)
1. Dike aquifers
2. Perched aquifers
3. Dike and perched aquifers
4. Basal aquifer
5. Bank storage

Each stream can be coded using a single number from each of the three categories. For example, a perennial stream which traverses and whose flow derives from dike aquifers would be coded 111, where the first 1 refers to perennial under General Behavior, the second 1 to rift zone under Basin Geology, and the third 1 to dike aquifers under Perennial Flow Provenance.

To the above a status code can be added. An elementary status code describes the condition and use of the stream, in particular whether a stream is diverted, receives effluent, and has been modified. The simple status code would be as follows:

Diversion

1. No
2. Yes

Receive Effluent

1. No
2. Yes

Modified

1. No
2. Yes

A stream which is diverted but does not receive effluent nor has been modified would have the status code 211. The basic classification code for the stream would then be 111.211, in which 111 refers to physical attributes and 211 to usage and condition.

Stream Diversions: Ditches and Tunnels

Diversion of streams for agricultural use was an ancient Hawaiian engineering achievement. Sugar farmers expanded on the Hawaiian practice by constructing ditches and tunnels to transport water from a drainage basin to distant areas outside the basin, especially to dry lowlands. As long ago as 1856 a ditch diversion for sugar irrigation was used on Kauai. Since then complex networks of diversion and transport structures have been built and vast quantities of water have moved from one drainage basin to another.

An average of about 625 mgd is diverted from streams throughout the State, principally for irrigation. Listed below are estimates of major diversions by island.

Island	Diversions (mgd)
Kauai	250
Oahu	30
Molokai	5
Maui	265
Hawaii	75
Total	625

These flows are transported from their drainage of origin to other areas for use. Flow diagrams of the major diversions are included in an appendix.

Record of Flows

Measurements of stream and diverted flows must have started with the Hawaiians because agriculture depends on an adequate quantum of water for irrigation. When the sugar industry began its explosive growth, estimates of the volume of water potentially available for irrigation had to be known before investment in diversion schemes could be justified. For example, measurements of all major streams in the Waipio Valley drainage (Island of Hawaii) were made by J.M. Lydgate

in 1889 preparatory to planning the Lower Hamakua Ditch. Similar instantaneous and short term measurements were made of sources in the other islands.

Continuous flow recording stations were not established until 1909 when the US Geological Survey (USGS) began its stream measurement program. Since then the USGS has amassed a large, extremely valuable data base of both continuous and stage stream flow, as well as of other parameters. In parallel with the USGS, plantations and landowners maintained measuring stations at ditch intakes and at land boundaries to record the volume of water originating in private and government lands.

The USGS data is the most complete. A summary of the number of gaging stations maintained over the 80 years of record by the USGS along with the numbers in 1979 and 1988 follows.

Period	Niihau	Kauai	Oahu	Molokai	Maui	Lanai	Hawaii
Total 80 yr	0	137	88	23	98	0	60
1979	0	26	32	10	18	0	24
1988	0	19	29	8	7	0	60

Flow measurements are vital to understanding, protecting and utilizing surface water resources, and long period records are needed to provide a sound statistical base. The above table shows that the USGS program has been substantially reduced in the last ten years. The program needs to be evaluated to determine whether additional gaging stations are justified.

Characteristics of Stream and Ditch Flows

Daily flow duration statistics are tabulated in an appendix for streams gaged by the USGS on each island except Niihau, Lanai and Kahoolawe. Daily flow durations are given in exceedance percentiles. This percentile simply means that all flows equal to or greater than the given flow occurred for the percent of time listed as the exceedance percentile. For example, the 90 percentile exceedance flow states that the listed flow was equaled or exceeded 90 percent of the time, or an average of 329 days of the year, and that flows less than the exceedance percentile occurred just 10 percent of the time, or an average of 36 days per year.

The 50 percentile exceedance flow is identical to the median flow in which 50 percent of the daily flows are equal to or greater than and 50 percent are less than the given flow. In the standard normal statistical distribution the median flow would equal the average flow, but this is not true for Hawaiian streams. However, ditch flows tend to follow the normal distribution because high flows are truncated by the limits of ditch intakes and carrying capacity.

Exceedance percentiles were calculated by the USGS for the period of record to 1979. Although a decade has elapsed since then, the values are acceptably accurate, especially those with a long record. For significant waterways, especially perennial

streams, the average for the period to 1979 differs by no more than five percent from the average calculated through 1988.

In Hawaii the 90 percentile exceedance flow is treated as equivalent to average base flow in perennial streams. The base flow, in turn, is attributed to groundwater seepage. During dry periods flow diminishes below the 90 percentile level, but the streams do not go dry.

Minimum Stream Flows and Preservation of In-Stream Values

Under the State Water Code, the Water Commission is charged with the responsibility of establishing and administering a state wide in-stream use protection program and must establish in-stream flow standards on a stream-by-stream basis "whenever necessary to protect the public interest". The standards established by the Commission shall specify minimum flows or depths of water required in a stream at given times of the year to "protect fishery, wildlife, recreational, aesthetic, scenic, and other beneficial instream uses".

According to the Code, beneficial in-stream uses include but are not limited to:

1. Maintenance of fish and wildlife habitats;
2. Outdoor recreational activities;
3. Maintenance of ecosystems such as estuaries, wetlands, and stream vegetation;
4. Aesthetic values such as waterfalls and scenic waterways;
S. Navigation;
6. In-stream hydro-power generation;
7. Maintenance of water quality;
8. The conveyance of irrigation and domestic water supplies to downstream points of diversion; and
9. The protection of traditional and customary Hawaiian Rights.

The establishment of permanent in-stream standards is an enormous undertaking, although the Commission has wide latitude in determining whether any given stream would require standards.

To preserve a stream environment in a perennial stream, some level of minimum flow is necessary. In establishing the minimum, flow characteristics need to be identified and ambient ecology understood. As a general rule, in stream values are significant only for perennial streams.

A perennial stream or reach of a stream needs to be identified. One approach is to choose a flow parameter which stipulates that there exists a lowest average flow over a specified period. In the stream flow data tables given in the appendix, the 14 day lowest average flow for the period of record is listed. This parameter states that in the entire period of record, the lowest average flow for any 14 day period was the

listed value. If the value is zero (0), then in at least one interval of 14 consecutive days the stream had no running water. Such an index can be used to identify truly perennial streams.

Presumably the 14 day average minimum flow greater than zero would be required to sustain an ecology dependent on running water. However, continuation of such a low average flow indefinitely would likely result in ecological damage. The minimum flow necessary to sustain the biology of a stream undoubtedly exceeds the 14 day low yet is probably not as great as, say, the median flow. Perhaps a value in the range between the 14 day low and the base flow (90 percentile exceedance) or, to be safer, the 75 percentile exceedance would be a reasonable compromise.

The average flow is usually about the same as the 25 percentile exceedance flow, which means that flows equal to or greater than the average occur only 90 days in a typical year. The other 275 days have lower flows. The average, therefore, is a poor parameter to employ in establishing minimum flows. Even the median is not reasonable. A minimum flow which assures continuation of a stream ecology is likely to lie between the 14 day average low flow and an exceedance percentile greater than the median but less than the 90 percentile exceedance.

Sensible use of the extensive stream flow data collected by the US Geological Survey over the past 80 years should be the basis for establishing the physical parameters of minimum stream flow standards. The proposed stream classification scheme may serve as the framework for utilizing these statistics.

QUALITY OF WATER

Groundwater

Groundwater which accumulates in the conservation zone of the high rainfall regions is superb in quality and needs no treatment before being used as drinking water. Typically it has only 10 to 20 mg/1 chloride (the measure of salinity), 35 to 45 mg/l silica (a measure of rock solution), and less than 1 mg/1 nitrate (a measure of pollution). Other constituents occur in concentrations that, like those above, are far below recommended drinking water limits.

The quality of groundwater is affected by introduction of dissolved matter generated by surface activities and the intrusion of salt water into basal lenses of fresh water. Historically the infiltration of surplus irrigation water was a primary source of introduced dissolved constituents, carrying with it higher salinities than occurring in pristine water along with fertilizer salts and pesticides and residues resistant to breakdown in the soil column. In recent years, the effluvia of urbanization has added to potential contamination from the surface. Numerous distributed and point sources of pollution threaten the purity of groundwater in regions outside the conservation zone.

in aquifers containing basal lenses in contact with sea water, the reality and threat of sea water intrusion is a matter requiring continual attention. Sea water intrusion is induced by natural perturbations to some extent (e.g. tidal movement and seasonal changes in recharge), but mostly by stresses accompanying the extraction of groundwater by pumping, especially with high capacity pumps and from deep wells.

Since groundwater development started nearly a century ago, the fresh water levels have contracted and sea water intrusion has advanced inland. These phenomena, however, are controllable when correct development practices are employed. Also, in many instances the effects of sea water intrusion are reversible after improper extraction techniques are corrected or the volume of groundwater removed from the lens is held consistent with the hydrologic balance.

Surface Water

The low flow of perennial streams originates from groundwater seepage, and consequently its chemical composition is similar to that of groundwater. Flows greater than the approximately 90 percent exceedance flow, on the other hand, incorporate direct surface runoff and its burden of sediments, suspended material and dissolved matter. Runoff from forested watersheds carries least burden while that from unvegetated agricultural and urbanized areas contributes a high sediment and chemical load.

The encroachment of urbanization and agriculture into forested watersheds deteriorates the quality of surface area. A greater fraction of the rainfall becomes direct surface runoff where the watersheds are altered, adding undesirable components to stream flow. Also, infiltration is reduced, thereby lessening recharge to groundwater.

VI. RESOURCE MANAGEMENT AND PROTECTION

WATERSHED MANAGEMENT AND CONTROL

Adequate management and control of watersheds is a prerequisite for our two major concerns--retaining sufficient acreage of watersheds to insure infiltration into groundwater aquifers to meet our needs, and to protect the quality of our raw water whether it is recharging groundwater bodies or impounded for use in either the treated or untreated state.

For many years watershed lands have been carefully guarded and increased in acreage, particularly on Oahu. In the not too distant future, this practice must be followed in the other counties. One example is in the Kona highlands where the maintenance and protection of the watershed should be a high priority consideration in view of the increasing need for more water in the Kona area. Other areas where watershed acreage should be increased are Waioli and Papaa on Kauai, and the Maunawili area on Oahu.

It is vital that a minimum area of conservation lands be set aside as watersheds for infiltration. At present, the State Land Use Commission has the authority to zone lands in conservation and agricultural areas.

Watershed boundaries are set by the Legislature. In the past, the Legislature has been responsive to the need to protect our watersheds and there is every reason to believe that it will continue to do so in the future. With the new law creating the Commission on Water Resource Management, it may be appropriate to study the advisability of transferring the responsibility of fixing watershed boundaries to the Commission.

Under existing law, the Commission has the authority to designate certain areas where groundwater may be safely withdrawn so as to protect the sources from overdraft. It would therefore seem logical that the Commission be given the authority to set limits on watershed areas which serve as intakes for the replenishment of groundwater aquifers. However, the legal and technological ramifications of such a change may be so complex that a thorough evaluation may be necessary before such authorization is sanctioned.

For many decades, municipalities throughout the county have been using unfiltered water for domestic purposes. These municipalities have been able to do this while meeting public health requirements at the same time because they have been successful in maintaining unfiltered supplies with high raw-water quality, effective watershed control programs, and reliable disinfection procedures.

However, because of the potential of sudden changes in raw-water quality, more and more water utilities are employing multiple barriers of treatment. At the least, these include filtration and disinfection.

The question of whether unfiltered water is acceptable has practically become moot. The United States Environmental Protection Agency (EPA) has stipulated that as of December 31, 1990, all surface sources of drinking water, with possibly a few exceptions, must undergo filtration and disinfection. All utilities confronted with this prospect will be faced with additional major capital and operating costs. Whether such a requirement will obviate the need for watershed control is open to question.

An uncontrolled watershed is exposed to a wide range of contamination possibilities resulting from the use of herbicides, industrial chemicals, and the dumping of various waste materials, and from humans and feral animals. Such a situation accompanied by treatment failures can give rise to very serious public health emergencies.

The EPA may grant a few exceptions to the filtration requirement in cases where the watersheds are owned and rigidly controlled by the purveyor, where the raw water is of superior quality, and where it can be shown that the proposed method of treatment, other than filtration, is capable of effectively removing viruses and other organisms.

In the State of Hawaii, all of the unfiltered surface supplies are either being phased out or are undergoing improvements resulting in treatment involving filtration and disinfection. The completion date of these improvements is sometime before December, 1990.

However, the need to control and protect the watersheds remains urgent. There is still a need to protect groundwater supplies, especially the shallow sources, from contamination. Moreover, there are indications that surface supplies will be used for recharge or direct use after treatment. All in all, a high level of watershed control is still necessary even under the surface water treatment rule imposed by the EPA.

Most of the watershed lands in Hawaii are owned and controlled by the State. Entry into and activities in the watersheds are governed by laws and rules and regulations enforced by the Division of Forestry under the Department of Land and Natural Resources. Entry into the watersheds is by permit from the Division of Forestry and is confined to scientific studies. Recreational, commercial, industrial and residential developments are prohibited.

FLOOD CONTROL AND MAINTENANCE OF DRAINAGE

Floods occur when stream channels overflow due to excessive rainfall which causes a temporary rise of the water level in a stream or natural water course. Floods can also inundate overbank lands generally referred to as the stream's flood plain. Floods can cause considerable damage to agricultural lands, public property, homes, and human and animal life. It would therefore be to our advantage to adopt flood control measures not only to minimize damage but to put flood waters to beneficial

use such as storage for recharge, low-flow augmentation, generation of hydroelectric power, support of fish and wildlife, irrigation, and other forms of reuse. This multiple-purpose development approach is frequently used in the development of flood control projects in Hawaii.

Flood control means the minimizing of flood damage by appropriate protective, preventive, and corrective measures. On the other hand, drainage involves the receiving and conveying of surface runoff using man-made facilities.

Flood control facilities confine storm runoff within natural water resources and standing bodies of water. These facilities may include ditches, streams, dams, and reservoirs. Drainage facilities collect surface and sub-surface runoff such as culverts, ditches, canals, and reservoirs. It is obvious that many of these installations are common to drainage and flood control projects. These installations, whether for flood control or drainage, serve the broader objective of maximum use of our water resources.

Drainage serves the useful purpose of reclaiming and improving lands for agricultural and other beneficial uses. However, overdrainage of interim lands can produce the negative effect of reducing or completely stopping recharge of our groundwater supplies.

Flood control reservoirs and dams serve the arid and semi-arid areas throughout the country. The conservation of surplus water for use during periods of low rainfall compensates for sharp variations in rainfall so that water for irrigation and other uses is available throughout most of the year.

Planning for flood control facilities should recognize the need to incorporate storage facilities into the plans so that critical areas would not suffer from shortage of water, especially for irrigation. Through the years, a number of reservoirs and dams throughout the State were built as flood control facilities. Some of the more prominent are the open reservoirs in Nuuanu Valley, Oahu.

As far back as the late 1920's, the now defunct Honolulu Sewer and Water Commission prepared conceptual plans to funnel flows from the reservoirs in Nuuanu and Kalihi Valleys to a central 25.0 mgd capacity plant for treatment and use for domestic purposes. It was also planned to eventually divert water from Manoa and Palolo streams to the proposed filter plant. The plant was never built but the whole scheme is a reminder to us of the far-sightedness of the engineers of more than 60 years ago in planning for a facility which may someday become a reality.

Recreation activities can also benefit from flood control. As the population increases and urbanization expands, more facilities will be needed for recreation such as swimming, fishing, boating, picnicking, and camping. The construction, operation, and maintenance of aquatic recreational areas will assume increasing importance and continuing demand. Recreational reservoirs and free-flowing streams for scenic enhancement can logically become elements of a multiple-purpose flood control

program.

Flood control and drainage can also provide the facilities and environment for the preservation and propagation of fish and wildlife and not be limited to domestic water use and irrigation. Care should be exercised that any drainage program be conceived to protect the habitat of fish and wildlife. Flood control can become a very vital function of government in its drive to preserve our natural resources for the benefit of future generations.

REGULATION OF DEVELOPMENT AND USE

Until recent times, governmental regulation of the development and use of water throughout the State has been largely confined to the City of Honolulu and Oahu. This has been attributable to the rapid urbanization and industrialization of the island, expansion of sugar cane and pineapple cultivation, the establishment of military activities and facilities, and the emergence of Honolulu as a hub for transportation in the Pacific arena.

In the early years of the Territorial government, there was already public concern over the steadily declining artesian head in Honolulu due to uncontrolled development and use of the groundwater resources. In 1925, the Territorial Legislature created the Honolulu Sewer and Water Commission whose responsibility was, among others, to investigate water resources on the island of Oahu.

Public outcry for better management and operation of the water system continued until 1929 when the Legislature created the Honolulu Board of Water Supply with complete responsibility to manage, operate, and regulate the waterworks and artesian water development in Honolulu.

In 1959, the Honolulu Board of Supervisors transferred the Suburban Water System to the Board of Water Supply. With this transfer, all water functions for the island of Oahu were finally vested in the semi-autonomous Board of Water Supply.

Water resources management for the remainder of the Territory (State) was the responsibility of the Territorial Division of Hydrography. The Hawaii Irrigation Authority (HIA) was created by the Legislature in 1953 with the responsibility to construct and operate small irrigation systems. The Hawaii Water Authority replaced the HIA in 1959 and was made responsible for the collection and correlation of all water resources data in the Territory. Following Statehood in 1959, water resources management became a function of the Department of Land and Natural Resources, where it now remains.

Under the leadership of the Board of Water Supply, water resources management on Oahu appeared to be well under control. However, increasing public apprehension over the State's water resources prompted the State to review the water resources situation on Oahu.

Historically, the State laws governing groundwater resources were Chapters 177 and 178, HRS 1975. Chapter 177 was the Groundwater Use Act which provided for the regulation of groundwater resources in designated areas. Chapter 178 was the Artesian Well Law which provided for the control of waste, notification of intent to drill, and allowed a person to transfer a flowing artesian well to the County. Chapters 177 and 178 have been superseded by the State Water Code which became effective on July 1, 1987 (codified in Chapter 174C, HRS 1987 Supplement).

In September of 1979, the first designation of a water control area was made when the Board of Land and Natural Resources designated the Ewa-Pearl Harbor and Wahiawa Districts. Subsequently, the Honolulu and Waialua districts were designated (see fig. 3). The designation of the other districts on Oahu may follow. To date, none of the districts in the counties of Hawaii, Maui and Kauai has been designated, although reviews are underway which may lead to designation of various areas in these counties.

In 1977, a State Water Commission was appointed by the Governor to assess the State's water resources following a prolonged drought which dropped Oahu's groundwater levels to record lows and caused hardship to farmers and ranches on the other islands.

In its report which was submitted early in 1979, the Commission made a number of recommendations, those pertaining to groundwater management were as follows:

1. Regulating the Pearl Harbor groundwater resources through Chapter 177

2. Establishing a permit system for water development and use

3. Formulation of a State Water Code

The Commission also recommended the passage of two bins by the Legislature; the first was an act to provide for public regulation of all water resources of the State under a "Water Use Control Board", and the second was to formulate a State Water Code. The above recommendations were generally adopted through the designation of the Pearl Harbor Groundwater Control area in 1980, and the establishment of a State Water Code by the Legislature in 1987.

The State Water Code provides for the creation of a Commission on Water Resource Management which has the responsibility of protecting, controlling, and regulating the ground and surface water resources of the State.

The development of the Code itself was the culmination of intense efforts by the Legislature, State and County agencies, community and professional organizations, and various private interests.

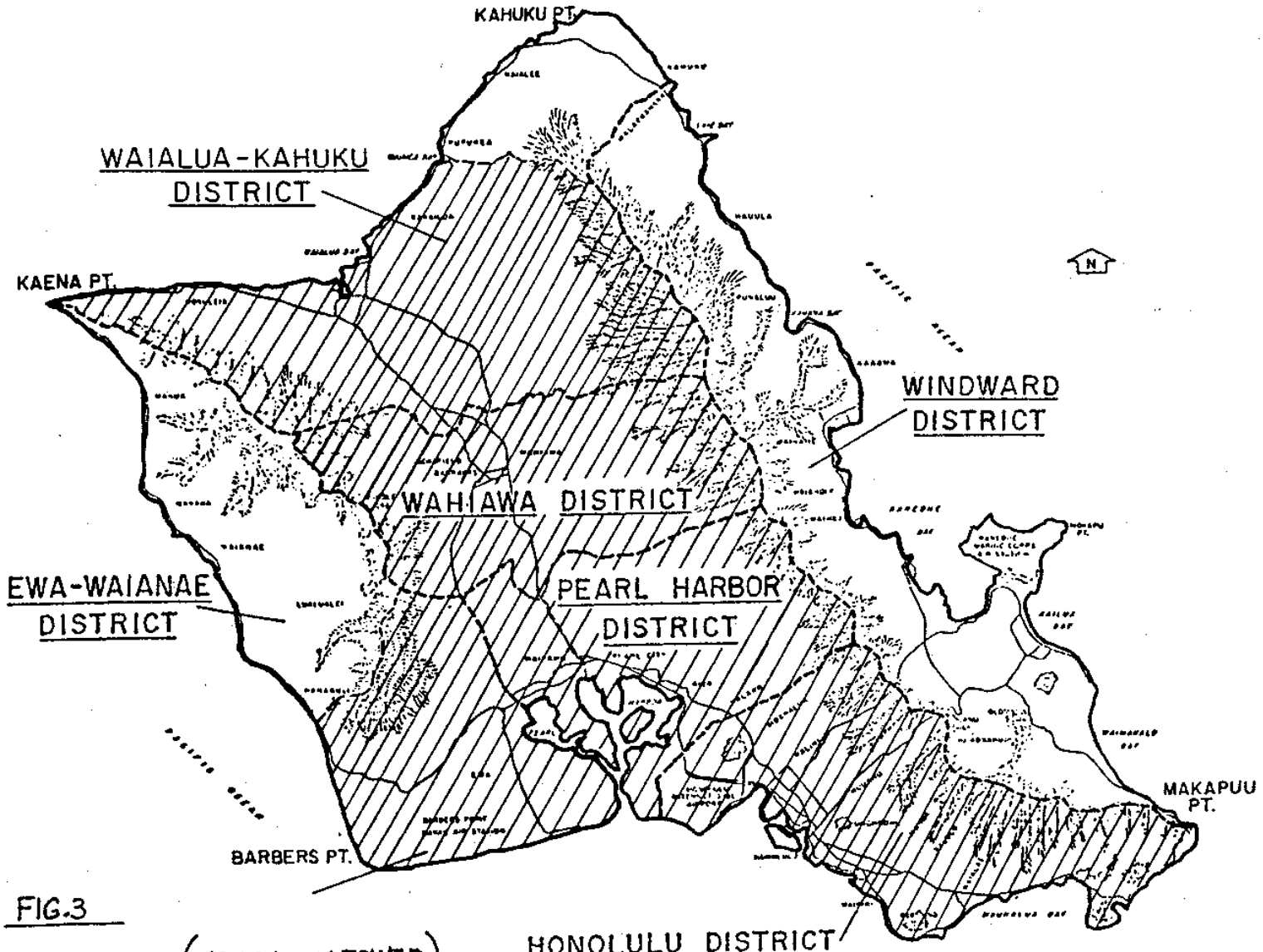


FIG. 3

DESIGNATED AREAS (CROSS-HATCHED)

ISLAND OF OAHU

As mentioned earlier, the formation of a Code and State regulation of water development and use were recommended by the first State Water Commission in 1979. Although not universally accepted, the Code represents the combined thinking of many and is at least a workable document that attempted to address the concerns of various interests. It should be looked upon as a dynamic document subject to change if necessary and open for periodic review and update.

The most important features of a water use and development regulating program are the establishment of designation procedures and criteria for water management areas to protect water resources from depletion, and the setting up of a permit system to control water use in these areas.

According to the Water Code, the criteria for designation of a groundwater control area by the Commission are as follows:

1. Whether an increase in water use or authorized planned use may cause the maximum rate of withdrawal from the groundwater source to reach ninety percent of the sustainable yield of the proposed water management area;

2. There is an actual or threatened water quality degradation as determined by the department of health;

3. Whether regulation is necessary to preserve the diminishing groundwater supply for future needs, as evidenced by excessively declining groundwater levels;

4. Whether the rates, times, spatial patterns, or depths of existing withdrawals of water body due to upcoming or encroachment of salt water;

5. Whether the chloride contents of existing wells are increasing to levels which materially reduce the value of their existing uses;

6. Whether excessive preventable waste of water is occurring;

7. Serious disputes respecting the use of groundwater resources are occurring; or

8. Whether water development projects that have received any Federal, state, or county approval may result, in the opinion of the commission, in one of the above conditions.

For surface water, the criteria are:

1. Whether regulation is necessary to preserve the diminishing surface water supply for future needs, as evidenced by excessively declining

surface water levels, not related to rainfall variations, or increasing or proposed diversions of surface waters to levels which may detrimentally affect existing instrearn uses or prior existing off stream uses;

2. Whether the diversions of stream waters are reducing the capacity of the stream to assimilate pollutants to an extent which adversely affects public health or existing instream uses; or

3. Serious disputes respecting the use of surface water resources are occurring.

All existing and new uses of water in a designated water management area require a permit by the Commission. Furthermore, any person making use of water in any area of the State shall file a declaration of use with the Commission even if no water management area has been designated.

The certificate issued under the latter condition is largely a matter of record. To obtain a permit when a water management area is involved, the applicant must show that the proposed use of water:

1. Can be accommodated with the available water source;

2. Is a reasonable-beneficial use as defined in section 174C(3);

2. Will not interfere with any existing legal use of water;

4. Is consistent with the public interest;

5. Is consistent with state and county general plans and land use designation; and

6. is consistent with county land use plans and policies.

It is noted that the registration requirement includes all wells and stream diversion works.

Under the Water Code, the Commission has emergency powers which can be exercised during periods of water shortage even where a water management area has been designated, and even if permits have been issued in compliance with an requirements. If the Commission deems that "insufficient water is available to meet the requirements of the permit system or when conditions are such as to require a temporary reduction in total water use within an area to protect water resources from serious harm," it may declare that a water shortage exists within all or any part of the area.

To summarize, the Commission has broad powers to order the "apportioning, rotating, limiting, or prohibiting the use of water resources" in any area if it declares

an emergency condition. In spite of having such broad powers, it is unlikely that the Commission would act precipitously or unilaterally in making decisions. We may expect the Commission to conduct necessary investigations and to confer with all interested parties before taking action.

WATER CONSERVATION

Since about 1975, increasing emphasis has been placed on water conservation on the national, state and local levels. At that time, the U.S. Water Resources Council stated that while the nation had an abundance of surface and groundwater supplies, it was estimated that by the year 2000, more than 20 percent of the country will have serious water shortages. In 1975, the American Waterworks Association (AWWA) adopted a policy which stated in part that "water is a renewable natural resource. it must be managed to best meet all the many needs of man. Every effective means to prevent and minimize waste and promote wise use should be employed by all entities, public and private, engaged in water resource activities".

The U.S. Water Resources Council defined water conservation as "activities designed to (1) reduce the demand for water, (2) improve efficiency in use and reduce losses and waste of water, or (3) improve land management practices to conserve water".

Generally, water utilities practice conservation by protecting the watersheds in order to realize dependable yields, reducing system leakage and losses, adopting universal metering, encouraging or requiring the installation of devices to reduce water use, implementing public education programs, adjusting water rates to influence demand, and as a last resort, rationing water use during severe shortages.

Water conservation can be beneficial to a water utility and its customers by reducing demand in dry years and prolonging short supplies during other emergency conditions. Efficient water use can also result in savings particularly on hot-water use. It has been estimated that hot-water use can be reduced almost one-third through effective water conservation measures.

Other energy savings can be realized through reduced water use by requiring less energy to treat and distribute water. Water conservation within the home and industry decreases the volume of wastewater flow. This in turn reduces treatment and collection system costs. In Hawaii, reductions in pumping costs could be very significant.

In planning a water conservation program, a water utility should consider some of the potential disadvantages involved. One of the most important considerations is the reduction of revenues, the effect of which is almost immediate. Therefore, careful advance planning is necessary for a utility to balance conservation against revenue loss.

Water conservation may postpone needed capital improvements so that the

utility must face inflated construction costs in the future. Water conservation can make available additional water to service undeveloped areas. Unless the conservation program is conceived with long-term considerations, problems can arise on land use and availability of water. Thus, close coordination between water conservation and land-use planning is necessary.

Water conservation cannot be regarded as a substitute for a utility's obligation to maintain an adequate reserve capacity. Conservation under normal conditions would make conservation under drought conditions more difficult. Without a reserve capacity, water shortages may become more frequent. This must be kept in mind in any long-range water supply planning program.

Many states and municipalities throughout the mainland have developed water conservation programs with varying degrees of success. Noteworthy programs have been implemented in cities such as Denver, Oakland (EBMUD), Los Angeles, and Washington, D.C..

Until recent years, Hawaii has not found it necessary to resort to mandatory restriction in water use. However, during the past several years, the island of Oahu and certain areas on Maui and Hawaii instituted conservation measures during the summer months. The Honolulu Board of Water Supply found it necessary to limit water use by mandate on a few occasions.

Water Conservation Programs

Water supply planning and water conservation programs are closely related because the latter affect both short-term and long-range water requirements and help reduce the risks of water supply deficiencies. Water conservation programs may involve short-term and long-range conservation measures. Short-term measures are usually referred to as emergency or drought measures. These may include such practices as drastically reduced lawn watering, bans on car washing, and limited flushing of toilets.

Long-range measures may include redesign of toilet tanks to reduce quantity of water for flushing, low-flow shower heads, pressure regulators, and water-efficient appliances. Table 2 shows what a long-term conservation program may include.

In industry, recirculation of cooling water and the re-use of treated wastewater must be considered. In agriculture, drip irrigation and tailwater recovery are effective conservation measures. The use of surface mulches and pressure regulators is also helpful.

In considering water conservation in its broadest sense, proposals that are non-restrictive or obvious must be justified on the basis of acceptability and cost effectiveness as compared with alternate supply projects. A careful evaluation of potential sources of supply, such as water reuse, must be made from the standpoint

Table 2 - Typical Long-Term Water Conservation Measures

Area of Application	Conservation Measure
General	Public education In-school education Metering Pressure reduction Pricing uniform commodity rates Incling commodity rates Seasonal rates Leak detection and repair System rehabilitation
Interior Residential Use	Low-flow shower heads Shower-flow restrictors Toilet-tank displacement bottles/dams Pipe insulation Faucet restrictors Water-efficient appliances
Devices for new construction	Low-flush toilets and ultra-low-flush toilets Low-flow shower heads Pipe insulation Faucet restrictors Water-efficient appliances
Power generation	Recirculation of cooling water Reuse of treated wastewater In-system treatment
Industrial & Commercial Use	Recirculation of cooling water Reuse of cooling & process water Reuse of treated wastewater Efficient landscape irrigation Low-water-using fixtures Process modification
Agricultural Irrigation	Off-farm conveyance systems Canal lining, canal realignment, canal consolidation Phreatophyte control On-farm distribution and irrigation systems Ditch lining or piping Water-control structures Land leveling or contouring Sprinkler irrigation Drip irrigation Subsurface irrigation Tailwater recovery Irrigation scheduling Improved tillage practices Surface mulches Pressure regulator
Irrigation system evaluations	Return-flow systems Field drainage Main drainage
Landscape Irrigation	Efficient landscape design Low-water-use plant material Scheduled irrigation efficiency Efficient irrigation systems Tensiometers

Source: Water Conservation, William O. Maddus, American Water Works Association, Denver, Colorado, 1987.

of capital and operational costs and public acceptance.

Although government must take the initiative in developing and pursuing a strong water conservation program, the success of such a program will depend on public participation and cooperation. Key community leaders and elected officials must be involved. Personnel from government agencies, private water companies, and environmental groups have vital roles to play. Representatives from industry, commercial associations, civic organizations, churches, labor unions, school boards, and the media can all make important contributions. All should be a part of an on-going public education program and planning efforts. Together, such a group could come up with a most cost-effective program for presentation to the public, and to the utility for final implementation.

Finally, any water conservation program must undergo periodic assessment to measure program effectiveness. As a follow-up to program assessment, updating of various program elements may be in order. This function may well be handled by an advisory committee reporting directly to the water department manager.

Practice of Water Conservation

Water conservation methods may be categorized in three general areas. These are resource conservation, water system conservation, and conservation by consumers. In addition, a fourth area dealing with public education should be considered. Resource and water system conservation are primarily the functions of a water utility. Residential water use is probably the most important since it accounts for about two-thirds of the total water sales.

1. Resource Conservation

Resource conservation is intended to assure optimum development of sources to protect them against contamination, waste, and overdraft. Appropriate laws, and rules and regulations must be adopted to protect the groundwater sources against pollution and improper use. In Hawaii, public ownership of watershed lands has long been advocated to conserve and protect underground water resources. Watersheds are infiltration areas that are crucial to the replenishment and preservation of our basal water resources.

Rules and regulations to control the drilling of private wells and to guard against wasteful operation have long been in effect in Hawaii, particularly the island of Oahu. However, the State Water Code which was passed by the Legislature in 1987 empowers the State Water Resource Management Commission to designate areas where the Commission feels that water resources therein are in danger of overdraft. Water use in these designated areas is now under the jurisdiction of

the Commission. In addition to that, the various county water departments now have the authority to impose mandatory restrictions on water use under certain conditions.

An important aspect of the resource conservation program is the continued surveillance of hydrologic conditions to provide data upon which long-term assessment of groundwater conditions can be made. The results of these assessments are the basis for corrective action in the overall management of our groundwater resources.

The preservation of our groundwater resources will gradually assume greater dependence on how effectively we utilize our total water resources. Wastewater reclamation, surface water recovery, desalination, improved irrigation practices, and other means to make greater use of our total water resources all play a part in protecting our groundwater resources against overdraft. The principal means of augmenting our existing natural water resources are described in greater detail in another section of this report.

2. Water System Conservation

A water utility can take various actions to effect savings by better operation and control of its transmission and distribution system. The two primary areas where water system conservation can be most effective are metering of water supplies and leak detection and control. To a lesser extent, reduction in water pressure can result in some savings.

Some water utilities bill their customers on a flat-rate basis. Many others, especially among the larger municipalities, require the installation of water meters and billing their customers for metered water use and water service. The practice of charging customers on the basis of water use provides a strong incentive for customers to use less water. According to the AWWA, studies conducted between 1955 and 1975 indicated that water savings resulting from metering ranged from 13 to 45 percent.

When the Denver Water Department started its large-scale metering project, a careful study was made to determine water savings due to metering. Data collected from 1980 to 1982 indicated that metered households use about 20 percent less water annually than unmetered households.

Distribution system losses through leaks are included in a general category referred to as unaccounted-for water. In addition to leaks, these losses include unmetered water use through fire hydrants, water

illegally taken from the distribution system, inoperative system controls, and water used for street cleaning and flushing of water mains and sewers, although the Honolulu BWS is now metering the water used for street and sewer flushing.

An AWWA report contains some comparisons of unaccounted-for water in various cities throughout the country with figures ranging from an average of 9.5 percent for cities in California to 36 percent in Boston. In 1976, the unaccounted-for water in Boston was 50.5 percent. After a program of leak detection, meter testing and replacement, and pipe relining and replacement, the unaccounted-for water in Boston dropped to 36 percent.

The cost-effectiveness of such a program must be determined by each individual municipality. In the final analysis, a good program of prevention is the best way to reduce leaks. This includes proper water system design, careful installation, and effective corrosion control measures.

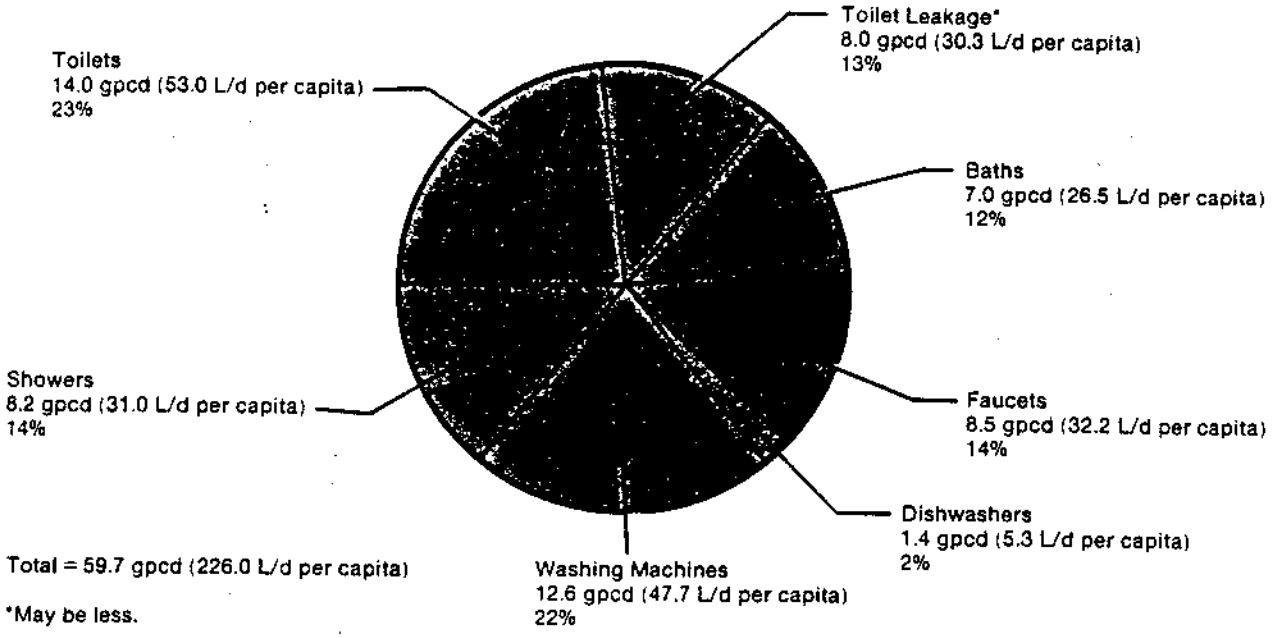
Although not a major factor, reduction of water pressure can save water. A 1984 report by HUD showed that in the cities of Los Angeles, Atlanta, and Denver, a reduction of pressure of about 30 psi resulted in a three to six percent decrease in water use. A similar study in Boston showed a decrease of eight percent. However, each water utility must determine whether it would be practical to operate at lower pressures where certain services may be affected such as fire-fighting capabilities.

3. Consumer Conservation

In general, residential water use averages about 65 percent of total urban water sales. Commercial use averages about 13 percent and industrial use about 14 percent. The rest is attributed to government and agricultural use. In Hawaii, the figures may vary somewhat. Honolulu, for example, reports that residential use averages about 61 percent, commercial 21 percent, industrial five percent, and government and agriculture about 13 percent.

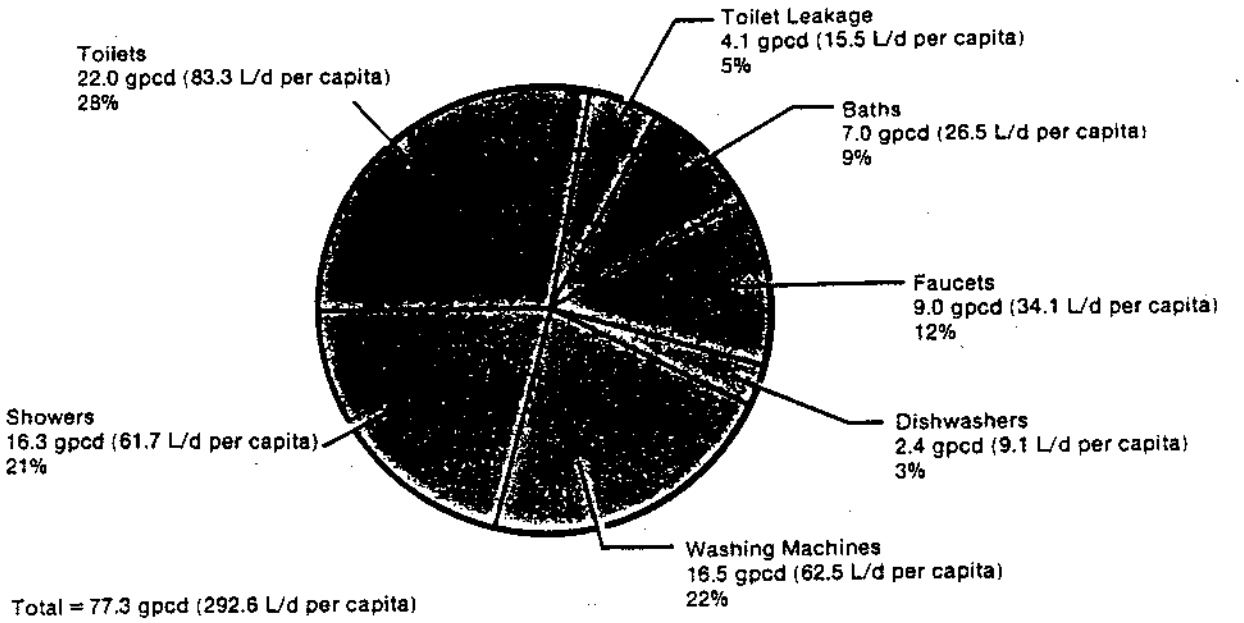
Residential water use can further be classified as water used inside and outside the house. A typical home uses between 60 and 80 gpcd. Because of wide variations in climate and landscaping, water used outside the home may vary between 30 and well over 100 gpcd. Figs. 4 and 5 show average inside water use for a conserving and non-conserving home, respectively.

Inside the home, most water is used in the bathroom. National figures show that a home constructed with water-efficient plumbing



Source:Residential Water Conservation Projects-Summary Report, Brown and Caldwell (June 1984).

Fig. 4 Average Inside Water Use for Conserving Home



Source:Residential Water Conservation Projects-Summary Report, Brown and Caldwell (June 1984).

Fig. 5 Average Inside Water Use for Nonconserving Home

Source: Water Conservation, William O. Maddus, American Water Works Association, Denver, Colorado, 1987.

fixtures uses more than 20 percent less water than a home with non-conserving fixtures. Some of the more common water-conserving fixtures are as follows:

a. Low-flush toilets - these units use no more than 3.5 gallons per flush. This can save up to 50 percent of the water used in older toilets. A new ultra low-flush toilet is now available which uses only 1.5 gallons per flush. It is more expensive than the standard models, but mass production will probably reduce the cost substantially.

b. Low-flow shower heads - ordinary shower heads deliver from five to eight gpm. A low-flow shower head uses about 2.75 gpm, resulting in a savings of roughly 50 percent or more.

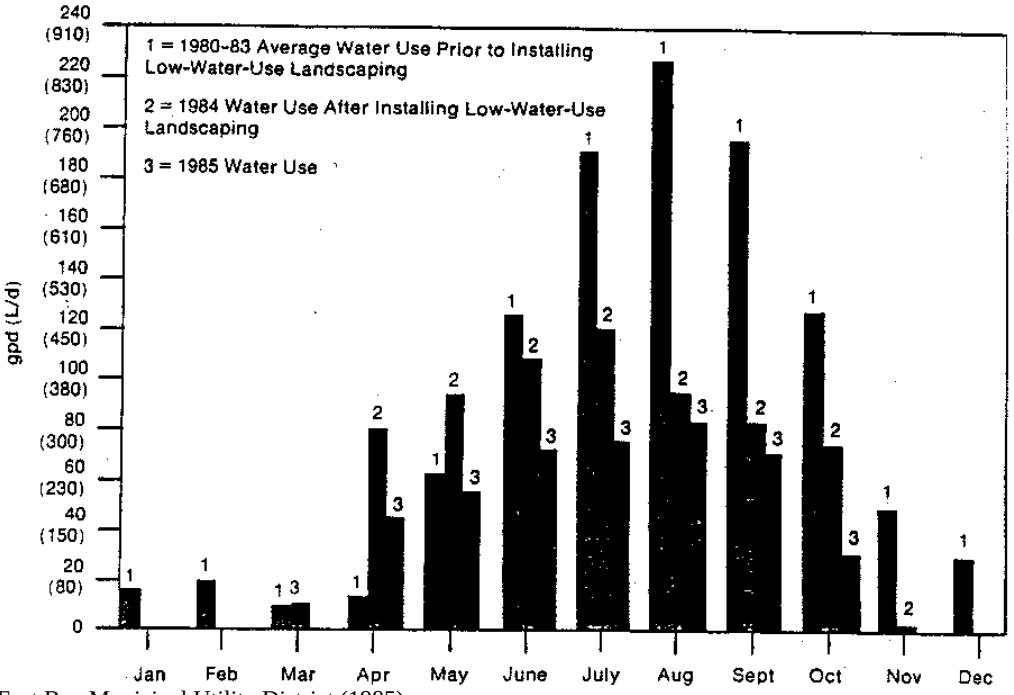
c. Low-flow faucets - no reliable data are available on water savings due to the use of low-flow faucets but the AWWA reports that the savings would probably be less than 1.0 gpcd.

d. Water-efficient dishwashers and clothes washers dishwashers and washing machines use significant amounts of water. New units on the market now make it possible to save about five gallons per load for dishwashers and about six gallons per load for clothes washing machines.

Many states now require the installation of water-efficient devices in new construction. Newer products are appearing on the market but have not gained wide acceptance mainly because of high costs.

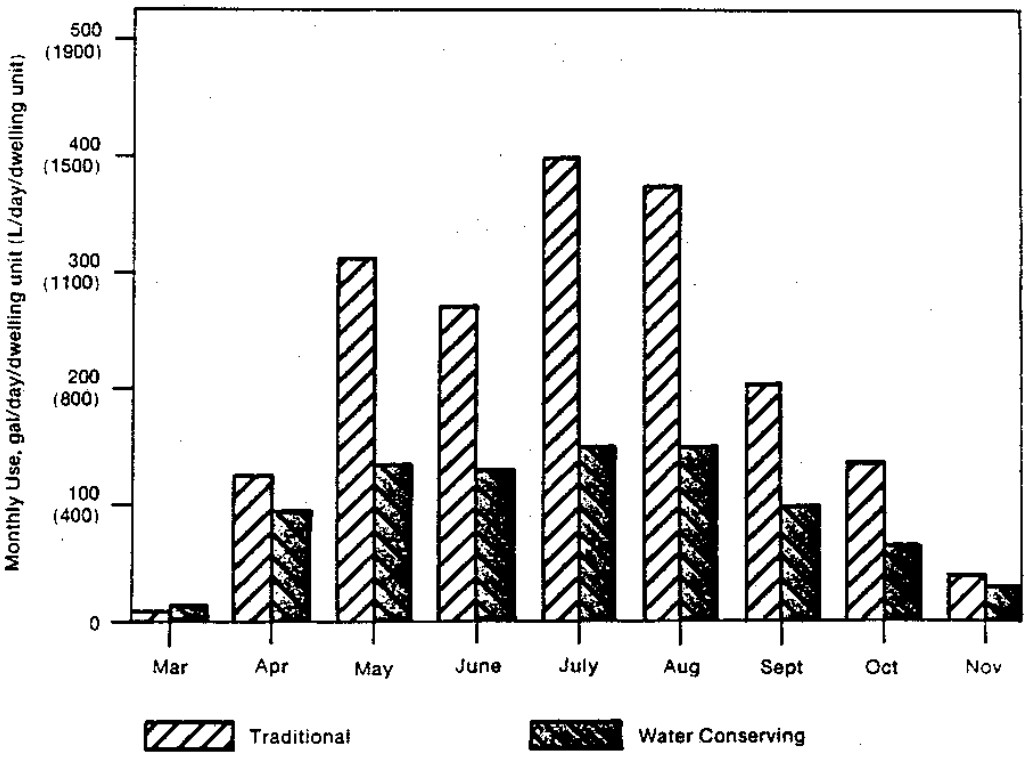
Water used outside the home is primarily water for landscape irrigation. Water conservation measures that can be used include improved irrigation techniques, better turf preparation, and alternative landscaping designs that reduce water use. Improved irrigation techniques can save from 20 to 50 percent of the water applied.

The potential savings from low water-use landscaping can be considerable. Studies in Denver and the East Bay Municipal Utility District show that savings from low water-use landscaping reduced water use by as much as 63 percent. Efficient irrigation combining appropriate choice of sprinkler heads, uniform water application rates, automatic controllers, and proper zoning of turf and planting beds can reduce water use substantially. Studies in Palm Springs, California indicated savings of 54 percent under controlled irrigation conditions. Figs. 6 and 7 are example of how savings can be affected through low water-use landscaping.



Source: East Bay Municipal Utility District (1985)

Fig. 6 Water Use at EBMUD's Demonstration Garden



Source: North Marin Water District (1986)

Fig. 7 Monthly Water Use of Conserving and Nonconserving Landscapes

Source: Water Conservation, William O. Maddus, American Water Works Association, Denver, Colorado, 1987.

Reduction of Commercial Water Use

Water use for commercial establishments is confined mainly to sanitation and landscape irrigation. Many of the residential water saving techniques apply to commercial establishments. Some of these are as follows:

a. use of retrofit water-saving devices
b. adjustment of valves on toilets and urinals
c. use of water-efficient appliances
d. use of low-flow shower heads
e. elimination of leaks
f. adoption of water-recycling practices, such as car wash water
g. use of low water-use landscaping
h. installation of automatic irrigation systems

Reduction of Industrial Water Use

Water use by industry is primarily for cooling, landscape irrigation, sanitation, and process water. Conservation of water used for irrigation and sanitation may be realized through the same methods recommended for residential and commercial users. Other means of reducing industrial water use are as follows:

a. converting once-through cooling systems to closed systems
b. reclamation of wastewater
c. eliminating waste of water used for cleanup
d. designing more efficient systems for process water use

In Hawaii, the potential of reducing industrial wastewater use is not great. Nevertheless, opportunities for savings still exist, especially in pineapple canneries, power generating plants, and milk processing plants. In contrast, during California's drought of 1976-77, many plants in the Los Angeles area reduced water usage by around 50 percent or more.

Pricing of Water

Water rates are designed to provide revenues for a utility to defray operating and capital expenses. Various types of rate structures have been designed by utilities to encourage water conservation, the principal types being:

a. Uniform rates - the uniform rate structure charges the same unit rate for all water usage. This method gives some incentive to conserve, especially to above-average per capita consumers.

b. Inclining rates - this rate is a unit charge which increases with water

usage, thus making the large users responsible for the incremental cost of providing the additional water consumed. This structure encourages the large users to conserve, especially if the rate increases are significantly large.

c. Seasonal rates - under these rates, the unit cost of water increases during peak seasonal use periods--primarily during the summer. This rate structure is becoming more common throughout the country. Its obvious objective is to provide consumers with the incentive of reducing water use during peak demand periods.

The rate structures listed above are basic concepts, subject to a number of variations and combinations depending on various local conditions. Water utilities must consider these conditions before developing rate structures that would best suit their needs.

4. Public information Programs

Public information systems are usually intended to develop a conservation ethic among water users. In order to achieve reductions in water use, it is vital for consumers to make a voluntary commitment to conserve water.

Public information programs can educate consumers on how waste can be prevented, such as indiscriminate flushing of toilets, running water unnecessarily while taking showers, shaving, brushing teeth, washing cars, or watering lawns. The public can be educated on water sources, the cost of operating a water system, the limited capacity of our sources, and the importance of water conservation.

The effectiveness of a public information program is difficult to measure. information from literature compiled by the AWWA reported that most programs mentioned a four to five percent savings. Early in 1977, the Honolulu BWS embarked on a public information program and made a direct plea to the public to conserve water. The effective savings noted for the year was about nine percent. Experience shows that in order to be effective, a public information program must be carried out on a long-term basis.

VII. AUGMENTATION OF RESOURCE

The adequacy of water resources to meet all needs throughout the State, especially on a long-range basis, must be viewed with due consideration of alternative water sources to augment our naturally-occurring water supplies. The big question is the order of priority in which the development of these sources is to be implemented.

The need for augmentation on the Neighbor islands does not appear to be urgent. In many areas, the problem is a matter of development and distribution rather than a scarcity of water. The situation for the island of Oahu seems to take on a relatively greater degree of urgency, although it is difficult to pinpoint at this time as to when augmentation must be implemented.

For the island of Oahu, some feel that all available surface and groundwater supplies will be fully committed by the turn of the century, and water demands beyond the year 2000 must be met by augmentation of various alternatives. Although groundwater supplies are largely developed, some are of the opinion that the eventual full development of these supplies and more importantly, their judicious management would enable us to extend their availability to comfortably beyond the year 2000.

Indeed, it is quite possible that water may not be the limiting factor in the development of Oahu, recognizing that growth may be impeded by such problems as traffic, housing, employment and various social needs.

However, the need for additional water supplies must be constantly reviewed, research continued, and priorities established so that the development of these supplies can be pursued in an orderly manner in the future. In this regard, the amount of lead time, funding, and the availability of technical resources are major considerations.

The principal alternative sources of water which may be used for augmentation are as follows:

1. DESALINATION

Because Hawaii is in the middle of the Pacific Ocean, there is a tendency among many to believe that desalination is the answer to our water needs. It is true that desalination is technologically possible, but the element of cost in comparison with that of other alternatives becomes a serious factor. Tables 3, 4 and 5 show the extent of desalination throughout the world.

Desalination on a municipal scale has been considered intermittently in the past. In the 1960s, the Honolulu BWS conducted studies on the feasibility of desalination using seawater and brackish water as sources. At that time, the estimated cost of desalting brackish water (up to about 1,500 ppm chloride) was $0.50/1,000 gallons, and for seawater, the cost was about $1.00/1,000 gallons.

DESALTING PRACTICES THROUGHOUT THE WORLD

TABLE 3
DISTRIBUTION OF DESALINATION CAPACITY WORLDWIDE

Region	Percentage
Western Asia (Middle East)	63
North America	11
North Africa	7
Europe	7
Pacific	4
Caribbean	2
Soviet Union	2
Other	4

TABLE 4
DISTRIBUTION OF DESALINATION CAPACITY BY PROCESS

Desalination Process	Percentage	
	United States*	Worldwide
Distillation	21	70
Electrodialysis	6	5
Reverse Osmosis	73	25

*Includes U.S. Virgin Islands

TABLE 5
SHARE OF WORLDWIDE DESALINATION CAPACITY—UNITED STATES

Desalination Process	Percentage
Distillation	3
Electrodialysis	13
Reverse Osmosis	32
TOTAL	11

Source: Desalting Practices in the United States Journal of the American Water Works Association, Vol. 81, November, 1989, Denver, Colorado, pp. 38, 39.

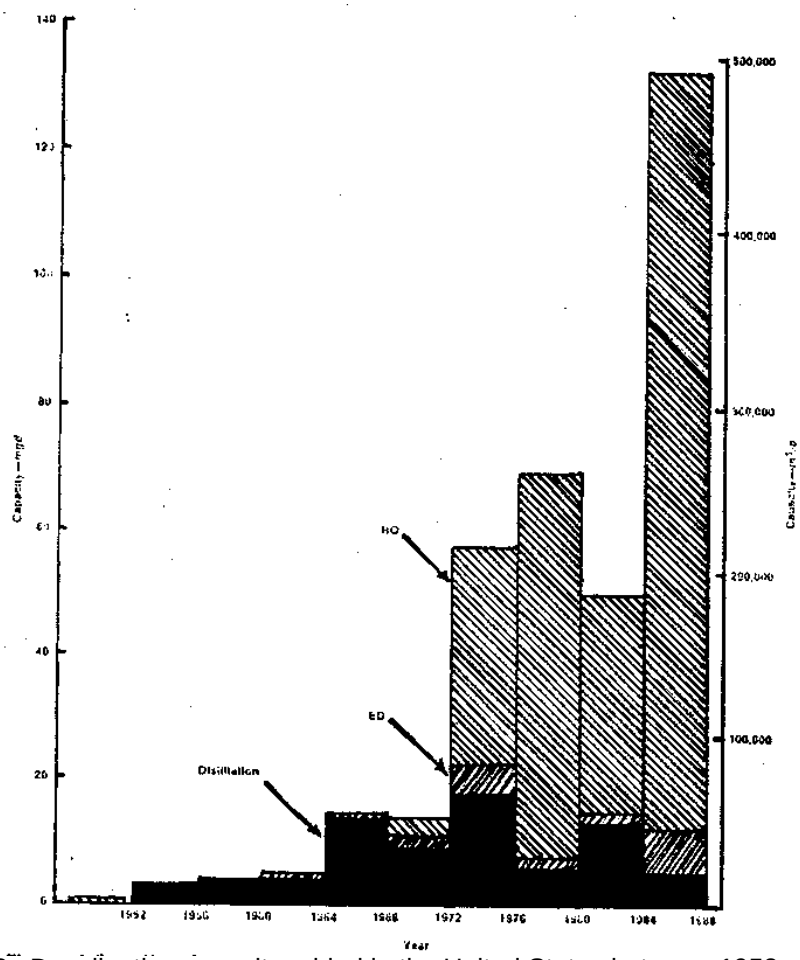


Figure 8. Desalination capacity added in the United States between 1952 and 1988
(US data include the Virgin Islands; Yuma, Ariz. facility included in the 1984-88 data)

RO = Reverse Osmosis
ED = Electrodialysis

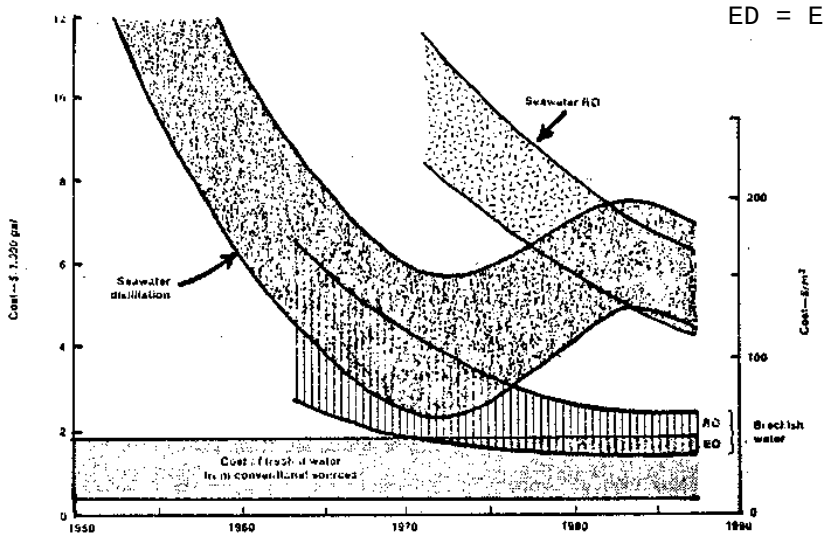


Figure 9. Range of desalting costs-1950-1987 *(Costs for distillation and RO, including capital and operating costs are for plants producing 3,700-18,500 m^3/d [1-5 mgd] of "polished" potable water. Costs may be higher than indicated when desalination equipment is operated inefficiently. The increasing distillation costs during the 1970s primarily reflect rising capital and energy costs. All costs are given in 1985 dollars.*

The State Department of Land and Natural Resources, with the assistance of the Campbell Estate, the BWS, and the University of Hawaii Water Resources Research Center, is installing a 1 mgd desalting plant in the Ewa district using brackish water as the source. Completion date is scheduled for the middle of 1990. The unit cost of water production is estimated at slightly more than $3.00/1,000 gallons by the project consultant. This does not include cost of storage and distribution which is usually several times greater than the cost of production by conventional means.

Large-scale studies and the use of demonstration plants to show the feasibility of desalination have taken place only during the past three or four decades. In general, the various methods considered were based on the principles of phase change (for example, distillation), membrane separation, and chemical reaction. Some of the methods more frequently referred to are as follows:

A. Phase Change Methods

1. Distillation (Evaporation) - this is the oldest desalination method and has been practiced throughout the world for the past several centuries. Distillation involves heating saline or brackish water until it forms water vapor. This vapor, which is largely salt-free, is condensed to the liquid form for storage and distribution.

   Although the distillation method is capable of handling large quantities of saline water, it has serious disadvantages of requiring a great amount of thermal energy, high capital costs, high operating and maintenance costs, and severe scaling and corrosion problems. It is not competitive with other desalination methods, especially in the conversion of brackish water. Fig. 10 is a simplified flow diagram of the evaporation method.

   Locally, the feasibility of using waste heat from a nuclear power electricity generating plant was considered by the BWS and Hawaiian Electric Company (HECO) in the 1960s, but the HECO considered the proposal premature at that time.

2. Freezing - this is another phase-change method which is characterized by the formation of ice crystals with the dissolved salts remaining in the solution. Fresh water is produced by separating the ice crystals from the solution and melting the crystals.

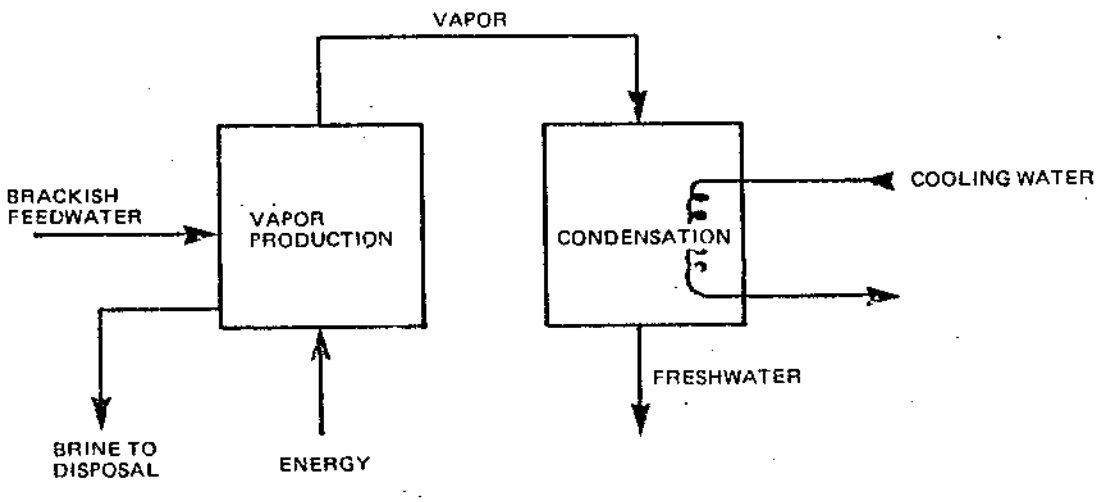


Fig. 10
Simplified flow diagram of evaporation method

Source: Desalting Brackish Water, James D. Mavis and Charles J. Krogh, Presented at the Alternative Water Sources in the Pacific Seminar, Honolulu, Hawaii, 1984

This process uses much less heat than the distillation method but it has substantially higher operating and maintenance costs. In addition, the qualities of fresh water produced by this method is limited, probably not more than 0.2 mgd. Fig. 11 is a simplified flow diagram of the freezing method.

B. Membrane Separation Methods

1. Reverse Osmosis - osmosis occurs when water passes through a semipermeable membrane separating two solutions of different salt concentrations. In natural osmosis, the passage of water is from the dilute solution to the concentrated solution until the concentrations of the two solutions become equal, or when the pressure on the concentrated solution side of the membrane rises to the osmotic pressure.

   The osmotic pressure may be referred to as the osmotic head or the difference of the depths of the liquid surfaces of the two solutions. When a pressure greater than the osmotic pressure is exerted on the more concentrated solution, reverse osmosis occurs. The result is a passage of water from the more concentrated to the less concentrated solution.

   In the reverse osmosis process, the concentrated solution can be either seawater or brackish water. Pressure greater than the osmotic pressure is applied and desalted water is collected on the dilute solution side of the membrane. This water is collected, stored and distributed to various users. Fig. 12 is a schematic diagram of the reverse osmosis process.

2. Electrodialysis - when salts are in solution, they are broken up into positively and negatively charged ions called cations (positively charged) and anions (negatively charged).

   Electrodialysis depends on the action of semipermeable membranes than can selectively pass either cations or anions (see fig. 13).

   When stacks of alternating cation and anion permeable membranes are placed in a direct current electric field and

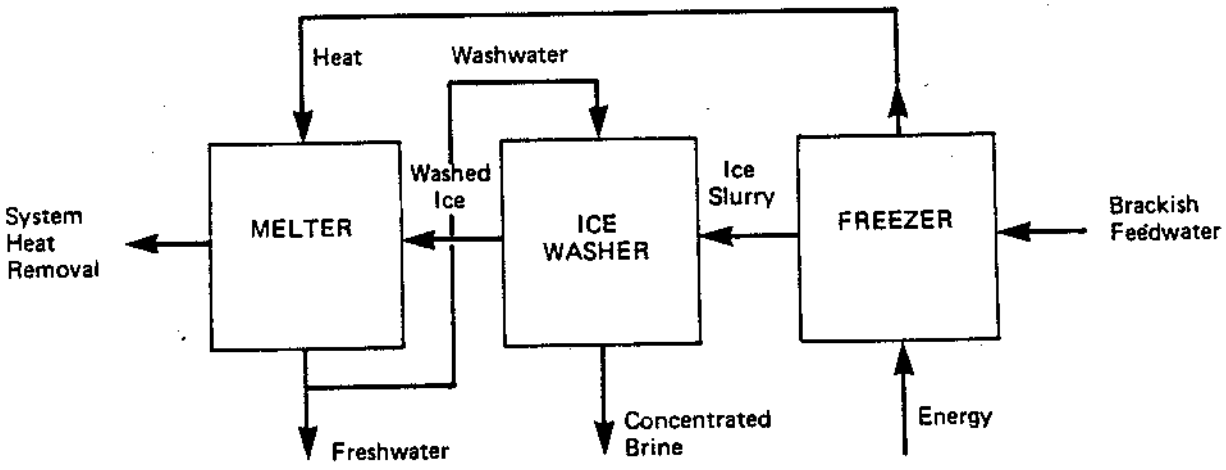


Fig. 11
Simplified flow diagram of freezing method

Source: Desalting Brackish Water, James D. Mavis and Charles J. Krogh, Presented at the Alternative Water Sources in the Pacific Seminar, Honolulu, Hawaii, 1984

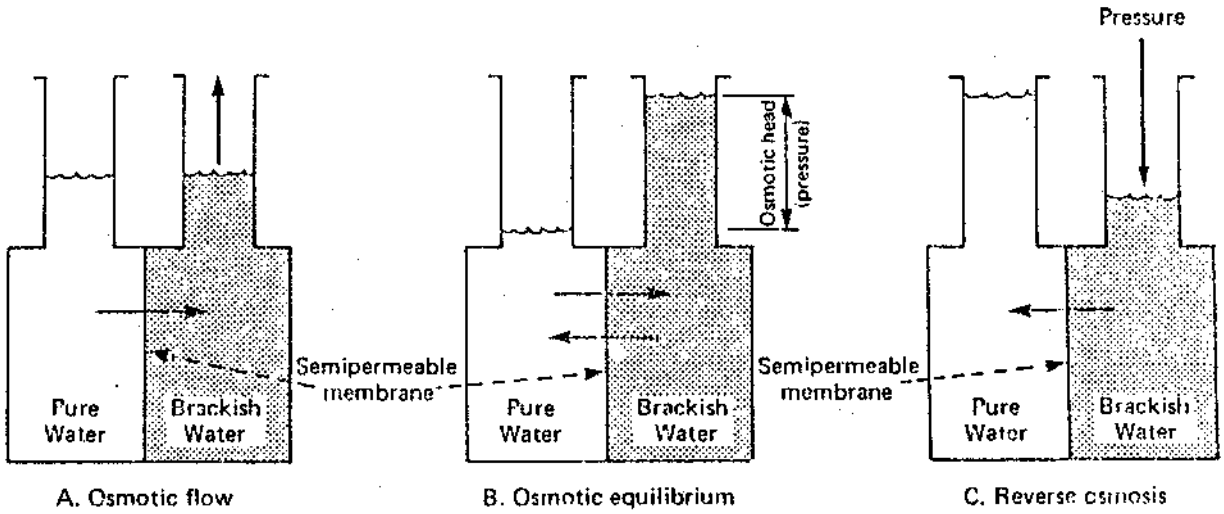
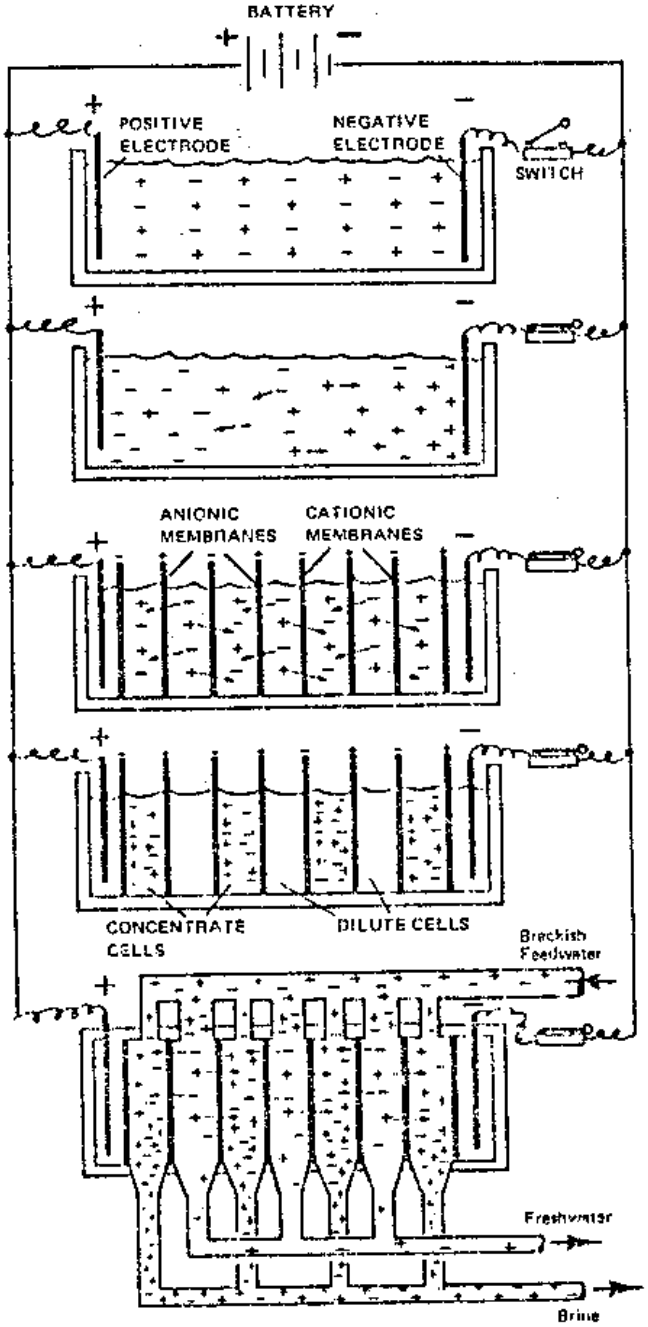


Fig. 12 Schematic of reverse osmosis process

Source: Desalting Brackish Water, James D. Mavis and Charles J. Krogh, Presented at the Alternative Water Sources in the Pacific Seminar, Honolulu, Hawaii, 1984



Sodium and chloride are strong electrolytes. When dissolved in water they separate into ions, which carry an electric charge. These ions tend to attract the dipolar water molecules and to be diffused fairly evenly throughout a solution.

If two electrodes are placed in a solution of ions, and energized by a battery or other direct current source, the current is carried through the solution by the charged particles and the ions tend to migrate to the electrode of the opposite charge.

If alternately fixed charged membranes (which are selectively permeable to ions of the opposite charge) are placed in the path of the migrating ions, the ions will be trapped between the alternate cells formed.

An anionic membrane will allow negative ions to pass, but will repel positive ions. A cationic membrane will allow positive ions to pass, but will repel negative ions.

If this continues, almost all the ions would become trapped in the alternate cells (concentrate cells). The other cells, which lack ions, are referred to as dilute cells.

In a continuous electrodialysis process, feedwater enters both the concentrate and product cells. Up to about half of the ions in the product cells migrate and are trapped in the concentrate cells. Two streams emerge from the device: one of concentrated brine and the other with a much lower sodium chloride concentration.

Adapted from The USAID Desalination Manual.

Fig. 13 Movement of ions in the electrodialysis process

Source: Desalting Brackish Water, James D. Mavis and Charles J. Krogh, Presented at the Alternative Water Sources in the Pacific Seminar, Honolulu, Hawaii, 1984

feedwater is passed between the membranes, the cations migrate to the negative electrode (cathode) and the anions move to the positive electrode (anode).

The membranes trap the ions in cells; between the membranes and the resulting solution is removed as waste brine. Water passing through the membranes is collected and removed for use as desalted water. In recent years, an electrodialysis reversal (EDR) system has been developed which reverses the polarity of the electrodes several times an hour. This reversal process minimizes scaling and other adverse effects on the membranes.

It should be noted that electrodialysis does not remove bacteria and other uncharged particles. Accordingly, it is necessary to stabilize and disinfect the product water before use.

C. Ion Exchange

Ion exchange, commonly referred to as demineralization, is a method based on chemical reactions in which dissolved solids (cations and anions) are removed from the solution by ion exchange resins. These resins are the sites of hydrogen and hydroxide ions which are "exchanged" with the cations and anions. The hydrogen and hydroxide ions combine to form water as the neutral product. The undesirable salt ions in the solution are "captured" by the resins and removed as wastes (see fig. 14). After a while, the hydrogen and hydroxide ions lost in the exchange process must be replaced through regeneration of the resins with acid and caustic solutions.

In effect, the regeneration process removes the ions from the water by the resins during the exchange process.

Ion exchange is used principally to obtain high-quality water for industrial applications. However, the high cost of regenerant chemicals makes the process uneconomical when treating water with high chlorides and dissolved solids.

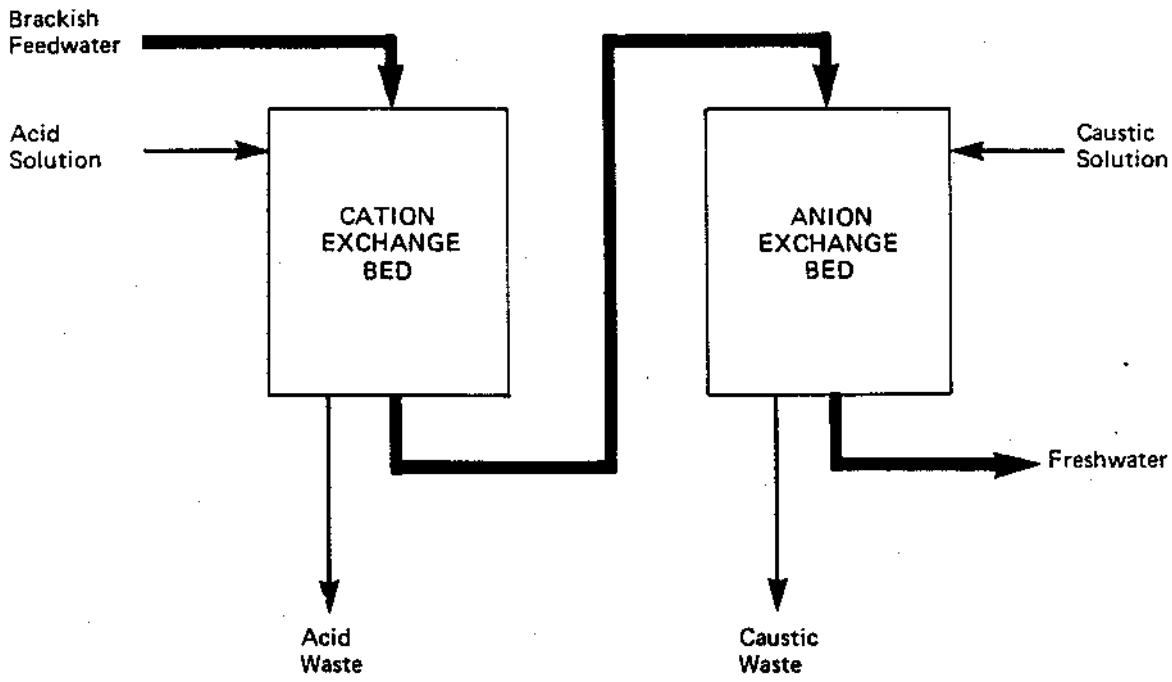


Fig. 14 Simplified flow diagram of ion exchange method

Source: Desalting Brackish Water, James D. Mavis and Charles J Krogh, Presented at the Alternative Water Sources in the Pacific Seminar, Honolulu, Hawaii, 1984

Comparison of Desalting Methods

The selection of desalting method is based on several considerations, principally economics, location of area of need, availability and quality of feedwater, operating problems, energy demand, quantity and quality of product water needed, and to some extent, environmental impact.

The distillation process, while capable of desalting large quantities of water, is burdened with high operational and capital costs.

The energy required for this method is considerable. It also has serious scaling and corrosion problems. Its application, therefore, is confined largely to the distillation of seawater. Moreover, the disposal of waste brine resulting from distillation must be dealt with carefully so as to not impair environmental quality.

The freezing method has limited applications, is relatively new, and is capable of producing only up to 100,000 gpd on a practical basis. Although it requires only about 15% of the energy used by the distillation process with minimal scaling and corrosion problems, its operating and maintenance costs are high because of the need to separate the ice from the brine, washing the ice crystals, and melting the crystals to form fres water.

Due to improving technology, the freezing method may have a future, especially in areas where only poor quality water sources are available and where large quantities of product water are not required.

The ion exchange method has been used principally to produce high-quality water for industrial purposes. The high cost of chemicals needed for regeneration has made this method impractical on a municipal scale. In addition, the relatively large quantities of waste resulting from the process together with the waste resulting from regeneration make large-scale production of water by ion exchange unattractive.

Figs. 15 and 16 show generalized comparisons (capital and operating) in the desalting of brackish water by the evaporation, reverse osmosis and electrodialysis methods.

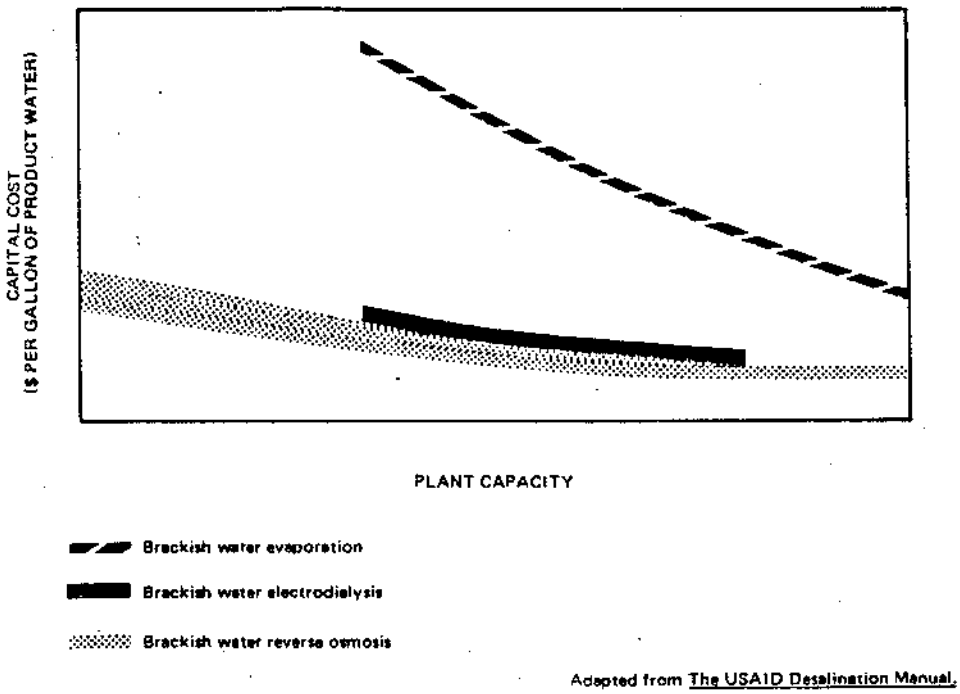


Fig. 15 Generalized capital cost relationship of evaporation, reverse osmosis, and electrodialysis

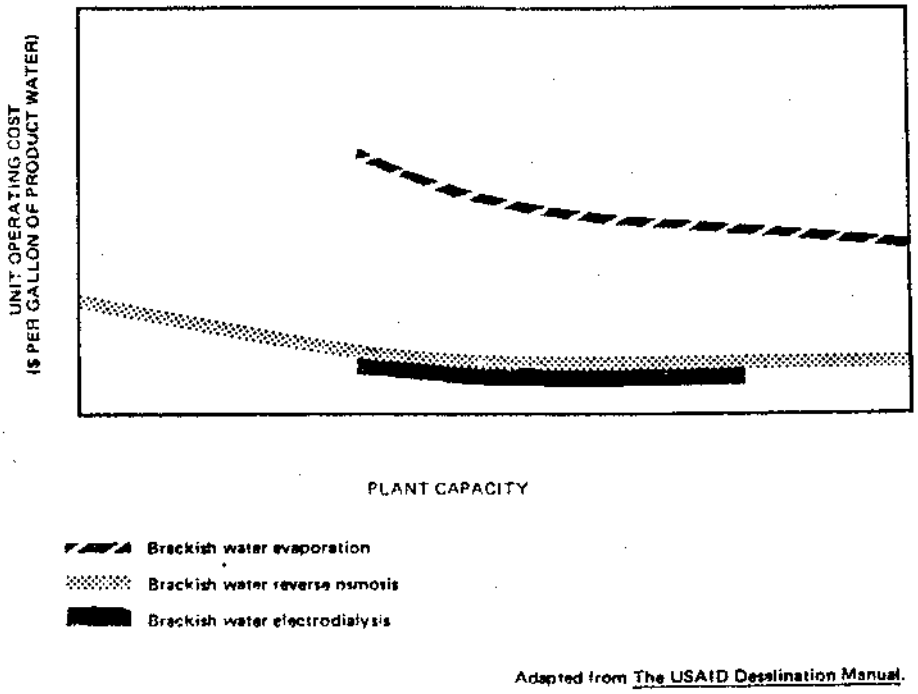


Fig. 16 Generalized unit production cost relationships of evaporation, reverse osmosis, and electrodialysis

Source: Desalting Brackish Water, James D. Mavis and Charles J Krogh, Presented at the Alternative Water Sources in the Pacific Seminar, Honolulu, Hawaii, 1984

Conclusion

For the foreseeable future and the view of the reasons cited above, we may conclude that, for municipal needs, the distillation, freezing, and ion exchange methods are not applicable in Hawaii. Improving technology may make them worthy of consideration in the future, but the most practical approach for Hawaii would be the electrodialysis and reverse osmosis methods using brackish water as the source.

However, it should be borne in mind that even if these methods were feasible, especially on Oahu where the need for augmentation is greatest, the sustainable yield of caprock brackish water is limited, probably not more than 15-20 mgd. For basal brackish water, the supply is greater, but care must be exercised in the use of this source because of possible jeopardy to the basal groundwater body and nearby wells.

2. IMPROVED IRRIGATION PRACTICES

Up until the late 1960's, irrigation of cane fields was done by the conventional furrow irrigation method where the cane was flooded by water applied to furrows. Sometime around 1968, overhead sprinkler systems became more widely used to irrigate the fields. By 1970, the sprinkler system of irrigation, although more efficient than furrow irrigation, was largely replaced by drip irrigation.

Results to date show that the adoption of drip irrigation by the sugar industry revolutionized irrigation practices in Hawaii and to a significant extent saved the sugar industry. This, together with the burning of bagasse to generate electricity, kept the sugar industry going on a viable basis.

The conversion of furrow to drip irrigation has resulted in better cane yields, higher production, and substantial decreases in water use. The reduction in the use of potable water for irrigation has occurred at a very opportune time particularly for the island of Oahu where water demands for urban development will continue to grow.

A recent study of the Pearl Harbor area indicated that the savings in water use due to drip irrigation are not as great as initially expected. Many thought a savings of up to 40% was possible. However, the Pearl Harbor study indicated that a savings of 20-25% is more likely to occur.

The use of sprinkler or drip irrigation has not been confined to cane irrigation. More and more, these methods are being used on a practical and research basis for crops such as macadarnia nuts and papayas.

3. WEATHER MODIFICATION

Weather modification as a means to increase precipitation has been the subject of research and experimentation in Hawaii since the early 1950's. In 1953, the then Territorial Cattlemen's Council, the Pineapple Research Institute, and the Hawaii Sugar Planters' Association jointly conducted research on spray seeding of clouds in Keanae Valley, Maui. The process called for seeding of warm clouds with water sprays from a ground-based installation to stimulate rainfall.

Some positive results were noted in increased size and number of raindrops, but the project indicated that more work was necessary before spray seeding could be considered for practical application.

Cloud seeding using chemical agents for seeding has also been attempted in certain areas on the mainland, but no large-scale effort has been made locally.

A potential problem that has not been fully explored is the possible build-up of chemical agents for seeding. Its potential impact on the environment should be carefully evaluated before further consideration is given to the viability of this method to produce or increase precipitation.

Conclusion

Whether weather modification can offer realistic and practical solutions to the State's water supply problems is uncertain at the present time. From a long-range standpoint, however, research and experimentation to determine its applicability should continue.

4. ARTIFICIAL RECHARGE

Artificial recharge is the process by which natural infiltration of surface water or precipitation into a groundwater body is supplemented by infiltration induced by man. It is accomplished by three basic methods: water spreading, through pits, shafts, and tunnels, and through wells.

Recharge through spreading increases infiltration to a groundwater body by expanding the ground area covered by water resulting in an increased volume of water available for percolation. Water can be spread by diversion into shallow basins or depressions, ditches, open irrigation systems, etc. Another method would be to build check dams across stream channels in order to spread the water over a larger area of the channel for greater infiltration into the stream bed and valley sides.

Where space is limited or in areas where impervious layers near ground surface restrict infiltration of water, recharge is achieved by diverting water into pits, shafts, or tunnels. These are used to either penetrate the impervious layer or to provide direct access to the groundwater body.

Recharge wells are used where there is inadequate space, or recharge to a deep confined aquifer is desired. In recent years, a number of injection or disposal wells have been located throughout the State. Some have referred to these wells as recharge wells, although their primary purpose is to serve as an avenue to dispose of undesirable liquids rather than to replenish the aquifer. In certain parts of the mainland, injection wells are used to dispose of brine generated in the pumping of oil wells.

In Hawaii, artificial recharge for the sole purpose of supplementing infiltration to the groundwater body is limited. For many years, the McBryde Sugar Company has been recharging the groundwater body in the Hanapepe River Valley (Kauai) through a system of tunnels and shafts and pumping the water for irrigation purposes. Records for this operation date back to 1924.

In 1965, the Department of Public Works of the County of Maui began recharging operations through a series of wells and pits in Kahului and Wailuku, but they serve only as disposal sites for storm run-off.

It is extremely doubtful whether this water recharges any fresh basal groundwater body. Records indicate that the Maui Agricultural Company (1935) and the Hawaiian Commercial & Sugar Company (1950) began to recharge the groundwater body with excess irrigation water by spreading in gulches and irrigation ditches and dumping it into old pits. The effect of this operation on the groundwater body is not known.

In the mid-1960's, recharge operations began at Puukapu and Hilo on the island of Hawaii. Although it is believed that recharge water entered into groundwater bodies, the primary intent of these projects was flood control and storm water disposal. Hydrologic data related to these operations are not available.

Artificial recharge in Hawaii incidental to irrigation practices probably constitutes the greatest amount of recharge to the groundwater body. Leakage from reservoirs and ditches, together with percolation in irrigated fields add up to a considerable amount of recharge.

At one time, it was believed that return irrigation water was responsible for greater than 60% of the total recharge. However, recent studies by Mink & Yuen (1987) indicated that the figure is closer to 40%.

Deliberate recharge to basal water bodies in Oahu is not known. Several plantation reservoirs, such as the Waiawa reservoir, probably lose some of their

seepage to the groundwater body but no records are available to substantiate this. The Honolulu BWS operates four open reservoirs in Nuuanu Valley but it is very doubtful that any of the seepage from these reservoirs reaches the basal water body.

Avenues through which water may reach the groundwater body are cesspools, especially on Oahu. However, no work has been done to determine the magnitude of this recharge which obviously is decreasing because cesspools are gradually beings replaced by centralized sewerage systems.

Conclusion

Artificial recharge as a direct means of replenishing the fresh groundwater body is not practiced in Hawaii. The significant recharge of our fresh water aquifers resulting from infiltration following irrigation is only incidental to the primary function of irrigation. The disposal of storm water in wells, pits, and tunnels adds very little to our groundwater supply.

The reason why recharge is not resorted to locally is probably due to the fact that our water supply problem has not reached a critical state, with the exception of areas on Oahu and possibly Maui where alternative sources may need to be relied upon in the not too distant future. The adoption of recharge as a solution depends on its effectiveness and cost as compared with other alternatives.

Recharge through return irrigation water will gradually become less significant because of the practice of drip irrigation and the reduction of sugar cane acreage. The building of check dams across valley streams to induce increased percolation may be feasible.

Diversion of stream flows and surface run-off into tunnels, shafts, and pits to recharge groundwater bodies has been the object of planning for many years, especially by the Honolulu BWS. However, no pilot studies were ever carried out.

Recharge in the future must be planned with a monitoring program to determine recharge rates, quantitative effects on the aquifer, and qualitative (pollution) impacts. Field tests and research may provide the answers to questions now facing recharge as a viable alternative.

5. SURFACE WATER RECOVERY

The collection, treatment and distribution of surface water for municipal, industrial and agricultural uses in Hawaii have not been widely practiced because the cheaper methods of developing groundwater have heretofore been

adequate to meet needs. By today's standards, the cost of developing groundwater is less than half the cost of recovering surface water.

However, as the development of groundwater sources approaches their sustainable yields in certain areas in the State, the feasibility of developing surface water is attracting more attention in the overall priority considerations of the various alternatives.

As contrasted with many areas throughout the mainland and the world, the recovery of surface water for domestic purposes in the State of Hawaii is minimal. The Molokai Water Project is probably the most important, and only a small portion of its total output is being used for domestic purposes.

In the 1960's, the Honolulu Board of Water Supply experimented with a modified slow sand filter in upper Nuuanu Valley, using water from Lulumahu Stream. The filter is still in operation today, contributing a valuable supply to the Upper Nuuanu water system.

Historically, there may have been a few local surface water treatment systems, but it is doubtful whether they are still in operation. For example, Libby cannery operated a slow sand filter in Wahiawa, Oahu where some of the water was used for domestic purposes but its operation was terminated a number of years ago.

The diversion of water from streams for irrigation is resorted to fairly extensively on all the principal islands, especially where there is or has been sugar can cultivation.

Impounding reservoirs have also been used for irrigation and flood control purposes in a few areas across the State. A few examples are reservoirs in Waimea (Hawaii), Wailua (Kauai), Waikamoi (Maui), Wahiawa (Oahu), Olinda (Maui), and Kapahi (Kauai).

In addition, the open reservoirs in Nuuanu Valley, Oahu were built principally as flood control reservoirs. A number of projects were intended to impound surface water for domestic use but never reached ft-uition. The most outstanding were the Kohakohau River Dam project on the island of Hawaii and the Kokee Water Project on the island of Kauai. Whether these projects will be reactivated remains to be seen.

The use of surface water for various purposes, especially domestic and irrigation, is gradually proceeding beyond the conceptual stage. This is becoming more and more evident on Oahu where groundwater sources are being used more judiciously and with a greater awareness of their limitations. Water from Kalauao Springs Park (Pearl Harbor) is now being used for irrigating highway landscaping by the State Department of Transportation and the Honolulu Board of Water Supply. The latter agency is also developing

plans for the treatment of water from Punaluu and Kahana streams for domestic purposes.

Preliminary work is now being pursued for the possible impounding of Waikele Stream water in the West Loch of Pearl Harbor where it can be treated and used for domestic purposes or irrigation. After dredging, the storage capacity of West Loch is estimated at an excess of five billion gallons, depending on the location of the dam. Added to this would be the feasibility of capturing some of the Pearl Harbor Springs leakage which has been the subject of speculation for several decades.

The general use of surface water can result in major benefits, particularly in areas with limited groundwater resources. It can be a valuable source of domestic water. It can provide water for industrial and agricultural use. impounding can also open up opportunities for fish propagation, recreation, and flood control.

However, attempts to impound water for such uses must take into consideration a number of important factors. One would be the effect on the environment and ecosystem. Another would be the effect diversion of water would have on stream flows on fishlife, farming, vegetation, and other uses downstream. Even land use and public health and safety could be affected.

With proper planning, design, construction, and operation of facilities, surface water developments can be appropriate adjuncts to our efforts to balance human needs against conservation and protection to the environment.

6. WASTEWATER REUSE

Reuse or reclamation of wastewater has been practiced on the mainland for a number of years, especially in areas where fresh water sources are limited. Up to the present time, wastewater reuse has been confined to irrigation and to a lesser extent industrial use and recharge of underground basins. Reuse of wastewater for irrigation has reduced the need to develop fresh water facilities, reduced the cost of wastewater treatment and disposal, and has reduced the amount of pollutants in receiving waters by diverting treated wastewater to land.

A survey in 1977 showed that wastewater from more than 200 treatment plants in California was reclaimed and applied to more than 360 locations. By the year 2010, the use of reclaimed wastewater in California is expected to triple the amount used in 1980.

There is no record of treated wastewater being used directly for domestic purposes at the present time. At least one municipality in California is using tertiary treated wastewater to replenish the supply to a recreation

pond.

The City of Denver in Colorado has built a pilot plant to use treated wastewater for domestic purposes but the effluent is not being used in the City's water system. It is anticipated that the process would have to undergo several more years of research and experimentation before any consideration is given to direct diversion for human use.

It appears that two major hurdles for use for domestic purposes are the removal of undesirable chemicals, especially organics and heavy metals, and the removal or inactivation of viruses in the effluent. It is likely that some post tertiary treatment would be necessary. With the necessity of total treatment, it could be that the cost of recovering wastewater for domestic consumption may be competitive with the cost of desalination at least of brackish water.

Standards for the use of treated wastewater for irrigation are being developed in several states throughout the country. Texas allows undisinfected secondary effluent for pasture irrigation. Florida is proposing the use of disinfected secondary effluent for fodder crops. Arizona requires a minimum of secondary treatment before wastewater can be used for fodder and seed crops. In South Aftica, the requirements are more stringent. Only heavily chlorinated tertiary effluent may be used and only for the irrigation of orchards, vineyards, and fodder crops.

In Hawaii, the reclamation of wastewater for irrigation and other uses was not actively considered until relatively recent times. At the present time, several golf courses, such as those at Sheraton Makaha, Oahu, the Kaneohe Marine course at Kaneohe, Oahu, courses at Keahou, Hawaii and Poipu, Kauai, and probably a few courses on Maui are irrigating with treated wastewater. Studies conducted by Steven Chang and Reginald Young in 1977 indicated that the use of treated wastewater for golf course irrigation is not hazardous to the public's health.

Probably the most extensive research on the use of treated wastewater for irrigation was conducted by the University of Hawaii Water Resources Research Center under Dr. Stephen Lau. In August of 1971, a pilot field study commenced with funding support from the Honolulu Board of Water Supply and the City and County of Honolulu. Field and laboratory studies were conducted using Oahu Sugar Company canefields, lysimeters, and secondary effluent from the City and County's Mililani Sewage Treatment Plant. The project concluded in June 1975 with the following observations:

(a) Mililani STP secondary treated effluent is a useable irrigation supply for sugar cane and grasslands in central Oahu.

(b) Analysis of percolates strongly suggests that the possibility of contaminating deep underground water sources is extremely

remote.

(c) Application of sewage effluent for the first year of a two-year cane crop increased sugar yield slightly. When effluent is used for the entire two-year crop cycle, sugar yield was reduced by roughly the same amount. This suggests that effluent and fresh water should be applied alternately on an annual basis or the effluent should be diluted by fresh water by 2S%.

(d) There was no significant clogging of the soil during the first two-year crop cycle.

From June, 1985 until November, 1988, the Water Resources Research Center, with funding assistance by the State Department of Land and Natural Resources and the Estate of James Campbell, conducted a study of groundwater recharge resulting from cane irrigation using primary effluent from the City and County's Honouliuli STP. The test fields were located in the Ewa plain, Oahu, and the objective was to determine the feasibility of replenishing an unconfined caprock limestone aquifer through irrigation with low-salinity primary wastewater effluent.

Test results indicated that the recharging process was feasible, producing groundwater of a quality suitable for non-potable urban and agricultural users. Irrigation by the flood irrigation method generated no significant environmental and public health concerns. On the other hand, sprinkler irrigation is not recommended because of potential health problems from the aerosolized effluent, lower rate of recharge, and higher cost of operation.

In general, studies and field tests to date indicate that the potential for wastewater reuse for irrigation in Hawaii is promising. A decision to adopt wastewater reuse on an operational basis should be preceded by a large-scale test operation which should provide additional information on various administrative and technical matters. Wastewater reuse represents a distinctly feasible alternative in our overall efforts to preserve our fresh water sources throughout the State.

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VOLUME II

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APPENDIX A

GEOLOGY AND HYDROLOGY OF THE PRINCIPAL HAWAIIAN ISLANDS

HAWAII
General Geology and Hydrology

General Geology and Geologic History

The island of Hawaii is the youngest and the most southeasterly of the emerged volcanic edifices of the Hawaiian chain. The island is composed of five large shield volcanoes, some rising more than 31,000 feet above the ocean floor. Its land area is 4034.7 square miles, more than twice the total land mass of the other main Hawaiian Islands. Its longest and shortest dimensions are 93 by 76 miles.

The geology of the island of Hawaii has been extensively studied. Much of the effort concentrated on the active volcanoes of Kilauea and Mauna Loa. Besides the early volcano studies of Jagger at the Volcano Observatory, benchmark papers which map the geology and outline the hydrology of Hawaii include Steams and Clark (1930), Wentworth (1938), Steams and Macdonald (1946), Wentworth and Macdonald (1953). Recently, the United States Geological Survey has been remapping the island (Professional Paper 1350, 1987). As part of this effort, Langenheim and Clague (1987) have codified existing map units into conformance with the 1983 North American Stratigraphic Code.

Essentially, the term “Volcanic Series” has been replaced by “Volcanics”, which reflects shield volcano. However, for Mauna Loa and Kilauea, which are composed entirely of basaltic rock, the term “Basalt” is used to separate the various units (e.g. Ninole Basalt). Rock units within the major “Volcanics” subdivision, are known as “Member”, and can have a descriptive term such as “Breccia”, “Flow” or “Ash”. For example, the Pahala Ash occurs between basalt groups of Mauna Loa and Kilauea. The geology of each of the shield volcanoes will be discussed in detail in later sections.

Because of the island’s recent geological history, the stages of volcano development as outlined by Steams (1946) and later revised by Macdonald and Abbott (1970), barely advanced beyond the erosional stage as seen in Kohala. Mauna Kea and Hualalai have reached the post-caldera stage, while Mauna Loa and Kilauea have only advanced to the caldera development and filling stages.

The island is composed of five coalescing shield volcanoes. Ages of the five shields (Clague and Dairymple, 1987) seem to indicate that they were almost contemporaneous. Kohala, the oldest at about 0.7 Ma (Dairymple, 1971), is also geomorphically the oldest in appearance. Although Hualalai was last active in 1800-01, its oldest rocks may be greater than 0.12 Ma.

Mauna Kea’s Laupahoehoe Volcanics last erupted about 3,600 years ago (Porter and others, 1977). Porter and others (1977) dated several samples from the older Hamakua Volcanic as old as 0.375 Ma. Mauna Loa is composed of three basalt groups. The oldest, the Ninole Basalt, has been dated at 0.54 Ma (Clague and Dairymple. 1987). Kilauea, currently the most active volcano in Hawaii, has been divided into

the older Hilina Basalt and the younger Puna Basalt. The Hilina Basalt is older than 25,000 years (Easton, 1987).

KOHALA AQUIFER SECTOR

The Kohala Aquifer Sector encompasses all of the Kohala volcano. Its southern boundary is delineated from Mauna Kea by the geological contact mapped by Stearns and Macdonald (1946). This contact is definitively located slightly north of the Waimea-Kawaihae Road but becomes an inferred contact east of Waimea Town. The inferred contact is slightly east of Puu Lala and Lalakea Gulch and extends to the sea near Kukuihaele.

The Kohala Sector is a single shield volcano. The volcano is composed of two rock units: 1) the Pololu Basalt; and 2) the Hawi Volcanics. The older Pololu Basalts are mainly thin-bedded tholeiitic basalt lava flows that erupted during the main shield building and caldera forming stages of development.

Alkalic basalts and mugearites crop out near the top of the section. Numerous cinder cones are also associated with the Hawi Volcanics. The Hawi Volcanics represent the alkalic postshield stage of development and are separated from the Pololu Basalts by an erosional unconformity (Stearns and Macdonald, 1946).

Following cessation of volcanic activity, deep amphitheater-headed valleys were scoured into the Hawi Volcanics and the underlying Pololu Basalts in the Waimanu System. Soils formed from the breakdown of lava flows, cinders, and from the deposition of alluvial and talus deposits. Underlying lavas remain relatively unweathered. Streams are short and usually intermittent in the Hawi and Mahukona Systems.

Calculated average daily rainfall for the Kohala Sector is 802 mgd or six percent of the total daily rainfall for Hawaii. Calculated mean rainfall for the Sector above the 50-inch isohyet amounts to 677 mgd. Average distribution of rainfall for the Sector is 3.3 mgd. Average distribution of rainfall for the Sector is 3.3 mgd/square mile.

Hawi Aquifer System (80101)

Geology

The Geological map of Steams and Macdonald (1946), shows that the bulk of the System is composed of Pololu Basalt, overlain by Hawi Volcanics in the southern part. Both rock units include lava flows and pyroclastic deposits.

The western boundary of the System coincides with Kohala volcano's northeast rift zone. A linear alignment of large Hawi and Pololu cinder cones is the surface expression of this rift zone. Hawi Volcanics lava flows, separated from the Pololu

Basalts by an erosional unconformity, were erupted from these vents and flowed west and east from the rift zone. Massive Hawi lava flows outcrop at the ocean near Pololu Valley; however, most Hawi lavas within the System end near elevation 1000 feet msl. Some lava flows follow pre-existing stream channels. Dikes do not outcrop with the System but occur at depth, underlying the northwest rift zone forming the western boundary of the System.

Soils developed from the Pololu Basalts are thick to moderately thick and are well-drained. These are in contrast to soils developed from Hawi Volcanics which tend to be poorly drained and range from thin to thick (Sato and others, 1973).

Sediments other than recent alluvium do not occur within the System.

Hydrology

A. Rainfall

Mean annual rainfall for the System varies from 20 inches near Upolu Point to about 125 inches above the western wall of Pololu Valley, the southeastern boundary of the System. Calculated mean daily rainfall is 184 Mgal, of which 162 Mgal falls above the 50-inch isohyet.

B. Streamflow

Perennial streams within the System are relatively small and have not been gaged (Matsuoka, 1983). Most streams are intermittent. The nature of the soils overlying the Pololu lavas, in conjunction with ash deposits and somewhat fresh lava flows, encourages infiltration.

C. Infiltration

A basal aquifer exists in the Pololu Basalts. Hydrologic records of Kohala Sugar Company shafts and wells drained near Upolu Point and Hawi indicate low strategic water levels indicative of lack of sedimentary caprock and recharge. A static water level of two feet occurs near Upolu Point, while 7.5 feet is measured in wells near Hawi (State of Hawaii, 1970).

Numerous water tunnels were constructed by the sugar companies above Hawi and Kapau. The tunnels develop perched water occurring in the Hawi Volcanics on a soil zone marking the unconformity between the Pololu Basalts and the Hawi Volcanics, and on ash layers intercalated with Pololu lavas (Steams and Macdonald, 1946, p.235). These tunnels are concentrated at an elevation of 1,000 - 1,500 feet msl.

High-level dike water may occur but at great depth, and its presence in the System would only be located by exploratory drilling. Overflow from dike water compartments feeds basal aquifers near the coast.

Waimanu Aquifer System (80102)

Geology

The large amphitheater-headed windward valleys which characterize this system are eroded deep into the shield-building and caldera-ponded Pololu Basalts. According to Steams and Macdonald (1946) the Hawi Volcanics only outcrop above the headwalls of these large valleys, at the crest of the Kohala Mountains. Erosion has stripped off any Hawi lava flows and pyroclastic deposits which may have occurred at lower elevations.

In Pololu Valley, massive Hawi lava flows have cascaded over the headwall, partially flooding the valley floor (Stearns and Macdonald, 1946, p. 177).

Erosion has exposed numerous volcanic dikes associated with Pololu Basalts and a few which are chemically Hawi in origin. Some of the latter are thick trachyte dikes occurring in the upper reaches of Pololu, Honokanenui, and Waipio Valleys (Stearns and Macdonald, 1946, p. 197). In addition, coarse-grained intrusive bodies of gabbro and diabase outcrop in areas where caldera-ponded lavas and breccias occur.

Large alluvial flood plains occur in Waipio, Waimanu, and Pololu Valleys. These flood plains are wide and flat, extending several miles inland. Other large valleys such as Honokanenui and Honopue are long and narrow, with a rather thin and unsorted alluvial layer following the valley bottom. The upper reaches of these valleys typically have masses of talus which have collected as thick deposits at the bases of extremely steep valley wails. In some cases, these talus deposits have dammed streams, causing deposition of silt. These dams were subsequently breached by the streams.

Hydrology

A. Rainfall

The largest share of the Sector's rainfall occurs within the Waimanu System where annual rainfall varies from less than 75 inches near the mouth of Pololu Valley to greater than 175 inches windward of the Kohala Mountain summit. Calculated mean daily precipitation is 480 mgd. Mean distribution of the rainfall is 6.9 mgd.

B. Streamflow

The Waimanu System is the most water-rich of the Sector. Groundwater discharging from high-level dike compartments make up much of the base flow of the streams. Plantation ditch systems capture most of this water and some of the rainfall runoff.

All of the streamflow captured by the irrigation ditches is used outside the System. The Kohala and Kehena ditches transport water to the Hawi Aquifer System, while the Hamakua Ditch carries water to the Honokaa Aquifer System in the East Mauna Kea Aquifer Sector.

Only a small fraction of streamflow that remains in stream channels discharges at the coast as surface water. Much of the flow percolates into unconsolidated and unsorted stream alluvium. However, a large stream such as Waimanu will discharge a tremendous flow into the ocean regardless of the size of the flood plain.

C. Infiltration

High-level aquifers are the most prevalent in the System. Windward valleys are deep enough to tap water stored between dike compartments. The large baseflow of these streams is the release of high-level groundwater. Perched aquifers discharging as springs and seeps are numerous. Perching members include ash deposits, massive lava flows, and intrusives. Perched aquifers, though numerous, are much less important than the dike aquifers. Stearns and Macdonald (1946) list several 0.25 mgd springs near Kukuihaele. Truncated basal aquifers occur near the coast. Limited sedimentary aquifers probably occur in the large flood plain deposits of Waimanu, Waipio, and Pololu Valleys. These aquifers may be somewhat brackish.

Mahukona Aquifer System (80103)

Geology

The geology of the System is similar to the Systems previously described. Pololu Basalt outcrops throughout but is overlain by Hawi Volcanics from crest to sea in several localities. The System's upper boundary is primarily in Hawi Volcanics. Much of the flank outcrops of Hawi rocks are represented by massive flows of benmoreites, mugearites and trachytes, which are the differentiated products of the alkalic basalt suite. Pololu Basalts are thin-bedded to massive basaltic flows and pyroclastic deposits.

Weathering and erosion have not had much impact upon the topography. Gullies eroded into the massive Hawi lavas and Pololu Basalts are narrow and steep-sided.

Sedimentary deposits do not occur in the Mahukona System. Finer cinder deposits may have been transported by wind as eolian soil downwind from the rift zone.

Hydrology

A. Rainfall

The Mahukona System is one of the driest regions of Hawaii. Rainfall varies from less than 10 inches to slightly greater than 75 inches at the upper boundary with the Waimanu System. Even though the System contains 47.3 percent of the Sector's land area, mean daily rainfall is only 17.2 percent of the Sector at 138 mgd. Distributed over the System, this only amounts to 1.2 mgd/sq.mi.

B. Streamflow

As mentioned previously, streams are almost nonexistent in the System. The few existing ones are intermittent and in the most juvenile stage of development. Where these water courses cross over massive Hawi lavas, little or no percolation takes place.

C. Infiltration

Records of coastal drill holes and abandoned wells from Mahukona to Kawaihae indicate low-water levels and brackish water occurring under unconfined basal conditions. Inland, at a much higher elevation, good quality water has been tapped.

Near the System's upper boundary with the Hawaii and Waimanu Systems, high-level dike water and perched sources may be present due to dikes associated with the Kohala's rift zone and with Hawi pyroclastic deposits.

EAST MAUNA KEA AQUIFER SECTOR

The East Mauna Kea aquifer encompasses the entire eastern half of the Mauna Kea shield volcano. The Sector extends from the Kohala-Mauna Kea geological contact in the north to the Mauna Kea-Mauna Loa geological contact at the Wailuku River in the south. The area of the East Mauna Kea sector is calculated to be 603.05 square miles or 14.9 percent of the island's total area.

Mauna Kea volcano, like Kohala, has geologically evolved to the post-caldera stage. Steams and Macdonald (1946) subdivided Mauna Kea's lavas into the shield-building Hamakua Series and the post-caldera Laupahoehoe Series. Recently, Langeheim and Clague (1987) recodified these series as Hamakua Volcanics and Laupahoehoe Volcanics, respectively.

Detailed geological mapping by Porter (1987) further subdivides the Hamakua and Laupahoehoe Volcanics into members associated with volcanism and glaciation (morainal deposits) that occurred during the Middle and Late Pleistocene. Porter

(1987) divides the Hamakua Volcanics into a lower Member, the bulk of the shield-building lavas, and the Hopukani Volcanic Member for late Hamakua lavas. Interbedded with these late shield eruptions are the Pohakuloa Glacial Member deposits.

The Laupahoehoe Volcanics have been subdivided into the Waikahalulu Volcanic Member, interbedded with an older Waihu Glacial Member and a later Makanaka Glacial Member. From this detailed mapping, Porter and others (1977) have determined that Mauna Kea last erupted about 3,600 years ago.

Hamakua Volcanics are primarily tholeiitic, olivine tholeiitic, and picritic: basalts (Steams and macdonald, 1946). The upper Hopukani Member of the Hamakua Volcanics is essentially post-shield alkalic basalt, ankaramite, and hawaiite flows and pyroclastics occurring mainly in windward gulches and the plain between Kohala and Mauna Kea (Porter and others, 1977). The Laupahoehoe Volcanics, as defined by the Waikahalulu Volcanic Member, is composed mainly of pyroclastics and lava flows of alkalic basalt, ankaramite, and hawaiite, unconformably overlying the Hamakua Volcanics (Steams and Macdonald, 1946).

According to Langenheim and Clague (1987, p. 62), Mauna Kea passed from shield-building into a post-shield stage which almost covered the original shield. Although the cap of differentiated lavas covered the summit of the original shield, a caldera is inferred to underlie the post-shield cap. Rift zones are also less conspicuous than those found on Mauna Loa or Kilauea. Alignment of cones suggests that there are southerly, westerly, and easterly rifts.

All of the Systems begin at Mauna Kea's summit, while the boundaries between Systems fan out along geological boundaries. Structural lineations such as cinder cone alignment, or a geological contact between Hamakua and Laupahoehoe Volcanics are used as the basis for boundaries between the Systems.

The calculated average daily rainfall for the Sector is 3.23 Bgal, or 24.0 percent of the Island's total mean rainfall. Total precipitation above the 50-inch isohyet is calculated to be 2.99 Bgal/d. Average distribution of this rain is 5.4 mgd/sq. mi.

Honokaa Aquifer System (80201)

Geology

The bulk of the volcanic rock is the Hopukani Member of the Hamakua Volcanics lava flows and cinder cones. None of the gulches in the System is eroded deep enough to expose lower Member Hamakua flows. Young Laupahoehoe lavas and cinder cones outcrop mainly at high elevation, though some massive hawaiite flows extend to the sea between Kakuihaile and Kapulena north of Honokaa.

Macdonald (1949) showed that much of the northern and eastern slope of Mauna

Kea is covered by a blanket of Pahala Ash, derived from Mauna Kea cinder cone eruptions. According to Macdonald (1949, p. 59), Pahala Ash typically forms a layer of palagonite tuff. Langenheirn and Clague (1987), however, ascribe Pahala Ash only to Kilauea and Mauna Loa.

Residual soils, as shown on the general soils map (Sato and others, 1973), range from bare rock to well-drained fine-textured soils. Many of these soils have been derived from ash and cinder deposits which blanket much of the System. Soils derived from the palagonite tuff defined as Pahala Ash by Macdonald (1949) form the Akaka-Honokaa-Kaiwiki soil association (Sato and others, 1973). These soils are constantly wet and very permeable; however, on dehydrating, the soil irreversibly becomes fine gravel-size aggregates.

Streams are not well developed in the System. Many gulches are short and steep-sided. The longer gulches begin at elevations between 5000-6000 feet and transport intermittent flow in their upper reaches. Perennial flow would occur where perched springs feed into a stream from massive perching of Laupahoehoe hawaiite.

Terrestrial sediments in the Honokaa System are practically nonexistent. Small patches of unconsolidated stream alluvium occur in some area. Wind may cause some of the ash deposits in the upper drier region of the System to form aolian deposits. Porter (1987) has mapped morainal deposits associated with glaciation of the summit.

Hydrology

A. Rainfall

The Honokaa System is the driest of the four Systems which compose the Sector. Isohyetal variation ranges from 20 inches near the summit of Mauna Kea to less than 100 inches at the coast. Mean daily rainfall for the System is calculated at 286 mgd.

B. Streamflow

There is a dearth of measured streamflow in the System. Any flow in the gulches is a fraction of the mean daily precipitation combined with groundwater discharge from perched springs.

Return irrigation water, transported into the System from the Hamakua Ditch, may also contribute to streamflow in the lower reaches of some streams. Flow from basal springs at the coast may enter some streams at or near the shore.

C. Infiltration

Basal groundwater underlies much of the Hamakua Coast from Hilo to Kukuihaele (Stearns and Macdonald, 1946). Good quality water is found inland and has been exploited by wells and shafts.

Perched water sources range from seeps of a few gallons to large springs of almost 0.5 mgd. (Stearns and Macdonald, 1946). Perching members include weathered ash, dense lava flows, and in some cases, very weathered a'a clinker. None of these perching members is very effective because recharge is so great that most of the water passes to the basal groundwater body, leaving only a small proportion for perching (Steams and Macdonald, 1946).

Pauuilo Aquifer System (80202)

Geology

The volcanic geology of the System is almost identical to that of the Honokaa System. The mapped distribution of Hamakua and Laupahoehoe volcanic rocks is almost equal in areal extent (Stearns and Macdonald, 1946; Macdonald, 1949). However, the bulk of the rocks of hydrological importance are Hamakua Volcanic lavas and their weathered products. Laupahoehoe Volcanics occur almost exclusively above 7,000 feet, and totally above 9,000 feet. Some Laupahoehoe lava reaches the coast, principally near Pauuilo and Ookala.

Streams, while cut into Hamakua Volcanics are larger and deeper than those in the Laupahoehoe Volcanics. Stream erosion may have stripped off a more extensive post-shield cap of unconsolidated Laupahoehoe pyroclastic deposits and thin lava flows, Hamakua Volcanics predominate below an elevation of 4,000 feet.

Laupahoehoe Volcanics consist of massive post-shield lava flows and pyroclastic deposits interbedded with glacial moraine deposits.

Sediments consist of unconsolidated stream-laid alluvium; glacial moraine deposits are found high on Mauna Kea. None of the valleys is old or extensive enough to develop a thick alluvial sequence.

Hydrology

A. Rainfall

Annual rainfall for the System varies from less than 20 inches at the summit to approximately 125 inches above Kukaiau. Mean daily rainfall is calculated at 459 mgd, which distributed over the System averages 3.1 mgd/sq. mi.

B. Streamflow

Streamflow data for the System is practically non-existent. A crest-stage partial-record station (7178.5) is in operation at Keehia Gulch near Ookala. Streamflow for the System is derived mainly from direct runoff of rainfall, with some flow coming from perched springs.

C. Infiltration

Basal groundwater is the most abundant resource available in the System. However, low-water table conditions along the coast require that potable supplies be recovered a mile or so inland from the shore. For example, Shaft 6, a Maui-type shaft at Ookala, has its portal 300 feet above sea level on the southeast side of Kaula Gulch.

Static water level is approximately six feet msl with a chloride range of 7-15 ppm (State of Hawaii, 1970, p.158). Similarly, Shaft 5 at Pauuilo begins at elevation 273 feet. Static water level is lower at about three feet msl. Consequently, the chloride content ranges between 25-71 ppm (State of Hawaii, 1970, p. 158). Pumpage for both shafts is about 1.5 mgd.

Wells that are drilled into low-head basal groundwater and penetrate 20 feet or more below sea level yield chloride values greater than 170 ppm. Pumpage from these wells is unknown (State of Hawaii, 1970, p. 145). One of these wells near Pauuilo, 450 feet from the shore, had a 2.2-foot head and yielded water with a chloride content of 367 ppm (Steams and Macdonald, 1946, p.241).

Perched water supplies are more numerous in this System due to greater rainfall. Many perched springs have been tunneled in an attempt to increase yields. Steams and Macdonald (1946) point out that one of these sources produces more than 2,500 gallons per day. Accordingly, many of the tunnels are unused (State of Hawaii, 1970, p. 166).

Hakalau Aquifer System (80203)

Geology

The geology of the System is similar to those previously described. The mapped distribution of Laupahoehoe Volcanics is greater at lower elevations in this System than in the previous two Systems, though Hamakua Volcanics remain the bulk of the volcanic rock underlying the region.

Laupahoehoe lavas have flowed down Laupahoehoe Gulch to the sea, forming a lava delta at the mouth of the valley (Steam and Macdonald, 1946, p. 162).

Although the east rift of Mauna Kea is not as well defined as rift zones typified by Kilauea or Mauna Loa, it is manifested by late Hamakua cinder cones and a prominent undersea ridge extending beyond Onomea Bay (Steams and Macdonald, 1946; Langenheim and Clague, 1987). Intrusive rock at depth, associated with this rift zone, may influence the flow of groundwater. Intrusive rocks underlying Laupahoehoe cinder cones near the summit may influence the direction of groundwater flow from the meager recharge which occurs at high elevation.

From the soils map (Sato and others, 1973), soil from the Akaka-Honokaa-Kaiwiki association predominate. At higher elevation soil from the Hanaipoe-Maile-Puu Oo association occurs. These soils are well-drained, dark brown to reddish-brown, and are medium textured to moderately fine textured. Above this group, soil associated with barren lava flows, ash and pumice occur. This soil group is extremely well-drained (Sato and others, 1973).

Steams have cut longer and deeper valleys into the flank of Mauna Kea in this System. An abundance of rainfall has increased the erosive power of streams considerably. Maulua Stream canyon has exposed the greatest section of Hamakua Volcanics on Mauna Kea; Steams and Macdonald (1946) measured a thickness of 650 feet in the valley.

As with the previously described Systems in this Sector, sedimentary deposits consist mainly of limited deposits of stream-lined gravel, moraine deposits, and wind-transported cinder and ash deposits.

Hydrology

A. Rainfall

For the Hakalau System, annual rainfall varies from less than 20 inches to greater than 300 inches. The least amount of rain occurs at the summit. Rainfall at the coast ranges between 100-150 inches. The greatest amount of precipitation occurs from 2,000-4,000 feet elevation inland of Pepeekeo. Calculated mean daily rainfall is 1.14 Bgal. Distributed evenly over the System this amounts to 6.8 mgd/sq. mi.

B. Streamflow

The U.S. Geological Survey operates crest-stage partial-record stations at Pohakupuka, Kapehu, and Aha streams within the System (USGS, 1987). Matsuoka (1983) presents streamflow data for Pohakupuka and Alia Streams prior to the crest-stage stations, and for Manowaiopae Stream near Laupahoehoe.

There is a large disparity between the mean flow and Q90 or “base flow” of the streams. The difference is primarily due to the flashy nature of the

streams and the small component of flow that can be attributed to groundwater. Most of the streams along this stretch of the Hamakua Coast are short. Their headwaters begin at the rainfall maximum so that most flows can be accounted for by precipitation. Base flow can be attributed to perched springs discharging into the stream channels.

C. Infiltration

Basal groundwater is the most abundant resource in the System. However, this source has not been much utilized. Pepeekeo Sugar Company drilled a well at elevation 304 feet to a depth of 328 feet. It served as a domestic source until it was abandoned in 1963. Wells 805005-01, 02 are USGS observation wells in Pepeekeo which have a chloride range from 14-27 ppm (USGS, 1987). No water-level data accompany these measurements.

Steams and Macdonald (1946 show numerous perched springs from elevation 2,000 feet to almost sea level. Many of these springs are comparatively large. Average discharge is much greater than the perched springs described in the previous Systems. The greater volume of discharge is directly related to the greater rainfall distribution in the Hakalau System.

Onomea Aquifer System (80204)

Geology

The volcanic rocks cropping out in the Onomea System are the same as described previously. The areal proportions of the Hamakua and Laupahoehoe Volcanics are about equal, although the Hamakua lavas predominate at lower elevations, while Laupahoehoe flows and pyroclastic deposits occur almost exclusively above 4,000-foot elevation. Thick deposits of vitric ash from explosive volcanic activity mantles much of the area above the Humuula Saddle to the summit. Some of the ash has been reworked by wind and water.

The System is bounded on the north and west by rift zones (Steams and Macdonald, 1946; Langenheirn and Clague, 1987). Intrusive dikes can influence the direction of flow of groundwater recharging the System.

The Wailuku River, the major stream in the System, has its headwaters beginning above 9,000 feet msl. It is one of the streams that drain the snow-melt from the summit plateau. At lower elevations, the river drains an immense, high rainfall watershed, to become the largest and longest stream on the island.

Sedimentary deposits include stream-laid gravels and alluvium, and reworked ash and cinder. Boulder beaches formed by wave erosion are common along the Hamakua Coast.

Hydrology

A. Rainfall

Annual rainfall varies from less than 20 inches to greater than 300 inches. The driest region is near the summit; the rainfall maximum is about five miles inland from Hilo. The calculated mean rainfall for the System is 1.38 Bgal/d, giving an average distribution of 7.5 mgd/sq. mi.

B. Streamflow

Major streams in the Onomea System are the Wailuku River, Kapehu Stream, Honolii Stream, and Kalaloa Stream. The latter has a crest-stage partial-record station while the others are gaged continuously.

Total measured streamflow is 544.8 mgd. This flow is conservatively 40 percent of the Systems rainfall. A much greater amount of runoff occurs but is not measured.

C. Infiltration

Basal groundwater is the most important and abundant resource in the System. As in the other Systems along the Hamakua Coast, basal groundwater is non-artesian and stands only a few feet above sea level near the coast. No basal wells or shafts have been constructed within the System.

As with other Systems, most groundwater development has utilized perched water. Many of the perched springs flow into the streams to become base flow. Many of the perched springs sources flow greater than 0.01 mgd, some as high as 2.0 mgd. Some perched springs fail during dry weather even though their average flow can be as high as 0.3 mgd (State of Hawaii, 1970).

WEST MAUNA KEA AQUIFER SECTOR

The West Mauna Kea Sector encompasses the western half of Mauna Kea shield volcano and is composed of the Waimea Aquifer System. The Sector extends from the Mauna Kea-Kohala geological contact in the north to the Mauna Kea-Mauna Loa geological contact in the south. Steams and Macdonald (1946, p. 169) point out that Mauna Loa and Mauna Kea were erupted simultaneously, and that during Laupahoehoe time, Mauna Kea lavas were deflected by Mauna Loa lavas. They conclude that Mauna Loa had attained its present bulk during the eruption of Laupahoehoe lavas.

The geology of Mauna Kea was discussed in detail for the East Mauna Kea Sector.

Much of the Sector below 5,000-foot elevation consists of Upper Hamakua Volcanics. Many cinder cones are situated concentrically, rather than radially, away from the summit. The farthest cone out is Puu Hinai at about 1,400-foot elevation.

Pahala Ash covers much of the western plain of Hamakua Volcanics. Ash thicknesses, determined from field localities, range from three feet to 25 feet. Thinner horizons are found farther from the summit than thicker ones.

Waimea Aquifer System (80301)

Geology

The essential volcanic geology of the System and Sector is described above. Many of the lava flows associated with Hamakua and Laupahoehoe Volcanics are alkalic basalt to hawaiite in composition. The more differentiated flows tend to be massive and not conducive to recharge by rainfall. Thick ash deposits associated with the Pahala Ash and numerous cinder eruptions are ubiquitous throughout the System.

Sediments include ash and cinder deposits reworked by water and wind, glacial moraine deposits at extreme elevations, and beach deposits of basaltic boulders and coral sand.

Hydrology

A. Rainfall

The Waimea System is one of the driest on the island. Annual rainfall ranges from less than 10 inches to nearly 50 inches. Most of the System receives less than 30 inches per year.

As typical of the dry, leeward areas of all the Hawaiian Island, the greatest share of rainfall comes from a few Kona and frontal storms which occur sporadically throughout the year. Mean daily rainfall is 243 mgd, equivalent to a distribution of 0.9 mgd/sq. mi.

B. Streamflow

All streams in the System are intermittent. The gulches carry storm runoff, but most of the time remain dry. The USGS maintains two crest-stage partial-record stations at Kamakoa Gulch and Popoo Gulch.

C. Infiltration

Non-artesian basal groundwater forms the most extensive aquifer of the System. Wells drilled near the coast are brackish. Well 8-5948-01, 0.7

miles east of Hapuna Beach, is 268 feet deep. The bottom of the well elevation is -24 feet msl. Water levels vary from 1.4-4.5 feet msl. Chloride values range from 460-480 ppm (USGS, 1987).

Four Lalamilo wells (State Well No. 8-5946-01, 02, 03, 04) drilled several miles inland and at elevations between 1,084 to 1,172 feet msl. have a head of about eight feet msl. Chloride values are less than 100 ppm (USGS, 1987).

Deep well 8-5239-01, drilled at Waikii at elevation 4,260 feet msl. penetrated 4,350 feet of Hamakua lava flows. Dike-impounded water was reached at elevation 1,509 feet msl. Chloride content measured during the pump test was 18 ppm. Temperature Measurements taken of the water column was 79°F at the top and 100°F at the bottom. The elevated temperatures can be explained by the normal geothermal gradient, and also by latent volcanic heat.

Perched water springs occur at high elevation and are associated with glacial moraine deposits and pyroclastics. Waihu Spring and seeps are the primary sources of water for Pohakuloa Military Camp and the State Park. The spring and seeps occur between 8,935 feet and 10,390 feet in Pohakuloa Gulch. Steams and Macdonald (1946, p. 292) report total spring discharges of about 50,000 gpd.

NORTHEAST MAUNA LOA AQUIFER SECTOR

Geologically, Mauna Loa is one of the most active volcanoes on earth. Since 1832 when the first historical eruption was noted, there have been 34 eruptions which covered about 13 percent of Mauna Loa's surface and produced a volume of 4.0 cu. km. (Lockwood and Lipman, 1987, p.509). Up until the 1950 eruption, the average frequency between historical eruptions was 3.6 years (Macdonald and Abbott, 1970, p.55). Since 1950, only two eruptions have occurred; a short-lived eruption in 1975, and one in 1984 that lasted three months and 26 days.

The early eruptive history of Mauna Loa is fragmentary. Extrapolating back in time, using the eruption rate of the last 146 years, the present bulk of Mauna Loa could have been built in 0.5 Ma (Lockwood and Lipman, 1987). Stearns and Macdonald (1946) and Macdonald and Abbott (1970) conclude that Mauna Loa has a compound origin, formed from at least three separate eruptive centers, the older two having been buried by the present one. Macdonald and Abbott (1970) divided Mauna Loa into the older Ninole shield, followed by the Kulani shield. Both are mostly covered by lavas emanating from the present eruptive center.

Following the classification of Langenheim and Clague (1987), the "Volcanic Series" of Steams and Macdonald (1946) have been codified as "Basalt". The oldest lavas belong to the Ninole Basalt, followed by the Kahuku Basalt, Pahala Ash, and finally,

the Kau Basalt.

During the growth of Mauna Loa, other volcanoes were developing contemporaneously. Interfingering lava from Mauna Kea and Hualalai occurs at depth. Kilauea grew on the south flank of Mauna Loa, its lavas also interlayered with Mauna Loa (Lockwood and Lipman, 1987, p. 514).

The Ninole Basalt consists of tholeiitic basalt, olivine tholeiitic basalt, and picrite basalt (oceanite). Overlying the lava flows are pyroclastic deposits. Their maximum exposed thickness is approximately 1,975 feet near Ninole Gulch. The base of the lava is not exposed (Langenheim and Clague, 1987, p. 75).

The Kahuku Basalt overlies the Ninole Basalt. The lavas consist of tholeiitic basalt, olivine tholeiitic basalt, and picrite basalt (oceanite). The group is mainly lava flows interbedded with minor tephra deposits. The maximum exposed thickness is 590 feet. The type locality of the Kahuku Basalt is the Kahuku fault scarp which trends north from South Point. The Kahuku Basalt outcrops on the south and east flanks of Mauna Loa (Langenheim and Clague, 1987, p. 75). Overlying the Kahuku Basalt is the Pahala Ash which is vitric, though somewhat palagonitized. Maximum exposed thickness is about 50 feet.

Overlying the Kahuku Basalt is the Kau Basalt which encompasses the historic and younger prehistoric lava flows. The composition of the Kau Basalt is similar to the Ninole and Kahuku Basalts. The Kau flows are intercalated with minor pyroclastic deposits. Its maximum exposed thickness is greater than 600 feet as seen in the west wall of Mokuaweoweo caldera (Langenheim and Clague, 1987, p. 75). The Kau Basalt interfingers with the Puna Basalt of Kilauea. It overlies the Laupahoehoe Volcanics of Mauna Kea and the Hualalai Volcanics.

The Northeast Mauna Loa Sector is divided into two Systems. Their mutual boundary essentially follows the muted expression of the northeast rift zone below Puukulua. A broad ridge extends northeast rift zone below Puukulua. A broad ridge extends northeast towards Hilo, reaching the coast slightly south of the city.

The Sector is Mauna Loa's windward flank. Calculated average daily rainfall for the Sector is 2.61 Bgal. Average distribution of this rainfall over the area is 6.5 mgd/sq. mi.

Hilo Aquifer System (80401)

Geology

Most of the exposed basaltic lava flows belong to the Kau basalt group. Historic and prehistoric lava flows erupted from the northeast rift zone outcrop throughout the System. The most recent of these is the 1984 eruption of Mauna Loa. Small outcrops of Kahuku Basalt occur near Hilo and Kaumana, with Mauna Loa's 1881

lava flow covering part of one of these outcrops (Stearns and Macdonald, 1946).

Lava flows are mainly pahoehoe flows at higher elevations and a'a flows at lower levels, though pahoehoe lava does occur at lower elevations far from the erupting vent. Small deposits of pyroclastic material are intercalated with many of the lava flows. Many recent lava flows have been channeled down the Wailuku River drainage.

Sedimentary deposits in the System are few and scattered. Small masses of wind-blown tephra may occur at high elevations.

Hydrology

A. Rainfall

Annual rainfall varies from less than 15 inches near the summit of Mauna Loa to greater than 250 inches above Kaumana. Hilo itself receives slightly less than 150 inches. The calculated average daily rainfall for the System is 1.23 Bgal. Average distribution of this precipitation is 6.3 mgd/sq. mi.

B. Streamflow

Streams are not well-developed within the System. The Wailuku River, described as part of the Onomea System, is the largest stream in the vicinity of the Hilo System. Waiakea Stream near Hilo (gage no 701200) was gaged continuously for 11 years (Matsuoka, 1983) and gave an average flow of 3.4 mgd.

Heavy rainfall in the Hilo System produces many small streams which are intermittent and not measured. Thin soils and relatively fresh permeable lava flows are not conducive to runoff but promote infiltration.

C. Infiltration

The largest aquifer is the non-artesian basal aquifer which underlies much of the northeast flank of Mauna Loa. USGS observation well 8-4203-04 at 47 feet msl, drilled to a depth of 201 feet, and has a water level of about 6.5 feet msl. This well is 1.0 mile south of the Hilo Airport and is owned by Hawaii Electric Light Company (USGS, 1987, p. 221). Steams and Macdonald (1946, p. 246) postulate a groundwater gradient of five feet per mile due to groundwater standing 17 feet msl at Olaa, about 3.5 miles from the coast. The vast quantity of recharge to the basal groundwater lend creates higher than normal non-artesian heads in the Hilo area.

An extremely large basal spring discharges into the Waiakea estuary. According to Stearns and Macdonald (1946, p. 225), J.F. Kunesh measured the flow from this spring at 146 mgd, making it equal in size to the largest

springs discharging in the continental United States.

High-level dike water may exist at some point inland from the coast. Dikes associated with the northeast rift of Mauna Loa could store groundwater at a high level; however, no wells have been drilled more than a few miles inland due to prohibitive costs.

Perched groundwater aquifers are important in the System and occur near the Mauna Loa-Mauna Kea contact. This water is associated with the Kau Basalt overlying Pahala Ash. Pahala Ash in this region is between nine to 20 feet thick. Springs discharging upwards of 1.5 mgd are reported in Steams and Macdonald (1946, p. 291). Tunnels have been driven into the Kau Basalt and Pahala Ash to try to recover some of the spring flow.

Keaau Aquifer System (80402)

Geology

A majority of the exposed basaltic lava flows belong to the Kau Basalt, though Stearns and Macdonald (1946) mapped a broad area of Kahuku Basalt flows from Kulani Cone east to Glenwood and Mountain View. Many of these Kahuku Flows emanated from spatter and cinder cones. Pahala Ash overlies these Kahuku lava flows.

According to Lockwood and Lipman (1987, p. 519), the Kahuku Basalts are greater than 4,000 years old. No historic flows (from 1832), with the exception of one lobe of the 1984 eruption, outcrop in the System.

Sedimentary deposits include reworked ash deposits, talus breccia associated with faulting, and boulder beaches at the coast.

Hydrology

A. Rainfall

Annual precipitation ranges from less than 15 inches to greater than 200 inches. The calculated average daily rainfall is 1.38 Bgal, giving the mean distribution of rainfall at 6.7 mgd/sq. mi.

B. Streamflow

The only measured stream in the System is Waiakea Stream near Mountain View (gage no. 700000). Average flow for 57 years of record is 7.49 mgd (USGS, 1987).

Due to the youthfulness of the topography, streams are not well developed.

During large storms, sheet runoff is common. Storm flow follows every rivulet possible. High permeability of the lavas and the dense vegetation at lower elevations allow this water to infiltrate readily.

C. Infiltration

As in the Hilo System, the non-artesian basal groundwater aquifer is the most important resource in the System. Wells drilled into this aquifer display heads ranging from seven to 17 feet msl. The wells with the lower water levels are nearer the coast, while the higher head is measured at the Olaa Mill near Keaau. The high non-artesian water levels are mainly due to tremendous rainfall recharge.

High-level dike water occurs at some point near Mauna Loa's dike-intruded northeast rift zone. No test holes have been drilled exploring this resource.

Perched aquifers are second in importance. Perched springs have been utilized in the past, with tunnels driven into them to exploit their flow. These perched springs are concentrated between 1,000 and 2,000 feet msl. The perching member is Pahala Ash.

SOUTHEAST MAUNA LOA AQUIFER SECTOR

The Southeast Mauna Loa Sector is the largest Sector defined for this study. Its planimetered area is 699.78 square miles. The sector is 17.3 percent of the island's total area.

The geological framework for Mauna Loa is described above in detail. Numerous outcrops of Kahuku Basalt are mapped south of Kapapala Ranch (Steams and Macdonald, 1946). Also occurring in the Sector are outcrops of older Ninole Basalt. Pahala Ash is found throughout. Mudflow and landslide deposits produced during the earthquake of 1868 occur in Wood Valley near Pahala.

Normal faulting is prevalent throughout the Sector (Steams and Macdonald, 1946, p. 39-40); (Macdonald and Abbott, 1970). The Kahuku fault scarp is 600 feet high at Ka Lae, and can be traced 10 miles north to where it gradually disappears. South of Ka Lae, the Kahuku fault can be traced for 18 miles beneath the sea.

Pali O Ka Eo seems to be an echelon extension of the Kahuku scarp. The Pali runs for three miles and is 250 feet high. North of the Kahuku fault is the Waiohinu escarpment which is 4.5 miles long and extends inland from Waikapuna Bay to Waiohinu. The scarp is less than 50 feet high. The fault moved several feet in 1868.

Further north is the Honuapo-Kaoiki fault system. The Kaoiki faults run for 18 miles, parallel to the Mauna Loa-Kilauea contact. The faults disappear beneath young Kau lavas. In some places, the Honuapo fault system begins. These faults are covered by

many Kau lava flows. Macdonald and Abbott (1970, p. 310) consider the Kaoiki faults to be a kind of "expansion joint" between Mauna Loa and Kilauea. When swelling or shrinking occurs with either volcano, faulting or earthquakes take place to adjust to the conditions.

The Sector is divided into four aquifer Systems. Their boundaries are determined in part by topography and by outcrops of Ninole and Kahuku Basalts. The Olaa (80501) and Kapapala (80502) Systems begin at Mokuaweoweo caldera and abut against the geological contact at the summit region of Kilauea. The Naalehu (80503) and Ka Lae (80504) Systems begin along the southwest rift of Mauna Loa, and, in the case of the Naalehu System, has its southeastern boundary along Kilauea's southwest rift zone and contact with Mauna Loa.

Much of the Sector is located in the rain shadow of Kilauea and the Northwest Mauna Loa Sector. Although the Southeast Mauna Loa Sector is the largest, its calculated mean daily rainfall is 2.01 Bgal. Average distribution for the Sector is only 2.9 mgd/sq. mi.

Olaa Aquifer System (80501)

Geology

The geology of the System is similar to that previously described in the Hilo System. Extensive Kahuku Basalt was erupted from Kulani Cone. The Kahuku surface was later covered by Pahala Ash and kau Basalt lava flows. Most of the historic northwest rift eruptions seem to lie outside the System, though part of the 1880 flow and the Keamoku lava cross it.

The topography is very youthful. No stream valleys occur. Lava channels and spatter ramparts serve as water courses during periods of heavy rainfall.

Soils encountered within the System are the older Akaka-Honokaa-Kaiwiki Association, the Kekake-Keei-Kiloa Association and the Hanipoe-Maile-Puu Oo Association all related to the Kahuku lavas and Pahala Ash. Most of the System is covered by barren lava and pyroclastic deposits (Sato and others, 1973).

Sedimentary deposits are insignificant. Wind and water may have reworked tephra deposits. Talus breccia. is found at the base of the Mokuaweoweo caldera. boundary fault scarp.

Hydrology

A. Rainfall

Annual rainfall varies from less than 15 inches to greater than 200 inches. Mean daily rainfall is calculated to be 541 mgd, giving the average

distribution as 4.2 mgd/sq. mi.

B. Streamflow

Streams have not formed. Lava channels may become waterways during periods of high rainfall. Due to the high permeability of the lava flows and associated soils, runoff occurs as sheet flow during the most severe storms.

C. Infiltration

Basal water may occur near Mountain View in dike-free flank lava flows. However, no wells or test holes have been drilled, so groundwater occurrence within the System is speculative. Subsurface structure, such as interfingering Mauna Loa and Kilauea Lava flows, dike-intruded lava, pyroclastic deposits, Pahala Ash buried by Kau lavas, can all influence the occurrence and flow of the groundwater in the System.

Dike-impounded groundwater would most likely occur at higher elevations. Dikes associated with the northwest rift zone and marginal dike complex could store great quantities of groundwater. Groundwater stored between dikes in the Olaa System could recharge basal aquifers in the Northeast and Northwest Mauna Loa Sectors.

Perched water sources may occur. None is shown on the geological map of Stearns and Macdonald (1946). Small quantities of perched water may be found in lava tubes whose floors are impermeable. Small pools of water occur in this fashion high on Mauna Loa, fed by rain and snow melt.

Kapapala Aquifer System (80502)

Geology

Kau Basalts predominate in the System. Most flows are prehistoric, ranging in age from 4,000 years ago to present (Lockwood and Lipman, 1987, p. S19). Historic flows cropping out in the System are from the eruption of 1880, 197S, and 1984. The latter two are confined within Mokuaweoweo caldera.

Stearns and Macdonald (1946) mapped small patches of Kahuku Basalt. These outcrops are near the Systems northern boundary juncture with its eastern boundary.

The Kaoiki fault complex runs through the lower end of the System. As described previously, the fault complex can be followed for 18 miles. The faults are normal with the down-dropped side on the east.

As with the Olaa System, the Kapapala System's geomorphic expression is youthful. Stream valleys have not had a chance to develop. Lava channels serve as water courses during heavy rainfall periods.

Reworked ash and cinder deposits, whether by water or wind, occur throughout the System. Talus breccia occurs at the base of the Mokuaweoweo caldera boundary fault. Frequent summit eruptions can cover these deposits.

Hydrology

A. Rainfall

Annual rainfall varies from less than 15 inches at the Mokuaweoweo caldera to less than 75 inches near the System's northern and eastern boundary at Kilauea. The Kapapala System is in a rain shadow as Kilauea and northeast Mauna Loa receive most of the orographic rainfall delivered by the trades. Most of the yearly rainfall is due to Kona storms and frontal storms.

Calculated daily precipitation is 185 mgal. Equally distributed over the entire System, the mean rainfall is 2.2 mgd/sq. mi.

B. Streamflow

There are no streams in the System. During periods of heavy rainfall, any depression in the young lava flows acts as stream courses. Sheet flow occurs during extreme storm conditions.

C. Infiltration

Groundwater data is unavailable for the types and extent of aquifers within the System. Interfingering of Mauna Loa and Kilauea lavas along the contact and dike intrusion into the Kilauea lavas probably do not allow basal water to exist in the System. Shaft 8, constructed in Pahala (Naalehu System) and down gradient from any groundwater flow from Olaa and Kapapala systems, has a static water level of 230± feet msl (State of Hawaii, 1970, p. 158). Groundwater is mostly high-level, held up between Kilauea's southwest rift zone and subsurface lithology of Mauna Loa. The Kaoiki fault complex may also influence the deep movement of groundwater along the System's eastern boundary.

Perched groundwater is found throughout the System. Water holes occur within lava tubes and depressions. Water is perched on Pahala Ash and impermeable lava flows.

Naalehu Aquifer System (80503)

Geology

Geologically, the Naalehu System is the most interesting of the Sector. The majority of the lava flows occurring within the System are Kau Basalt ranging in age from prehistoric to the 1950 lava flow. Large areas of Kahuku Basalts with overlying deposits of Pahala Ash cover the region. Most of the Kahuku lavas lie between Kapapala and Pahala town (Steams and Macdonald, 1946). Pahala Ash ranges up to 55 feet thick in the System as measured by Stearns and Macdonald (1946, p. 73).

North of Naalehu and southwest of Pahala, the Ninole Basalt outcrops within the Honuapo fault system. As discussed, the Ninole Basalt is the oldest lava exposed on Mauna Loa. Steams and Macdonald (1946) and Macdonald and Abbott (1970) propose that the Ninole Basalt is a remnant from an earlier volcano covered by more recent Mauna Loa lavas.

Lipman (1980) believes that the Ninole Basalt was faulted into place, rather than representing an older volcanic edifice; that is, the lavas were erupted from the present location of Mokuaweoweo caldera.

Shallow stream valleys are cut into the older Kahuku Basalt. According to Steams and Macdonald (1946, pp. 48, 49), the canyons of Wood, Punaluu, Ninole, Hilea, and Waiohinu were eroded then partially filled by more recent Kau Basalts. They speculate that prior to burial, these canyons were two to six miles in length, one to one and one-half miles in width and 1,000 to 5,000 feet deep.

Some of the canyons cut into the Kahuku Basalts contain stream-laid alluvium. A mudflow deposit in Wood Valley is a major sedimentary occurrence in the System. Saturated and weathered Pahala Ash southwest of Wood Valley exhibits thixotropic properties, in that the soil is a solid until agitated. In 1868, heavy rainfall combined with a large earthquake, triggered the mudflow. The mudflow formed two branches. The smaller one flowed one mile into Wood Valley, while the larger flowed overland for two miles (Macdonald and Abbott, 1970, pp. 192, 193).

Hydrology

A. Rainfall

Annual precipitation varies within the System from less than 15 inches to almost 150 inches above Pahala and Naalehu. Calculated mean daily rainfall is 999 Mgal, which distributed evenly over the System is 2.8 mgd/sq. mi.

B. Streamflow

The Naalehu System is the only one in the Sector that has streams gaged by the USGS (Matsuoka, 1983). Streams occur in the valleys eroded into Kahuku Basalt and partially filled by prehistoric Kau lava flows. Heavy rainfall in the higher elevations southwest of Kapapala Ranch to Naalehu contributes to streamflow.

Heavy rainfall resulting from Kona and frontal storms causes lava channels in the Kau Basalt to act as stream courses. Overland sheet flow is prevalent at high elevation during storms.

C. Infiltration

A major aquifer underlying the System is basal. Well 8-0632-01, 3.3 miles north of Naalehu and monitored by the USGS (USGS, 1987), exhibits water levels of 0.5± feet. The well is drilled to a depth of 140 feet into Ninole Basalt from an elevation of 102 feet msl. Water quality data are not available; however, the low head suggest brackish water. Three wells drilled for the Kau Sugar Company at Honuapo (Wells 8-0533-01, 02 and 8-0632-01) exhibit water levels of about 2.5 feet msl with chloride values between 150-625 ppm.

Other wells in the Naalehu System monitored by the USGS have chloride values which range from four to 180 ppm. A chloride value of four ppm is exceedingly low for Hawaii, and is representative of high-level water in a rainy area.

High-level aquifers area also important resources. Shaft 8, Well no. 1128-01 at Pahala has a static water level of 230 feet msl (State of Hawaii, 1970). Another well (8-1229-01), owned by the State and located above Pahala, has a static water level of 380± feet msl. A chloride value listed for this source is seven ppm.

Several very large springs discharge at the coast near Punaluu. Ninole Spring is the second largest basal spring on the island. Estimated visible discharge is 25 mgd (Steams and Macdonald, 1946, p. 262). A water sample collected by them showed a chloride content of 435 ppm. The spring discharges from a lava tube in a late Kau Basalt flow. Steams and Macdonald (1946, p. 262) believe that the spring originates from the ancient Ninole Valley drainage system that was buried beneath Kahuku and Kau Basalt.

Kawaa Spring, two miles southwest of Ninole Spring, is another large basal spring. Estimated visible discharge is 10 mgd (Stearns and Macdonald, 1946, p. 262). They believe that Kawaa Spring originates from the partially lava-filled Hilea Valley. At the shore, the springs are brackish; however, a

half-mile inland a test pit produced water of 47 ppm chloride (Stearns and Macdonald, 1946, p. 262.

Perched groundwater occurs on weathered Pahala Ash and soil horizons. Numerous springs and tunnels at one time were utilized for sugar production and domestic use.

Ka Lae Aquifer System (80504)

Geology

The geology of the Ka Lae System is similar to the geology described in the previous System. The majority of the rocks exposed are historic to prehistoric Kau Basalts. The historic lava flows range from 1832 to 1950 (Stearns and Macdonald, 1946; Lockwood and Lipman, 1987).

Near Ka Lae, the Kahuku fault scarp has exposed older Kahuku Basalt lava flows. Patches of Kahuku Basalt are also exposed between Ka Lae and Kaalualu near Pakea Point (Steams and Macdonald, 1946). The Waiohinu fault north of Kahuku fault trends in a southeasterly direction. Lateral motion of several feet occurred along the fault during the earthquake of 1868 (Macdonald and Abbott, 1970, p. 309).

Soil associations, as defined by Sato and others (1973), formed from weathered lava and ash. Fresh and slightly weathered lava flows dominate the soil association of the System. Other associations include the Kekake-Keei-Kiloa association and the Puu-Pa-Pakini-Waiaha association.

Sedimentary deposits are minor and few. Ash reworked by wind and water occurs throughout the System. Black sand or hyaloclastite deposits are found along the shore. Green sand, formed from olivine phenocrysts, weathered out of olivinerich flows exposed at the coast. Talus is deposited at the base of the Kahuku fault scarp.

Hydrology

A. Rainfall

Annual rainfall varies from less than 20 inches to slightly greater than 75 inches. Calculated daily precipitation is 284 mgd. Average distribution of rain is 2.1 mgd/sq. mi.

B. Streamflow

Streams of any consequence are short and intermittent and mainly occur south of Pakea Point. None is gaged by the USGS. During Kona and

frontal storms, all gullies, lava channels, spatter ramparts, and depressions will flow with sheet runoff. Since most of the lava flows are very permeable, a storm of some intensity must take place before water flows off Mauna Loa.

C. Infiltration

The primary utilized aquifer in the System is basal. Numerous dug wells and Hawaiian water holes are found along the coast south of Pakea Point (Steams and Macdonald, 1946; State of Hawaii, 1970). Some of these wells were constructed adjacent to basal springs discharging at the coast and are listed as containing potable water (State of Hawaii, 1970). However, most are brackish with chloride values greater than 1,000 ppm. A well was drilled at Ka Lae to serve an old U.S. Army airport. The reported chloride content was about 600 ppm (State of Hawaii, 1970).

Perched groundwater is found at an elevation of approximately 2,000 feet msl. Perched springs and tunnels produce moderate quantities of water. The most notable is Haao (Waiohinu) Springs which lies 2,300 feet msl and produces about 0.6 mgd. Another is Portuguese Spring. It discharges at 2.650 feet msl, and flows at 0.25 mgd. Both springs are used for domestic purposes (State of Hawaii, 1970, pp. 178, 179). Several tunnels found near the springs are abandoned or produce small quantities for ranch use.

SOUTHWEST MAUNA LOA AQUIFER SECTOR

This Sector covers Mauna Loa from its shared boundary with the Southeast Mauna Loa Sector, from Ka Lae to Mokuaweoweo caldera along the southwest rift zone. It then runs northeast, following the shared boundary with the Northeast Mauna Loa Sector, until the boundary is adjacent to the 1859 eruption vent on Mauna Loa's northwest flank. At this juncture, the Sector boundary turns northwest, following the 1859 lava flow until the boundary reaches the geological contact with Hualalai. The Sector boundary swings west, following this contact until the coast.

The Southwest Mauna Loa Sector encompasses 637.77 square miles, 17.3 percent of the island's total area. It includes three Systems: Manuka (80601), Kaapuna (80602), and Kealakekua (80603). Boundaries between the Systems are somewhat arbitrary, though they are determined mainly by topography and contacts between recent Kau lava flows and prehistoric flows.

The geology of Mauna Loa has been described in detail previously. The Sector is covered only by historic and prehistoric Kau basalt lava flows (Stearns and Macdonald, 1946; Lockwood and Lipman, 1987).

Numerous prehistoric and historic littoral cones occur in the southern part of the Sector where lava flows entered the ocean. Cinder and spatter cones outcrop high

on Mauna Loa along the southwest rift zone. Recent lava flows include those from eruptions of 1868, 1887, 1907, 1916, 1919, 1926, and 1950. A'a is more prevalent than pahoehoe along the southwest rift zone (Lockwood and Lipman, 1987).

At Kealakekua Bay, the Kealakekua fault scarp begins at the north side of the Bay and runs five miles to the southeast, and then trends south for a mile until it disappears beneath late Kau flows. The scarp is 1,250 feet high. Stearns and Macdonald (1946, p. 37) believe that the fault is formed from a series of faults rather than only one.

The Kaholo fault scarp is traced for 16 miles northward of Milolii to Honaunau. The scarp attains a height of 500 feet at Pali Kaholo, but for the most part, is less than 250 feet high (Steams and Macdonald, 1946, p. 39). Kau Basalt flows have spilled over the escarpment to form broad lava plains and fans at its base. At Hookena, the fault reaches the sea and rapidly looses its height. Steams and Macdonald (1946) speculate that the Kaholo fault may be an echelon extension of the Kealakekua fault when the former reaches Honaunau.

The Southwest Mauna Loa Sector is in a tradewind and rain shadow due to the immensity of Mauna Loa. Wind direction in the northern part of the Sector tends to be variable and more easterly in the southern part. Rainfall is not orographic, but rather related to diurnal variations. Kona storms and other frontal disturbances also contribute much to the yearly rainfall.

Manuka Aquifer System (80601)

Geology

Volcanic rocks exposed in the System are historic and prehistoric lava flows belonging to the Kau Basalt. Historic lava flows in the System emanated from the eruptions of 1868, 1887, 1907, 1916, and 1950. Pahoehoe lavas are common near the vents along the rift, while a'a flows are more prevalent at lower elevations.

Many littoral cones developed at the coast when lava entered the sea. Most of these cones formed at the flow margins of prehistoric lava flows.

The topography of the System is youthful. No large valleys or gulches have been eroded into the lavas. Lava channels and flow margins act as water courses during periods of heavy rainfall.

Sato and others (1973) say that the main soil association in the System is the lava flows association. Also shown on the general soil map is a small amount of Kekake-Keei-Kiloa association. This soil is very shallow, excessively drained and organic.

Due to the youthfulness of the System, sedimentary deposits are rare. Sediments are mainly due to the reworking of hyaloclastite into small sand beaches. Marine erosion has also produced rounded beach cobbles and boulders. At higher elevations tephra has been reworked by wind and water.

Hydrology

A. Rainfall

Annual rainfall varies from less than 20 inches near Ka Lae (South Point) to greater than 75 inches between elevations of 4,000 and 5,000 feet msl. Mean daily rainfall calculated for this study is 390 mgd. Mean distribution of this rainfall is 2.3 mgd/sq. mi.

B. Streamflow

There are no perennial streams in the System. Runoff in lava channels and depressions happens during periods of heavy rainfall. Highly permeable young lava flows allow most rainfall to infiltrate.

C. Infiltration

Basal groundwater is the major aquifer. At the shore water holes and ancient Hawaiian dug wells take advantage of any depression in which basal groundwater would seep. Due to the permeability of the lavas, diffuse springs occur all along the coast. Basal water levels are near sea level, and therefore, water quality is brackish due to tidal influences. Other coastal dug wells north of the System typically have chloride contents between 1,000 and 3,000 pprn (State of Hawaii, 1970).

Dike-impounded, high-level water may be present inland and near the southwest rift. Lack of groundwater data in this region makes this assumption speculative, though it is analogous to other Hawaiian rift zone conditions.

Pahala Ash does not crop out in the System; therefore, perched groundwater, if it occurs, is associated with local geologic structure and is not a major source of groundwater. Lava tubes sometimes contain perched water due to their impermeable floors.

Kaapuna Aquifer System (80602)

Geology

The volcanic geology of the System is nearly identical to that of the Manuka System. The entire System is covered with historic and prehistoric lava flows of

the Kau Basalt (Stearns and Macdonald, 1946; Lockwood and Lipman, 1987). Historic flows outcropping in the System are from the eruptions of 1851, 1919, and 1926. Lava flows are typically pahoehoe and a'a. Scattered along the southwest rift zone are numerous historic and prehistoric cinder and spatter cones and fissure vents from which flows emanate. A few littoral cones are found along the coast, but not in the quantity occurring in the Manuka System.

Besides the rift zone, the most prominent structural feature in the System is the Kaholo fault zone described previously. The fault extends 16 miles along almost the entire length of coast. Its downthrown side is to the west.

Stream valleys or gulches are rare due to the youthfulness of the topography. Kiilae Stream south of Honaunau is one of the few identifiable streams. Irregular lava flow margins and channels help conduct runoff during periods of heavy rainfall.

Sedimentary deposits are scarce. They consist mainly of beach deposits including boulders, cobbles and volcanic sand (hyaloclastite). Reworked ash and cinder occurs at high elevation along the rift zone.

Hydrology

A. Rainfall

Annual rainfall for the System varies from less than 15 inches at Mokuaweoweo caldera to about 125 inches in a zone of high precipitation above Honaunau. The System is in the tradewind shadow of Mauna Loa so that the rainfall is diurnal rather than orographic. Calculated mean daily rainfall for the System is 479 mgd. Mean distribution of rainfall is 2.0 mgd/sq. mi.

B. Streamflow

Streams are rare in the System. Kiilae Stream south of Honaunau was gaged by the USGS for 22 years (Matsuoka, 1983). Mean flow for that period was 0.1 mgd, but no flow conditions were common. During periods of heavy precipitation, any depression, lava channel or flow contact will channelize runoff. High permeable of the lava and soils allow much of the water to infiltrate.

C. Infiltration

Basal groundwater underlies the Kaapuna Systems from the coast to an unknown distance inland. Few data are available, but water levels and quality should be similar to those occurring in the Manuka System. Greater rainfall and infiltration in the northern part of the System would cause higher water levels in this region. However, for the most part water levels

are typically one to two feet msl.

Well 8-1953-01, drilled near Kauluoa Point at an altitude of 205 feet msl to a depth of 228 feet, has a chloride value of 1,500 ppm (State of Hawaii, 1970). Diffuse basal springs discharge along the coast.

Dike-impounded, high-level water may be present at high elevation, near the southwest rift, though its presence is speculative. It is more likely that perched water is present prior to its movement into the basal system. Perching members can include ash deposits, dense lava flows, and high-level intrusive bodies.

Kealakekua Aquifer System (80603)

Geology

All of the volcanic rocks exposed are historic and prehistoric lavas belonging to the Kau Basalt (Steams and Macdonald, 1946; Lockwood and Lipman, 1987). They are Pahoehoe and Na accompanied by pyroclastic deposits of spatter and cinder cropping out along the rift zone and near eruptive vents. Dense ponded flows are prevalent in and around Mokuaweoweo caldera. Beside Mokuaweoweo caldera, the Kealakekua fault system, described previously, is the largest structural feature in the System.

Lavas from Mauna Loa and Hualalai interfinger at depth since both volcanoes erupted simultaneously in the past. The subsurface geological contact may dip to the south.

As with the other Systems in the Sector, sedimentary deposits are limited mainly to beach deposits derived from wave erosion of lava flows and the production of hyaloclastite as lava enters the sea. Reworked cinder deposits also occur.

Hydrology

A. Rainfall

Annual rainfall in the System varies from less than 15 inches at Mokuaweoweo caldera to about 125 inches inland of Kealakekua Bay. Rainfall is diurnal rather than orographic due to Mauna Loa blocking the tradewinds. Average calculated daily rainfall is 351 mgd. Because most of the System's area receives less than 50 inches of rain per year, distribution of total rainfall is only 1.6 mgd/sq. mi.

B. Streamflow

Major streams do not occur in the System. Gullies are shallow and short.

Lava channels, margins and other depressions channelize runoff during periods of heavy rainfall. High permeability of the soil and lava allows most rain to infiltrate.

C. Infiltration

A basal groundwater aquifer is found at the coast and extends inland for an unknown distance. Numerous basal springs discharge at the shore. Wells drilled into the basalt lava flows encounter water levels of one to two feet msl. Well 8-2554-01, drilled at an elevation of 175 feet msl, has a head of about two feet. Chloride content was measured at 1,190 ppm (State of Hawaii, 1970).

High-level, dike-impounded and perched water may occur inland at high elevation. Springs and wells are present (Steams and Macdonald, 1946; State of Hawaii, 1970). Prehistoric and historic vents with subsurface dike structures and buried tephra deposits may cause some water to be held at higher elevations. Ranches in the System do not use any perched springs but rely on rain catchment for water supply.

NORTHWEST MAUNA LOA AQUIFER SECTOR

The Northwest Mauna Loa Sector encompasses the northwest quadrant of the volcano and consists entirely of the Anaehoomalu system. The Sector shares its southern boundary with Mauna Loa's Northeast Sector. Its western boundary is the Southwest Mauna Loa Sector and the Kiholo System of the Hualalai Sector. Its eastern boundary is the West Mauna Kea Sector and the Kiholo System of the Hualalai Sector. Its eastern boundary is the West Mauna Kea Sector. The shared boundaries with Hualalai and Mauna Kea follow the geological contacts as mapped by Stearns and Macdonald (1946).

The geology of Mauna Loa is described in detail previously. From the geological map it is evident that Kau lavas from Mauna Loa filled a depression that existed between Mauna Kea and Hualalai. Steams and Macdonald (1946, p. 139) speculate that Hualalai may have grown on top of Ninole Basalt, an older Mauna Loa volcano. Lavas from Mauna Loa interfinger with those of Hualalai and the Laupahoehoe basalts of Mauna Kea.

Anaehoomalu Aquifer System (80701)

Geology

The lavas represented in the System are historic and prehistoric flows of Kau Basalt (Stearns and Macdonald, 1946; Lockwood and Lipman, 1987). The 1859 lava flow is the longest and most voluminous historical flow on record (Macdonald

and Abbott, 1970, p. 56), and traces the western boundary of the System.

Other historical flows from Mauna Loa's northeast rift zone lap up against Mauna Kea in the Humuula saddle area. Many prehistoric Kau lava flows interfinger at depth with Mauna Kea flows in this area. Stearns and Macdonald (1946) mapped numerous Laupahoehoe Basalt cinder cones and one Kohala cinder cone surrounded by Kau Basalt within the Sector. Prehistoric pyroclastic cones of Kau Basalt also occur.

Sedimentary deposits are limited to beach deposits, and possible reworked ash and cinder.

Hydrology

A. Rainfall

The Anaehoomalu System is one of the driest on the island. Annual rainfall varies from less than 10 inches at the coast to about 45 inches in the interior. Mean daily rainfall is calculated at 317 mgd. Distributed evenly over the System's 291 square miles, daily rainfall is 1.1 mgd/sq. mi.

B. Streamflow

Due to the Sector's youthful geology, streams are not well-developed. Storm runoff is channeled between lava flows, in depressions, lava channels, spatter ramparts or escapes as sheet flow. The USGS has not gaged any runoff in the Sector (Matsuoka, 1983)

C. Infiltration

The lower portion of the Sector/System is underlain by basal groundwater of low head. Ancient dug wells and water holes produce brackish water.

There are no wells in this Sector to record water levels or chloride values. However, wells 8-5548-01 and 8-5648-01, drilled at elevation 814 feet msl and 620 feet msl, respectively, at Waikoloa near the Sector's boundary, have heads of five to six feet with chloride content between 300 and 500 ppm. Other Waikoloa wells 8-5745-01, 02, drilled at an altitude of 1,213 feet msl and 1,203 feet msl, respectively, yield excellent quality water at 23 ppm chloride. Static water level for these wells is about 16 feet msl.

High-level groundwater may exist far from the coast as dike-impounded water. Perched water may also be present in small quantities. None of these supplies has been explored.

KILAUEA AQUIFER SECTOR

The Kilauea Sector encompasses Kilauea shield volcano as defined by the geological mapping of Steams and Macdonald (1946) and Macdonald and Abbott (1970). The entire Sector abuts Mauna Loa on the west, and its geological contact with Mauna Loa is also a common boundary with the Northeast and the Southeast Mauna Loa Sectors.

The stratigraphy of Kilauea is discussed by Easton (1987). He revised and updated Steams and Macdonald (1946), who in turn organized stratigraphy of earlier workers (e.g. Stone, 1926; Stearns and Clark, 1930; Wentworth, 1938).

In the stratigraphic nomenclature now used, the oldest exposed lava flows belong to the Hilina Basalt and are older than 25,000 years. Within this unit are four ash members. From oldest to youngest they are: The Halape Ash Member, the Kahele Ash Member, the Pohakaa Ash Member, and the Moo Ash member. Overlying the Hilina Basalt is Pahala Ash. Easton (1987) places the eruption of the ash between 10,000 and 25,000 years ago.

Overlying the Pahala Ash is the Holocene Puna Basalt. The Puna Basalt is subdivided into prehistoric and historic flows. Intercalated with the Puna Basalt are two ash members. The Uwekuhuna Ash Member is associated with the prehistoric flows, while the Keanakakoi Ash Member is historic.

Like Mauna Loa, Kilauea is one of the most active volcanoes on earth. Holcomb (1987) concludes that 50 percent of Kilauea's surface is less than 500 years old and 90 percent is younger than 1,100 years old. His mapping reveals that Kilauea's surface consists of 67 percent tube-fed pahoehoe, 14 percent surface-fed pahoehoe, and 16 percent a'a.

Structurally, Kilauea consists of a summit caldera from which two rift zones extend. The summit caldera is two by three miles across, and 400 feet deep at its western edge (Macdonald and Abbott, 1970, p. 312). Halemaumau is a deep pit crater within the caldera. Kilauea Iki is another pit crater at its eastern boundary.

The east rift zone extends from the caldera to Cape Kurnukahi, and is about two to three miles wide. Holcomb's findings (1987) reveal that the submarine Puna Ridge continues another 38 miles beyond Cape Kumukahi. He divides the rift into three segments: the upper segment extends from the sununit to Napau Crater and is dominated by pit craters; the middle segment runs from Napau Crater to Heiheiahulu lava shield; the third segment runs form Heiheiahulu to Cape Kumukahi. The middle and lower parts of the rift are typified by closely spaced fissures, faults, and grabens.

The southwest rift zone does not extend far beyond the shore, and parallels Mauna Loa's Kaoiki fault system. Holcomb (1987) believes that buried Kaoiki fault may influence rift structure.

Normal fault systems are well developed east of the caldera. The Koae fault system

trends east-northeast between the rift zones. Its downthrown sides of the faults are towards the caldera. The Hilina fault system, south of the Koae system, has its downthrown block to the south. Its prominent faults are the Hilina, Poliokeawe and the Holei Palis.

All lava flows exposed at Kilauea are tholeiitic, olivine tholeiitic, and picritic basalts. No chemically evolved lava flows are present. Intrusives include dikes, sills, and the Uwekuhuna laccolith exposed in the western wall of the caldera.

Pahoa Aquifer System (80801)

Geology

Holcomb (1987, p. 287) shows that many of the surface flows in the System are Puna Basalts between 350 and 500 years old. These lavas surround smaller regions 750 to 1,000 years old, and some areas that range in age from 1,500 to 10,000 years. Near Cape Kumukahi and the east rift, lava flows are much younger and include lavas that erupted within the last 30 years.

Associated with the east rift zone are numerous tensional cracks and normal faults. These tend to be north of the main eruption zone. Dikes intrude much of the lava near the rift zone. Away from the zone, lavas are dike-free.

Streams have not cut very deeply into Kilauea. Old lava channels and boundaries channelize excess runoff to the sea. Most runoff seeps into the ground due to high permeability of the lava flows.

Due to the youthfulness of the lava flows, sedimentary deposits are scarce. However, wave action has produced round beach boulders and cobbles in a very short period of time. Reworked ash and cinder occur in small amounts.

Hydrology

A. Rainfall

Variations in annual rainfall range from about 45 inches to almost 200 inches. Calculated average daily rainfall is 1.53 Bgal. Distributed evenly over the System, daily rainfall is 6.8 mgd/sq. mi.

B. Streamflow

As mentioned above, streams are not well enough developed in the System to measure. Young unweathered lava flows are more conducive to infiltration than to runoff. Heavy rainfall accompanying Kona storms and other frontal disturbances cause sheet runoff to occur.

C. Infiltration

Basal groundwater underlies much of the System from Pahoa town to the sea. Wells drilled near Pahoa for municipal supply come from an aquifer with a water level of about 17 feet msl and chloride values of less than 10 ppm. Shaft 8-3080-01 and well 8-3081-01, drilled near Kapoho, draw from a basal aquifer with a water level of three feet msl and chloride values of several hundred pprn (State of Hawaii, 1984). Geothermal wells drilled near Pahoa Wells Nos. 8-2883-01-06) reached basal water with a head of about 11 feet msl. (D. Nakano, personal communication, 1989).

High-level, dike-impounded water undoubtedly occurs near the east rift and near the summit region of Kilauea. Perched water may also be present in the System. Several test holes were drilled near Mountain View to explore for perched water. However, none was found.

Kalapana Aquifer System (80802)

Geology

Holcomb (1987) states that the ages of the puna Basalt lava flows range from about 10,000 years old to the present. A few outcrops of older Hilina Basalt is found exposed in the Hilina fault system.

The east rift zone is a major structural feature in the System. Tensional cracks and faulting are common. Pit craters due to magma withdrawal are also common in the upper part of the rift zone. The Hilina fault system begins in the Kalapana System, but does not attain its full displacement. Dike-intruded lavas occur at depth and are prevalent along the rift and marginal rift zone.

Lava flows are both pahoehoe and a'a. Cinder and spatter cones and deposits of wind-blown tephra are common along the east rift zone.

Sediments consist of beach deposits formed by wave action on fresh lava flows, hyaloclastite deposits (Kaimu Black Sand Beach, Kalapana), and wind-blown ash, cinder, and Pele's hair. These latter deposits have been reworked by wind and rain. At the bases of the cliffs and pit craters, talus and talus breccia are common.

Hydrology

A. Rainfall

Total annual precipitation varies from about 45 inches to about 125 inches. Mean daily rainfall is calculated to be 746 mgd. Evenly distributed over the area, rainfall is 3.9 mgd/sq. mi.

B. Streamflow

Due to the System's youthful geology, streams are not developed. Most storm runoff is sheetflow, or is channelized along lava margins or channels. The high permeability of the lavas allows most of the rain to infiltrate. The USGS does not maintain any gage within the system (Matsuoka, 1983).

C. Infiltration

Basal groundwater occurs near the coast and extends an unknown distance inland. Steams and Macdonald (1946) show that there are many basal springs and ancient Hawaiian wells and water holes from Cape Kumukahi to Apua Point. The basal lens is truncated by the east rift zone and its southern extension of the dike complex.

Wells 8-2487-01, 02 and 8-2102-01, drilled south of Kapoho and several miles inland at elevations of 200 to more than 700 feet msl, have water level of two to three feet msl. Chlorides range from 90 ppm to almost 300 ppm. Pumping rates are 50 to 500 gallons per minute (gpm).

Hawaiian water holes and dug wells at the coast typically produce water of more than 700 ppm chloride (State of Hawaii, 1970).

Small perched supplies are also present within the System. Green Lake, occupying the crater of Kapoho Cone, is thought to be perched upon tuffaceous deposits (Steams and Macdonald, 1946, p.255). The water level is eight feet msl and is not thermal. Chloride content was measured at 70 ppm.

Hilina Aquifer System (80803)

Geology

Most of the lava flows exposed in the System belong to prehistoric members of the Puna Basalt. Historic flows are found at the summit and part way down the southwest rift. Many of the prehistoric exposed flows are older than 500 years (Holcomb, 1987). Small pockets of Pahala Ash crop out along the Hilina Fault and in the Puu Kapukapu fault zone. Hilina Basalt, older than 25,000 years, outcrops in the Hilina and the Puu Kapukapu fault zones, underlying Pahala Ash.

The Hilina fault zone dominates the southern part of the System. The downthrown side of the fault is to the south. Vertical displacement of the Hilina Pali is 1,500 feet and total downthrown of the seaward block is more than 2,000 feet (Macdonald and Abbott, 1970, p. 315).

The Koae fault zone, below the summit region and north of the Hilina fault zone,

shows the downthrown side to the north. Monoclinal folds associated with the faulting also occur. Macdonald and Abbott (1970) believe that faulting acts as a joint to accommodate shrinkage and swelling of the volcano.

Sedimentary deposits are ash and cinder laid down by wind or reworked by wind and water. Talus outcrops at the base of the fault scarps. Several small littoral cones of hyaloclastite mapped by Steams and Macdonald (1946) occur at the shore.

Hydrology

A. Rainfall

Annual rainfall varies from less than 20 inches to almost 50 inches at Halemaumau. Calculated average daily rainfall is 81 mgd. Mean distribution of rainfall is 1.4 mgd/sq. mi.

B. Streamflow

Streams are not found in the System. Runoff from torrential rain storms is as overland sheet flow. Water follows any depression, lava channel or flow margin. High permeability of the lavas allows much of the precipitation to seep into the ground.

C. Infiltration

Hawaiian dug wells and water holes are found along the coast between Apua Point and Naliikakani Point. These basal sources are typically brackish with water levels only a foot or two above sea level.

High-level water may occur inland from the coast. Perched water may also occur in small quantities and discharge as seeps. Perching members include dense lava flows and weathered ash beds.

Keaiwa Aquifer System (80804)

Geology

Lava flows and ash beds in the System belong to historic and prehistoric Puna Basalt eruptions. Many of the eruptions near the summit region took place in the 20th century. These include numerous eruptions within Halemaumau, the western part of Kilauea caldera and environs, and the 1919-1920 eruptions of Mauna Iki along southwest rift zone.

A large area southeast of the Great Crack is covered by lava flows produced by the 1823 eruption. A large area extending from the caldera southwest is covered

by the Keanakakoi Ash Member of 1790 and other 18th century lavas. Other flows exposed range in age from 300 to 10,000 years (Holcomb, 1987).

Structurally the System is dominated by the southwest rift zone and faulting along the Koae fault system associated with it. The Great Crack from which 1823 lavas welled up is 14 miles long, and in some places is 50 feet wide and 70 feet deep (Macdonald and Abbott, 1970, p.71).

Sedimentary deposits include reworked ash and cinder, small pockets of beach deposits, and limited quantities of talus.

Hydrology

A. Rainfall

Annual rainfall ranges from less than 20 inches to slightly more than so inches near the summit of Kilauea. Calculated mean daily rainfall is 162 mgd. Distribution of rainfall per square mile is low at 1.8 mgd.

B. Streamflow

As with the previous System in the Sector, streams are not developed on Kilauea due to its youthfulness. Runoff quickly infiltrates because of the high permeability of the lavas.

However, runoff from torrential rain storms becomes sheet flow and follow any depression. The Great Crack must channelize much of the flow during these conditions.

C. Infiltration

Basal groundwater of low head is present at the coast, discharging as brackish springs. Well 8-1128-02, drilled southeast of Pahala at an elevation of 304 feet msl into Puna Basalt, has a static head of 8.6 feet msl. Chloride content is very low at nine ppm (State of Hawaii, 1984).

Small, perched sources may occur in the ash deposits, but these are ephemeral and active only after heavy rains. Dike-impounded water is most likely present, but development of this water has not been tested.

HUALALAI AQUIFER SECTOR

The Hualalai Aquifer Sector includes all of the Hualalai shield volcano as defined by mapping of Steams and Macdonald (1946) and Macdonald and Abbott (1970). The entire Sector is surrounded by Mauna Loa and shares a common boundary with the Southwest Mauna Loa Sector (Kealakekua System) and the Northwest Mauna Loa

Sector (Anaehoomalu System). This Sector has been divided along the volcano's main northwest-southeast rift zone into two Systems: 1) the Keauhou System (80901), and 2) the Kiholo System (80902).

The Stratigraphy of Hualalai volcano as discussed in Langenheim. and Clague (1987, p. 77) is an updated version of Steams and Macdonald (1946). The Hualalai Volcanics is composed of post-shield stage lavas and pyroclastics of alkalic basalt and rare hawaiite. The base of the Hualalai Volcanics is not exposed. Included with the volcanics are the Waawaa Trachyte Member (formal designation) and the Kona ash beds (informal designation). The Hualalai Volcanics interfinger with Mauna Loa's Kau basalt.

Tholeiitic basalt has been reported from the submarine extension of the volcano's northwest rift zone (Clague, 1982) and in several water wells. Picritic tholeiite basalt inclusions have been collected from Waha Pele (Moore and others, 1987).

Hualalai is volcanically still active. The last eruption occurred in 1801. Data presented by Moore and others (1987) indicate that 95 percent is less than 1,000 years old. Puu Waawaa is dated at 0.105 My, while the oldest basaltic flows exposed are almost 13,000 years old. (Moore and others, 1987).

The rift zone is well-defined and dotted with numerous cinder and spatter cones and spatter ramparts, and small lava shields. A less well-defined rift trends north and is dotted by cinder cones. Included on the north rift is the Puu Waawaa Trachyte Member, a pumice cone of extremely viscous lava. A thick trachyte flow emanated from the vent forming Puu Anahulu (Macdonald and Abbott, 1970). Many of the lava flows outcropping along the rift zone show evidence of extreme fluidity.

Keauhou Aquifer System (80901)

Geology

The lava flows exposed belong to the Hualalai Volcanics. Most of the flows are less than 5,000 years old, though some near Kilauea are more than 10,000 years old (Moore and others, 1987, p. 574). The youngest lavas belong to the 1801 lava flow at the northwest comer of the System.

Short and shallow stream valleys have been eroded into the surface of the volcano. The most prominent is Waiaha Stream near Holualoa. Higher rainfall in this region accounts for rapid erosion.

Sediments consists mainly of beach deposits and reworked tephra.

Hydrology

A. Rainfall

Rainfall in the System is diurnal, as it is throughout the wind shadow of Mauna Loa and Mauna Kea. Annual rainfall ranges from less than 20 inches along the northwest coast to about 125 inches in the Kahaluu forest Reserve. Calculated mean daily rainfall is 356 mgd. Equal distribution over the System is 2.1 mgd/sq. mi.

B. Streamflow

Streams are not well developed in the System. Matsuoka (1983) reports that Waiaha Stream at Holualoa was gaged (759500) for 11 years. Mean streamflow for this period is 0.8 mgd. Presently, Waiaha Stream and neighboring Keopu Stream are gaged by crest stage partial-record stations. High permeability of the lava flows does not allow for much runoff.

C. Infiltration

Basal groundwater occurs throughout the System for several miles inland. Many ancient Hawaiian dug wells and waterholes occur along the coast. Stearns and Macdonald (1946, p.287-288) present data showing that most of these wells have chloride contents between 1,000 and 1,400 ppm. Numerous springs also discharge below sea level.

Basal wells drilled south of Kailua have better quality water than those drilled north of Kailua. Greater recharge from rainfall south of Kailua cause the higher water levels and lower chlorides.

High-level, dike-impounded water may occur near the rift zones. Moore and others (1987, p.576) report that either high-level dike or perched water was encountered during the eruption of Waha Pele which resulted in massive phreatic explosions. Blocks of trachyte and basalt as large as 0.4 m were deposited over an area of 10 square kilometers.

Small quantities of perched water may also occur. Steams and Macdonald (1946, p. 271) report water in lava tubes and depressions. The annealed bottoms of lava tubes prevent water from seeping down. Pumping some of these sources show an estimated quantity of 5,000 to 50,000 gallons.

Kiholo Aquifer System (80902)

Geology,

All of the exposed volcanic rocks belong to the Hualalai Volcanics. The oldest

rocks belong to the Waawaa Trachyte Member and are greater than 0.10 My (Moore and others, 1987). A majority of the remaining flows are less than 5,000 years old. The youngest erupted in 1800. The 1800 lavas flowed northwest and form a lava delta on the south side of Kiholo Bay.

The Kiholo System does not have any stream valleys. This is because of the System's dry climate and young topography. Lava channels, flow margins, and spatter ramparts channelize storm runoff.

Sediments occurring in the System are insignificant. Beach deposits create as small beaches. Reworked ash and cinder also occur.

Hydrology

A. Rainfall

Rainfall varies from less than 10 inches at the coast to 45 inches at mid-elevation, making this System one of the driest in the island. Calculated average daily precipitation is 172 mgd. The quantity of rain is so low that the mean distribution of rainfall is only 1.2 mgd/ sq. mi.

B. Streamflow

Streams are not found in the System. Storm runoff is either channelized in lava channels, flow margins, and depression, or occurs as overland sheet flow. The young basaltic lavas are highly permeable and allow most rainfall to infiltrate. The Waawaa Trachyte Member is extremely massive and impermeable, so that any rain falling on it runs off.

C. Infiltration

Basal groundwater underlies the coastal areas of the System and extends an unknown distance inland. Ancient Hawaiian wells and waterholes along the shore, with water levels slightly above sea level, produce brackish water of several thousand ppm chloride.

Data clearly show that basal water taken from wells some distance back from the coast produce slightly brackish and in some cases, potable water. Well 4658-01 produces good quality water from a basal aquifer with a head of about seven feet.

Well 4650-01, drilled to explore for geothermal energy, is located near Puu Anahulu. Its high water level may be associated with dikes that belong to the weak north trending rift zone. High-level, dike-impounded groundwater should be present within the rift zone. The eruption at Waha Pele provides evidence for its occurrence.

Near the eastern boundary of the System is Waikulukulu Spring, a perched source at elevation 5,143 feet msl. Stearns and Macdonald (1946) have it mapped as an ancient Hawaiian water source. Since Ahuaumi Heiau is located nearby, exploitation of this water source by the Hawaiians was unlikely. Other perched sources may be present in lava tubes at other localities.

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KAUAI
Geology and Geologic History

The island of Kauai is the oldest and most northwesterly of the main Hawaiian Islands. The island is the exposed top of a large single-shield volcano, most of which is submerged. Its land area is 549 square miles (Department of Business and Economic Development, Hawaii Data Book 1987), some 50 square miles less than Oahu.

Geologic relationships mapped in the field, along with petrological examination of the rocks as outline in Hinds (1930), Steams (1946), and Macdonald and other (1960), have produced a good understanding of the island's geology.

The central caldera of the Kauai volcano is the largest in the Hawaiian Islands, with a diameter of almost 12 miles (Macdonald and Abbott, 1970, p. 381). During the caldera stage a fault-bounded graben formed (Macdonald and others, 1960, pp. 90-94) on the southern flank of the shield. This fault valley is known as the Makaweli Depression and was filled by lavas supplied from overflowing of the caldera.

At a later time, the eastern flank of the shield collapsed to form another large caldera, seven to 10 miles across, known as the Lihue Depression, and a smaller caldera mapped in the Haupu Peak area. Stearns (1946, p. 87), however, reports that Haupu Ridge represents a separate volcano that grew on the flank of the main Kauai shield. Macdonald and others (1960, pp. 21, 22) point out that eastern dipping lavas on the western end of Haupu lavas are an extension of it.

Macdonald and others (1960, p. 95) say that the only evidence for a collapse origin of the Lihue Depression other than its circular shape are abnormally steep dips found in lava flows outcropping in Kalepa and Nonou ridges. These dips suggest a structural origin due to basin subsidence. Post-erosional lava flows, pyroclastic, and associated breccia deposits have buried any exposed boundary faults which may have been present.

From the geologic map (Macdonald and others, (1960), the post-caldera stage, prevalent on many of the other Hawaiian shield volcanoes, does not seem to have occurred on Kauai. However, a recent study (Clague and Dairymple, 1987, p. 51) describes a single post-caldera flow.

Langenheim and Clague (1987) have codified existing map units into conformance with the 1983 North American Stratigraphic Code. Essentially, the term "Volcanic Series" has been changed to "Volcanics", and reflects shield, caldera, and post-caldera stages of volcanism of a particular shield volcano. It can also denote a separate suite of eruptions such as post-erosional (e.g. Koloa Volcanics). Rock units within the major "Volcanics" subdivision, are known as "Member", and can have a descriptive term such as "Breccia", "Flow" or "Ash".

For Kauai, the Waimea Canyon Volcanics represent shield, caldera and other volcanic

rocks associated with the main growth of the island. Within this broad rock suite are: 1) the Napali Member representing the shield-building lavas, 2) the Olokele Member representing the caldera-filling lavas and a few flows that may be post-caldera, 3) the Makaweli Member representing the graben-filling lavas, 4) the Haupu Member representing lavas filling the Haupu flank caldera.

After the eruption of the Waimea Canyon Volcanics, a long period of weathering and erosion produced tremendous cliffs and canyons, reducing the bulk of the Kauai shield considerably.

The Koloa Volcanics represent a resurgence of volcanic activity from at least 40 vents that was marked by thick and massive lava flows and explosive pyroclastic eruptions. These vents are concentrated around the southern and eastern flanks of the shield. Underlying and interbedded within the Koloa Volcanics is the Palikea Breccia Member which is composed of breccia and stream deposited conglomerates.

LIHUE AQUIFER SECTOR

The Lihue Sector is essentially the eastern half of the island and includes five aquifer Systems. The Sector encompasses the Kawahau, Lihue and Koloa groundwater districts of Macdonald and others (1960), or the Lihue and Koloa hydrographic areas of the 1979 State study.

For this study, the planimetered area of the Lihue Sector is 227.37 square miles or 41.5 percent of the island's total land area. The Sector boundary traces the coastline from Kilauea Point in the northeast to Port Allen in the south. The interior boundary extends north from Port Allen, skirting the east side of the Hanapepe River canyon to Mt. Waialeale. From Mt. Waialeale it trends northeastward along a ridge which divides the Hanalei River headwaters from the headwaters of the North Fork of the Wailua River. This ridge extends to the Makaleha Mountains, then north to Kilauea Point following a narrow ridge dividing the Kalihiwai watershed from the Kilauea watershed.

Geologically, the Lihue Sector essentially coincides with the Lihue Depression and rocks of the Koloa Volcanics. Thin bedded lavas associated with the Napali member of the Waimea Canyon Basalt outcrop on the surface as isolated mountains and hills surrounded and embayed by younger lavas and ash deposits of the Koloa Volcanics, or as thin weathered ridges extending eastward from Mt. Waialeale. High precipitation and heavy vegetation have deeply weathered much of the volcanics of the Napali Member.

Stream configuration varies in the Sector. Streams in the Wailua and Hanamaulu Systems meander the flat Lihue Depression. Streams in the Koloa and Kilauea Systems tend to be shorter and straighter. Streams in the Anahola System are relatively short, though they meander across a Koloa Volcanics surface. Undoubtedly, many of the streams of the Lihue Sector have had their courses profoundly affected by the eruption

of the Koloa Volcanics.

Koloa Aquifer System (20101)

Geology

The surface geology of the Koloa System in mainly post-erosional Koloa Volcanics overlying older thin-bedded shield-building flank lavas of the Napali Member and dike-intruded caldera lavas and breccia of the Haupu Member.

The Koloa Volcanics were erupted from approximately 23 northeast-trending vents (Macdonald and Abbott, 1970) within the boundaries of the System. Koloa Volcanics exposed include nephelinic to alkalic basalt lava flows and pyroclastic deposits interbedded with boulder conglomerates. These flows and tephra deposits mantle existing topography and give the area a gentle geomorphic expression.

Examination of published well logs (Macdonald and others, 1960) suggests that Koloa Volcanics are several hundred feet thick where test wells T-4 and T-5 are drilled, east and south of Lawai. Macdonald and others (1960, p. 137) say that T-4 penetrated Koloa Volcanics for 600 feet. However, it cannot be determined if the rocks penetrated are Koloa Volcanics (p. 189). At the coast, from Port Allen east to Makahuena Point, Koloa Volcanics outcrop almost exclusively.

Waimea Canyon Volcanics outcrop within the Koloa System as heavily vegetated ridges in the Kahili Mountain area, as kipukas of high ground surrounded by Koloa Volcanics, and as Haupu Ridge. The lavas are mainly tholeiitic basalts and tholeiitic olivine basalts.

Many of the exposures are weathered, with laterites common in roadcuts and a saprolitic zone identified from drilling logs. These weathered zones commonly extend 50 to 100 feet deep with primarily flow structures preserved. Napali Member lavas outcrop near and above the Lawai area in the vicinity of Alexander Reservoir, and in the Kahili Mountain area. These flows are thin-bedded and are dike-free, though north-south dike has been mapped (Macdonald and others, 1960) in Kapalao Peak.

In Haupu Ridge, dike-intruded lavas of the Napali Member occur. Dike trends are essentially east-west and north-northwest, though on the westem end of the ridge trends are variable. Macdonald and others (1960) found that thick ponded flows of the Haupu Member outcrop for 2.6 miles along Haupu Ridge and represent a small flank caldera that formed on the main shield. Small breccia deposits at the contact of the Napali and Haupu Members mark the western, and southern boundary of the caldera. Macdonald and others (1960, p. 40) place the eastern boundary 0.25 miles S 58 W of Hokunui Peak. The number and concentration of dikes mapped do not seem to represent a dike complex but do suggest minor rift zones with weak alignment.

Sedimentary deposits within the System are mainly beach and dune deposits, young poorly-associated alluvial deposits associated with existing streams, older well-cemented, poorly-sorted alluvium, and Palikea Member conglomerate of the Koloa Volcanics.

Hydrology

A. Rainfall

Mean annual rainfall for the System varies from 30 inches at the coast to greater than 200 inches at Puu Kapalao. Calculated mean daily rainfall is 177 mgd. Average distribution of rainfall over the Koloa System is 3.5 mgd/sq. mi.

B. Streamflow

Even though precipitation is high, stream discharge is relatively low. Seven years of measured streamflow (1963-70) at the U.S. Geological Survey's (USGS) Lawai Stream Gage No. 16052500 average 5.28 mgd. Presently, only crest-stage recorder measurements of maximum flow are available for this gage.

Streamflow data for Wahiawa Stream is not available. However, Wahiawa Stream supplies the 800-million-gallon Alexander Reservoir above Eleele. Surface water diverted from tributaries of the Wailua River, outside of the System, supplies the 2.5 billion-gallon Koloa Reservoir.

C. Infiltration

Infiltration for the System is 83 mgd. Infiltration into the Napali Member shield basalts and Koloa Volcanics allows for both basal and perched aquifer recharge. Noncontributory sediments consist mostly of alluvial and coastal beach deposits.

Records of drilled wells in the Koloa System indicate that both basal and perched groundwater aquifers are used to supply the needs of the area.

Basal aquifers occur within the Napali Member Basalts and Koloa Volcanics. Water level records of wells drilled below Koloa Volcanics, into flank flows show head elevations ranging from 30-140 feet above mean sea level, suggesting mixed basal and high-level conditions in wells and drill holes near Lawai.

Deeply buried dikes may control groundwater levels. Basal water is developed in Koloa Volcanics from McBryde Sugar Shafter 3 situated in the Lawai Stream valley about a mile inland from the coast.

Perched groundwater occurs in the Koloa Volcanics as small discontinuous aquifers that vary in thickness and size. Large and small streams in the Koloa System may receive a portion of flow from perched spring discharge. Because most of the rainfall in the System infiltrates into the Koloa Volcanics, much of the groundwater in the System may be perched.

High-level dike water has not been clearly identified but probably exists.

Hanamaulu Aquifer System (20102)

Geology

The geology of the Hanamaulu System is similar to the Koloa System in that older Napali Member basalts crop out as high ridges below the summit region of the island, in the Haupu Ridge and as isolated ridges and peaks at lower elevations. The low, weathered Napali surface of the Lihue Depression was covered by the Koloa Volcanics and associated Palikea Member conglomerate.

Unlike the Koloa System where the Koloa Volcanics were erupted from many vents, Kilohana Crater, a small-shield volcano, dominates the real geology of the System. Older Koloa vents may have erupted, but these have been buried by lavas emanating from Kilohana Crater. Lavas ponded against Haupu Ridge and formed a large plain surrounding Napali lava flows exposed in Kalepa Ridge (Macdonald and others, 1960).

Streams existing prior to the eruption of the Kilohana shield had their courses altered to flow around the shield. Consequent streams originating from the summit of Kilohana Crater add their flow as tributaries to streams flowing around the base of the vent. An example is Halenanahu Stream flowing south, a tributary for the Kuia-Huleia Stream system.

Sedimentary deposits include consolidated and unconsolidated beach and dune sands, older well-consolidated alluvium and colluvium, and younger unconsolidated alluvium. Much of the older alluvial and colluvial deposits are found as aprons around the slopes of ridges of Napali Member lavas. The younger alluvial deposits, brought by streams, occur in the valley bottoms. The greatest amount of streamlaid alluvium is found near the mouths of Huleia and Hanamaulu streams. Beach and dune deposits occur along the coast as long, narrow strips.

Hydrology

A. Rainfall

Mean annual rainfall for the Hanamaulu System varies from a little less than 50 inches at the coast to greater than 300 inches in the interior. The calculated mean daily precipitation for the System is 217 mgd, averaging

a rainfall distribution of 3.9 mgd/sq. mi.

B. Streamflow

Major streams draining the System are the Kuia-Huuleia Streams and their tributaries. These streams begin below Kahih Mountain and flow south of Kilohana shield. Hanamaulu Stream's headwaters are in wetlands on the western flank of Kilohana and flow north of the shield.

Measurement of streamflow is complicated by the fact that water is transported into and out of the System by a series of ditches and tunnels, or simply diverted from the streams for agricultural use in the area.

C. Infiltration

Similar to the Koloa System, basal, perched and high-level dike aquifers occur in the Hanamaulu. System. Basal water occurs in the Napali lava flows. Perched aquifers are found within the Koloa Volcanics. High-level aquifers occur in the west wall of the Lihue Depression where Napali lavas and dikes are found, and in Haupu Ridge.

As indicated by streamflow data, streams in the System are spring-fed and gaining. Perched aquifers within the Koloa Volcanics continually add water to the major streams as the streams cut deeper into the Kilohana shield. Several tunnels have been driven into the Koloa VoIcanics by the Lihue Plantation Company (Tunnel 8) and the County of Kauai (Tunnel 9). They are both quite long, 1,000 feet and 1,575 feet, respectively. Macdonald and others (1960, p. 134) report that Tunnel 8, excavated in 1935, increased its flow from 0.25 mgd to 2.4 mgd during excavation to a length of 1,000 feet into a Koloa lava flow. The perching member is an underlying red clay.

Tunnel 9, constructed in three sections, attempts to intercept spring discharge that would normally enter a tributary of Huleia Stream. The perching member is a red soil layer underlying a Koloa lava flow. The altitude of the tunnel is approximately 300 feet. The tunnel has a base flow of 0.6 mgd.

Records of drilled wells indicate basal water occurs in Napali lavas in Kalepa Ridge and in a well 1.3 miles north of Hanamaulu Park. Basal water levels vary from 10 to 16 feet. Dikes intruding Kalepa Ridge may influence water levels. Recharge from Koloa Ridge probably occurs. The wells in Kalepa Ridge are sensitive to head changes, and the chloride content fluctuates accordingly.

High-level dike sources probably occur in the west wall of the Lihue Depression, but as noted by Macdonald and others (1960 p. 133), no large springs are visible. Leakage from dike compartments flowing directly into

Koloa Volcanics in contact with the Napali lavas may occur. High-level dike water in Haupu Ridge would be the same as seen in the Koloa System, that is, small bodies of water are most likely to be found in the wetter western end of the ridge.

Brackish coastal aquifers exist in sediments occurring as flood plain deposits of large streams and in the coastal plain at the base of Kalepa Ridge. These aquifers are small and are sensitive to draft. At the present time (?) they are not being utilized.

Wailua Aquifer System (20103)

Geology

The volcanic geology of the Wailua System is almost identical to the Hanamaulu System in that voluminous flows from Koloa Volcanics overlie older Napali lavas. Koloa Eruptions in this System originated from the Kilohana shield and from the Hanahanapuni shield. Napali Member lavas outcrop in high ridges radiating out from Mt. Waialeale and Makaleha Mountains.

Nonou Mountain is the northern extension of Kalepa Ridge, breached by the Wailua River, Dike intrusions cluster at the southern end of Nonou Mountain, becoming scarce to the north. Puupilo, a Napali Member outlier about a mile west of Nonou Mountain, is surrounded by Koloa lavas.

Great masses of alluvial and colluvial material are found at the base of Mt. Waialeale and the Makaleha Mountains. Much of this material is old and well-consolidated. Within the major stream valleys is younger, unconsolidated alluvium. Beach sand and alluvium occur over a wide area near Kapaa. These sediments, graded to sea level, lie on Koloa Volcanics.

Hydrology

A. Rainfall

Rainfall varies from greater than 50 inches at the coast to more than 400 inches at Mt. Waialeale. Calculated mean daily precipitation is 364 mgd. The amount of rainfall is so high that the mean distribution is 6.9 mgd/sq. mi.

B. Streamflow

Streamflow in this System is dominated by the Wailua River and its tributaries. The USGS's Water Resources Data for Hawaii and Other Pacific Areas, Water Year 1987) states that the total average discharge for the Wailua River, including ditch diversions for agriculture, is 184 mgd. Although this is about 51 percent of rainfall, much of the water that

supplies the Wailua River is groundwater leaking from perched sources within the Koloa Volcanics. High-level dike water may supply some of the flow in the upper reaches of the Wailua River system.

C. Infiltration

Geological distribution of the Koloa Volcanics and the Napali Member indicates that the bulk of the infiltration occurs in the Koloa Volcanics, even though Napali rocks outcrop in the highest rainfall areas. Infiltration into coastal sediments is small.

The Wailua System contains basal, perched, high-level dike, and brackish sedimentary aquifers. However, wells are few.

Abundant rainfall and high infiltration into the Koloa Volcanics allow for perched water bodies to drain into the Wailua River and its tributaries. Perched water occurs within permeable zones underlain by poorly-permeable lavas from Kilohana and Hanahanapuni shields contain these aquifers.

Basal water occurs in the Napali lavas in Nonou Mountain and possibly in Napali flows underlying Koloa Volcanics near the coast. Dikes in Nonou Mountain and Puu Pilo indicate that basal water is influenced by these intrusives. Macdonald and others (1960, p. 152) present a log for Well 9 which shows a head of 55 feet. This well is drilled just east of Nonou Mountain, about a mile from the coast. Although the well begins in Koloa Volcanics, the driller's log to 230 feet suggests that it ends in Napali flows. The 55-foot head could be accounted for by dikes, or by the capping feature of the Koloa rocks.

High-level dike water occurs inland at the base of Mt. Waialeale and in the Makaleha Mountains. All of the exposed dikes are associated with the Waimea Canyon Volcanics.

Unexposed dikes of Koloa Volcanics that intrude Napali lavas could influence the occurrence of high-level water at lower elevations. Some of the perched aquifers could have originated from leakage of dike water into overlying Koloa Volcanics.

Small brackish sedimentary aquifers exist in recent alluvial and beach deposits which form a coastal plain, interrupted by Koloa Volcanics, that extend from Hanamaulu to Kapaa. The amount and quality of groundwater in the sediment is unknown. However, it is assumed that these aquifers freshen considerably near the mouths of the larger streams discharging into the ocean.

Small quantities of perched are found in the larger deposits of consolidated alluvium and talus in the high rainfall regions. Most of the water probably

leaks off into tributaries of the Wailua River or infiltrates to recharge Koloa Volcanics.

Anahola Aquifer System (20104)

Geology

The volcanic geology of the Anahola System is nearly identical to previously described Systems. Rocks of the Napali Member and Koloa Volcanics cover this System to almost equal extent. The rugged Makaleha Mountains are essentially dike-free, thin-bedded Napali member lava flows which formed outside of the caldera and made up the flank of the Kauai shield.

Some of these older lavas are very weathered, producing residual and humic soils. Fluid Koloa Volcanics were erupted from vents south, east, and north of the Makaleha Mountains, and form a relatively flat lava and ash surface surrounding the high Makaleha Mountains. Koloa lava flows may be somewhat thick near the coast due to great amounts of erosion that reduced the Makaleha and Anahola Mountains.

Old and well-consolidated alluvial and colluvial material is found at the base of the Anahola Mountains. Smaller amounts of this material is seen cropping out in valleys indenting the Makaleha Mountains. Young unconsolidated alluvium is found at the mouths of major streams and at the coastal plain at Kapaa. Beach deposits are interbedded with the latter.

Hydrology

A. Rainfall

The Anahola System is drier than the other Systems in that the rainfall varies from slightly less than 50 inches to slightly more than 150 inches at the summit of Namahana Peak. Total mean daily rainfall is 197 mgd for the area. Equal distribution of the rain over the entire area is 4.0 mgd/sq. mi.

B. Infiltration

Basal, perched, and possibly high-level dike aquifers are found within the System. Lack of well data requires one to make inferences on the occurrence of groundwater by analogy with similar geological regimes.

Test Well No. 14 was drilled 496 feet into Napali lavas of the Anahola Mountains (Macdonald and others, 1960, pp. 199, 200). During drilling, water levels decreased from 252.2 feet to a final water level of 51 feet. This aquifer may be influenced by dikes intruding the lava flows. Much

of the infiltration to groundwater in the Makaleha Mountains flows seaward under the Koloa Volcanics.

Shaft No. 1 near Kapaa captures perched water in the Koloa Volcanics. This water is near sea level and could represent an unconfined basal aquifer that is supplied by leakage from either Nonou Mountain or by perched water bodies within the Koloa Volcanics, but a higher level. Undoubtedly, other perched water aquifers are found within these volcanics. Perched water is a principal resource in the Anahola. System.

Small brackish sedimentary exist in coastal regions and stream mouths. Small aquifers are also found in talus slopes and older alluvial deposits.

Kilauea Aquifer System (20105)

Geology

Except for the Namahana and Haleone parks of the Makaleha Mountains and Karnooka. Ridge which are composed of Napali Member dikes and weathered lava flows, the exposed volcanic rocks are Koloa lava flows and soils derived from them. Generally, areas of low relief are covered by the post-erosional volcanics.

A large mass of older consolidated alluvial and colluvial material is mapped between Karnooka Ridge and the Makaleha Mountains (Macdonald and others, 1960. Small deposits of recent stream alluvium are in the Kilauea Stream Valley.

Hydrology

A. Rainfall

Rainfall varies within the System from less than 75 inches at the coast to more than 150 inches at Namahana Park. Total mean precipitation for the System is 85 mgd, equivalent to 4.6 mgd/sq. mi.

B. Streamflow

Numerous small streams drain the Makaleha Mountains and meander across the flat plain of Koloa Volcanics. Many of these supply large open agricultural reservoirs. Kilauea Stream is essentially the confluence of Pohakuhonu and Halaulani streams.

The USGS long-term measurement of mean discharge for 14 years of record (1957-1972) for Pohakuhonu Stream is 5.09 mgd. Similarly, the 29-year (1959-1987) average discharge for Halaulani Stream is 7.30 mgd. Agricultural ditches divert water from Moloaa, Puu Ka Ele, and Pohakuhonu streams.

C. Infiltration

Most recharge occurs on Koloa Volcanics, though Napali Member basalt coincides with the high rainfall regime of the System.

The common groundwater aquifers in the System are perched. Koloa Volcanics in the form of lava flows and associated permeable clinker zones allow small bodies of perched water to occur. Kilauea Stream picks up much of its flow from groundwater discharging from these sources.

A basal aquifer may exist in Napali lavas buried beneath the Koloa Volcanics. It would be recharged by infiltration in the Makaleha Mountains and leakage from Koloa Volcanics at higher elevations.

Small sedimentary aquifers may be found in the alluvial and talus deposits occurring at the base of the Makaleha Mountains. Recharge is by direct runoff and rainfall.

HANALEI AQUIFER SECTOR

The Hanalei Aquifer Sector covers the northern to northwestern portion of the island. The Sector includes four Systems: Kalihiwai (20201), Hanalei (20202), Wainiha (20203), and Napali (20204). Most of the Hanalei Sector coincides with the Hanalei hydrographic area of Macdonald and others (1960) and the Hawaii Water Resources Plan (1979).

For the present study, the planimetered area of the Sector is 122.94 square miles, which is 22.4 percent of the island. The coastal boundary for the System, from west to east, begins at Polihale and ends at Kilauea Point. From Kilauea Point, the inland boundary follows the common boundaries described previously to Mt. Waialeale.

At Waialeale, the top of the Wainiha Pali escarpment separates the Hanalei Sector from the Waimea Sector. At Kilohana Peak, the Sector boundary intersects with the inferred boundary fault of the main caldera, turns southwest, and essentially follows this fault to Halemanu Stream. The Sector boundary continues to follow the top of the Waimea Canyon escarpment to the intersection of Polihale Ridge near Puu Lua, and then trends due west to the coast.

Except for the Kalihiwai System and part of the Hanalei System, the Sector is mainly devoid of Koloa Volcanics. Most of the volcanic rocks either belong to the shield-building lavas of the Napali Member or the caldera-filling lavas of the Olokele Member of the Waimea Canyon Volcanics. Intrusive dikes occur in abundance, cutting Napali lavas in the Napali System. A few dikes intrude thick Olokele flows in upper Wainiha Valley.

Weathering and subsequent stream and wave erosion have sculpted great valleys along the windward flank of the shield, and short, steep valleys along the Napali Coast. Erosion of these great valleys was furthered by the release of high-level groundwater from dike compartments. In contrast, there are long and narrow valleys on the dry leeward coast, south of Honopu Valley to Polihale.

Kalihiwai Aquifer System (20201)

Geology

Geologically, this System is similar to the Kilauea System. Volcanic rocks and their weathered soils are predominately from Koloa vents scattered throughout the System. Thin-bedded, shield-building Napali flows crop out in the Makaleha Mountains in the east wall of Kalihiwai Valley. A few east-west trending dikes cut through Napali flows that form Puu Maheu. The western ridge and boundary line is exclusively Koloa Volcanics which overlie and mantle Napali lava flows.

Intercalated between Koloa lava flows are Palikea Member breccia and conglomerate beds. These beds form extensive layers at Waihunehune Falls near the confluence of Pouli and Kaumoku streams. Palikea. Member beds are also mapped downstream interbedded with Koloa flows at Hoopouli Falls, and in the Kalihiwai streambed, directly overlying Napali flows. Thin layers of tuffaceous soil are also found intercalated with Koloa flows.

Small masses of older noncalcereous; and consolidated alluvium outcrop in streambeds. Younger unconsolidated stream alluvium occurs near the mouth of Kalihiwai River. Beach deposits occur as narrow strips along the coast and at the mouth of streams.

Hydrology

A. Rainfall

Isohyetal variation ranges from less than 75 inches at the coast to about 200 inches at the coast to about 200 inches near Hanalei Park. Mean daily rainfall for the System is calculated at 102 mgd. Distribution of rainfall per square mile is moderately high at 5.8 mgd.

B. Streamflow

The System is dominated by Kalihiwai River, and to a lesser degree by Anini Stream. USGS measurements of Kalihiwai River from 1914-1923 show a median flow of 20.67 mgd (32.0 cfs) and a 90 percentile exceedance of 11.63 mgd (18.0 cfs). The gage was located at an altitude of 700 feet and measured a drainage area of 3.64 square mile (Matsuoka, 1981, p.25).

The location of the gage placed it above the 150-inch isohyet. Calculated mean daily rainfall in this isohyetal range is 53.9 mgd. Anini Stream has not been measured.

C. Infiltration

Groundwater information for the Kalihiwai System is scarce. Macdonald and others (1960) list two County of Kauai tunnels (1 and 2) as penetrating Koloa Volcanics at elevations of 28 feet and 190 feet, respectively. These tunnels tap perched sources within the Koloa Volcanics.

Several wells (2-1126-01, 02) were drilled by the Eagle County Development of Puohenui. Well no. 2-1126-01, drilled at an elevation of 349 feet msl, is 763 feet deep. Drilling logs do not adequately describe the geological formations encountered, although Koloa Volcanics were penetrated. Perched water occurred throughout drilling, with water levels dropping as drilling progressed.

A small basal groundwater lens may occur beneath the Koloa Volcanics in Napali lavas, or possibly within the Koloa rocks near the coast. A lens may be developed in the Napali rocks that form Puu Maheu, though the dikes that intrude these rocks may form small dike reservoirs of groundwater.

Brackish groundwater within the alluvial deposits at Kalihiwai Bay is produced by infiltration and mixing of river and ocean water.

Hanalei Aquifer System (20202)

Geology

The Hanalei System is geologically more complex and diverse than Systems described previously. Hanalei River is essentially a geological contact, and effectively separates Koloa Volcanics east of the river with Napali Member and Olokele Member lava flows west of the river. Only above the Waipunanea Stream confluence with the Hanalei River are scattered Koloa Volcanic lava flows and large masses of Palikea Member conglomerates and breccia. Napali lavas crop out below Mt Waialeale and extend north between Namolokama Ridge and the river.

Macdonald and others (1960) mapped Olokele (caldera-filling lavas) flows in faulted contact with the shield-building lavas. The caldera boundary fault is inferred, though geological relationships are analogous to other less weathered Hawaiian volcanoes.

The fault trends north-northeast until Puu Ki where it swings west. Measurement of dips and strikes of lava flows on either side of the fault indicates dips of 10

degrees for Napali flows, and one to four degrees for the Olokele flows.

Olokele Member flows of the Waimea Canyon Volcanics are thick, massive lavas ponded within the caldera. The rocks consist of tholeiitic, tholeiitic olivine, and picrite basalt. Associated with Olokele rocks and the caldera boundary fault are masses of talus breccia.

Volcanic dikes with variable strikes, intrude Napali and Olokele flows. Many of the dikes exhibit cross-cutting relationships and many more dikes intrude the Napali flows than the Olokele lavas.

Hanalei River drains most of the System and cuts deeply into the shield lavas. Associated with the river are large deposits of older consolidated and younger non-consolidated alluvium. An extensive flood plain deposit of younger alluvium occurs at the mouth of the river. It covers an area of 3.30 square miles.

Waioli Stream drains below Namolokama Peak, cutting both the massive Olokele flows and Napali lavas near the coast. Extensive deposits of older alluvium and colluvium cover the bottom of Waioli Valley. Younger sediments are interbedded with those of the Hanalei flood plain.

Hydrology

A. Rainfall

Annual average rainfall for the System varies from about 80 inches at the coast to more than 400 inches at Mt. Waialeale. Mean daily rainfall for the System is calculated to be 274 mgd. Distributed evenly over the System, the 274 equals about 8.4 mgd/sq. mi.

B. Streamflow

Hanalei River dominates the drainage of the System. The USGS's stream gage is located 4.9 miles upstream from the River's mouth. Hanalei Tunnel diverts Hanalei River water and its tributary, Kaapoko Stream at a point upstream of the gage to the North Fork of the Wailua River for irrigation. Mean daily discharge of the Hanalei Tunnel over 33 years of record is 17.7 mgd (27.4 cfs) as reported by the USGS. Mean discharge (24 years) for the Hanalei River, excluding diversion of the Hanalei Tunnel, is 137 mgd (212 cfs).

Hanalei River is cut deeper into the shield than many of the adjacent streams and therefore acts as a sink so that underflow of groundwater from outside the System discharges into its channel.

Waioli Stream was gaged by the USGS from 1914-1932 (Matsuoka, 1981). Mean daily over this period was 20.2 mgd (31.3 cfs).

An approximate mean discharge for the System is 17S mgd, about 64 percent of the 274 mgd rainfall. This high percentage indicates a high component of groundwater discharge into the streams, probably from the basaltic rocks of the Napali and Olokele lava flows.

C. Infiltration

Basal and high-level aquifers within the Waimea Canyon Volcanics are the most important in the Hanalei System. As mentioned above, a tremendous discharge of groundwater occurs from Napali, and possibly Olokele flows, into Hanalei River. High-Level dike aquifers direct underflow of groundwater from outside the System into the Hanalei sink. Seaward flow of groundwater most likely occurs, creating a small truncated basal lens at or near the coast.

Perched groundwater bodies occur in the Koloa Volcanics on the east side of Hanalei River and may contribute to streamflow.

Sedimentary aquifers occur in the Hanalei River flood plain. Several alluvial welds drilled near the mouth of the river produce relatively potable water. Other more limited sedimentary aquifers may exist in the alluvial and colluvial deposits of Waioli Valley and in the extensive valley-filling sediments of the Hanalei River.

Wainiha Aquifer System (20203)

Geology

The volcanic rocks that make up this System are basaltic lava flows of the Napali and Olokele members of the Waimea Canyon Volcanics. Outcrops of Koloa Volcanics occur as small lava flows on valley floors. Olokele lavas are most abundant. The caldera boundary fault, with its associated talus breccia beds, is found several miles inland from the coast. When the fault crosses Laau Ridge, separating Lumahai and Wainiha rivers, it swings to the southwest through Kilohana Peak on the Wainiha Pali.

Many dikes outcrop in upper Wainiha Valley and along the coast to Haena. in upper Wainiha, the dikes trend southeast and west-southwest. At Haena, the trend is southwesterly. Scattered dikes and sills have been mapped, intruding the Olokele flows.

Measured dips of Napali lavas at Haena are as high as 13 degrees. A measured dip of an Olokele flow in upper Wainiha Valley is five degrees.

Koloa Volcanics in this System consist mainly of small short lava flows. Two of

the large outcrops are located at the mouths of the Lumahai and the Wainiha rivers at Wainiha Bay. Other scattered Koloa flows are associated with the palikea Member conglomerates.

An extensive deposit of older consolidated alluvium is found in the Lumahai River valley. Lumahai River appears to be a graded stream; erosion is in equilibrium with its base flow. Surprisingly, little consolidated alluvium occurs in the Wainiha River valley. Wainiha River is much steeper, and appears not to be a graded stream. Older consolidated alluvium occurs in Limahuli Stream valley. Younger non-consolidated alluvium from narrow flood plains at the mouths of Lumahai and Wainiha rivers.

Calcareous beach deposits are found from Lumahai and Limahuli Valley. These become more extensive toward Haena and Limahuli Valley.

Hydrology

A. Rainfall

Average annual rainfall varies from about 80 inches at the coast to more than 400 inches at Mt. Waialeale. Calculated mean input from precipitation for the System is 369 mgd. Equal distribution of this rainfall over the System is 9.54 mgd/sq. mi.

B. Streamflow

The USGS gaged the Lumahai River from 1914-1933. The mean daily discharge for this period was 74.29 mgd (115 cfs). Wainihia River's average daily discharge is 89.15 mgd (138 cfs) for 32 years of record (USGS, Water Data Report HI-87-1).

High-level, dike-impounded groundwater may discharge into Wainiha River's lower reaches as the valley cuts dike-intruded Napali lavas. High rainfall in the upper reaches of the Lumahai and Wainiha rivers accounts for the high mean values of measured discharge

C. Infiltration

Basaltic aquifers in the System are predominately high-level, especially in the Wainiha area. Napali lavas at Lumahai are essentially dike-free and may support a truncated basal aquifer at the coast. Northwest of Lumahai River, dike concentration increases such that any aquifer in balance with saline water would be classified dike-basal.

Aquifer storage within the Olokele lavas is unknown. Clinker zones between massive flows can store large quantities of water. However, hydraulic connections between clinker zones are limited so that these

aquifers may behave more like perched aquifers.

The small patches of Koloa Volcanics may contain small perched aquifers. Small sedimentary aquifers exist in stream-laid alluvium and flood plan sediments at Wainiha Bay. A brackish aquifer may occur in the coastal sediments at Haena.

Napali Aquifer System (20204)

Geology

The volcanic rocks which comprise the Napali System are composed entirely of Napali Member lava flows and associated dikes. The caldera boundary fault is located slightly east of the System boundary. Dikes trend predominately east-west near Kalalau Valley, and more west-northwest at Nualolo Aina Valley, south of Kalalau. No dikes have been mapped south of Makaha Valley to Polihale Ridge (Macdonald and others, 1960).

Chemical weathering and erosive forces combine to produce the most spectacular topographic features on Kauai. Thin basaltic ridges separate large amphitheater valleys typical of the northwestern part of the System. South of Honopu, valleys become longer and narrower, separated by wider interfluvial ridges.

Sediments are mostly stream-laid alluvial deposits and beach sands. The valley floor of Kalalau, like other wetter valleys north of it, is covered by older consolidated alluvium.

Hydrology

A. Rainfall

The Napali System is the driest in the Sector. Annual mean rainfall varies from less than 50 inches in the south to slightly more than 150 inches near Pihea Peak. Calculated mean input from rainfall is 112 mgd, giving an average rainfall distribution over the System as 3.32 mgd/sq. mi.

B. Streamflow

All of the stream valleys, from Hanakapiai in the north to Milolii in the south, support perennial streams. Deep erosion into the shield has intersected numerous dike compartments which discharge into the streams.

C. Infiltration

The main aquifers in the System are high-level, dike-impounded reservoirs. The major perennial streams in the System all receive a large proportion of their flow from high-level springs and seeps tapped by deep erosion of the

shield lavas. Many major springs are plotted on the geological map in association with mapped dike structures (Macdonald and others, 1960). Perched springs are also present in the upland areas bordering Kokee and the Alakai Swamp (Takasaki, 1977).

Basal water occurs in the southwestern portion of the System near the shore. The inland extent of the lens in unknown. Lack of coastal sediments, combined with low rainfall north of Polihale Ridge, suggest a thin lens, susceptible to salt intrusion.

Small sedimentary aquifers may occur in the alluvial deposits of the larger wetter valleys. Intermittent streams in the south may also possess small alluvial aquifers.

WAIMEA AQUIFER SECTOR

The Waimea Sector is essentially the central and southwestern portion of Kauai. The Sector includes the dry leeward slope and Kekaha-Mana coastal plain, the Alakai Swamp, and the canyons of Waimea, Olokele, and Hanapepe. The boundaries of the Sector are similar to the Waimea Hydrographic District of Macdonald and other (1960), except that their boundary followed Hanapepe River and ended at Awaawapuhi Valley. The Hawaii Water Resources Plan (1979) divided the Hydrographic Area into two areas. The present study divides the Sector into four Systems: Kekaha, Waimea, Makaweli, and Hanapepe. The Hanapepe System was added to better reflect natural geologic divisions within the Sector.

The planimetered area for this Sector is 197.73 square miles, 36.1 percent of the total island area. Total land area that is equal to or greater than the 50-inch isohyet is only 98.27 square miles.

The volcanic geology of the Sector is quite varied. Thin-bedded, shield building Napali Member lavas occur southwest of Waimea Canyon and south of Olokele Canyon. Massive caldera-ponded Olokele Member lavas make up the bulk of rocks cropping out in upper Waimea Canyon and Olokele Canyon.

Koloa Volcanics overlie the Napali and Makaweli members from Waimea to Hanapepe. These are mainly lava flows with minor pyroclastic deposits which erupted from vents three to four miles inland from the coast.

The Kekaha-Mana coastal plain includes interbedded marine and terrestrial sediments. This coastal plain is the largest on Kauai and behaves as a caprock wedge. Thickness varies; however, wells drilled in the central part of the plain, midway between the coast and the basalt-sediment contact, penetrated more than 200 feet of sediment (Burt, p. 10, 1979). No wells have been drilled at the coast.

Kekaha Aquifer System (20301)

Geology

Only lava flows of the Napali System outcrop in the System. These flows are similar to other shield-building Napali flows described for other Systems. Thick residual soils developed upland of the Kekaha-Mana coastal plain and support intense sugar cultivation.

Near the rim of Waimea Canyon, several small pit craters have been mapped (Macdonald and others, 1960) with their attendant massive ponded lava flows. Dikes, striking southwest, occur in some of the valleys above the Kekaha-Mana coastal plain.

Logs of wells drilled into the 17.6 square mile Kekaha-Mana coastal plain exhibit alternating layers of terrestrial (boulders, clay) and marine (coral, sand) sediments.

Well 2-0146-04 penetrated about 256 feet of sediment (Burt, 1979). Other wells encountered thinner sequences of sediment. No wells are located at the coast.

Surface sediments mapped by Macdonald and others (1960) include marly lagoonal sediments and beach dune deposits at Barking Sands and Waimea.

Hydrology

A. Rainfall

The Kekaha System is the driest on Kauai. Annual mean rainfall ranges from less than 30 inches to slightly more than 50 inches. Calculated mean contribution from precipitation is 91 mgd, equal to a distribution over the area of 2.17 mgd/sq. mi.

B. Streamflow

Streams in the System are intermittent. One of the longer gulches, Nahomalu, was gaged for nine years (1963-7 1). Over the nine-year period, no flow occurred 90 percent of the time, and a discharge of 0.26 mgd (0.4 cfs) was exceeded only 10 percent of the time (Matsuoka, 1981). Other streams are similar, only flowing during high rainfall periods. Much of this runoff is lost to the sea and cannot be utilized.

C. Infiltration

In addition to natural recharge from rainfall, the Kokee Ditch provides irrigation water to the upland cane fields overlying Napali lavas. Mean flow of the ditch (Matsuoka, 1981) is 15.63 mgd (24.2 efs). Two other ditches, the Kekaha Ditch and Waimea Ditch, divert water from Waimea

River to the System. The Kekaha Ditch, measured below Tunnel 12 (Gage No. 0270), had a mean flow of 32.2 mgd (49.9 cfs) over 27 years of record (Matsuoka, 1981). The Waimea Ditch had an 11-year (1960-71) average flow of approximately 3.0 mgd (Burt, 1979, p. 32). Much of this flow irrigates the upland fields and only some of this water reaches the coastal plain.

The major aquifer of the System is basal groundwater in the Napali lavas. About 60 Kekaha Plantation wells and shafts have been drilled to basalt to tap this resource. Burt (1979, p. 15) reports that discharge from these sources range from less than 1.4 mgd to 22.0 mgd from shafts with as little as five feet of drawdown.

Average pumpage was 24.0 mgd from 1958-1968, 42.0 mgd from 1969-1973, and 30.0 mgd from 1974-1978 (Burt, 1979). Water from these sources irrigates sugar fields on the coastal plain. Chloride content varies in depth and pumpage. The greater the depth and pumpage, the higher the chloride value. Chlorides for wells and shafts typically range from 300 to 2100 ppm.

Leakage from the basal aquifer, in addition to return irrigation water from cane fields, puts a significant proportion of water into the sediments of the coastal plain. Groundwater in this sedimentary aquifer is high in chlorides and dissolved solids. At the present time, this aquifer is not utilized.

Waimea Aquifer System (20302)

Geology

Olokele Member lavas predominate. Napali flows and dikes occur in the western wall of Waimea Canyon to the headwall of Waiahulu Stream, a tributary of Waimea River. Some Makaweli Member basalts crop out north of Kapukapaia Ridge-Waimea River junction. Associated with the faulted contact of the Makaweli-Olokele Members and the inferred Makaweli Depression graben fault are the Mokuone Breccia beds.

Overlying the Olokele Member flows near the northeast comer of the System is a Koloa Volcanics vent with extensive lava flows. Some minor vents occur near the mouth of Waimea Canyon (Macdonald and others, 1960).

Sediments in this System are confined to the young unconsolidated alluvial deposits of the Waimea River system and a relatively small flood plain at its mouth.

Hydrology

A. Rainfall

Annual rainfall varies from less than 30 inches at the coast to about 250 inches in the Alakai Swamp. Total average input of rainfall for this System is calculated at 219 mgd., providing the average distribution of the rain as 4.52 mgd/sq. mi.

B. Streamflow

Waimea River and its tributaries dominate the drainage pattern. A portion of the flow from Waimea River is diverted for sugar irrigation in Kekaha and for power generation above Stream Gage 0310. This gage measures flow from a 57.8 square mile drainage basin (including streams not planimetered in this System). Mean discharge for 46 years of record (1911-17, 1945-68, 1970-72, 1976-87) is 80.1 mgd (124 cfs). Addition of Kekaha and Waimea Ditch diversion increases average discharge to about 115 mgd. Some streamflow may originate from groundwater springflow. Olokele lavas in the Waimea Canyon region are very massive and dense and are not conducive to recharge.

C. Infiltration

A truncated basal aquifer occurs in Napali lavas on the west side of Waimea Canyon. County of Kauai Well no. 2-5840-01, drilled north of Waimea Town at an elevation of 167 feet msl, pumps water from a basal aquifer. The static head was measured at nine feet. Chlorides range from 90 to 100 ppm. The well, drilled in 1966, produces about 0.5 mgd with a drawdown of 25 feet.

High-level aquifers may be present in the dike-intruded Napali lavas beginning several miles north of Waimea Town. Small springs overflowing dike compartments are present. It is unlikely that the massive Olokele and Makaweli lavas would be conducive to groundwater development. Small perched water bodies are probably associated with these massive flows.

A small alluvial aquifer may exit in the Waimea River flood plain. Its size and water quality are unknown.

Makaweli Aquifer System (20303)

Geology

The Makaweli System is dominated by Makaweli Member lavas, and somewhat less so by Olokele Member flows. Napali lavas outcrop in the eastern portion of the System, separated by faults from the two other Members of the Waimea Canyon Volcanics. Dikes with northwest and northeast strikes are encountered in the middle reaches of Olokele Canyon where Napali Member lava flows outcrop.

Mokuone Breccia beds are exposed on the down-thrown side of the Makaweli Member cinder cones that were erupted along the fault trace.

Koloa Volcanics overlie unconformably the Makaweli and Napali lavas, extending to the coast from Makaweli Landing to Hanapepe. Numerous small isolated flows of Koloa Volcanics outcrop within Olokele Canyon.

Sediments, younger than the Mokuone Breccia deposits and consisting of consolidated alluvium, occur in Olokele Canyon, its tributaries, and smaller valleys between Waimea Town and Hanapepe. Beach deposits along this stretch of coast are few and minor.

Hydrology

A. Rainfall

Total annual rainfall for the System exhibits great variation, from less than 30 inches at the coast to more than 400 inches at Mt. Waialeale. Average daily input of rainfall is 208 mgd, equivalent to a distribution of 3.1 mgd/sq.mi.

B. Streamflow

The Makaweli River begins below the confluence of the Olokele River, Kahana Stream, and Mokuone Stream. Mean daily discharge (44 years of record) for the Makaweli River, measured near Waimea (Water Resources Data, Hawaii and Other Pacific Areas, Water Year 1987) at Stream Gage No. 0360, is 55.2 mgd (85.5 cfs).

The Olokele Ditch diverts stream water far sugar irrigation for upstream of Gage No. 0360. Pertinent data flow for the ditch, gathered by Matsuoka (1981), indicate that Gage No. 0320 (period of record 1911-1916) had an average flow of 45.3 mgd (70.2 cfs).

Downstream of this gage, a penstock divides the flow so that a majority of the water goes east in the Olokele Ditch to irrigate fields between Makaweli and Hanapepe River. About three mgd (five cfs) are also diverted just upstream of Gage no. 0360 to irrigate taro fields in the vicinity of the gage-

Some streamflow originates in tributaries that contribute to the Waimea River basin but are part of the Makaweli System. This quantity is measured by Waimea River Gage no. 0310.

C. Infiltration

Several wells and shafts have been drilled into Napali Member flows

between Waimea and Hanapepe. Two of these, Well No. 2-5534-03 and Well No. 2-5635-01 (Olokele Sugar Company, Shaft 7), encountered basal groundwater conditions. Macdonald and others (1960, p. 140) speculate that basal groundwater encountered in the Napali Member is due to the restraining of groundwater flow by the Makaweli lavas to the west, and the Koloa Volcanics which cap the Napali lavas at the coast.

Well No. 2-5534-03 was drilled in 1967 for the County, about one mile north and west of Hanapepe at an elevation of 97 feet msl. Initial static water level was about 20 feet msl with a chloride content of 44 ppm. Well depth is 109 feet of casing, the bottom 40 feet perforated. Average pumpage is 0.5 mgd with an eight-foot drawdown.

Shaft 7's portal is at an elevation of 372 feet msl and descends to a pump at an elevation of about 20 feet msl. The Shaft penetrated about 40 feet of Koloa Volcanics then enters Napali lavas. Average draft for 35 years of record is 1.54 mgd (USGS file). Chlorides normally hover about 150 ppm but rose 160 ppm in 1973 when average draft increased to 3.13 mgd that year. It is unknown from available data whether the high chloride content is due to stress of the lens or from return irrigation water. Static head is about 17.5 feet msl but draws down to approximately 14 feet when the pump is running.

Macdonald and other (1960, p.44) report that the Makaweli Member lavas are less permeable than the Napali lavas, and like Olokele lavas, would support perched springs. Small springs have been observed in a tributary of Olokele Canyon (Macdonald and others 1960, p.144). Perched springs may also occur in Mokuone Breccia beds and Koloa Volcanics in the high rainfall regions.

Small sedimentary aquifers may exist in the Makaweli River flood plain and upstream in the alluvial material laid down in Olokele Canyon.

Hanapepe Aquifer System (20304)

Geology

Most of the volcanics exposures in the System are lavas of the Napali Member. Koloa lavas overlie Napali flows in scattered, but somewhat extensive outcrops. The upper western boundary of the System is slightly west of the caldera boundary fault so that a sliver of Olokele flows occur within the System. Basaltic dikes intrude the Napali flows. The majority of these dikes strike west-southwest.

The Hanapepe River forms an extensive flood plain of consolidated and unconsolidated alluvial deposits which extend at least four miles upstream from the coast.

Hydrology

A. Rainfall

Total annual rainfall varies from less than 30 inches at Hanapepe Town to slightly less than 400 inches at the headwaters of Hanapepe River. Calculated average daily precipitation is 135 mgd; the average distribution is 6.0 mgd/sq. mi.

B. Streamflow

Determination of average daily discharge for the Hanapepe River basin is complicated by the upstream diversion of Koula (Hanapepe) Ditch for irrigation water. The mean daily discharge for 63 years of record for Hanapepe River measured at Stream Gage No. 0490 (Water Resources Data, Hawaii and other Pacific Areas. Water Year 1987) is 54.7 mgd (84.7 cfs). Discharge measurement of Hanapepe Ditch downstream of the intake for 35 years of record shows a mean discharge of 24.2 mgd (37.4 cfs).

C. Infiltration

A continuation of the basal aquifer described for the Makaweli System occurs near the coast. Water level data are not available within the Hanapepe River valley. However, a static head of about 20 feet is not unreasonable considering the location of Well No. 2-5534-03 as described above.

High-level perched aquifers of unknown extent exist within the Koloa Volcanics and unconsolidated alluvium in the Hanapepe River valley. Macdonald and others (1960, p. 145) describe Tunnel 10 as developing about 0.3 mgd of water from alluvium at an elevation of 196 feet ms1. They also conclude that high-level dike aquifers in Hanapepe are scarce or absent due to the paucity of dike structures in the Napali lavas.

A sedimentary aquifer of unknown extent occurs in the Hanapepe flood plain. No subsurface data are available.

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NIIHAU
General Geology and Hydrology

Introduction

Niihau, the second smallest island in the Hawaiian archipelago is 71.1 square miles in area. It is separated from Kauai by the 17-mile wide Kaulakahi Channel. Maximum elevation is 1281 feet msl at Paniau Peak.

Since the late 1800s the island has been used as a sheep ranch to which cattle and horses have been added. However, due to the island being in the rain shadow of Kauai, long dry periods interspersed by periods of intense rain, make ranching difficult. To supplement the ranching operation, kiawe charcoal production and helicopter tours of the island have been added.

Goats, introduced to Hawaii by Captain Cook, found their way to Niihau and quickly denuded much of the foliage. Erosion of the upland areas caused stripping of the red soil and redeposition of it into ponds and bays (Steams, 1947). Since the extermination of the goats, reforestation has taken place, but mainly with alien species. Kiawe, a known phreatophyte, has caused the drying up of springs and water holes. Wiliwili (Erythrina sandwicensis), an endemic tree grows well in the upper valleys. Grasses have been introduced primarily for range improvement.

in this report, Niihau will be considered as a single Aquifer Sector having just one Aquifer System. Due to the island's dry conditions, small amount of recharge and limited aquifers, it is convenient to consider Niihau as a single Sector.

Geologically, the island is structurally similar to other older shield volcanoes in the Hawaiian chain; that is there are flank lavas, dike-intruded lavas, post-shield lavas, and a number of post-erosional vents that erupted lava flows and tuffs. Eolian and water-laid material form an extensive sedimentary cover.

Geology and Geological History

Volcanic Geology. Hinds (1930) conducted the first real geological fieldwork on Niihau. He recognized two separate volcanic events interbedded with coral deposits, and later deposition of terrestrial sediments and eolian sand. He also considered that the eastern flank of the original shield had been down-dropped by faulting, and subsequent wave erosion created the precipitous eastern sea cliff and submarine bench. Prior to Hinds, Hitchcock (1909) described the geomorphology of the island, while Powers (1920) collected and discussed its igneous rocks.

Detailed fieldwork was conducted by Steams (1946; 1947). His work produced a detailed geological map and provided a comprehensive account of the island's geology. Macdonald (1947) described the petrography of the samples collected by

Steams and added to the descriptions of the rocks collected by Powers (1920).

Hinds (1930) and Steams (1946; 1947) recognized that Niihau has evolved through several stages of volcanic activity, erosion, and deposition of marine and terrestrial sediments by changes in sea level. The early shield-building stage produced thin fluid basaltic lava flows which poured from the northeast trending rift zone. Both pahoehoe and a'a lavas are present, all flows dipping to the southwest. Numerous dikes associated with the rift zone, ranging in thickness from 0.5 to 17 feet, intrude the shield. Associated with these dikes are several intrusive plugs which are believed to be the cores of deeply eroded post-shield cones (Macdonald and Abbott, 1970, p. 396). These shield-building lavas were named the Paniau Volcanic series by Steams (1946), and later renamed the Paniau Volcanics (Langenheim and Clague, 1987) to conform to the new North American Stratigraphic Code.

Paniau Volcanics are composed of tholeiite, olivine tholeiite, and picritic (oceanite) basalts (Macdonald, 1947; Macdonald and Abbott, 1970). Post-shield basaltic hawaiite is also present. In some regions explosive activity produced vitric ash beds up to 5 feet thick. These beds are sometimes associated with small springs (Stearns, 1947).

A long period of weathering and erosion ensued after the Niihau shield was built. Stearns (1947, p. 19) speculates that the island was much higher at that time, and therefore, wetter. Streams cut deep canyons into the shield. Accelerated erosion produced large alluvial fans which extend from the eroded volcanic uplands to far below present sea level. A wave-cut bench exists at -300 feet. Coral growth helped to create a terrace several miles wide around the main volcanic mass (Macdonald and Abbott, 1970, p. 399).

Overlying and separated from the Paniau Volcanics and alluvial fans by a profound erosional unconformity are the post-erosional Kiekie Volcanics (Langenheirn and Clague, 1987). These eruptions consist of both lava flows and tuffs. Stearns (1947) mapped 9 vents from which these effusives emanated. The lava flows are generally pahoehoe of variable vesicularity.

Sediments. The sedimentary rocks of Niihau are subdivided by Stearns (1947) into the older consolidated, Late Pleistocene deposits, and the Recent unconsolidated sediments.

Oldest are consolidated dunes of volcanic sand. These poorly permeable dunes are between 10 and 150 feet thick and outcrop in the northern coastal plain. Steams (1947) concludes these cross-bedded dunes of black and brown volcanic sand composed of basaltic glass and olivine originated from the formation of Lehua Island.

Consolidated and partly consolidated calcareous dunes occur in small patches near Keawanui Point on the west, and outcrop extensively in the south. These permeable dunes are cross-bedded and range in thickness from 10 to 150 feet. They were created when sand was blown inland when the sea was 60 feet lower than today

(Stearns, 1947).

Small outcrops of fossiliferous limestone crop out as emerged beaches and reefs. These deposits are found about +100 feet (Kaena Stand of the Sea) above sea level on Kawaihoa cone and about +25 feet (Waimanalo Stand of the Sea) above sea level on Kawaewae cone (Steams, 1947). Steams (1978, p. 11) places the Kaena Stand during the Yarmouth interglacial stage at 650,000 years ago, and the Waimanalo Stand during the Sangamon interglacial stage at 125,000 years ago.

The Recent unconsolidated sediment includes poorly-sorted boulder alluvium in the valleys giving way to soil and pebbles outcropping along the coastal plain. Talus is present at the base of cliffs, as is red lateritic soil washed down from the uplands. Other unconsolidated material includes beach sand and unconsolidated dune sand. About a dozen playa lakes are found on Niihau. The largest, Halalii, contains lacustrine beach deposits blown in by the prevailing east-northeast tradewinds, and red soil washed into the playa lake during wet periods (Steams, 1947).

General Hydrology

Rainfall. Rainfall data from Niihau is sparse and includes only a few years of record. A summary of rainfall data collected by Mr. Aylmer Robinson at Kiekie (See Steams, 1947, p. 31) is presented in Table 1. This record is for the years 1919-1925, which as stated in Steams (1947) was probably wetter than normal. Kiekie is located on the drier western (leeward) side of the island.

Table 1

Year	Rainfall (in.)
1919	17.74
1920	29.19
1921	21.62
1922	18.99
1923	36.33
1924	22.95
1925	27.06
Ave.	26.27
Std. Dev.	5.75

Steams states that Mr. Robinson thought that the average of 26 inches of rain was too great. Rainfall occurs sporadically throughout the year. December and January are months of heaviest precipitation. A convective rainfall, known locally as naulu showers, occurs when neither tradewinds nor kona weather occurs, probably during the transition months between summer and winter when climatic conditions are unsettled.

The Hawaii Water Resources Plan (1979) estimates the mean daily rainfall at 88 Mgal, or an average yearly precipitation of 26.4 inches. The Plan also identifies the maximum rainfall as 40 inches in the vicinity of Paniau though no reference is given. The Plan apparently used the data (26-inch average) given in the Steams (1947) report, even though Mr Robinson thought the amount too great.

For the present study, a mean rainfall of 20 inches is assumed for the entire island. Twenty inches is a conservative though reasonable estimate considering the lack of rainfall data. More importantly, Niihau is a low island, and is in the rain shadow of Kauai. Calculated mean yearly rainfall for Niihau translates to a daily average of 67.7 Mgal. Evenly distributed over the island, the rainfall is 0.95 Mgal/d/sq.mi.

Streamflow. There are no perennial streams on Niihau. Neither continuous nor stage records of streamflow have been collected. Niihau has about a dozen playa lakes which act as natural reservoirs that hold storm runoff. All of these lakes are shallow, and evaporation occurs quickly (Stearns, 1947). Most are barely above sea level. The two largest lakes are Halulu and Halalii. Total area of the playa lakes is 1.1 square miles (State Department of Business and Economic Development Data Book, 1987, p. 160). Assuming the average depth of the playa lakes as 2 feet, then their total storage is 4.5 billion gallons. Steams (1947, p. 5) lists 15.7 square miles of Niihau's land above the 500-foot contour. Theoretically, if all of the upland runoff from a storm is channeled into the playa lakes, then a storm of about 1.7 inches would be required to fill the lakes. If the area of contribution is about 20 square miles, which would take into account elevation below 500 feet and the 1.1 square mile water surface area, then a 1.3-inch storm would be required to fill the lakes. Obviously the depths of the lakes and runoff patterns are variable, so that the actual amount of storm runoff required may be greater or less. Stearns mentions that 8 inches fell at Kiekie in April, 1945, and when he visited Niihau in May, all playa lakes were filled with water.

Infiltration. Lack of basic hydrologic data make the estimation of infiltration difficult. Rainfall-runoff characteristics have not been established for Niihau. Factors that influence infiltration are topography, the distribution of geological units, and the presence and concentration of phreatophytes such as kiawe. An estimate can be made, however, by using the mass balance equation:

$$P = ET + RO + I$$

where P is the average rainfall, ET is the average evapotranspiration, RO is the average direct runoff, and I is average infiltration. Average infiltration can be calculated if an estimate of the other elements of the equation can be determined. If mean rainfall is equal to 20 inches/year, and employing an ET value of 73 percent of rainfall (Mink and Yuen, 1989) based on Pearl Harbor studies of Giambelluca for annual rainfall less that 55 inches/year, then a combined RO and I is 5.4 inches/year, and ET is equal to 14.6 inches/year, or 49.4 Mgal/d. In the absence of a runoff/rainfall ratio, it is assumed that 50 percent of the combined RO and I is

assignable to runoff. A mean annual infiltration of 2.7 inches or 3.3 Bgal occurs. On a daily basis this becomes 9.1 Mgal/d of recharge. Distribution of infiltration on a square mile basis is only 0.13 Mgal/d. The Hawaii Water Resources Plan (1979) calculate a recharge rate of 10 Mgal/d.

Aquifers. Steams (1947) lists a number of dug wells, water holes, and small springs on Niihau which tap several different types of aquifers. Table 2 is a summary from Stearns (1947, pp. 34-35), including only those wells and water holes that were analyzed for chloride content. His table lists 57 known water holes and wells, mapped from north to south. The chlorides listed below only present a range and were based on water samples in May, 1945, after 8 inches of rain fell during April, 1945.

Table 2

Well No.	Type of Well	Depth	Cl (ppm)	Aquifer
1	Water hole	6	142	Tuff, Lehua Is. vent
6	Water hole	3	313	Red silt
7	Dug Well	17.5	1000	Paniau Volcanics
9	Dug Well	27	626	Paniau Volcanics
11	Water hole	6	330	Beach sand
13	Dug Well	50	1420	Paniau Volcanics
14	Water hole	8	2070	Alluvium
17	Water hole	6	828	Basalt, Kiekie Volcanics
20	Water hole	4	3390	Beach sand
21	Water hole	4	540	Brown silt
23	Dug Well	15	2390	Basalt, Kiekie Volcanics
27	Water hole	5	5740	Eolianite
28	Water hole	5	2060	Basalt, Kiekie Volcanics
30	Water hole	5	5420	Laterite
31	Water hole	5	4700	Silt
32	Water hole	8	1200	Basalt, Kiekie Volcanics
33	Water hole	5	1150	Unknown
36	Water hole	5	2700	Laterite
42	Water hole	5	1810	Alluvium
44	Water hole	7	1010	Dune sand
47	Water hole	5	902	Laterite
48	Dug Well	8	81	Dune sand
49	Dug Well	8	206	Dune sand
50	Water hole	4	1610	Eolianite
51	Water hole	4	2700	Eolianite

Besides the use of water holes and wells for sources of supply, several springs are described by Steams (1947). Kalualohe Spring supplies Halulu Lake, and flows from a small cavern, over an outcrop of red soil. Steams believed the water to be of basal origin and measured a discharge rate at 10 gpm; it was too salty for cattle.

Waiokanaio Spring discharges from crevices in basalt in Waiokanaio Gulch. It is perched at an altitude of 500 feet msl. The perching member is vitric tuff cut by dikes. Discharge from the spring was measured at 1.5 gpm. According to Stearns, discharge had decreased from 2.5 gpm due to transpiration by kiawe trees nearby. Another perched spring is Kaali Spring which also discharges about 1 gpm from a vitric tuff bed. Both springs had chloride contents greater than normally expected. The higher chlorides are due to leaching of salt spray form the soil by percolating groundwater.

Steams (1947, P. 33) states that basal groundwater occurs in all formations which extend below sea level, and includes those sources listed in Table 2. As basal aquifers, he lists beach sand, calcareous dunes, alluvium, eolianite, Kiekie Volcanics, and Paniau Volcanics. Table 3 summarizes each type of aquifer.

Table 3

Aquifer Type	Remarks
Beach sand	Water quality is poor, though permeability is good.
Calcareous Dunes	Water quality is good. Dune sand is permeable.
Alluvium	Water quality and permeability are variable. Quality is poor (water bitter) near playa lakes due to salts other than NaCl.
Eolianite	Water quality is variable, becoming salty in dry weather. Permeability is good.
Kiekie Volcanics	Water quality and permeability are variable. Wells in basalt near ocean are salty due to high permeability. Marginal quality water found in laterites associated with Kiekie Volcanics. Water in tuff from Lehua Island is good, but permeability is poor.
Paniau Volcanics	Water quality marginal and permeability variable. Dense lava flows are poor producers, but clinker zones are permeable. High level dike-impounded groundwater may be an untapped supply. At the time of Stearns' (1947) report, no wells or tunnels had been attempted in the dike-intruded lavas of the Paniau Volcanics. He recommended that wells or tunnels be constructed at the heads of valleys cut into the dike zone. The quality of this source may be marginal, similar to the perched springs, because salt from sea spray is leached out of the soil and carried downward by percolating groundwater.

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MAUI
General Geology and Hydrology

The shape, topography and geology of Maui reflects the island's formation as two separate volcanoes that under today's sea level conditions are joined along the "isthmus". The older, smaller and more eroded volcanic center constitutes West Maui, while East Maui is the product of a younger, much larger and less dissected volcanic shield.

West Maui embraces two easily defined Aquifer Sectors, Wailuku and Lahaina, because of its limited extent and the consistency of its hydrogeological features, but East Maui is too large and diverse to reduce so simply. Instead it is divided into four Aquifer Sectors, the most westerly of which, the Central Sector, starts with the isthmus and extends to the northwest and southwest rift zones of the East Maui volcano centered in Haleakala. Proceeding clockwise the second Sector (Koolau) incorporates the northern slope of the volcano from Maliko Gulch to Nahiku. The third Sector (Hana) wraps around the eastern bulge of the island to Kipahulu, while the fourth (Kahikinui) embraces the steep southern slope of Haleakala from Kipahulu to Cape Kinau.

In West Maui three principal volcanic formations occur. The oldest, most widespread and hydrogeologically important is the Wailuku volcanics, which consists of primitive basalt and olivine basalt. Covering the Wailuku formation in many areas are andesitic-trachytic rocks of the Honolua volcanic series. Still later in the volcano's history the Lahaina volcanics erupted, but its distribution is limited to the vicinity of Lahaina.

In addition to the volcanic formations, alluvial deposits play an important role in controlling groundwater occurrence and behavior. The most important sedimentary formation is the "old alluvium", a moderately indurated agglomeration of clay and gravel. Unconsolidated recent alluvium is normally not important in groundwater hydrology.

The surface of East Maui is dominated by andesitic rocks of the Kula volcanic series and basaltic rocks of the Hana volcanic series, but the oldest formation on which all other for m-ations rest is the Honomanu volcanic series. Although the Honomanu is exposed over just a few square miles of gulch country, it constitutes the principal developable aquifers. It consists of basalt and olivine basalt typical of the early emissions of Hawaiian volcanos. The more viscous rocks of the Kula series were erupted toward the final construction of the main volcano. Much later, after the volcanic shield had been deeply eroded, the Hana series covered both the Kula and Honomanu volcanics.

The Honomanu series is the premier aquifer formation. The Kula is important because in places it retards the flow of groundwater while in others it acts as an aquifer. Like the Honomanu series, Hana basalts constitute excellent aquifers,

especially in the eastern portion of the island.

A thick alluvium wedge blankets West Maui below an elevation of about 800 feet from Waihee southward to Waikapu, forming a caprock and an unconformity between the volcanic rocks of East Maui and West Maui in the isthmus. Elsewhere sediments are common but are not critical in the control of groundwater accumulation and flow.

Most groundwater development sites in East Maui are in the Central Aquifer Sector, and from their records a reasonably good understanding of groundwater conditions has evolved. In the Koolau Sector few wells have been drilled; much groundwater is developed, but as low flow of streams. In the Hana Sector several deep wells have been drilled, while in the Kahikinui Sector only a few shallow wells have been attempted.

In West Maui many wells and infiltration galleries produce water for municipal and irrigation use. Most of the sites are in the Iao Aquifer System in the Wailuku Sector and Honokowai System in the Lahaina Sector. Hydrogeology and aquifer conditions are considerably better known in West than in East Maui.

MOLOKAI
General Geology

Introduction

The geology of Molokai has been studied in detail by Steams (1946) and Macdonald (1947). Since their landmark 1947 paper, subsequent geological studies have concentrated on the geochemistry and petrology of the volcanic rocks, (Beeson, 1976; Clague and others, 1982), the geochronology of the lavas (Clague and others, 1982; McDougall, 1964; Naughton and others, 1980), and the fossil bones of flightless birds (Steams, 1973).

J. D. Dana, traveling with the U.S. Exploring Expedition recognized that Molokai was formed by the coalescence of two volcanic shields (Steams and Macdonald, 1947). He postulated that the tremendous sea cliff of windward East Molokai was created by faulting. Lindgren (1903) was the first to conclude that West Molokai became extinct before East Molokai but incorrectly thought that Kalaupapa was faulted down in relation to the windward sea cliff. Powers (1920) conducted early petrological studies. He described trachyte lavas that evolved in East Molokai and recognized that the Kalaupapa peninsula is composed of volcanics younger than East Molokai.

The volcanic rock series named by Steams (1946) for West and East Molokai have been updated into the new strati-graphic acode and nomenclature (Lagenheim and Clague, 1987). West Molokai Volcanics remain undifferentiated, and the East Molokai Volcanics continue to be subdivided into the Lower and Upper members. Separated from the East Molokai Volcanics by an erosional unconformity is the Kalaupapa peninsula (Kalaupapa Volcanics). The Kalaupapa volcano is a small shield welded to East Molokai (Macdonald and Abbott, 1970). It is also believed that when eustatic sea level was low due to glaciation, the island of Molokai formed part of a large island referred to as Maui Nui (Macdonald and Abbott, 1970; Naughton and others, 1980).

West Molokai Volcanic Rocks. The West Molokai volcano is the smaller and older of Molokai's two main shields. It covers roughly about a third of the island's present landmass. Although a caldera has never been located on West Molokai (Stearns and Macdonald, 1947), and may never have existed, the presumed center of volcanic activity is about 11 miles from the center of the East Molokai caldera. A Bouger gravity map of Molokai (Moore and Krivoy, 1965) shows a region of high gravity coinciding on the ground with a series of normal faults.

The West Molokai Volcanics erupted mainly along a major east-northeast rift zone that cuts the summit area and along a minor northwest rift zone. The result is two broad structural arches, one trending southwestward and the other northwestward (Stems and Macdonald, 1947). Eruptions of thoefitic basalt compose most of the shield, with a thin cap of post shield alkalic olivine basalt and hawafite (Macdonald and Abbott, 1970). Associated with the northwest trending rift zone are 16 cinder and spatter cones and dikes outcropping in the sea cliff along the north shore. A dike

swarm parallel to the southwestward trending constructional arch outcrops at the head of Waiahewahewa Gulch.

Erosion of West Molokai by streams is slight due to its low elevation and dry conditions. East Molokai partially blocks the easterly tradewinds, further enhancing West Molokai's dry climate. Most gulches are relatively shallow and narrow. Wave erosion caused the development of a 500-foot sea cliff on the north side, but the south side of the island is minimally eroded by wave action.

Sediments. Much of the exposed sediments are calcareous deposits of wind blown sand. Strong tradewinds have created large dunes down wind of Moomomi Beach. Some of these dunes are 60 feet high and 0.5 mile wide. The deposits extend inland as much as 4 miles. Many of the dunes are unconsolidated and active. Older dunes are consolidated (Macdonald and Abbott, 1970).

A large deposit of beach sand occurs at Papohaku Beach at the west end of West Molokai. A sizeable quantity of this sand was quarried and used for construction and for supplementing Oahu's beaches.

Deep lateritic soil covers the surface of West Molokai. The presence of the soil indicates a long period of weathering with little erosion. At a lower elevation, soil was removed by wave erosion during periods of higher stands of the sea (Macdonald and Abbott, 1970).

East Molokai Volcanic Rocks. East Molokai encompasses about two-thirds of the island and is for the most part inaccessible. East Molokai is an evolved shield which progressed through the shield-building and caldera-filling stages of development before undergoing a period of quiescence and renewed post-shield volcanic activity. Much later, post-erosional volcanics erupted at Mokuhooniki Island and at Kalaupapa (Macdonald and Abbott, 1970).

East Molokai was formed along two principal rift zones extending from the caldera (Stearns and Macdonald, 1947). One of them trends west-northwest while the other strikes eastward. The former caldera is located in the Pelekunu-Wailau region. Exposures of fault breccia and hydrothermally altered rocks outline the extent of the caldera as being 4.5 miles long and 1.5 miles wide (Steams and Macdonald, 1947). Within the south wall of Olokui Peak masses of intrusive gabbro are exposed in Wailau Valley. Vitric tuff beds also are associated with the caldera-filling lavas and act as perching members for large springs which discharge into Pelekunu Valley (Macdonald and Abbott, 1970). Abundant rainfall, aided by geologic structure carved out the great windward valleys of East Molokai. Release of high level groundwater by erosion accelerated down-cutting by streams.

The 4000-foot high sea cliff which truncates the northern side of East Molokai is the result of wave erosion. Anomalous dipping lavas seen along the coast near Wailau

and Waikolu Valleys are the result of minor faulting. This faulting is not at all related to the formation of the sea cliff as was once previously thought (Lindgren, 1903).

Post erosional activity took place after much of East Molokai was dissected by stream and wave erosion. The small tuff cone of Mokuhooniki erupted off the eastern end of the island. Kalaupapa shield volcano erupted about a million years after the cessation of East Molokai Volcanics. The lavas which erupted from Kalaupapa were very fluid alkalic olivine basalts (Macdonald and Abbott, 1970). The summit crater, Kauhako, is 450 feet deep and contains a pool of brackish water.

Sediments. Windward valleys of East Molokai are alluviated with boulders and cobbles of basalt. The beaches tend to be formed of boulders and basaltic sand. On the lee side of East Molokai, soil washed from the volcanic slopes have produced extensive mud flats. Deposition of mud was greatly accelerated by the introduction of hooved animals and the subsequent destruction of upland forests. The terrestrial sediments overlie and have killed near shore coral reefs. Other fringing reefs occur farther offshore. Fossiliferous coral deposits outcrop 25 and 100 feet above sea level east of Kaunakakai (Macdonald and Abbott, 1970).

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LANAI
General Geology and Hydrology

The geology of Lanai was effectively described by Steams (1940), and all subsequent geological discussions have leaned heavily on his work. The island is a volcanic dome whose focus of eruptive activity, the caldera, collapsed to form Palawai Basin. Volcanic activity was restricted to the effusion of primitive basalt, the first stage in an eruptive history. No secondary flows followed, and pyroclastic activity leading to cinder, ash and tuff deposition was neither extensive nor voluminous.

The only major geological rock unit is the Lanai basalt. Sedimentary accumulations produced by erosion of the dormant volcano lie chiefly in the lower reaches of valleys and in the Palawai depression. Marine sands in protected locations along the coast form attractive beaches.

Three rift zones radiate from the caldera, the principal one to the northwest and subsidiary ones to the south and southwest. Dikes are associated with the rift zones and Stearns identified at least 275 of them. Faulting occurred along the margin of the caldera, but most traces are difficult to detect. Suggestions have been offered that the faults may be responsible for impounding water at high elevations. Nowhere else in Hawaii has this been demonstrated, however; the likely cause of high level water tables is containment of groundwater in small aquifers bounded by dikes.

The surface and subsurface rocks of the island are permeable to infiltration to such a degree that surface runoff infrequently reaches the sea. No perennial streams exist on Lanai. Weak springs caused by local perching conditions exist in gulches leeward of the crest and perhaps at one time were more productive than now, but they were never reliable enough to serve as a water supply. In windward Lanai in upper Mauanalei Gulch perennial springs flowed but eventually were diverted by tunnels. Under pre-development conditions Maunalei Stream flow may have reached the sea for appreciable periods each year.

The simple geology of Lanai is reflected in the occurrence of its water resources. Potential surface water supplies are virtually absent because of the perviousness of the rocks, while fresh to brackish groundwater underlies the whole island. Fortunately, subsurface complexities in the caldera and rift zones provide an environment for the accumulation of high level groundwater. Aquifers of normal basaltic lava lying between poorly permeable dikes and other equally dense caldera rocks contain fresh water to elevations in excess of 1500 feet. The extent of the favorable conditions is limited to less than 25 square miles, about one sixth of the island. Recent exploratory drilling has encountered warm, somewhat brackish water at the periphery of the fresh high level water zone.

The remainder of the island is underlain with brackish basal water in a thin lens. Salinity is generally too high for the basal water to be useful for agriculture.

KAHOOLAWE
General Geology and Hydrology

The island of Kahoolawe is the smallest of the main Hawaiian Islands. This 45 square mile island is roughly 11 miles long, 6 miles wide, and triangular in shape. Kahoolawe has always been a dry island. Periodic burning by the Hawaiians and the introduction of goats and sheep by early explorers helped cause much of the island's vegetation to be destroyed. Prior to the Second World War, Kahoolawe Ranch Company leased the island for ranching purposes and, according to Steams (1940), made strides in reclaiming the land. Kiawe (Prosopsis chilensis), a known phreatophyte, was introduced to Kahoolawe in the early 1900's as a reforestation effort.

During World War II, the U. S. Navy took over control of Kahoolawe for use as a bombing target range. The island has remained a bombing range ever since. Starting in the late 1970's, pressure by the "Protect Kahoolawe Ohana" and the State government has caused the Navy to open the island for limited public use. Much of Kahoolawe has been cleared of ordnance, and erosion control and new reforestation have begun.

The "Protect Kahoolawe Ohana," the State, the U. S. Navy, and the U. S. Geological Survey are beginning to reexamine the island's water resources. Much of the data collected is in preliminary form and not available.

In this report, Kahoolawe will be considered as one Aquifer Sector having a single Aquifer System. Geologically, the island is structurally similar to other shield volcanoes in the Hawaiian chain; that is there are flank lavas, dike-intruded rift zone lavas, and ponded caldera flows. Due to the island's dry conditions, small amount of recharge, and limited aquifer, it is convenient to consider Kahoolawe as a single Aquifer Sector.

Geology and Geological History

Volcanic Geology. Steams (1940), who did the first geological field work, provided a sound interpretation of Kahoolawe's geology. The island is similar to other shield volcanoes within the Hawaiian archipelago, and like neighboring Lanai, it is a single volcanic edifice. Macdonald and Abbott (1970, p. 318) consider Kahoolawe to part of the Maui Nui volcanic complex, which consists of 6 major and one minor volcanoes. Shallow seas separate Kahoolawe from Maui and Lanai, which, in turn, are similarly separated from Molokai. The Maui Nui complex may have existed as a large island during lower sea level stands. Bathymetry south of Kahoolawe exhibits a steep slope, about 10 degrees (Mark and Moore, 1987), which drops rapidly to depths greater than 11,000 feet within 10 miles from shore (Fornari and Campbell, 1987).

Stearns (1940) recognized that Kahoolawe evolved through several stages of volcanic activity. Though the island's eruptive center is located at its eastern end, the

island is skewed to the southwest due to volcanic eruptions which occurred along this rift zone. A reconnaissance Bouger anomaly map of Kahoolawe (Furumoto, 1965) clearly defines the caldera region of the east and the rift zone of the southern half of the island as an area of greater gravity. The higher Bouger anomaly suggests that dense rock associated with the rift lies beneath Waikahalulu Bay in the southwest. Surface expression of the rift zone is Kealialalo and Kamama vents north of Waikahalulu Bay. Dikes have been mapped in Ahupu Gulch (G. Bauer, unpublished data) north of the island's topographic divide. These dikes average 2.5 feet in width.

All volcanic rocks on Kahoolawe have been mapped as the Kanapou Volcanics (Langenheirn and Clague, 1987), known previously as the Kanapou Volcanic Series (Steams, 1940). The shield-building stage consists of tholeiitic thin-bedded fluid pahoehoe and massive a'a flows that mainly outcrop in the southern sea cliffs and where stream and wave erosion have cut deep enough to expose them. The central crater expanded to form a caldera roughly 3 miles in diameter. Kanapou Bay on the eastern end of the island is eroded deeply into thick and massive caldera-filling tholeiitic lava flows.

Erosion has also exposed the caldera boundary faults on the north and south ends of Kanapou Bay. Shield-building lavas rest unconformably adjacent to flat-lying caldera lavas. About 40 dikes, trending east-west and averaging less than two feet thick crop out at the north end of Kanapou Bay. These dikes form the major east rift zone. Steams (1940) also pointed out that Kahoolawe's northern end juts out farther from the island's east-west axis than the south side and speculated that cones of Kealialuna and Kolekole were erupted along this northern rift.

Steams (1940) concluded that as the caldera was filling up, the small shields of Kealialuna and Kolekole were being formed to the north. After the caldera filled, there was a period of quiescence followed by renewed activity. Lava shields and explosive pyroclastic cones dot the summit region and the southwest rift zone. Most of the lava is tholeiitic, but some vents trend toward alkalic composition (Fodor and others, 1987). Renewed post-erosional activity which occurred within Kanapou Bay is evidenced by tuff cones and a dike intruding talus. These post-erosional vents are also tholeiitic.

Wind erosion, in combination with the loss of vegetation by burning, goats, and sheep, has caused much of Kahoolawe's soil cover to be transported. A significant portion of the soil has been simply washed away or blown out to sea. Near the summit of the island only small patches of soil remain. Much of the surface is a weathered hard pan. Soil that has not blown off the island lies downwind of the summit, forming a dust cap (Steams, 1940). Sheet runoff has also effectively removed soil from the summit region. Some transported soil occurs at lower elevations either in the gulches or as a soil matrix between cobble and boulder rubble.

Stream erosion has carved straight steep-sided gulches into the flanks of the volcano. Topographic relief is usually less than several hundred feet. Badland geomorphology is prevalent near Lua Makika, the island's summit. Commonly the

highly weathered basalt erodes into chasms 20 to 30 feet deep but only several feet across. In some cases the canyons have coalesced into larger depressions which contain scattered boulders of spheroidally weathered basalt and ventifacts. Blow-out structures are common on the flanks of Lua Makika.

Sediments. Sediments consist mainly of beach and dune deposits. Strong and prevalent easterly winds cause large dunes of sand and soil to occur in the southwest comer of Kanapou Bay. The beach is almost a quarter mile wide, and some of the dunes are nearly 20 feet high. Large coral sand and coral rubble beaches are found in the southwestem-westem portion of the island. Beachrock is also common at these beaches.

All large valleys which cut into the northern and western flanks of the volcano terminate with beaches consisting of coral and basaltic sand mixed with soil washed from the uplands. Olivine sand beaches are common between Hakioawa and Ahupu gulches.

Hydrology

Rainfall. Rainfall data from Kahoolawe is sparse and includes only a few complete years of record. Recently, in conjunction with the "Protect Kahoolawe Ohana," the U. S. Geological Survey installed a recording raingage near Hakioawa (K. Takasaki, per comm., 1989). Its purpose is to increase the sparse data base.

Table 1 presents rainfall records collected by Eben Low from 1904 to 1917. The gages were located on the windward and summit areas of the island. No gages were located lee of the island's axis or at the western end. Mean, standard deviation and correlation of rainfall between each station are calculated and listed.

Table 1

Year	(1) Kuheia Coast	(2) Kealialuna Moderate Elev	(3) Kealialalo S.W. Rift	(4) Moaula Near Summit
1905	13.15*	---	---	---
1912	7.44	8.23	5.33	10.24
1913	16.60	16.42	11.80	18.34
1914	12.17	13.31	9.93	12.39
1915	10.93*	9.80*	7.57*	12.85*
1917	11.44	13.60	7.60	20.78
Mean	11.96	12.27	8.45	14.92
S.D.	2.99	3.26	2.48	4.43

Correlations: 1,4: 0.61; 2,4: 0.75; 3,4: 0.44
1,2: 0.93; 1,3: 0.96; 2,3: 0.90

*--Estimated from 9 months' record.

Table I shows that the best correlation of rainfall occurs between gages at low and moderate elevation. Presumably, it was these gages which collected both tradewind rainfall from the northeast and kona rainfall. All gages correlated poorly with the Moaula gage near the summit. Kealialuna, however, did correlate the best since it is upwind and northeast of Moaula. Standard deviation was the greatest at the Moaula gage. Greater variability of rainfall at Moaula could be in part due to its location near the summit, and to the high wind velocity at this location. Stearns (1940) noted that maximum rainfall at any one of these gages for the years of 1923, 1936, 1937, and 1938 were 18 inches, 23 inches, 27.5 inches and 24.5 inches respectively.

For the present study, a mean total rainfall of 20 inches is assumed for the entire island. Twenty inches is reasonable considering, first, the lack of data from Kahoolawe, and second, that three of the years reported by Steams (1940) are above 20 inches. Calculated yearly mean contribution of rain equate to a daily average of 42.8 Mgal. Average areal distribution is 0.95 Mgal/d/sq.mi. The Hawaii Water Resources Plan (1979) assigns a total daily rainfall input of 40 Mgal, and shows a maximum isohyet of 25 inches at Lua Makika.

Streamflow. There are no stream flow data available for Kahoolawe. Recently, the U. S. Geological Survey in conjunction with the "Protect Kahoolawe Ohana," set up a recording gage in Hakiowa Gulch (K. TakasakL per. comm., 1989). It is hoped that this gage, and the recording rain gage, will provide data to better determine rainfall-runoff characteristics. The Hawaii Water Resources Plan (1979) gives the total

runoff at 18 percent of rainfall or 7 Mgal/d.

There are no perennial streams on Kahoolawe. Runoff from infrequent rain storms is flashy. Lack of vegetation and soil near Lua Makika, Kahoolawe's summit, exacerbates runoff. The clay-rich hardpan is the uppermost surface of saprolite and is not conducive to infiltration. It becomes even more impermeable as the surface clays swell with the sudden addition of water. Gullies and canyons draining the eastern end of the island are steep-sided and deep in contrast to the broad short gulches at the western end.

As shown in Steams (1940, Figure 26), much of the soil from the eastern "dust bowl" has become an eolian soil "dust cap" at the western end. Runoff characteristics are also different in that the greater amount of soil and attendant increase in vegetation do not allow for rapid runoff. During severe storms, sheet flow is common. Pools of water persist for days within the gullies as bank storage replenishes the water that evaporated.

Infiltration. Lack of basic hydrologic data make the estimation of infiltration difficult. Rainfall-runoff characteristics vary from east to west. The presence of hardpan, soil cover, slightly weathered lava surfaces, and the concentration of the phreatophyte, kiawe, vary widely over the island. All of these factors affect the amount of infiltration that occurs. However, an estimate can be made using the mass balance equation:

$$P = ET + RO + I$$

Where P is average rainfall, ET is average evapotranspiration, RO is average runoff, and I is average infiltration. Average infiltration can be calculated if an estimate of the other elements of the equation can be determined. If mean rainfall is equal to 20 inches/year, and employing an ET value of 73 percent of rainfall (Mink, Chang, and Yuen, 1989), then the combined RO and I is equal to 5.4 inches/year, and ET is equal to 14.6 inches/year. Assuming that 50 percent of the combined RO and I would equal the runoff, mean annual infiltration of 2.7 inches occurs. This translates to a daily recharge rate of 5.8 Mgal/d. Infiltration on a square mile basis is only 0.13 Mgal/d. The Hawaii Water Resources Plan (1979) calculates a recharge of 3 Mgal/d.

Aquifers. Resistivity measurements by G. R. MacCarthy are reported in Steams (1940). Four stations on the island's eastern half were measured. His results indicate that there is a thin Ghyben-Herzberg lens underlying this region, as water levels between 0.5-1.5 feet above sea level were reported. MacCarthy's data seem to indicate that dikes within the rift zone do not seem to affect groundwater levels; however, the paucity of data make this conclusion tenuous. Other factors that could contribute to low water levels within the dike zone are the small number (40) of dikes reported by Steams (1940) cropping out at Kanapou Bay, only 4 dikes in Ahupu Gulch (G. Bauer, unpublished data), and very low recharge. The parallelism and spacing between dikes could allow groundwater to leak out and intrusion of sea water to easily occur. The actual geometrical extent of the lens is also unknown.

Small seeps were observed in the sea cliff above Kanapou Bay (Steams, 1940; G.

Bauer, per. comm., 1989). Flows from these seeps were measured at less than 0.5 gpm. Stearns (1940) reported that one seep discharged at 230 feet msl, just above a dike.

G. Bauer sampled water on May 3, 1983 from a large bomb crater near Hanakanaia Bay know as "Sailor's Hat." The assumption was that if basal water leaked into the crater it would be visible at low tide. The resulting chloride value was 20,300 ppm. High evaporation created brine conditions which obliterated any hint of fresher water that may have seeped into the crater.

Apparently the Hawaiians and the ranch made use of alluvial water and storm runoff stored in cisterns. According to Steams (1940), at the turn of the century 50 inhabitants could obtain potable water from alluvial wells in some of the windward gulches. From 1919 on, however, potable supplies diminished. He attributes the degradation of the resource to kiawe transpiring groundwater that had previously supplied these wells. At the time, Stearns visited the island two dug alluvial existed and five others were filled in. The alluvial well at Hakioawa still exists. A sample collected by Steams (1940) in 1939 produced a chloride concentration of 12,600 ppm. G. Bauer (per. comm., 1989) collected a sample from the Hakioawa well July 7, 1982 which had a chloride value of 10,300 ppm. Water quality within the alluvial aquifers is sensitive to seasonal variations in rainfall.

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APPENDIX B

SUSTAINABLE YIELDS

SUSTAINABLE YIELD
Explanation of Column Headings

Sector: In the Aquifer Classification, the Sector is the largest subdivision within an island. It encompasses a region having hydrogeological similarities, but its aquifers are not necessarily hydraulically continuous.

System: Aquifer Systems are subsets of Sectors. Normally aquifers within a System are hydraulically connected. Water balances are computed for each- System.

Code: The Aquifer Code is an identifier in which the first number refers to the island, the following two numbers to the Aquifer Sector and the last two numbers to the Aquifer System.

A(sg.mi): The Aquifer System area in square miles.

P(in/yr): Weighted average annual rainfall in the System in inches per year. Rainfall is taken from the DLNR isohyetal maps, which generally are representative, but where the rainfall gradient is steep or distorted the weighted averages may diverge appreciably from actual conditions. This phenomenon is evident particularly where stream runoff exceeds basin rainfall. Part of the discrepancy results from groundwater contributions to a stream from outside the topographic boundaries of the drainage basin, but much is attributable to generalizing the isohyets.

RO(in/yr): Average total stream flow in inches per year for an Aquifer System. The average is derived from correlation between recorded average stream flows and average rainfall within the System, or other Systems with similar environments, then extrapolated to the entire System at its weighted average rainfall. Correlations between average rainfall and average runoff are not very good but nevertheless are the only reasonable estimators for working water balances on a System scale. The correlations assume a power (log-log) relationship between average runoff and average rainfall. The empirical equation has the form:

$$RO = aP^n$$

in which a and n are constants.

ET(in/yr): Actual loss of water to the atmosphere by evapotranspiration from a natural, vegetated surface is difficult to establish accurately, but good estimates have been made for Hawaiian conditions. In high rainfall areas, which usually are in the mountains, potential evapotranspiration is suppressed by cloud cover and temperature, while in the sunny lowlands it is limited by lack of available soil moisture. In environments having 55 inches or more rain per year the average evapotranspiration is estimated as 40 inches per year. This value is based on work of Ekern in the Koolau Range of Oahu and Giambelluca in the high rainfall region of southern Oahu. For averages less than 55 inches per year, evapotranspiration is taken as 73 percent of rainfall, an estimate based on Giarnbelluca's water budget for the Pearl Harbor region. No matter how small the annual average rainfall, not

all is lost to evapotranspiration. A portion goes to surface runoff and some infiltrates to the saturated zone.

I(in/yr): The difference between average rainfall and the combination of average runoff and evapotranspiration is infiltration to groundwater. For all Aquifer Systems this column is calculated employing data in the previous columns. The following column, I(mgd), is not always calculated from I(in/yr).

I(mgd): Infiltration reported as mgd. In some cases an estimate other than the one that would follow from the previous column is given. These few cases are restricted to Oahu and Maui where more detailed water budgets have been calculated.

SY(mgd): Sustainable yield is derived for the steady state relationship among head, infiltration and net draft, which is equivalent to sustainable yield. The infiltration value is given in the I(mgd) column. The calculated sustainable yield assumes that all groundwater is pumped from basal aquifers seaward of the high level zone except where high level water approaches the coast. The relationship is:

$$D/I = 1 - \{h(e)/h(0)\}^2$$

in which D is allowable draft (sustainable yield), I is infiltration, h(0) is initial head and h(e) is the equilibrium head.

Assigning a value for 1, the controlling variable in the equation is h(e). This head is selected to preserve the quality of water produced at the steady state. Where the initial head was low, the ratio h(e)/h(0) must be high and the ratio D/I small. The head ratio used to obtain sustainable yield is based on experience with known aquifers, such as those of Honolulu and southern Oahu. The sustainable yields are calculated from the following:

h(0) Range(ft)	h(e)/h(0)	D/I
4 – 10	.75	.44
11 - 15	.70	.51
16 – 20	.65	.58
21 – 25	.60	.64
>26 and HL	.55	.75

h(0): Initial head before the start of groundwater development. The head refers to a specific location, and h(e) is specified for that location. Many initial heads are estimated because of absence of information.

KAUAI
Estimated Sustainable Yields by Aquifer System

Sector	System	Code	A(sq.mi)	P(in/yr)	RO(in/yr)	ET(in/yr)	I(in/yr)	I(mgd)	SY(mgd)	h(0)
Lihue	Koloa	20101	50.72	73	9	40	24	56	30	15
Lihue	Hanamaulu	20102	55.22	83	13	40	30	79	40	15
Lihue	Waialua	20103	52.46	146	59	40	47	117	60	15
Lihue	Anahola	20104	49.89	83	13	40	30	71	36	15
Lihue	Kilauea	20105	18.63	96	19	40	37	33	17	15
		Total:	226.92					359	183	
Hanalei	Kalihiwai	20201	17.69	121	36	40	45	38	16	20
Hanalei	Hanalei	20202	32.81	176	97	40	39	61	35	20
Hanalei	Wainiha	20203	38.69	200	137	40	23	42	24	20
Hanalei	Napali	20204	33.75	70	8	40	22	35	20	20
		Total:	122.94					176	95	
Waimea	Kekaha	20301	59.22	33	1	24	8	23	12	10
Waimea	Waimea	20302	48.40	95	19	40	36	83	42	10
Waimea	Makaweli	20303	67.76	65	7	40	18	58	30	10
Waimea	Hanapepe	20304	22.35	127	41	40	46	50	26	10
		Total:	197.73					214	110	
		Total	547.59					749	388	

OAHU
Estimated Sustainable Yields by Aquifer System

Sector	System	Code	A(sq.mi)	P(in/yr)	RO(in/yr)	ET(in/yr)	I(in/yr)	I(mgd)	SY(mgd)	h(0)
Honolulu	Palolo	30101	4.43	82	16	40	26	6	5	38
Honolulu	Nuuanu	30102	8.62	101	25	40	36	20	15	42
Honolulu	Kalihi	30103	6.33	90	20	40	30	12	9	40
Honolulu	Moanalua	30104	10.92	79	9	40	30	24	18	38
Honolulu	Waialae	30105	18.77	50	5	37	8	6	3	7
		Total:	49.07					68	50	
Pearl Harbor	Waimalu	30201	32.10	89	13	40	36	63	45	35
Pearl Harbor	Waiawa	30202	34.97	101	15	40	46	73	52	35
Pearl Harbor	Waipahu	30203	25.75	39	3	29	7	70	50	35
Pearl Harbor	Ewa	30204	19.08	29	2	21	6	6	3	20
Pearl Harbor	Kunia	30205	9.02	46	3	34	11	16	8	25
		Total:	120.92					228	158	
Central	Wahiawa	30501	68.87	100	18	40	42	138	104	HL
		Total:	68.87					138	104	
Waianae	Nanakuli	30301	4.67	31	1	23	8	2	1	HL
Waianae	Lualualei	30302	13.86	36	2	27	8	5	4	HL
Waianae	Waianae	30303	7.66	38	2	28	8	3	2	HL
Waianae	Makaha	30304	8.09	41	2	31	9	4	3	HL
Waianae	Keaau	30305	11.33	39	2	29	9	5	4	HL
		Total:	45.61					19	14	
North	Mokuleia	30401	33.22	46	3	34	10	16	9	15
North	Waialua	30402	17.19	45	3	33	9	8	5	15
North	Kawailoa	30403	35.69	85	12	40	33	56	32	15
		Total:	86.10					80	46	
Windward	Koolauloa	30601	32.57	107	21	40	46	71	42	15
Windward	Kahana	30602	16.24	141	65	40	37	29	15	12
Windward	Koolaupoko	30603	27.22	97	26	40	31	40	30	HL
Windward	Waimanalo	30604	19.60	69	11	40	18	17	13	HL
		Total:	95.63					157	100	
		Total	466.20					690	472	

MOLOKAI
Estimated Sustainable Yields by Aquifer System

Sector	System	Code	A(sq.mi)	P(in/yr)	RO(in/yr)	ET(in/yr)	I(in/yr)	I(mgd)	SY(mgd)	h(0)
West	Kaluakoi	40101	44.6	22	1	16	5	7	2	2
West	Punakou	40102	35.2	17	1	12	4	6	2	2
		Total:	79.8					13	4	
Central	Hoolehua	40201	13.8	29	1	21	7	4	2	4
Central	Maunawainui	40202	24.6	18	1	13	4	5	2	4
Central	Kualapuu	40203	18.2	39	2	29	8	9	7	10
		Total:	56.6					18	11	
Southeast	Kamiloloa	40301	17.2	35	2	26	7	7	3	5
Southeast	Kawela	40302	23.7	48	3	35	10	11	5	5
Southeast	Ualapue	40303	17.7	69	7	40	22	18	8	5
Southeast	Waialua	40304	14.9	75	9	40	26	19	8	5
		Total:	73.5					55	24	
Northeast	Kalaupapa	40401	4.5	45	3	33	9	3	2	HL
Northeast	Kahanui	40402	5.5	60	5	40	15	4	3	HL
Northeast	Waikolu	40403	4.5	85	18	40	27	6	5	HL
Northeast	Haupu	40404	2.6	83	17	40	26	3	2	HL
Northeast	Pelekunu	40405	7.4	99	27	40	32	12	9	HL
Northeast	Wailau	40406	13.3	98	26	40	32	20	15	HL
Northeast	Halawa	40407	13.9	66	10	40	16	10	8	HL
		Total:	51.7					58	44	
		Total	261.6					144	83	

MAUI
Estimated Sustainable Yields by Aquifer System

Sector	System	Code	A(sq.mi)	P(in/yr)	RO(in/yr)	ET(in/yr)	I(in/yr)	I(mgd)	SY(mgd)	h(0)
Wailuku	Waikapu	60101	135.53	43	3	31	9	6	2	4
Wailuku	Iao	60102	17.81	97	39	40	18	15	20	28
Wailuku	Waihee	60103	11.87	111	50	40	21	12	8	11
Wailuku	Kahakuloa	60104	10.22	96	33	40	23	11	8	10
		Total:	53.43					44	38	
Lahaina	Honokohau	60201	13.23	128	61	40	27	17	10	15
Lahaina	Honolua	60202	17.61	87	24	40	23	19	8	7
Lahaina	Honokowai	60203	22.67	63	11	40	12	13	8	7
Lahaina	Launiupoko	60204	18.29	75	17	40	18	16	8	6
Lahaina	Olowalu	60205	6.81	63	11	40	12	4	3	5
Lahaina	Ukumehame		10.61	50	7	36	7	4	3	5
		Total:	89.22					73	40	
Central	Kahului	60301	9.54	20	1	15	4	2	1	5
Central	Paia	60302	60.73	27	1	19	6	17	8	7
Central	Makawao	6030	52.93	38	3	28	6	15	7	7
Central	Kamaole	60304	89.22	28	2	20	6	25	11	7
		Total:	212.42					59	27	
Koolau	Haiku	60401	35.71	96	20	40	36	61	31	10
Koolau	Honopou	60402	18.87	144	36	40	68	57	29	10
Koolau	Waikamoi	60403	26.08	180	67	40	73	91	46	10
Koolau	Keanae	60404	55.56	185	74	40	71	188	96	10
		Total:	135.16					397	202	
Hana	Kuhiwa	60501	13.14	257	167	40	50	31	16	10
Hana	Kawaipapa	60502	32.60	170	60	40	70	109	48	5
Hana	Waihoi	60503	15.18	158	51	40	67	40	20	10
Hana	Kipahulu	60504	30.22	148	41	40	67	96	49	10
		Total:	91.14					276	133	
Kahikinui	Kaupo	60601	20.73	89	13	40	36	36	18	7
Kahikinui	Nakula	60602	30.94	47	2	34	11	16	7	5
Kahikinui	Lualailua	60603	68.11	38	2	28	8	26	11	5
		Total:	119.78					78	36	
		Total	701.15					927	476	

HAWAII
Estimated Sustainable Yields by Aquifer System

Sector	System	Code	A(sq.mi)	P(in/yr)	RO(in/yr)	ET(in/yr)	I(in/yr)	I(mgd)	SY(mgd)	h(0)
Kohala	Hawi	80101	56.95	68	5	40	23	62	27	5
Kohala	Waimanu	80102	69.95	144	60	40	44	147	110	HL
Kohala	Mahukona	80103	113.91	25	1	17	7	38	17	4
		Total:	240.81					247	154	
E.MaunaKea	Honokaa	80201	105.82	57	3	40	17	71	31	5
E.MaunaKea	Paauilo	80202	150.16	64	5	40	19	136	60	5
E.MaunaKea	Hakalau	80203	166.72	143	60	40	43	341	150	7
E.MaunaKea	Onomea	80204	180.35	157	79	40	39	335	147	7
		Total:	603.05					883	388	
W.MaunaKea	Waimea	80301	282.14	18	1	13	4	54	24	5
		Total:	282.14					54	24	
9										
NE.MaunaLoa	Hilo	80401	193.73	134	8	40	86	793	347	7
NE.MaunaLoa	Keaau	80402	207.27	140	9	40	91	898	393	7
		Total:	401.00					1,691	740	
SE.MaunaLoa	Olaa	80501	129.51	88	2	40	46	284	124	7
SE.MaunaLoa	Kapapala	80502	83.50	47	1	35	11	44	19	7
SE.MaunaLoa	Naalehu	80503	352.00	60	4	40	16	268	117	5
SE.MaunaLoa	Ka Lae	80504	134.77	44	1	32	11	71	31	4
		Total:	699.78					667	291	
SW.MaunaLoa	Manuka	80601	167.26	49	1	36	12	96	42	4
SW.MaunaLoa	Kaapuna	80602	241.76	42	1	31	10	115	50	4
SW.MaunaLoa	Kealakekua	80603	226.75	33	1	24	8	86	38	4
		Total:	635.77					297	130	
NW.MaunaLoa	Anaehoomalu	80701	291.01	23	1	17	5	69	30	5
		Total:	291.01					69	30	
Kilauea	Pahoa	80801	222.00	144	10	40	94	994	435	7
Kilauea	Kalapana	80802	193.36	81	2	40	39	359	157	5
Kilauea	Hilina	80803	59.24	29	1	21	7	20	9	5
Kilauea	Keaiwa	80804	89.99	38	1	28	9	39	17	4
		Total:	564.59					1,412	618	
Hualalai	Keauhou	80901	166.72	45	1	33	11	87	38	5
Hualalai	Kiholo	80902	146.22	25	1	18	6	42	18	5
		Total:	312.94					129	56	
		Total	4,031.09					5,449	2,431	

APPENDIX C

STREAM DATA

STREAM DATA

Explanation of Column Headings

Column	Explanation
Stream	Name of watercourse. Name followed by D means Ditch.
A(sq.mi)	Area of drainage basin in square miles. Ditches are not given drainage areas.
El(ft)	Elevation above sea level of the measuring site in feet.
Div.	States whether a stream is diverted (Y) or not (N) and receives input (I) from elsewhere.
Record	Gives the years of continuous flow measurements. The latest year is 1979 because the data were extracted from the formatted statistical data base on file at the US Geological Survey.
Q(90)	The 90 percentile exceedance flow. The given value is equaled or exceeded 90 percent of the time.
Q(50)	The 50 percentile exceedance flow, identical to the median flow. The given value is equaled or exceeded 50 percent of the time.
Q(av.)	The average daily flow.
14d Low	The lowest average flow for any consecutive run of 14 days in the period of record.

Island of Kauai
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Lawai	6.62	37	Y	62-73	.8	3.0	8.3	.34
Koloa D.		620	D	64-71	5.3	15	21.3	1.3
Koloa Tunnel		386	D	66-71	4.4	9.3	16	3.1
Kamooloa	5.79	340	Y,I	63-71	.1	.6	15	.04
Kamooloa			D	39-41				
Upper haiku D.		470	D	63-71	.1	6.9	9.0	0
Lower Haiku D.		400	D	63-71	1.1	3.3	8.1	.51
Kuia	5.09	393	Y,I	63-66	.4	3.5	17	.4
Kuia	.40	1050	N	39-41				
Waiahi-Kuia Aqdt.		730	D	64.71	0	2.1	6.4	0
Huleia	17.6	260	Y,I	12-16,67-71	5.3	10	32	4
Hanamaulu		420	D	10-20	8.6	32	29.6	0
Hanamaulu	6.41	90	N	11-13			13.7	
Lihue		550	D	10-19	.2	9.2	9.5	0
S. F. Wailua	22.44	240	Y	11-79	4.6	36	116	1.9
S. F. Wailua	20.2	550	Y	74-				
N. Wailua D.		1106	D	32-79	14	19	18.8	.07
N. Wailua D.		1070	D	65-79	18	24	24.0	11
Stable D.		710	D	36-79	0	.3	10.6	0
N. F. Wailua	5.29	650	Y,I	14-79	3.5	50	73.1	.49
Kanaha		540	D	10-55	.2	2.4	7.39	0
N. F. Wailua	14.6	480	Y	10-14			87	
E. Br. N. F. Wailua	6.27	500	N	12-79	17	32	48.2	8.6
Aahoaka D.		400	D	66-72	0	0	.01	0
N. F. Wailua	17.9	18	Y,I	52-79	8.4	73	127	2.4
Uhau Iole	1.00	760	N	12-13				
Keahua	1.58	750	N	12-13				
Kawi	.81	750	N	12-13				
Wailua		462	D	36-79	.6	14	15.0	0
Left Br. Opaekaa	.65	750	N	60-79	.6	1.8	2.61	.12
Wailua	52.6	0		62-				
Kapaa D.			D	09-11				
Konohiki	3.38	30	Y	64-				
Konohiki	.65	458	N	11-13			1.0	
Konohiki	.89	230	Y	12-12			0.7	
Kaehulua	1.90	50	Y	11-13				
N. F. Kaehulua	1.39	110	Y	11-13				
S. F. Kaehulua	.04	150	Y	11-13				
Makaleha D.		518	D	36-79	.2	7.3	6.73	0
Kapaa	3.05	470	Y	10-20	15	27	35	12
Kapahi D.		377	D	09-79	.2	4.5	6.33	0
Tunnel D.			D	09-11				
Pipe D.			D	09-11				
Kapaa	3.86	382	Y	36-79	0	5.9	20.3	0
Kapaa	14.0	15	N	62-				
Kapahi D. & Kapaa			D	36-79	3.7	13	24.7	2.2
Akulikuli	.42	340	Y	64-				
Akulikuli Spring		350	S	11-13			1.6	
Kaneha			D	09-13			10.8	

Island of Kauai
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Homaikawaa	.88	55	N	64-				
Anahola	1.29	1140	N	12-13				
Anahola D.			D	15-21				
Anahola D.		8.25	D	36-79	0	.5	4.51	0
Anahola D.		8.22	D	21-79	0	2.9	4.16	0
Anahola	4.27	295	N	10-79	4.5	9.7	22.4	2.2
Lower Anahola D.		290	D	09-14			8	
Lwr. Anahola D.		276	D	36-79	0	2.7	3.06	0
Lwr. Anahola D.			D	09-10				
Anahola	4.27	295	Y	10-12				
Anahola	9.24	0	Y	65-79	5.9	15	34.2	3.5
Ka Loko D.		750	D	32-68	1.9	3.8	5.27	.93
Puu Ka Ele D.		426	D	32-67	0	3.4	3.88	0
Ross D.		341	D	56-67	1.3	3.1	3.6	.01
Kalihiwai D.		413	D	60-68	2.5	4.3	6.2	1.9
Kalihiwai D.		409	D	34-67	.3	2.8	3.46	0
Pohakuhonu	1.73	402	Y	57-72	1.6	3.5	7.89	.79
Halaulani	.12	900	N	22-25	1.7	2.7	4.4	1.19
Halaulani	1.90	392	N	57-79	4.5	7.2	11.4	2.9
Kalihiwai	3.64	700	N	14-23	18	32	4.9	11
Puukumu	.91	210	N	64-				
Kalihiwai	4.12	550	N	12-13				
Hanalei D.		388	D	56-62	0	0	3.5	0
Hanalei Tunnel		1210	D	32-79	2.4		27.4	0
Hanalei	7.17	625	Y	14-55	19	49	77.0	12
Hanalei Str. & Tun.	7.17	625	N	32-55	43	68	96.6	34
China D.		70	D	11-20	14	29	17.6	.37
Hanalei	19.1	36	Y	12-79	61	130	238	34
Kuna D.	21.0	50	D	12-19			26	
Hanalei			Y	62-				
Waioli	1.81	550	N	14-33	11	20	31.3	8.5
Lumahai	6.95	700	N	14-33	37	67	115	25
Lumahai	13.0		N	12-13				
Wainiha	10.2	960	N	52-79	49	79	138	36
Wainiha	11.6	850	N	14-16			6.9	
Wainiha Cannal				10-16				
Wainiha C.				11-12				
Wainiha C.				11-12				
Wainiha	20.6	70	N	12-16			8.8	
Hanakapiai	2.73	450	N	31-52	4.7	8.4	17.0	2.6
Hanakoa	.50	470	N	31-52	.7	1.8	5.62	.33
Kalalau	1.55	960	N	31-55	3.7	5.2	7.01	2.8
Kokee D.		3310	D	26-79	6.3	20	24.2	.21
Nahomalu	3.81	237	N	62-71	0	0	.41	0
Hoea	7.58	29	N	62-64				
Kawaikoi	3.95	3420	N	07-79	4.3	13	34.1	1.5
Waiakoali	1.58	3490	N	09-25	1.3	3.5	8.3	.70
Kauaikinana	.84	3440	N	19-25	.7	2.2	5.4	.31
Mohihi	1.68	3420	N	20-71	.8	3.0	8.53	.05

Island of Kauai
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Mohihi	2.20	3400	N	09-10				
Kekaha D.			D	09-68	37	55	55.7	0
Kekaha D.			D	10-12				
Kekaha D.			D	10-12				
Kekaha D.		470	D	08-34	32	51	49.9	.48
Waimea	20.0	840	Y	16-68	13	19	51.9	9.7
Koaie	1.68	3770	N	19-68	2.9	8.2	28.4	1.19
Koaie	9.97	850	N	15-71				
Waialae	1.79	3820	N	20-79	2.6	6.7	22.1	1.3
Waialae	2.81	3500	N	10-16	3.9	9.9	19	2.2
Waialae	7.87	800	N	16-21	6.7	16	32	5.4
Waimea	86.5		Y	43-				
Waimea	57.8	25	Y	10-79	1.7	15	128	0
Waimea	44.2	490	Y	21-56	.1	1.4	77.1	0
Waimea D.			D	11-21	.3	5.2		0
Waimea D.		131	D	60-71	.1	3.6	3.91	0
Waimea & Makaweli	83.8		Y	45-68	15	50	221	8.3
Mokihana	4.83		N	62-				
Olokele	4.85	1500	Y	15-16				
Olokele D.		1450	D	10-17	46	66	70.4	27
Olokele D.		1250	D	09-17	48	64	64	44
Halekua	.56	4000	N	12-14				
Makaweli	26.0	18	Y	43-79	12	29	87.2	6.8
Makaweli	25.9	30	Y	11-17	8.9	23	110	6.4
Poowaiomahaihai D.			D	11-13				
Hiloa D.		700	D	11-15	25	37	34	16
Koula	12.6	300	Y	10-16	14	34	70	11
Koula	6.45		Y	11-13				
E. F. Koula	2.74		Y	11-15				
Hanapepe	18.5	222	Y	17-79	15	32	86.4	8.0
Hanapepe	20.5	500	Y	29-32				
Hanapepe	26.6		Y	49-				
Hanapepe D.		550	D	11-15			13	
Hanapepe D.		500	D	30-38	31	44	43	2.8
Hanapepe D.		490	D	10-49	25	39	37.4	0
Hanapepe D.		450	D	29-32			32	
Hanapepe D.		450	D	12-17			33	
G. Ditch		50	D	29-35			0.8	
Manuahi	5.44	250	N	17-20			13	

Island of Oahu
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Moanalua	.94	660		69-78	0	0		0
Moanalua	.62	700		69-78				
Moanalua	2.73	338	N	26-78	0	0	3.12	0
Kalihi	.60	820	N	67-71	.1	.4		.08
Kalihi	2.61	464	N	14-79	1.	3.0	6.68	.15
Kalihi	5.18	70	N	62-79	1.2	3.9	10.8	.55
Moole				18-23	0	.1		0
Nuuanu	3.35	632	Y	14-79	.9	3.7	7.05	.16
Waihi	1.14	290	Y	13-79	.5	1.7	3.60	.10
E. Manoa				15-39	.4	1.0	1.08	
Waiakeakua	1.06	295	Y	13-79	1.7	3.6	4.86	.79
Manoa	4.99	100	Y	09-18	1.3	7.1		.37
Pukele	1.18	345	N	26-79	.3	.8	1.94	.11
Waiomao	1.04	374	Y	11-71	.1	.5	1.86	0
Palolo	3.63	95	Y	52-79	.6	1.8	5.64	.24
Kaukonahua	1.38	1150	N	13-79	1.7	7.7	16.5	.20
Kaukonahua	1.17	1200	N	13-53	1.2	4.9	11.3	.31
Mauka				47-68	.1	3.8	4.05	0
Kaukonahua	4.86	930	Y	47-68	1.9	13	35.3	0
Kaukonahua	1.93	1070	N	11-57	.8	5.7	12.5	.09
Kaukonahua	4.04	860	Y	57-79	2.0	8.8	21.1	0
Kaukonahua	.86	980	Y	57-72	0	.3	2.16	0
Kaukonahua	5.26	845	Y	47-58	2.3	13	25.2	.68
Poamoho				58-79	0	1.0	4.85	0
Poamoho	1.79	1150	Y	47-74	.1	1.5	4.25	0
Poamoho	1.79		N	58-74	.7	3.1	9.34	.07
Kipapa	4.29	690	N	57-79	.3	2.4	10.5	0
Kipapa	13.8	90	Y	67-68				
Waikele	45.70	1	Y	51-79	12	25	41.3	2.7
Waiawa	26.40	2		52-79	3.7	7.3	32.1	2.3
Waimalu	5.97	10		52-71	.4	1.3	8.28	.15
Kalauao	2.59	12	Y	57-79	0	.2	2.82	0
Kalauao	2.61	4	Y	53-57	1.0	4.9		.8
N. Halawa	3.45	320	N	29-33 & 53-79	0	.3	5.67	0
Halawa	8.78	17	Y	53-62	1.1	3.8		0
Pearl H. Spr.				31-64	11	19	17.3	2.1
Pearl H. Spr.				31-48	4.3	5.5	5.70	3.9
Pearl H. Spr.				31-45 & 52-26	2.0	3.7	3.46	0
Pearl H. Spr.				31-43 & 52-54	1.8	28		.39
HEC Tunnel				40-46 & 52-67	15	17	16.3	11
Pearl H. Spr.				31-47	7.1	12.5	11.4	5.1
Pearl H. Spr.				31-65	17	25	24.4	13
Makaha	2.31	939	N	59-79	.1	.5	1.94	0
Kaupuni	3.58	374	Y	60-73	0	.3	1.16	0
Puea				60-67	.3	.5		.26
Punawai	.60	600	Y	31-44	.1	.2	.38	.03
Helemano	14.20	2	Y	68-79	0	.2	10.8	0
Opaeula	2.98	1120	N	59-79	.9	4.3	13.3	.04
Opaeula	5.96	18	Y					

Island of Oahu
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Kamananui	9.79	20	N	58-79	.2	3.7	16.1	0
Kamananui	3.13	590	N	63-79			10.5	0
Kaiwikoele	.97	700	N	68-71	0	0		0
Punaluu				53-79	.2	5.8	8.29	0
Punaluu	2.78	212	Y	53-79	1.4	12	16.8	0
Punaluu	2.78			53-67	15	21	2635	12
Kaluanui	1.11	110	N	67-79	.3	1.3	3.80	0
Koloa	.90	500	N	14-18	.4	2.0		.23
Kahawainui	.53	500	N	14-18				
Malaekahana	.64	450	N	63-71	.1	.3		0
Malaekahana	.69	440	N	14-18	.01	.05		0
Kahana	3.74	30	Y	59-79	15	23	35.2	12
Kamooalii	3.21	118	N	67-76	4.2	7.3		3.6
Kamooalii	3.81	116	Y	77-79	4.0	6.4		3.7
Kamooalii	4.38	39	Y	59-79	6.0	11	14.0	4.2
Luluku	.44	220	Y	67-71	.9	1.6		.69
Ahlo				14-16	6.3	8.9		4.7
Haiku	.97	272	Y	14-78	.8	1.6	2.71	.3
Iolekaa	.29	320	Y	40-70	.3	.5	.67	.16
Kahaluu	.28	358	Y	36-71	.2	.8	2.01	.07
Kahaluu	3.73	0	Y	67-69	4.0	7.7		2.8
Waihee SF	.03	616	Y	62-79	1.0	1.8	1.77	.48
Waihee NF	.03	639	Y	62-79	1.3	1.8	1.81	.78
Waihee	.31	259	Y	61-66	3.1	4.3		2.6
Waihee	.93	143	Y	36-79	3.1	7.4	7.99	1.0
Waihee	.97	170	Y	75-79	2.7	4.1		
Waihee	2.26	1	Y	67-71	9.9	13		8.5
Waiahole T				51-69	30	39	39.9	26
Waiahole WW				51-69	0	0	2.32	0
Waiahole NP				51-69	31	42	41.7	2.8
Waiahole ADIT 8				51-69	36	50	49.6	12
Waiahole	1.22	160	N	11-16	21	42		18
Waiahole	.99	250	Y	55-68	3.3	5.2	9.5	2.4
Waikane	2.22	75	Y	60-79	2.1	4.1	8.37	1.3
Waimanalo	2.16	19	Y	67-71	.6	1.7		.39
Maunawili				54-68	.5	2.8	2.55	0
Makawao	2.04	80	Y	13-79	1.3	2.6	4.94	.69
Maunawili	5.34	10	Y	67-71	4.4	8.7		3.8

Island of Molokai
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Kakaako	.55	1020	N	63-72				0
Keolewa	.18	1950	N	40-44				.02
Waialala				40-60	.01	.03	.02	0
Mokomoko	.23	2200	Y	40-48	.03	.17		0
Kapuna	.18	1900	N	40-50	0	0		0
Kaunakakai	6.57	240	I	50-79				0
EF Kawela	.45	3625	Y	47-71	0	.4		0
Punaula	.24	1200	N	47-72	.1	.4	1.25	.03
Papio	.94	640	Y	63-79	0	.1		0
Halawa	4.62	210	N	17-74	5.1	14	29.3	.91
Papalaua	2.00	100	N	20-24	3.5	10		1.9
Pulena	4.38	591	N	20-57	9.0	20	34.9	5.8
Waiakeakua	1.41	698	N	20-57	4.4	7.6	11.7	2.7
Kapuhi	1.20	870	N	68-70	2.5	3.8		2.0
Kawainui	1.18	770	N	68-79	1.7	4.9	8.25	1.1
Pelekunu	2.59	552	N	20-79	4.6	9.3	16.4	2.5
Pilipililau	.49	1000	N	69-79	.6	.9	1.37	.52
Lanipuni	1.09	418	N	20-57	4.6	8.3	14.4	2.5
Molokai T E			CN	66-79	.1	2.1		0
Molokai T W			CN	65-79	2.8	4.5		22
Waikolu	1.99	900	Y	56-79	.7	2.8		.18
Waikolu	2.99	650	N	20-23	5.1	8.9		4.9
Waikolu	3.68	252	Y	19-79	6.3	12		2.8

Island of Maui
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Waiehu	.70	870	Y	11-17				
Waihee				13-17				
Makamakaole	.40	1500	Y	39-52	.9	1.7	2.92	.72
Kahakuloa	3.47	330	N	39-79	5.4	8.9	16.8	3.4
Waikapu				11-17	3.7	6.8		2.7
Palolo				11-17	2.4	3.4		.89
Honokohau	4.11	870	N	13-79	14	24	39.2	8.9
Honokohau				07-13	23.4	36.6		19
Honolua	2.90	840		13-17	1.1	5.0		.62
Honokowai				12-67	4.4	6.9	8.94	2.9
Honokowai	1.10	1440	Y	11-17	.3	1.3		.32
Kahoma				11-17	3.1	4.4		2.6
Kahoma	1.19	1940	Y	12-17	.08	6.2		0
Kanaha	1.51	1057	N	16-32	3.3	5.0	7.66	2.4
Kanaha	1.83	540	Y	11-16	.8	1.6		.64
Kahoma	5.22	90	Y	63-79	0	0	3.19	0
Kauaula	1.84	1550	N	14-17				
Kauaula				12-17	6.2	9.5		5.6
Launiupoko	1.13	1280	Y	11-17	.8	1.6		.77
Olowalu				11-67	3.8	6.6	7.46	1.0
Olowalu	4.08	130	Y	63-73	0	0	3.70	0
Ukumehame	3.75	410	N	11-20	5.0	8.1		4.4
Kauhikoa				10-29	.1	10	24.7	0
Awalau	.23	2260		65-71	.2	2.7		.1
Kulanihakoi	14.4	35	N	63-70	0	0		0
Makapipi				48-66	1.9	4.1	4.45	.79
W. Makapipi				32-45	0	.9	1.05	0
Makapipi	1.93	920	Y	32-45	0	3.1	10.2	0
Hanawi	3.49	1318	N	14-79	2.9	7.2	22.5	1.5
Hanawi	5.03	500	Y	32-47	17	21	42.0	13
Kapaula	.69	1346	N	22-63	4.8	5.3	16.6	.45
Kapaula	.93	540	Y	32-47	2.0	2.8	11.6	
Koolau				00-79	11	28	34.0	0
Waiaaka	.10	650	Y	32-47	.6	.9	1.24	.49
Paakea	.34	650	Y	32-47	3.3	4.2	6.46	2.9
Waiohue	.32	1316	N	22-63	3.6	6.7	11.5	2.2
Kopiliula	4.31	1292	N	14-58	3.3	9.1	27.7	1.4
E. Wailuaiki	3.11	1329	N	14-58	3.9	10.3	30.6	2.0
W. Wailuaiki	3.66	1343	N	14-79	3.5	11	34.9	1.0
W. Wailuaiki	1.93	1268	N	14-58	1.6	5.2	14.5	.56
E. Wailuaiki	.51	1287	N	14-58	1.3	3.8	8.65	.50
Wailuanui	2.51	620	Y	32-47	.5	1.4	13.5	.27
Taro Feed D.				34-68	2.5	3.5	3.55	0
Koolau				10-19	31	87	101	0
Honomanu	2.54	2900	N	20-69	.5	2.1	12.7	.14
Honomanu	3.17	1733	N	14-64	1.7	6.2	22.8	.24
Kula D., Haipuaena				45-79	.1	.4	.7	.01
Haipuaena	.27	4320	Y	46-68	0	0	.86	0
Haipuaena	.63	2860	Y	19-35	.6	1.8	5.62	.2

Island of Maui
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Haipuaena				38-60	1.3	2.7	3.05	.09
Haipuaena	1.16	1512	Y	14-67	1.1	5.4	14.9	.15
Spreckels				22-79	3.1	16	23.5	.17
Koolau				32-79	37	93	116	0
Manuel Luis				18-79	.4	2.0	8.13	.03
Puohokamoa	.14	2800	N	20-33	.4	.9		.11
Puohokamoa	.48	2900	Y	19-69	.3	1.4	3.84	.07
Puokamoa	.45	2800	Y	19-35	.6	1.7	5.47	.09
Puohokamoa	2.35	1322	Y	13-72	3.7	14	33.1	1.0
Koolau				22-30	41	110		13
Spreckels				28-39	.1	1.5		0
Manuel Luis				30-35	.6	2.3		.33
Waikamoi	2.10	5750	N	50-67	0	0		0
Waikamoi	2.50	4487	N	53-68	0	.1	2.05	0
Waikamoi	3.46	3000	Y	18-35	.7	2.3	12.2	.2
Waikamoi	.07	3020	Y	18-33	.5	1.5		.31
Waikamoi	3.93	1294	Y	22-58	2.0	8	25.3	.33
Waikamoi	3.98	1150	Y	11-22	2.2	9.3	28.2	.63
Alo	.47	1248	N	11-58	1.0	3.1	7.39	.27
Center				18-30	2.4	9.6	21.1	.81
Kaaiea	.58	1310	N	22-62	.9	2.9	6.83	.43
Spreckels				18-30	.3	2.3	8.92	.08
Oopuola	.20	1205	N	30-58	.3	1.2	2.69	.12
Oopuola	.58	960	Y	11-15	.8	2.5		.53
Nailiihaele	3.49	1205	Y	11-75	5.8	17	37.5	2.1
Kailua	.80	3080	N	18-35	.08	.5	6.31	0
Kailua	1.10	2840	N	63-71	.2	1.1		.05
Kailua	2.41	1253	N	13-58	2.7	9.8	29.2	.15
Hoolawanui	1.34	1219	N	11-72	1.7	5.6	12.0	.46
Hoolawaliilii	.55	1245	N	12-58	2.2	4.4	7.55	.84
Honopou	.64	1208	N	11-79	.8	2.5	4.65	.15
Wailoa				23-79	69	170	171	3.6
Hamakua				18-79	.5	4.9	36.2	0
Hamakua				18-65	0	.1	2.78	0
Hanapou	2.00	557	Y	32-47	.1	.2	1.97	.09
Lowrie				10-79	4.6	28	37.3	0
Honopau	2.20	441	Y	32-47	.4	.7	2.37	.15
Haiku				10-79	.6	4.7	24.9	0
Honopou	2.30	383	Y	32-47	.6	1.2	7.8	.1
Hamakua				12-23	36	84	77	22
Halehaku	.13	2610	N	65-71	.1	.5		.05
Opana				65-79	.3	2.0	3.05	.12
Kapuni	1.19	740	N	63-72	0	0		0
Kukui	.76	90	N	63-68	.3	1.5		.07
Palikea	6.29	1546	N	27-79	.1	5.4	57.3	0
Hahalawe	.43	885	N	27-69	1.4	3.2	5.54	.43
Kaeleu				40-45				
Hana				41-45				

Island of Hawaii
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Kawainui	1.58	4.60	N	64-79	.6	4.3	14.0	.02
Kawaiki	.45	4090	N	68-79	.3	1.7	4.04	.05
Hamakua				64-79	.7	4.8	7.91	.08
Hamakua				68-79	0	3.2	5.70	0
Hamakua				75-79	.6	6.6		0
Hamakua				78-79	0	.1		0
Kehena				18-66	.5	5.6	11.5	0
Alakahi	.87	3900	Y	64-79	.6	3.1	6.53	.04
Wailoa	143	150	Y	64-69	42	51		38
Hamakua				64-73	0	0		0
Hamakua				64-73	35	46		25
Hamakua				64-73	36	47	29	66
Honokaa				64-73	13	16		5.5
Hamakua				64-73	17	24		8.0
Waiilikahi	.76	2740	N	39-60	1.1	4.3	10.1	.35
Kaimu	.90	1980	N	39-52	.7	3.2		.32
Punalulu	.66	1870	N	39-52	.5	2.4	6.37	.16
Waiaalala	.12	1880	N	39-52	.3	.6	1.09	.17
Paopao	.32	1910	N	39-52	.3	1.1	3.35	.21
Kukui	.22	1940	N	39-66	.4	.9	1.95	.17
Awini				28-72	4.3	16	17.6	0
Awini				07-17 & 63-72	4.2	18	18.7	0
Honokane Iki				28-72	.1	.9	1.70	0
Honokane Nui	4.96	1080	Y	63-69	17	21		15
Kohala				63-72	20	33		0
Kohala				27-72	23	38	40.8	.05
Kohala				13-20	20	36		
Kohakoha	2.51	3273	Y	56-79	.01	1.9	8.47	0
Keanuiomano	4.30	2410	Y	64-72	0	1.3		0
Waikoloa	.78	3570	N	47-71	1.9	4	7.14	.86
Waikoloa	1.18	3460	Y	47-79	1.9	4.2	8.68	.78
Pohakupuka	2.76	250	N	62-79	2.1	7.7	27.1	.37
Manowaiopae	1.04	900	Y	65-72	.9	3.4		.16
Honolii	8.0	2350	N	24-32	2.0	13		62
Honolii	11.6	1540	N	11-79	12	38	125	2.3
Alia	.58	489	N	62-72	5.6	12		1.5
Waiakea	17.40	1934	N	31-79	1.7	8.9	11.9	0
Waiakea	33.6	369	Y	57-67	0	.01		0
Olaa		1970		75-79	3.6	10		1.4
Olaa				58-66	0	0		0
Wailuku	10.2	6840	N	64-66				
Wailuku	34.8	4250	N	65-79	.01	.24	2.83	0
Wailuku	43.4	3520	N	67-79	.4	2.9	27.6	0
Wailuku	97.2	1280	Y	23-40	3.1	26.7	101	0
Wailuku	230	1070	Y	28-79	14.3	83.8	286	.44
Wailuku	256	80	Y	77-79	19	160		9.9
Hilo Bd. Sch.				32-46	11.5	14.5	14.2	2.3
Kapehu	4.84	950	Y	29-37	7.7	28.3		2.3
Kapehu				54-62	0	2.8		0

Island of Hawaii
Stream Flow Data (cfs)

Stream	A(sq.mi)	El(ft)	Div.	Record	Q(90)	Q(50)	Q(av.)	14d Low
Kapehu				38-62	.1	2.7	2.27	0
Ninole	1505	2080	N	66-79	0	0	3.91	0
Paauau	1.74	972	N	62-79	0	0	.76	0
Waiaha	1.89	3280	N	60-79	0	0	.31	0
Waiaha	8.74	2580	Y	60-71			.95	0
Waiaha	9.35	1910	Y	58-68	0	0	1.16	0
Kiilae	.67	2898	N	58-79	0	0	.21	0
Hilea	9.17	2940	N	66-79	0	1.2	8.69	0
Hilea	1.86	2880	N	66-79	0	0	3.00	0
Hauani	.47	3117	Y	56-79	.1	.4	1.50	0

APPENDIX D

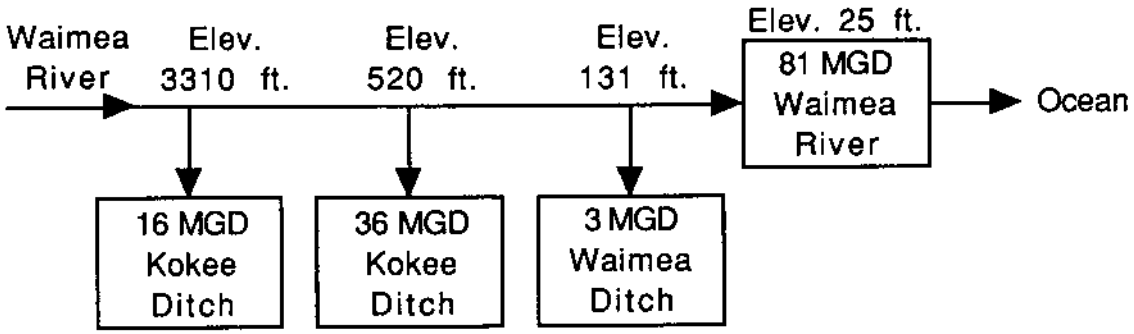
MAJOR STREAM DIVERSIONS

KAUAI

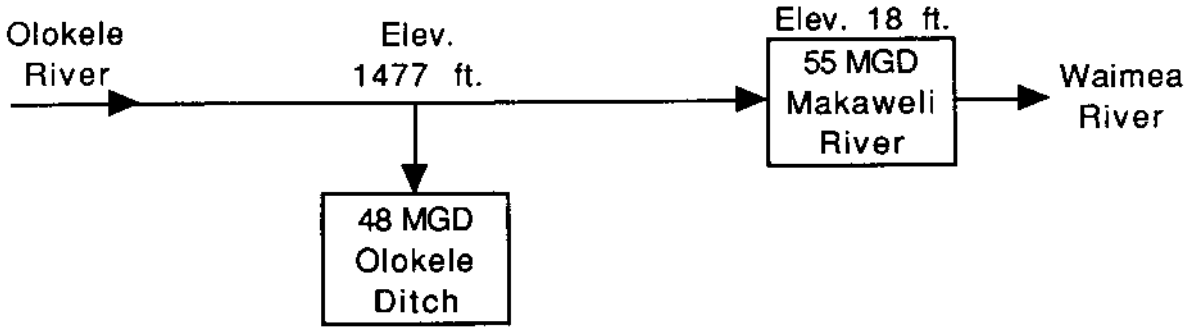
Major Stream Diversions

Indicated Flows Are Averages

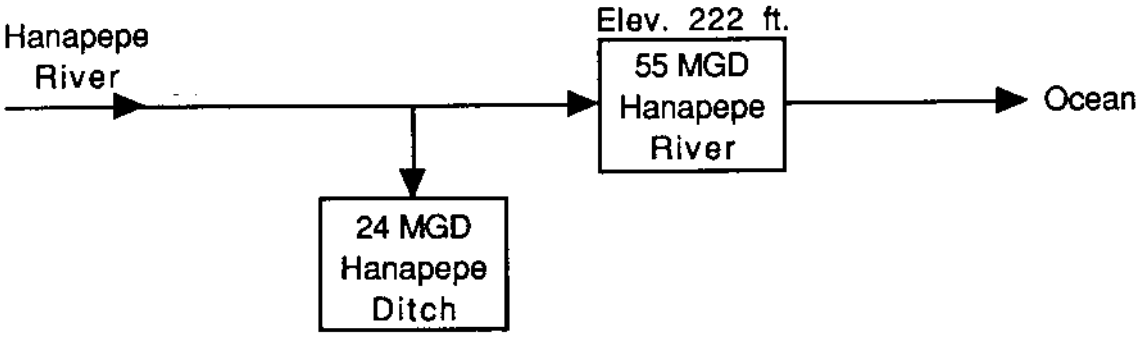
Waimea River Drainage: Waimea Aquifer System



Makaweli River Drainage: Makaweli Aquifer System



Hanapepe River Drainage: Hanapepe Aquifer System

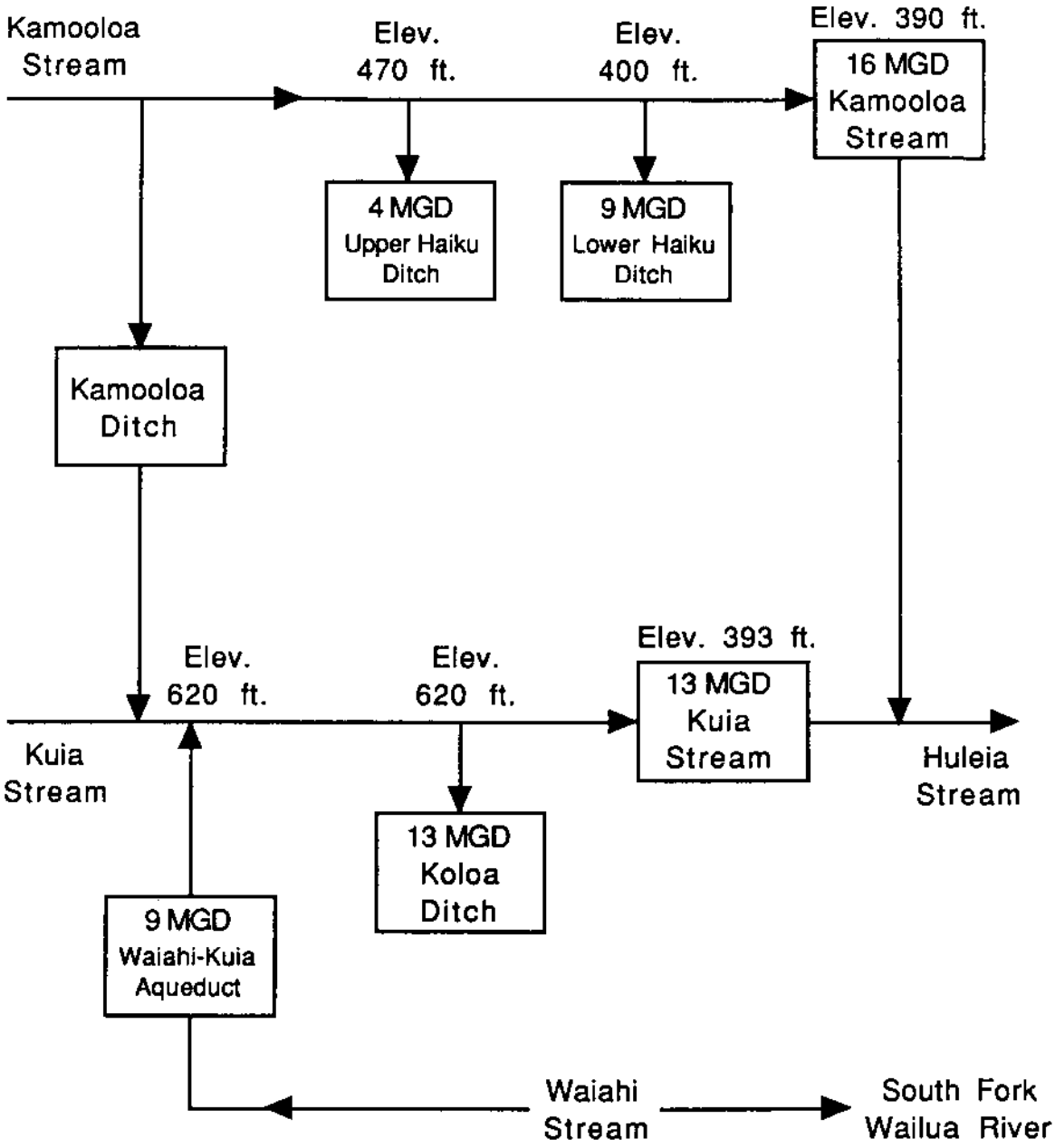


KAUAI

Major Stream Diversions

Indicated Flows Are Averages

Streams in Hanamaulu Aquifer System

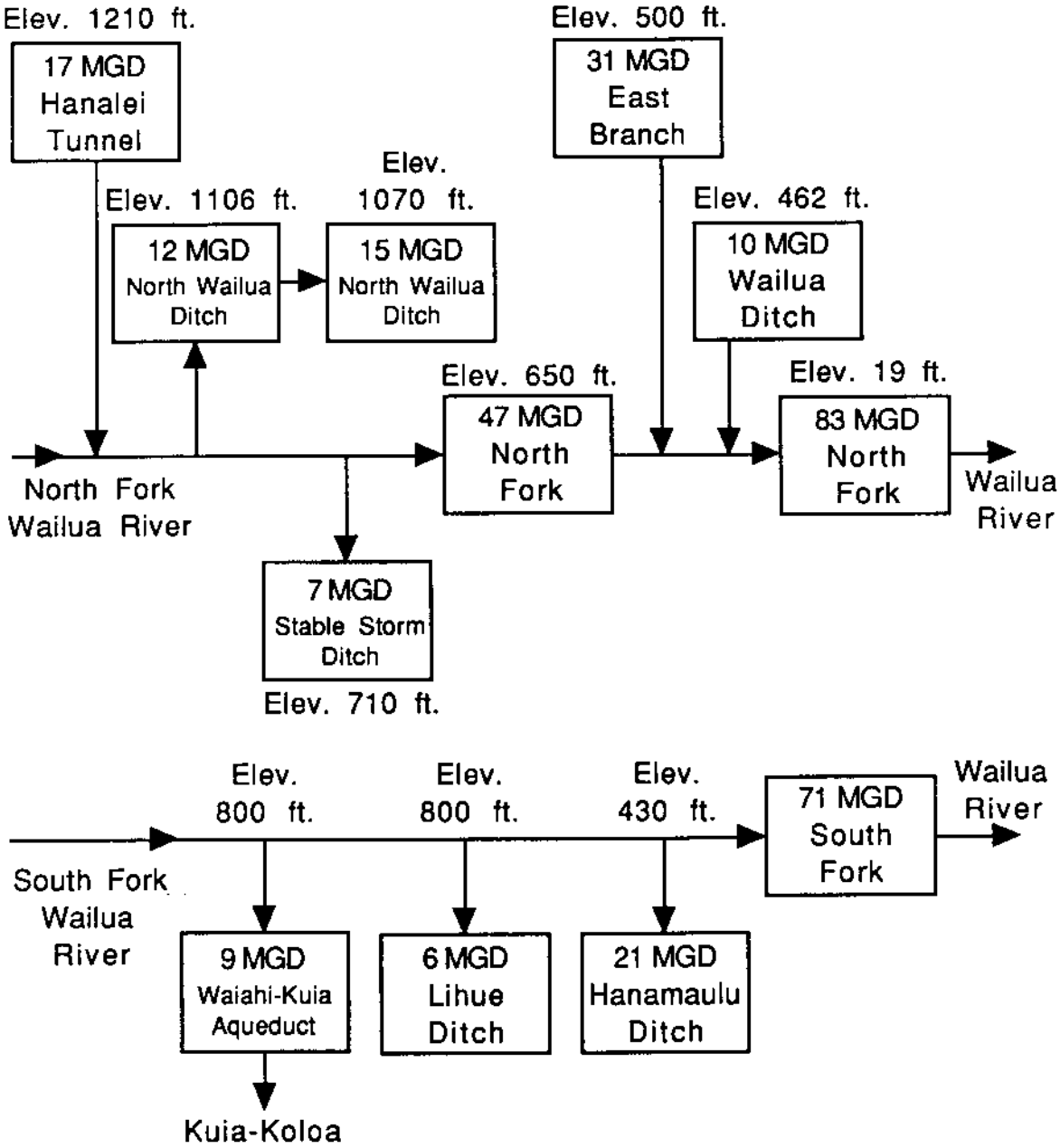


KAUAI

Major Stream Diversions

Indicated Flows Are Averages

Wailua River Drainage: Wailua Aquifer System

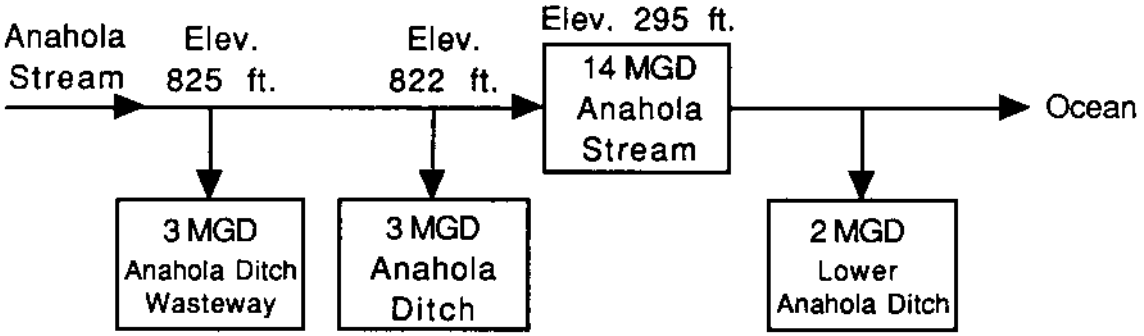


KAUAI

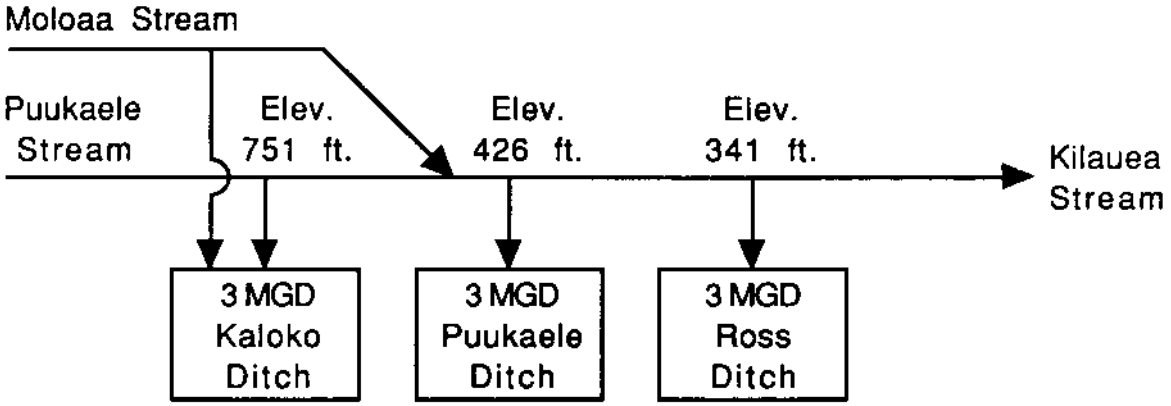
Major Stream Diversions

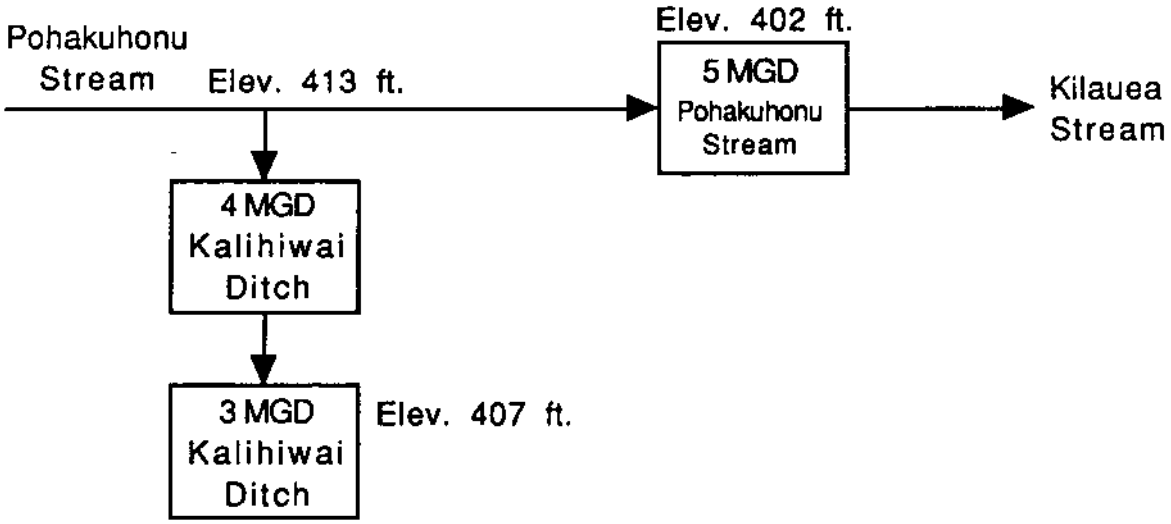
Indicated Flows Are Averages

Anahola Stream: Anahola Aquifer System



Streams in Kilauea Aquifer System



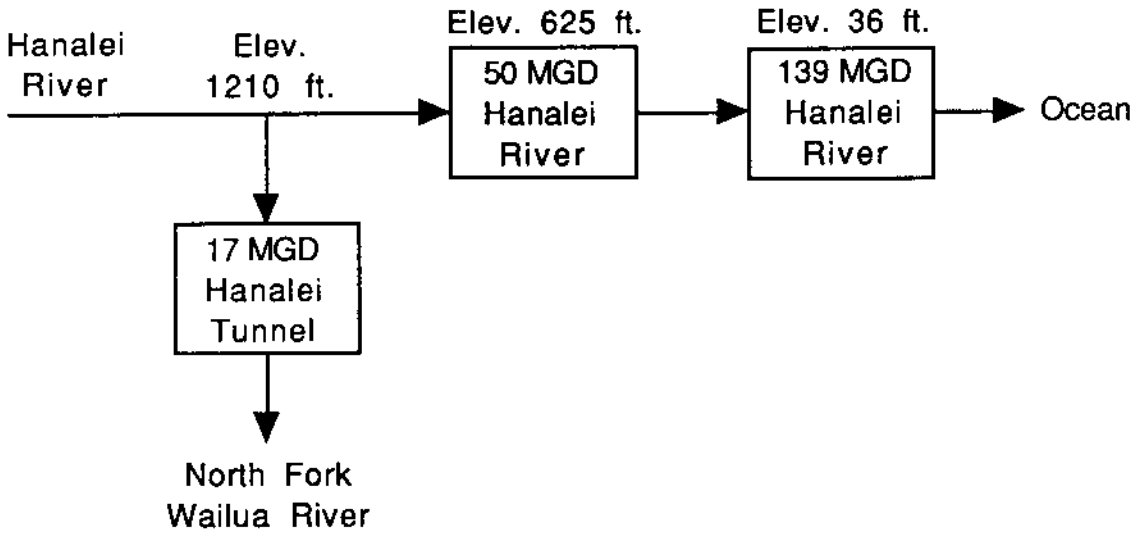


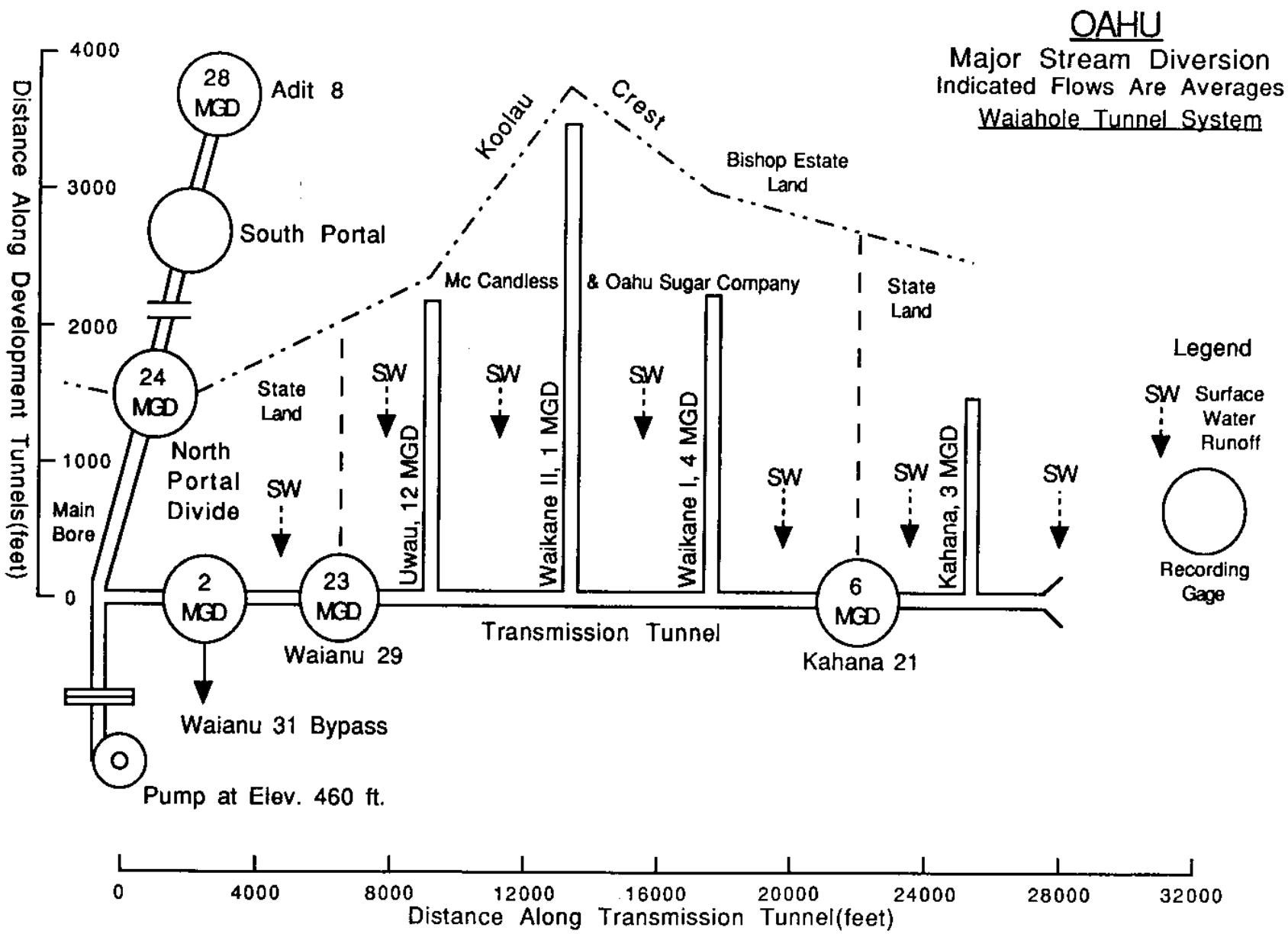
KAUAI

Major Stream Diversions

Indicated Flows Are Averages

Hanalei River: Hanalei Aquifer System

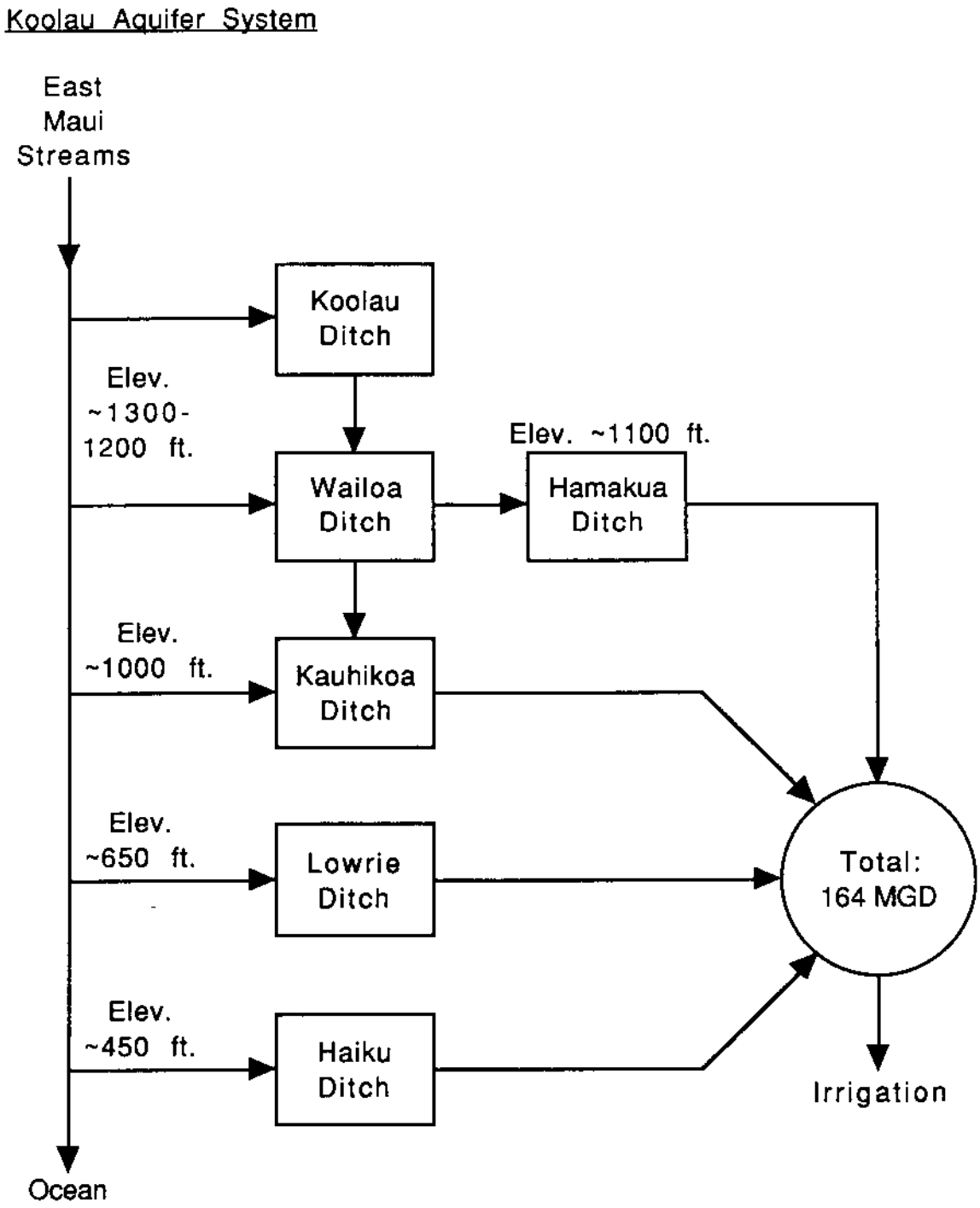



OAHU
Major Stream Diversion
Indicated Flows Are Averages
Waiahole Tunnel System
Distance Along Development Tunnels(feet)
4000
3000
2000
1000
0
28 MGD
Adit 8
South Portal
24 MGD
North Portal Divide
Main Bore
2 MGD
Waianu 31 Bypass
Pump at Elev. 460 ft.
23 MGD
Waianu 29
State Land
SW
Uwau, 12 MGD
Mc Candless
Koolau Crest
Waikane II, 1 MGD
& Oahu Sugar Company
Waikane I, 4 MGD
Bishop Estate Land
State Land
6 MGD
Kahana 21
Kahana, 3 MGD
Transmission Tunnel
Legend
SW Surface Water Runoff
Recording Gage
0
4000
8000
12000
16000
20000
24000
28000
32000
Distance Along Transmission Tunnel(feet)

MAUI

Major Stream Diversions

Indicated Flows Are Averages

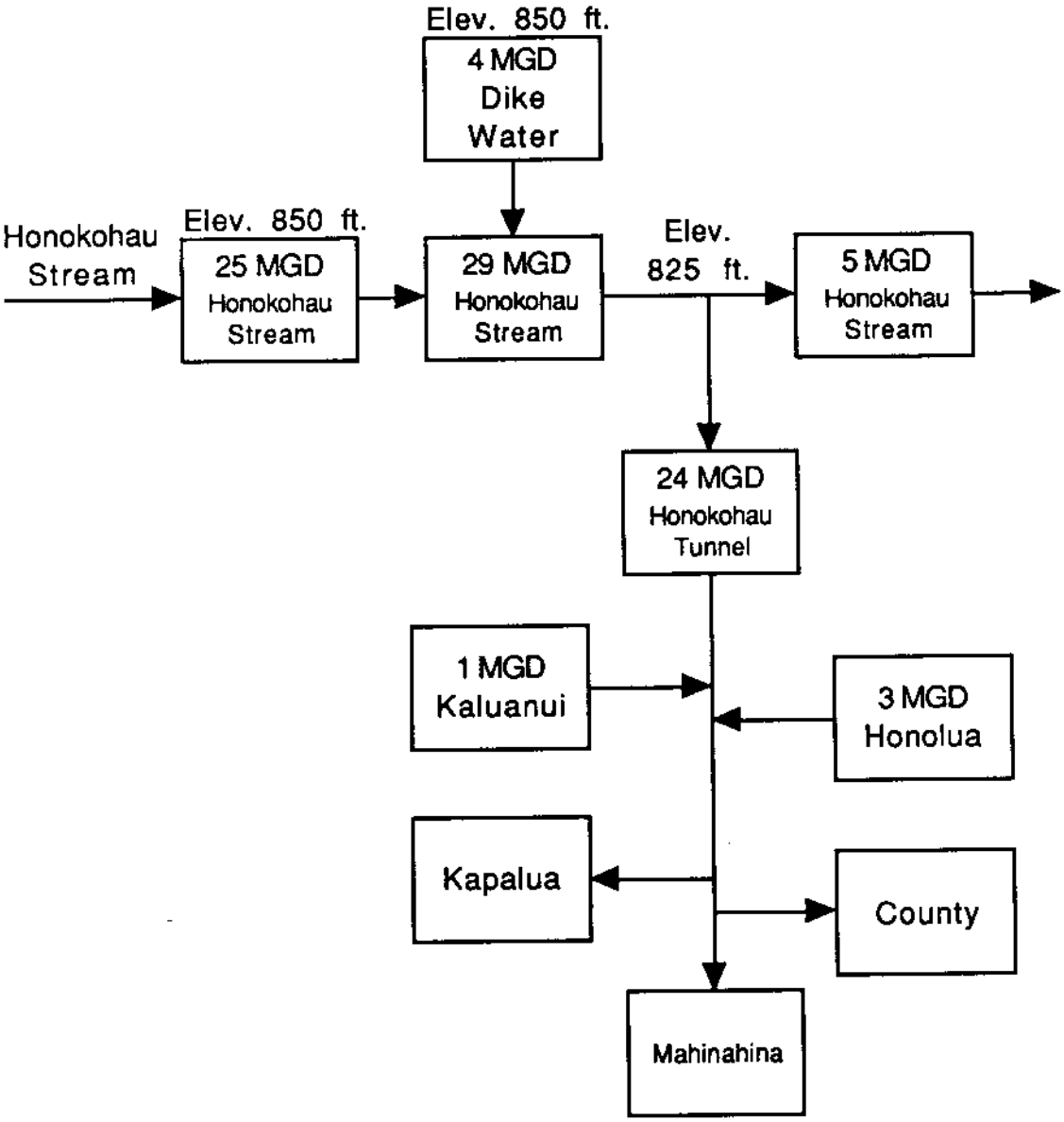


MAUI

Major Ditch Systems

Indicated Flows Are Averages

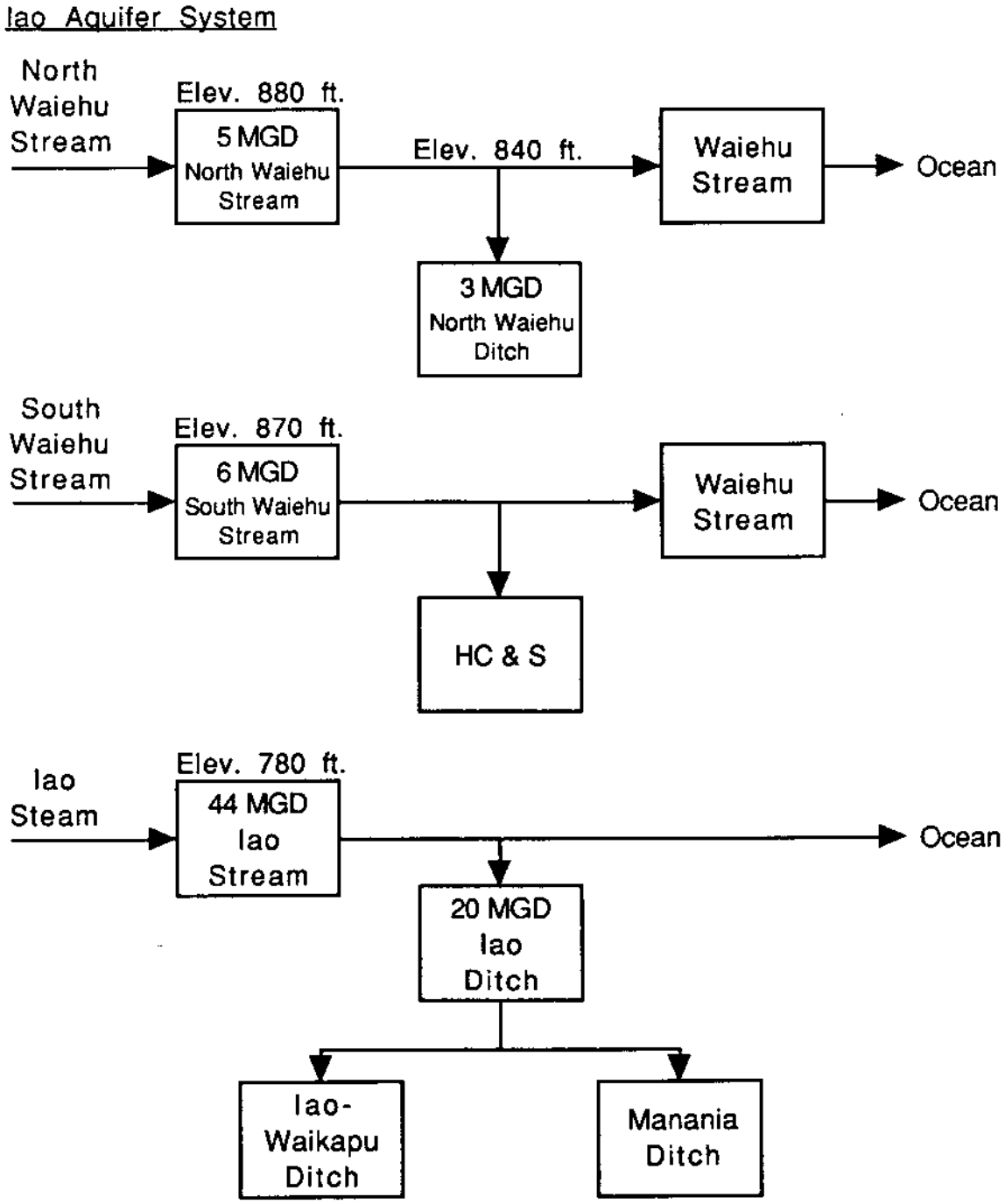
C & H



MAUI

Major Stream Diversions

Indicated Flows Are Averages

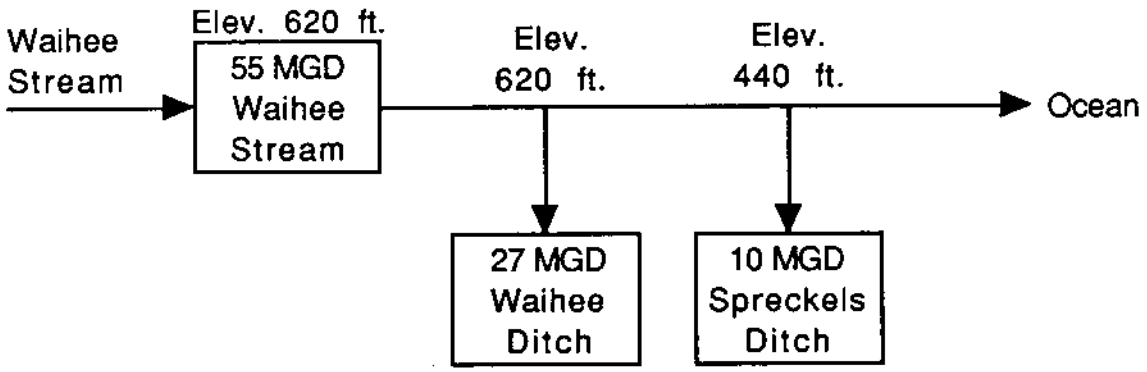


MAUI

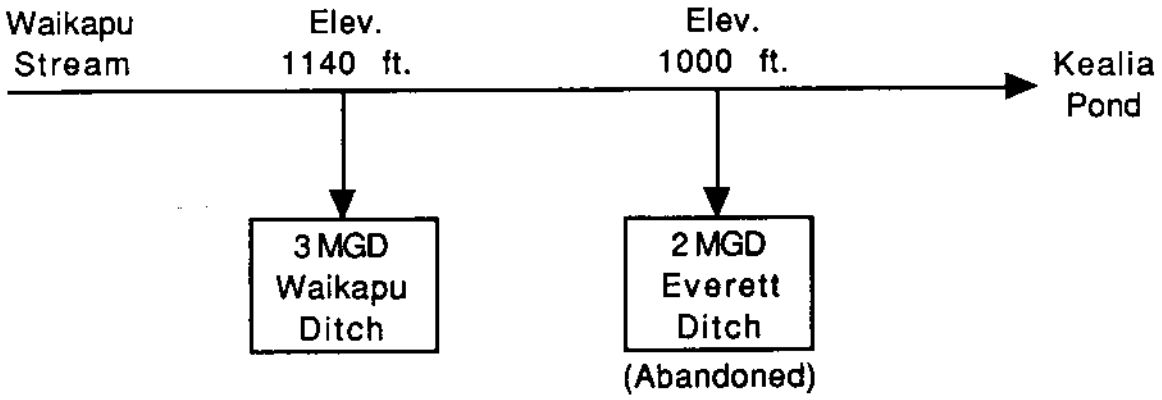
Major Stream Diversions

Indicated Flows Are Averages

Waihee Aquifer System



Waikapu Aquifer System



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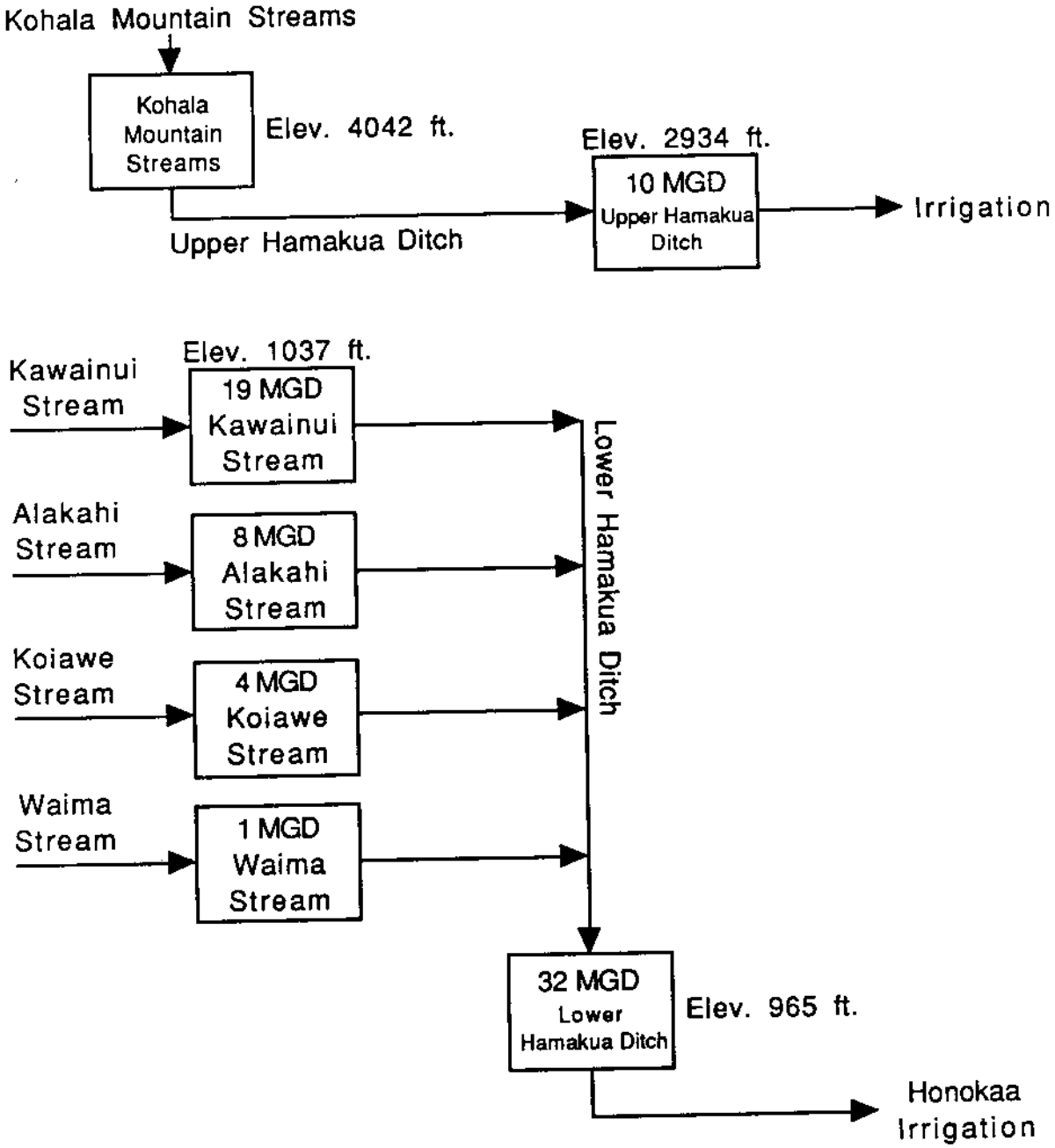
Major Stream Diversions

Indicated Flows Are Averages

Waipio Drainage: Waimanu Aquifer System



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Major Stream Diversions

Indicated Flows Are Averages