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[12] ABSTRACT (PURPOSE, METHOD, RESULTS, CONCLUSIONS)

In response to the need to identify and describe aquifers for each island of the state of Hawaii to serve as a framework for groundwater protection strategy, a program has been initiated to classify and assign codes to the principal aquifers of the state. This third report provides Aquifer Codes and Status Codes for the island of Kauai. The Aquifer Codes incorporate locational and descriptive indices, while the Status codes indicate the developability, utility, quality, uniqueness, and vulnerability to contamination of the groundwater resources. The codes were generated for Hawaiian conditions of groundwater occurrence and behavior in preference to using the DRASTIC approach suggested by the U.S. EPA. Each Aquifer Type within an Aquifer System is assigned an Aquifer Code consisting of an eight-digit number. An Aquifer Code is unique and non-repeatable in the state. Accompanying the Aquifer Code is a Status Code of five digits. A Status code is specific to an Aquifer Code. The Kauai classification includes 3 Aquifer Sectors, 13 Aquifer Systems, and 77 Aquifer Codes.

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AQUIFER IDENTIFICATION AND CLASSIFICATION FOR KAUA'I:
Groundwater Protection Strategy for Hawai'i

John F. Mink
L. Stephen Lau

Technical Report No. 186

September 1992

Project Completion Report
for
Identification of Class I: Special Groundwaters
Highly Vulnerable to Contamination, Kaua'i
Agency No.: Log No. 90-443
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ABSTRACT

In response to the need to identify and describe aquifers for each island of the state of Hawai'i to serve as a framework for groundwater protection strategy, a program has been initiated to classify and assign codes to the principal aquifers of the state. This third report provides Aquifer Codes and Status Codes for the island of Kaua'i.

The Aquifer Codes incorporate locational and descriptive indices, while the Status codes indicate the developability, utility, quality, uniqueness, and vulnerability to contamination of the groundwater resources. The codes were generated for Hawaiian conditions of groundwater occurrence and behavior in preference to using the DRASTIC approach suggested by the U.S. EPA.

Each Aquifer Type within an Aquifer System is assigned an Aquifer Code consisting of an eight-digit number. An Aquifer Code is unique and non-repeatable in the state. Accompanying the Aquifer Code is a Status Code of five digits. A Status code is specific to an Aquifer Code. The Kaua'i classification includes 3 Aquifer Sectors, 13 Aquifer Systems, and 77 Aquifer Codes.

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INTRODUCTION

An aquifer classification protocol has been devised to provide a framework within which to identify and describe groundwater resources throughout the state of Hawaii (Mink and Lau 1987, 1990). The framework is necessary because a standard nomenclature, either locational or descriptive, has not been uniformly applied by investigators when referring to groundwater resources, causing confusion as issues of water supply and water contamination are debated in public forums. The aquifer classification allows hydrologists, engineers, decision-makers and lay persons to avoid misunderstandings by using a common reference frame.

The intent of the classification is to simplify hydrology so discussions at all levels of scientific-engineering comprehension are meaningful. It is designed for practical application. Boundaries for subdivisions of the classification must be drawn, even though in most cases the boundaries are approximations because the actual conditions of groundwater occurrence and behavior are poorly known. For example, where hydrogeological conditions have not been satisfactorily unravelled, boundaries are drawn along topographic divides to embrace complete surface drainage basins, even though topography is infrequently a reflection of subsurface hydrogeology. For the island of Kaua'i, virtually all boundaries in the classification are along topographic divides.

AQUIFER CLASSIFICATION AND AQUIFER CODES

The classification scheme reported by Mink and Lau (1987) is the starting point for developing an Aquifer Code for the island of Kaua'i. Classification is based on a hierarchy of descriptors beginning with general location by Island and Sector, to which belongs a set of Aquifer Systems, within which are a variety of Aquifer Types. Sectors primarily reflect broad hydrogeological features and, secondarily, geography. Aquifer Systems are more specifically defined by hydrogeological continuity, in particular, hydraulic connections among units; Aquifer Types are differentiated by distinctive features of hydrology and geology.

In brief, the hierarchy is as follows:

a. Island—The global factor
b. Sector—A large region with hydrogeological similarities
c. System—An area within a Sector showing hydrogeological continuity
d. Type—Portions of a System having the same hydrological and geological features.

Not identified, but following Type in the hierarchy, is the Aquifer Unit, which is defined as an identifiable aquifer within an Aquifer Type.

Islands are coded by number in conformance with the first digit of the Hawaii State well numbering system originated by the U.S. Geological Survey (1976). Each Sector is coded with a two-digit number and by a Hawaiian geographic name except where locational confusion might result, in which case the general locators North, South, East, West, and Central, or a traditional geographic term such as Windward, are used. A two-digit number is applied to each Aquifer System, which also can be referred to by a geographic name. Three digits describe fundamental hydrology and geology to constitute the Aquifer Type.

The numerical code has the form, 2 03 01 122, in which the first number is the Island, the next two represent the Sector, the following two the System, and the last three the Type. Island numbers are 1 (Ni'ihau), 2 (Kaua'i), 3 (O'ahu), 4 (Moloka'i), 5 (Lāna'i), 6 (Maui), 7 (Kaho'olawe), and 8 (Hawai'i). Sector numbers start at 01 for each Island, and System numbers also start at 01 in each Sector.

Aquifer Types

Hydrology is uniquely described by a pair of digits and geology by a single digit. Identifying characteristics with their codes are as follows.

HYDROLOGY. Aquifer Types are defined as either basal or high-level, and as either unconfined or confined. Their numbers with brief descriptions are as follows:

No.	Type	Description
1	Basal	Fresh water in contact with seawater
2	High Level	Fresh water not in contact with seawater
1	Unconfined	Where the water table is the upper surface of the saturated aquifer
2	Confined	Aquifer is bounded by impermeable or poorly permeable formations; top of the saturated aquifer is below the surface of the groundwater (piezometric surface)
3	Confined or Unconfined	Where the actual condition is uncertain

Using the above coding, groundwater can be 11 (basal, unconfined) or 12 (basal, confined), or 21 (high level, unconfined) or 22 (high level, confined). Where confining conditions are unclear, the second digit is taken as 3 (confined or unconfined).

GEOLOGY. Aquifers are categorized as occurring in the flank lavas of the volcanic domes, in rift zones characterized by dikes, on poorly permeable perching members, or within the sedimentary sequence. Flank aquifers normally are horizontally extensive and display the lowest heads and usually carry basal water; rift aquifers are segmented into compartments by

dikes; perched aquifers lie on impermeable formations but are not ordinarily very extensive; and sedimentary aquifers are comprised of alluvial and marine sediments deposited by erosion and biogenic processes. The geologic codes are as follows:

No.	Type	Description
1	Flank	Horizontally extensive lavas
2	Dike	Aquifers in dike compartments
3	Flank/Dike	Indistinguishable
4	Perched	Aquifer on an impermeable layer
5	Dike/Perched	Indistinguishable
6	Sedimentary	Non-volcanic lithology

One of the above numbers attached to the two hydrology numbers completes the Aquifer Type.

The sequence of all numbers from island through geology is called the Aquifer Code. Each Aquifer Code has an eight-digit code which is unique. An example of an Aquifer Code for groundwater occurrence in Kaua'i is

2	Kaua'i (Island)
03	Waimea (Aquifer Sector)
01	Kekaha (Aquifer System)
122	Basal, confined, dike (Aquifer Type)

The Aquifer Code for the above is 2 03 01 122. There can be no repetition elsewhere in the state. Suited to computer data basing, the code has great retrieval flexibility.

A variety of important information related to the aquifers can be appended to each Aquifer Code. Certain hydrogeologic parameters and quantities, such as rainfall, infiltration, sustainable yield and storage, can be appended to the code to expand its utility. For example, items relevant to groundwater contamination can be expressed as a separate numerical code and attached to the Aquifer Code.

The hydrology of Kaua'i is not as well understood as for O'ahu; consequently, large areas are broadly defined in comparison to the O'ahu network of Systems and Types. Nevertheless a total of 77 Aquifer Codes has been assigned to the island. Three Aquifer Sectors have been named, two with four Aquifer Systems each and the other with five Aquifer Systems (Fig. 1).

Table 1 lists the Aquifer Codes for the island of Kaua'i along with the Aquifer Sector and System names. Also listed is the Status Code of each Aquifer Type. The Status Code, which is described in the next section, summarizes elements crucial to the groundwater protection strategy.

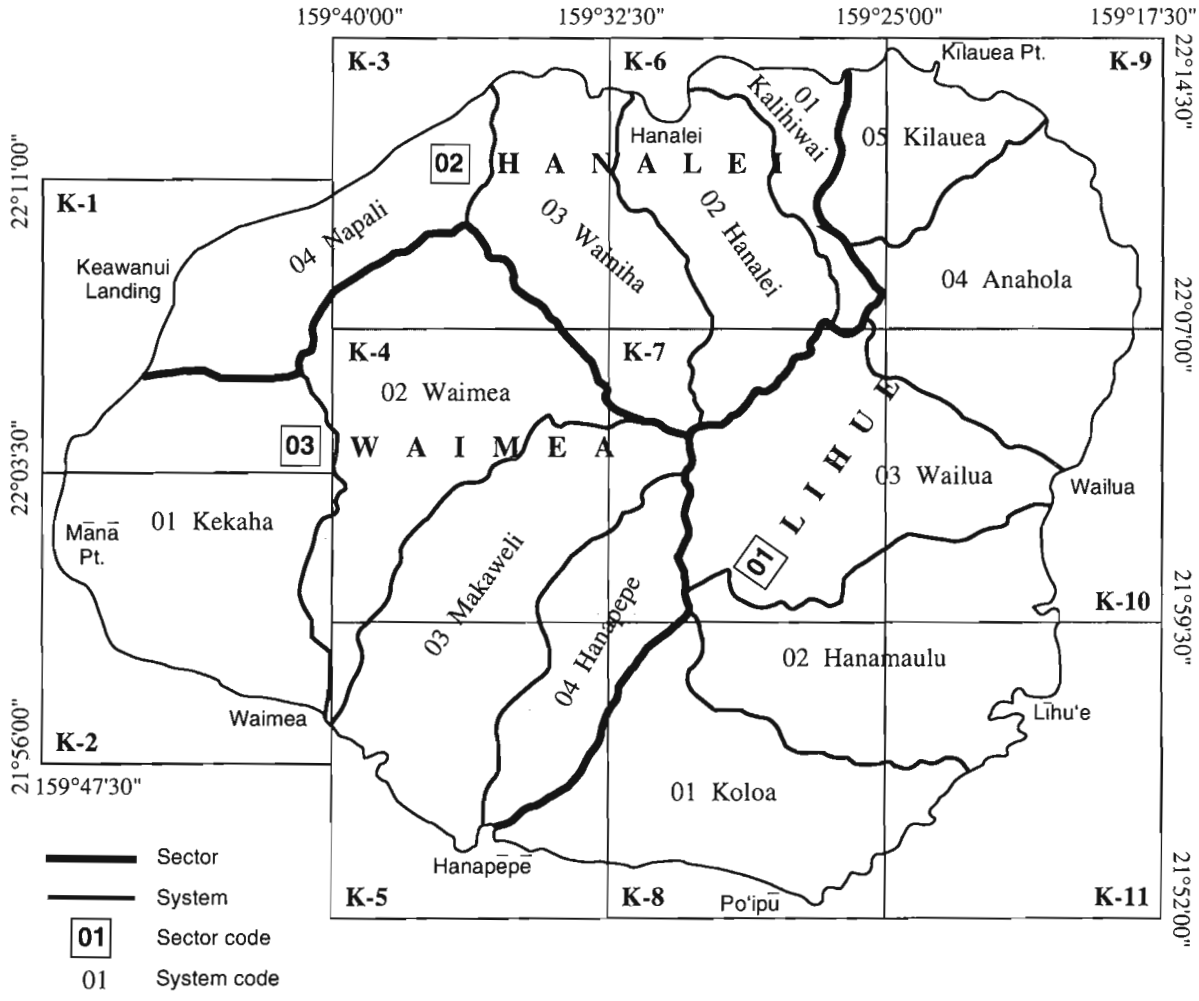

Figure 1. Aquifer codification by Sector and System for Kaua'i, Hawai'i

TABLE 1. AQUIFER AND STATUS CODES FOR KAUA'I, HAWAI'I

Kaua'i Is.	Aquifer Sector	Aquifer System	Aquifer Type	Aquifer Code	Status Code	Quadrangle No.
2	01 Lihue	01 Koloa	212	20101212	11111	8, 11
			212	20101212	21111	7, 8
			214 212	20101214 20101212	21111 21113	8
			214 212	20101214 20101212	21111 21112	5, 8
			112	20101112	21111	8, 11
			112	20101112	11111	8
			111 122	20101111 20101122	21111 21113	5, 8
			116 111	20101116 20101111	33221 11112	8, 11
			116 112	20101116 20101112	11111 21212	11
		02 Hanamaulu	212	20102212	21111	7, 8, 11
			214 222	20102214 20102222	11111 21113	7, 8, 10, 11
			112	20102112	11111	10
			112	20102112	21111	11
			111 122	20102111 20102122	21111 21112	10, 11
			116 111	20102116 20102111	22211 21212	10, 11
		03 Wailua	212	20103212	21111	6, 7, 9, 10
			214 222	20103214 20103222	21111 21112	7, 10
			112	20103112	11111	10
			111 122	20103111 20103122	21111 21112	10
			111 122	20103111 20103122	21111 21113	10
			116 111	20103116 20103111	22211 21212	10
		04 Anahola	212	20104212	11111	9
			212	20104212	21111	6, 7, 9, 10
			214 222	20104214 20104222	21111 21112	7, 9, 10
			111 122	20104111 20104122	11111 11113	9, 10
			116 111	20104116 20104111	22211 21212	9, 10

TABLE 1.—*Continued*

Kaua'i Is.	Aquifer Sector	Aquifer System	Aquifer Type	Aquifer Code	Status Code	Quadrangle No.
2	01 Lihue	05 Kilauea	212	20105212	21111	6, 9
			214 222	20105214 20105222	21111 21112	6, 9
			111 122	20105111 20105122	21111 11113	6, 9
			216 214	20105216 20105214	11111 21112	6
	02 Hanalei	01 Kalihiwai	212	20201212	11111	6
			212	20201212	21111	6, 7, 9
			111 122	20201111 20201122	21111 11113	6
			214 222	20201214 20201222	21111 11113	6
			116 111	20201116 20201111	22211 21222	6
		02 Hanalei	212	20202212	21111	6, 7
			215	20202215	21111	6, 7
			214 212	20202214 20202212	21111 21113	6, 7
			112	20202112	21111	6
			111 122	20202111 20202122	21111 11113	6
			116 112	20202116 20202112	22211 21112	6
		03 Wainiha	212	20203212	21111	3, 6
			215	20203215	21111	3, 4, 6, 7
			214 215	20203214 20203215	22111 21112	7
			112	20203112	11111	3, 6
			111 122	20203111 20203122	21221 21113	3, 6
			111 122	20203111 20203122	23221 21113	3
			116 122	20203116 20203122	22211 21112	3, 6
			116 112	20203116 20203112	22311 21222	3
			116 112	20203116 20203112	22311 21223	3
		04 Napali	212	20204212	21111	1, 3
			112	20204112	21111	1, 3

TABLE 1.—*Continued*

Kaua'i Is.	Aquifer Sector	Aquifer System	Aquifer Type	Aquifer Code	Status Code	Quadrangle No.
2	03 Waimea	01 Kekaha	212	20301212	21111	1, 2, 4
			112	20301112	11111	1, 2, 5
			116	20301116	22311	1, 2
			122	20301122	21223	
		02 Waimea	212	20302212	21111	1, 2, 3, 4
			215	20302215	21111	1, 3, 4
			213	20302213	21111	2, 4, 5
			214	20302214	22111	4, 7
			215	20302215	21112	
			112	20302112	11111	5
			116	20302116	22211	2, 5
			122	20302122	11122	
		03 Makaweli	215	20303215	21111	4, 7
			212	20303212	21111	4, 5, 7
			214	20303214	22111	4, 7
			215	20303215	21112	
			213	20303213	21111	4, 5
			214	20303214	21111	4, 5
			213	20303213	21112	
			113	20303113	21111	5
			111	20303111	21111	5
			113	20303113	21112	
			111	20303111	21111	5
			122	20303122	21113	
			116	20303116	22311	5
			111	20303111	21222	
		04 Hanapepe	212	20304212	21111	4, 5, 7, 8
			215	20304215	21111	4, 7
			214	20304214	21111	5
			212	20304212	21112	
			214	20304214	21111	7, 8
			212	20304212	21113	
			214	20304214	21111	5
			213	20304213	21112	
			111	20304111	21111	5
			122	20304122	21113	

TABLE 1.—*Continued*

Kaua'i Is.	Aquifer Sector	Aquifer System	Aquifer Type	Aquifer Code	Status Code	Quadrangle No.
2	03 Waimea	04 Hanapepe	116 111	20304116 20304111	22211 22112	5

NOTE: Where aquifers are in vertical sequence, the Aquifer and Status Codes are separated by a division line in order of occurrence, with the uppermost aquifer appearing first.

*See Aquifer Classification Explanation, p. 25.

GROUNDWATER PROTECTION: STATUS CODE

Concepts of EPA's groundwater classification conforming to Hawai'i conditions are used to devise a groundwater Status Code that describes development stage, utility, salinity, uniqueness, and vulnerability to contamination of the aquifers. The Status Code is conveniently attached to the Aquifer Code, and the combination is an efficient representation of location, hydrology, geology, utility, water quality, and contamination potential of groundwater resources in every part of the island.

The five-digit Status Code consists of a single number from each of five separate descriptive categories. The categories and their status elements with identifying numbers are as follows:

A. Development Stage
   1. Currently used
   2. Potential use
   3. No potential use

B. Utility
   1. Drinking
   2. Ecologically important
   3. Neither

C. Salinity (mg/l Cl^-)
   1. Fresh (<250)
   2. Low (250–1000)
   3. Moderate (1000–5000)
   4. High (5000–15,000)
   5. Seawater (>15,000)

D. Uniqueness
   1. Irreplaceable

2. Replaceable

E. Vulnerability of Contamination

1. High
2. Moderate
3. Low
4. None

Only one number from each major category listed above is allowable in the Status Code. For instance, a currently developed groundwater source (1), used for drinking (1), having a salinity of less than 250 mg/l Cl^- (1), being irreplaceable (1), and highly vulnerable to contamination (1), would have the Status Code 11111. If it were ecologically important but not suitable for drinking with a salinity of 750 mg/l Cl^-, other categories being the same, the code would be 12211.

The categories and their elements are derived from the U.S. EPA (1984) groundwater classifications modified by fundamentals of the Hawaii groundwater environment. Application of a detailed vulnerability assessment, such as a modified form of DRASTIC, could be used in the vulnerability to contamination category.

Brief explanations of the Status Code categories and their elements are as follows.

DEVELOPMENT STAGE. Aquifers are differentiated according to those already being used (currently used), those with potential utility (potential use), and those having no potential developability.

UTILITY. Identifies aquifers by use. Groundwater classed as drinking may also be ecologically important, but that classed as ecologically important may not be used for drinking. Drinking takes precedence over ecologically important.

SALINITY. The gradation of groundwater from fresh to seawater is a feature of all basal aquifers in Hawai'i. Basal aquifers comprise, by far, the most voluminous sources of groundwater. Chloride content is the class definer rather than total dissolved solids (tds) because it is routinely reported in the Hawai'i literature. The class limits inevitably are somewhat arbitrary but incorporate the following logic.

1. Fresh (<250 mg/l): The upper limit of the standard for drinking water is 250 mg/l Cl^-.
2. Low (250–1000 mg/l): Much agriculture, in particular sugarcane, can be irrigated with water containing up to 1000 mg/l Cl^-.
3. Moderate (1000–5000 mg/l): Brackish water of this salinity may serve as feed water for desalinization in the future.
4. High (5000–15,000 mg/l): The high salinity class, not yet seawater, is arbitrarily designated for water that is between potentially economically valuable water and seawater.

5. Seawater: True seawater has a chloride content of 18,980 mg/l.

UNIQUENESS. The classes irreplaceable and replaceable are direct EPA derivatives. Over the long term, virtually all potable water in the state of Hawai'i should be considered irreplaceable.

VULNERABILITY TO CONTAMINATION. In the Hawaiian Islands because of the geographical limits of the resources, interconnection among groundwater sources and the relatively rapid time of groundwater travel, aquifers can be described simply as being either vulnerable or not vulnerable to contamination. Most unconfined aquifers are vulnerable; confined aquifers may or may not be. A refinement in the degree of vulnerability may be instituted by using some modified form of the DRASTIC, or similar, index. The one used in this classification (high, moderate, low, none) is based on familiarity with environmental conditions.

Summary

In summary, a groundwater classification scheme which includes source as well as status information has been created. The Aquifer Code consists of locators, hydrology, and geology, and reads as follows: Island-Aquifer Sector-Aquifer System-Aquifer Type. The code consists of eight digits: one for the Island, two each for Sector and System, and three for Type (two for hydrology, one for geology).

The Status Code contains five digits and, combined with the Aquifer Code, results in a 13-digit code. For example, the code 20301112 (11111) defines an aquifer in Kaua'i, Waimea Sector, Kekaha System, in which the groundwater is basal and confined in dike lavas. The last five digits within parentheses tell that the aquifer is currently used to supply drinking water having less than 250 mg/l Cl^-, and that it is an irreplaceable source highly vulnerable to pollution.

Although the original scope of the project referred specifically to Class I (special) groundwater, all other groundwater in Kaua'i has been classified. As a matter of interest, Class I groundwater Status Codes are either 11111 (drinking) or 12n11 (ecologically important), in which n is a number (1–5) defining the salinity range (<250 to >15,000 mg/l Cl^-).

AQUIFER CLASSIFICATION MAPS

Accompanying this explanation of Aquifer Codes and Status Codes are maps for Kaua'i (reduced from USGS base 1:24,000-scale quadrangles) on which are plotted Sector, System, and Type boundaries. Within each Aquifer Type area is an Aquifer Code to which is appended the Status Code within parentheses.

Where aquifers occur in vertical sequence, Aquifer and Status Codes for each aquifer are separated by a division line. The numerator code is for the upper aquifer and the denominator for the lower aquifer.

General Geology and Hydrology of Kaua'i

In most geological aspects, Kaua'i is the most complex of the Hawaiian Islands. It is the oldest of the main islands, has subsided more than any other, and its original volcanic shield underwent large scale structural displacement and erosion before much of it was covered with extrusions of renewed volcanism. The post-erosional volcanics are the most voluminous of this class of rocks in the island chain. Kaua'i would be a much smaller land mass had not the Koloa volcanic series filled deep valleys and covered the irregular topography of the eroded primary volcanic dome in the eastern half of the island.

The publication of G.A. Macdonald, D.A. Davis, and D.C. Cox (1960) is the basic document on which all subsequent geological and hydrological descriptions have depended. The authors located the caldera of the original volcano in the high interior of the island, and identified a smaller eruptive center in the southeast on Hā'upu Ridge. They named the primary basaltic rocks the Waimea Canyon volcanic series. Within this series the innumerable lava flows which accumulated to form the volcanic dome are called the Napali formation, while the rocks filling the main caldera are named the Olokele formation. The southwestern part of the original shield collapsed and was filled with the Makaweli formation, which resembles the Olokele formation. The Napali are the most permeable rocks in the island.

In the small caldera in the southeast of the island the rocks are called the Hā'upu formation but are an extension of the principal Waimea Canyon series. All of the rocks of this primary series are predominantly olivine basalts.

Investigations subsequent to the original work of Macdonald, Davis, and Cox in particular gravity surveys (Krivoy, Barker and Moe 1965), suggest that the main caldera either extended into or is located in the eastern part of the island. The closed high gravity anomaly, which is characteristic of calderas in each of the other Hawaiian Islands, is in the "Lihue Depression" east of Mt. Wai'ale'ale. This relatively low region is covered with the Koloa volcanic series which was laid down long after the initial volcano had become dormant.

Before emplacement of the Koloa series, the original shield was deeply eroded, essentially to the shape it now has where the later lavas are absent. The Koloa consists of a range of formations from olivine basalt to nepheline basalt. It filled the valleys and covered the eroded topography of much of eastern Kaua'i. These rocks are much less permeable than the Napali formation of the Waimea Canyon volcanic series because they were deposited as nearly flat

layers in contrast to the moderately dipping Napali lavas on the flanks of the volcanic dome. Flat layers tend to be massive and devoid of permeability elements; dipping layers, on the other hand, are fractured and frequently separated by highly permeable rubble beds. The Olokele and Makaweli formations in the Waimea Canyon series are also relatively flat-lying, but they are more permeable than the Koloa.

Groundwater occurs in all of the formations, chiefly in high level aquifers starting a few miles inland. In the Koloa series perched groundwater is common, while in the Napali formation groundwater is trapped between dikes or moves freely in flank lavas. Dikes have been mapped in the Waimea Canyon volcanic series throughout the island, but where their frequency is low, aquifers behave as flank aquifers.

Basal groundwater occurs within one or two miles of the coast in Koloa and Napali rocks in eastern Kaua'i. In the west the flank of the original volcanic dome reaching from the Waimea Canyon divide to the coast is mostly underlaid with basal groundwater.

The aquifers most susceptible to contamination are those perched in the Koloa lavas as well as those in the Waimea Canyon series unprotected by a cover of Koloa rocks or sediments. Aquifers in the Waimea Canyon series lying beneath a cover of Koloa or sediments are less likely to suffer contamination. Sedimentary aquifers are also exposed to contamination, but few significant aquifers of this type occur. The largest extent and thickness of sediments comprises the Mana Plain in western Kaua'i. The coastal plain is a complicated succession of marine and terrestrial sediments which behave as a caprock on underlying Napali rocks. The sediments are saturated with brackish water except at their inland margin.

Rainfall for the entire island averages 98 in./yr (2 489.2 mm/yr), higher than for any other island in the archipelago. High rainfall coupled with extensive occurrences of high level aquifers results in an unusually large percentage of total rain draining to the sea as stream flow. In the eastern half of the island, perched aquifers in the Koloa sustain perennial stream flow in numerous small streams. Larger streams reaching inland to the mountains drain dike aquifers in the Waimea Canyon series as well as perched Koloa aquifers. In the interior, drainage from Alaka'i Swamp supports many headwater streams flowing into major rivers like Waimea, Olokele, Makaweli, Hanapepe, Wainiha, and Lumahai. In the hydrologic balance, the greatest fraction of rainfall not consumed in evapotranspiration reaches the sea as defined stream flow rather than as a groundwater underflow.

AQUIFER SECTOR: LIHUE (201)

Aquifer System: Koloa (20101)

BOUNDARIES. The western boundary is the Hanapepe drainage divide. The northern boundary separates streams draining south from those draining east by following the crest of Haupu Ridge. Total area is 51 miles^2 (132.09 km^2).

HYDROLOGY. Average annual rainfall is 73 in. (1 854.2 mm). Perennial streams are sustained by drainage from perched aquifers in the Koloa series. Streams are modest to small in size and outflow.

GEOLOGY. The dominant geology consists of Koloa series covering the Waimea Canyon series. The Koloa thickens toward the south coast. Napali formation ridges striking off Haupu Ridge plunge beneath the Koloa, and in the east the Napali stands above the Koloa platform. Old alluvium is associated with the Napali, and recent alluvium with the Napali and the Koloa.

GROUNDWATER. In the Koloa discontinuous high level perched aquifers occur; toward the coast these aquifers become basal. The principal developable groundwater resources are in the Napali; either where it stands above the Koloa or where it is covered. Wells have been drilled in the Napali for municipal and irrigation purposes. Smaller capacity wells exploit the Koloa for limited irrigation supplies.

ENVIRONMENT. Irrigated sugarcane is the principal crop. Tourism is important, and residential areas are expanding to support tourism.

Aquifer System: Hanamaulu (20102)

BOUNDARIES. Hanamaulu lies to the north of the Koloa Aquifer System. Its western boundary is the Hanapepe drainage divide, and its northern boundary is the Wailua drainage divide. Total area is 55 miles^2 (142.5 km^2).

HYDROLOGY. Average annual rainfall is 83 in. (2 108.2 mm). The headwaters of the major streams rise in the Napali formation, but most of each drainage basin is in the Koloa series. Perched aquifers sustain perennial flow. The major streams (Hulē'ia, Nāwiliwili, and Hanamā'ulu) are moderate in size.

GEOLOGY. Napali formation outcrops in Kīpū-Hā'upu on the south boundary, in the interior at the Hanapēpē boundary, and as the isolated Kālepa Ridge near the east coast. Most of the area is covered with Koloa. Old alluvium blankets the lower slopes of Kīpū-Hā'upu, and recent alluvium fills the middle and lower courses of stream valleys.

GROUNDWATER. Perched water in Koloa and high level dike aquifers in the Napali drain to streams. Near the coast the aquifers become basal. Several small capacity wells develop water in Koloa aquifers for municipal use.

ENVIRONMENT. Sugarcane covers large areas and is irrigated with water collected from streams and transported in a network of ditches and tunnels. The largest community in the island, Lihue, is in the System.

Aquifer System: Wailua (20103)

BOUNDARIES. The entire System is contained within the Wailua drainage basin divides. Total area is 53 miles^2 (137.3 km^2).

HYDROLOGY. Average annual rainfall is 146 in. (3 708.4 mm), reflecting extremely high rainfall in the interior where the boundary reaches to Mt. Wai'ale'ale, the wettest place in the United States and perhaps in the world when averaged over many years. The Wailua River is one of the major rivers in the state of Hawaii. It is sustained by the high rainfall in the interior as well as voluminous seepage from perched aquifers in the Koloa and high level dike aquifers in the Napali formation.

GEOLOGY. The headwater tributaries of the Wailua River drain from the Napali formation. Most of the Aquifer System is covered with the Koloa series. Some outliers of the Napali rise above the Koloa platform. Old alluvium derived from the Napali lies in valleys far inland. Recent alluvium covers stream valleys on the Koloa.

GROUNDWATER. The perched Koloa aquifers are inferior to the high-level aquifers in the underlying Napali. Both types of aquifers account for a large fraction of stream flow. Toward the coast the aquifers become basal. Groundwater has not been developed by means of wells.

ENVIRONMENT. Sugarcane is irrigated with surface water taken from numerous tributaries of Wailua River. Water is also imported from the Hanalei drainage by way of a tunnel through the mountain forming the divide on the north. Tourism is expanding.

Aquifer System: Anahola (20104)

BOUNDARIES. The south boundary is the Wailua drainage divide, and the north boundary the Hanalei-Kawaihau District line which also is a drainage divide. The north boundary reaches the sea just north of Moloa'a Bay. The interior boundary follows the crest of the Makaleha Mountains. Total area is 45 miles^2 (116.6 km^2).

HYDROLOGY. Average annual rainfall is 83 in. (2 108.2 mm). Numerous small- as well as a few moderate-size streams drain the region. The largest are Keālia-Kapa'a and Anahola. The streams rise in the Napali formation in the Makaleha Mountains but perennial flows are sustained by drainage of perched aquifers in the Kōloa.

GEOLOGY. The Makaleha Mountains are exposures of the Napali formation. Where the mountains plunge beneath the Koloa platform an unconformity of old alluvium occurs. A large remnant of the Napali rises above the Koolau platform near Pāpa'a.

GROUNDWATER. The Koloa carries poorly permeable perched aquifers while the Napali contains high level dike aquifers. The Napali is exploited with wells for irrigation and municipal water supply. The Koloa aquifers are ignored because of their poor characteristics.

ENVIRONMENT. Sugarcane is no longer an important activity in the region. At one time pineapple was a principal crop but it is no longer cultivated. A small area of diversified farming produces specialty crops such as papaya. Ranching and dairying are pursued.

Aquifer System: Kilauea (20105)

BOUNDARIES. The eastern boundary is the Hanalei-Kawaihau District line along the Moloa'a drainage divide, and the western boundary is the Kalihiwai drainage divide. Total area is 19 miles^2 (49.2 km^2).

HYDROLOGY. Average annual rainfall is 96 in. (2 438.4 mm). The principal drainage is Kilauea Stream, which is moderate in size. Other smaller, shorter streams reach the coast.

GEOLOGY. In the interior the Napali formation of the Makaleha Mountains dips below a blanket of old alluvium and the Koloa. Most of the System is a platform of Koloa series rocks.

GROUNDWATER. Near the coast, aquifers in the Koloa are basal; about 1.5 mile (2.4 km) inland they are high-level perched. Napali ridges in the interior mountains and as isolates in the Koloa platform carry high-level dike aquifers. No producing wells have been drilled.

ENVIRONMENT. At one time sugarcane covered the lowlands. A system of intakes, ditches, tunnels and reservoirs, many of which are still used, provided an irrigation supply. A large wetland rests on old alluvium at the base of the interior mountains. Diversified farming, including guava orchards, is practiced. Agriculture zoned residential developments are underway.

AQUIFER SECTOR: HANALEI (202)

Aquifer System: Kalihiwai (20201)

BOUNDARIES. The Aquifer system is comprised solely of the Kalihiwai drainage basin which rises in the Makaleha Mountains. Total area is 18 miles^2 (46.6 km^2).

HYDROLOGY. Average annual rainfall is 121 in. (3 073.4 mm). Kalihiwai is a major stream, though not as great a river as Hanalei in the next System to the west. Tributaries are

perennial because they drain perched aquifers in the Koloa and high-level dike aquifers in the Napali formation.

GEOLOGY. The Napali formation of the Makaleha Mountains in the interior plunges beneath the Koloa, which covers about two thirds of the System. Napali ridges extend into the Koloa platform. Old alluvium lies at the base of the Makaleha Mountains and reaches far upstream in the valleys.

GROUNDWATER. Aquifers in the Napali formation are productive and are being exploited for domestic water supply. Koloa perched aquifers are not yet being used. Near the coast the groundwater is basal, but throughout most of the System it is high level.

ENVIRONMENT. Sugarcane, once the dominant crop, is no longer grown. Agricultural residential developments are increasing.

Aquifer System: Hanalei (20202)

BOUNDARIES. The Hanalei River drainage boundaries incorporate the whole of the Aquifer System. On the west is the Lumahai divide, on the east the Kalihiwai divide. The interior boundary reaches almost to Mt. Wai'ale'ale. Total area is 33 miles^2 (85.5 km^2).

HYDROLOGY. Average annual rainfall is 176 in. (4 470.4 mm), among the wettest drainage basins in the State. The headwaters of the River start in the Waimea Canyon volcanic series rocks. The eastern half of the drainage is in the Koloa series. At an elevation of 625 ft (190.5 m) average flow of the river is 63 mgd (2.76 m^3/s) and the 95 percentile flow is 26 mgd (1.14 m^3/s). At this point 18 mgd (0.79 m^3/s) is diverted to the Wailua drainage by way of a tunnel.

GEOLOGY. The interior of the drainage is in the Olokele formation of the Waimea Canyon series. Downstream the Napali formation forms the west side of the drainage, the Koloa the east. Hanalei Valley separates the predominantly Koloa geologic province of eastern Kaua'i from the Waimea Canyon series on the west. Old alluvium reaches far up the valley. In the lower valley a wide and thick sequence of sediments extends inland as the valley floor.

GROUNDWATER. Near the coast, groundwater is basal in both the Koloa and Napali formations as well as in the sediments. Upstream, starting a mile (1.6 km) or so inland, aquifers are high level. Potable water wells are drilled on the east side of the valley where they penetrate Koloa rocks before reaching the Napali formation.

ENVIRONMENT. Hanalei is famous for its diversified agriculture, especially taro and other water loving crops. Tourism is important. The rugged interior is unoccupied.

Aquifer System: Wainiha (20203)

BOUNDARIES. The System is composed of the drainage basins of the Wainiha and Lumahai rivers, each a major river. On the west the drainage divide of Hanakāpīai Stream is the divide, on the east the Hanalei divide is the boundary. The interior incorporates a part of Alakai Swamp below Mt. Wai'ale'ale. Total area is 39 miles^2 (101.0 km^2).

HYDROLOGY. With an annual average rainfall of 200 in. (5 080.0 mm), the System is the wettest in Kaua'i and one of the wettest in the State. The two rivers and their tributaries are perennial, draining mostly high level aquifers in the Waimea Canyon volcanic series. At elevation 960 ft (292.6 m) the average flow of Wainiha is 63 mgd (2.76 m^3/s) and the 95 percentile flow is 29 mgd (0.92 m^3/s). At elevation 700 ft (213.4 m) the average flow of Lumahai is 74 mgd (3.24 m^3/s) and the 95 percentile flow 21 mgd (0.92 m^3/s).

GEOLOGY. The Olokele formation covers the upper two thirds of the System, and the Napali formation the lower third. Both formations are intersected with dikes, but more visibly so in the Napali. Small patches of the Koloa have minor hydrologic significance. Old alluvium reaches far inland in the major valleys, almost to 1000 ft (304.8 m) in Wainiha. A narrow coastal plain of sediments separates the Napali formation from the sea.

GROUNDWATER. Groundwater occurs chiefly in high level dike aquifers in the Napali and Olokele formations. Drainage from these aquifers sustains much of the flow in Wainiha and Lumahai. Wells have not been drilled.

ENVIRONMENT. Lumahai is a wild river while Wainiha is harnessed for hydropower. Along the coast are dwellings, otherwise the area is too rugged to occupy.

Aquifer System: Napali (20204)

BOUNDARIES. The eastern extreme is at the Hanakāpīai-Wainiha divide. The interior boundary follows Kaunuohua Ridge, which separates streams draining to the Nāpali Coast from those draining into the Waimea drainage basin. The western boundary follows Polihale Ridge to the northern extremity of the Mana Plain. Total area is 34 miles^2 (88.1 km^2).

HYDROLOGY. Average annual rainfall is 70 in. (1 778.0 mm). Short, steep streams drain to the Nāpali Coast. The maximum drainage distance is 2.5 miles (4.02 km), and the average is 1.5 miles (2.41 km). Some of the streams may be perennial, the longest are Hanakāpīai and Kalalau. Both are perennial, draining aquifers in the Napali formation.

GEOLOGY. The entire System lies outside the caldera limits and is underlain by the Napali formation. The valleys are alluviated, the deeper ones with old alluvium. Dikes are common. Patches of alluvium occur at the mouth of streams, otherwise bedrock plunges into the sea.

GROUNDWATER. High level dike aquifers in the Napali formation contain most of the groundwater. The dike aquifers may become basal very close to the coast. No water development has taken place.

ENVIRONMENT. The region is part of the Nāpali Coast, which is a tourist attraction but is unoccupied. Sightseeing by helicopter or boat is the common activity.

AQUIFER SECTOR: WAIMEA (203)

Aquifer System: Kekaha (20301)

BOUNDARIES. The northern boundary is Polihale Ridge, and the eastern boundary the drainage divide of Waimea Canyon. Total area is 59 miles^2 (94.9 km^2).

HYDROLOGY. Having an annual average rainfall of just 33 in. (838.2 mm), Kekaha is the driest Aquifer System in Kaua'i. Surface drainage is by way of small, non-perennial streams that debouch onto the Mana Plain. The Plain originally was a vast swamp but is now artificially drained to allow cropping.

GEOLOGY. The region is a part of the southwest flank of the original volcano. Napali lavas terminate as a fossil sea cliff along a mile wide coastal plain of terrestrial and marine sediments. The Mana Plain is the most extensive and thickest accumulation of sediments in the island. Inland a few dikes have been mapped.

GROUNDWATER. High-level dike aquifers may occur in Napali lavas in the interior near the Waimea Canyon divide. Otherwise the flank lavas contain basal groundwater. The Napali aquifer beneath the Mana Plain caprock is artesian. This aquifer has been developed as a source of irrigation supply. The sediments are saturated with brackish to salty water. Upward leakage into the sediments from the Napali artesian aquifer is the cause of the original swamp conditions. When artificial drainage of the Plain ceases, it will again become a swamp. Potable water is developed from wells near Kekaha and Waimea. These wells are located at the inland edge of the Plain.

ENVIRONMENT. The Mana Plain and a portion of the bedrock slope is devoted to irrigated sugarcane. The source of water is wells and stream flow diverted from the Waimea drainage. Along the shore is a military installation. On the coastal plain near Kekaha is the only landfill now in use on the island.

Aquifer System: Waimea (20302)

BOUNDARIES. The Waimea Aquifer System consists solely of the Waimea River drainage above the confluence with the Makaweli River. Total area is 49 miles^2 (78.8 km^2).

HYDROLOGY. Average annual rainfall is 95 in. (2 413 mm). Much of the Alakai Swamp falls in the drainage, supporting perennial flow of headwater tributaries. Waimea River is another of Kaua'i's major water courses and also one of the largest in the state. Downstream of many diversions but upstream of Makaweli, average flow is 83 mgd (3.64 m^3/s). High level dike aquifers in addition to perched water of the Alakai Swamp contribute base flow to the streams.

GEOLOGY. The Waimea River drainage consists of the Waimea Canyon volcanic series and includes its three principal formations (Napali, Olokele, and Makaweli). The Napali is especially intruded with dikes, forming high level dike compartment aquifers. The other formations also contain high level aquifers. The lower valley is filled with sediments. Old alluvium is found far up the valley.

GROUNDWATER. In the narrow lower valley, groundwater occurs as a basal lens in sediments and the Napali formation. Most groundwater, however, fills high-level dike aquifers further inland. Groundwater discharges into streams and the river. At several locations the river is diverted into ditches and tunnels for transport to sugarcane fields. No other water development has taken place.

ENVIRONMENT. Waimea Canyon, one of the premier observable natural features in Hawai'i, occupies the middle portion of the drainage. At the upper limit of the drainage is Koke'e Park.

Aquifer System: Makaweli (20303)

BOUNDARIES. The western boundary is the Waimea drainage divide above the confluence with Makaweli River. The eastern boundary is the Hanapepe drainage divide. Total area is 68 $miles^2$ (109.4 km^2).

HYDROLOGY. Average annual rainfall is 65 in. (1 651.0 mm). Several major streams are headwater tributaries to Makaweli River, which in turn empties into the Waimea River near its mouth. Olokele and Mokuone drain into the Makaweli River.

GEOLOGY. Much of the headwater region is underlaid with the Olokele formation. Farther downstream the Olokele is replaced by the Makaweli and Napali formations. In the lower quadrant the Koloa series appears and from here eastward increases in area. Napali ridges dip beneath the Koloa platform near the coast. Old alluvium occurs in Makaweli far upstream. Along the coast the shallow valleys draining the Koloa formation are covered with recent alluvium.

GROUNDWATER. High-level groundwater in Waimea Canyon series dike aquifers dominate the interior. Within about 2 miles (3.2 km) of the coast groundwater is basal in both the Koloa

and underlying Napali formations. Attempts have been made to develop Koloa groundwater with wells, but capacities are small. Several successful wells are in the Napali formation. A network of collection and transmission structures divert stream water for irrigation.

ENVIRONMENT. Sugarcane is irrigated on the modestly sloping lower portion of the System, especially on the Koloa formation but also on ridges of the Napali formation.

Aquifer System: Hanapepe (20304)

BOUNDARIES. The System is equivalent to the Hanapepe drainage basin. Total area is 22 miles^2 (35.4 km^2).

HYDROLOGY. Average annual rainfall is 127 in. (3 225.8 mm). Hanapēpē is one of Kaua'i's major rivers. It mostly drains dike water in the Napali, but several large exposures of Koloa rocks contribute perched water. Average flow in the river is 56 mgd (2.45 m^3/s) downstream of diversions. The Hanapēpē Ditch diverts an average of 24 mgd (1.05 m^3/s).

GEOLOGY. The Napali formation dominates the regional geology. In the interior the Olokele formation replaces the Napali. Large isolated sectors of Koloa cover the Napali in the mid and lower valley. To the east of Hanapepe lies the Koloa Aquifer System where the Koloa formation becomes the dominant rock. The lower valley is filled with sediments. Old alluvium reaches far upstream.

GROUNDWATER. Successful wells exploit the Napali formation in the lower valley. The Koloa formation is not developed for water. Stream flow is diverted for irrigation of sugarcane.

ENVIRONMENT. Sugarcane is grown in the lower part of the Aquifer System. Hanapēpē, a population center, surrounds the mouth of the Hanapēpē River.

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APPENDIX CONTENTS

Appendix Figures

AQUIFER CLASSIFICATION EXPLANATION

AQUIFER AND STATUS CODES*

	Aquifer Code	=	Island
		+	Aquifer Sector
		+	Aquifer System
		+	Aquifer Type
Thus,	20301122	=	Aquifer Code
where	2	=	Kauai
	03	=	Waimea
	01	=	Kekaha
	1	=	basal
	2	=	confined
	2	=	dike
and			
	(11111)	=	Status Code
where	1	=	currently used
	1	=	drinking
	1	=	fresh, <250 mg/l Cl^-
	1	=	irreplaceable
	1	=	high vulnerability to contamination

IS.	AQUIFER SECTOR	AQUIFER SYSTEM
2	01 Lihue	01 Koloa
		02 Hanamaulu
		03 Wailua
		04 Anahola
		05 Kilauea
	02 Hanalei	01 Kalihiwai
		02 Hanalei
		03 Wainiha
		04 Napali
	03 Waimea	01 Kekaha
		02 Waimea
		03 Makaweli
		04 Hanapepe

*Where aquifers are in vertical sequence, the Aquifer and Status Codes are separated by a division line in order of occurrence, with the uppermost aquifer appearing first.

AQUIFER TYPE:	Hydrology†	
1	Basal	Fresh water in contact with seawater
2	High Level	Fresh water not in contact with seawater
1	Unconfined	Where water table is upper surface of saturated aquifer
2	Confined	Aquifer bounded by impermeable or poorly permeable formations, and top of saturated aquifer is below groundwater surface
3	Confined or Unconfined	Where actual condition is uncertain

AQUIFER TYPE:	Geology‡	
1	Flank	Horizontally extensive lavas
2	Dike	Aquifers in dike compartments
3	Flank/Dike	Indistinguishable
4	Perched	Aquifer on an impermeable layer
5	Dike/Perched	Indistinguishable
6	Sedimentary	Nonvolcanic lithology

†1st two digits from hydrologic descriptors (pts. 1, 2).
‡Last digit from geologic descriptor.

STATUS CODE (GROUNDWATER)

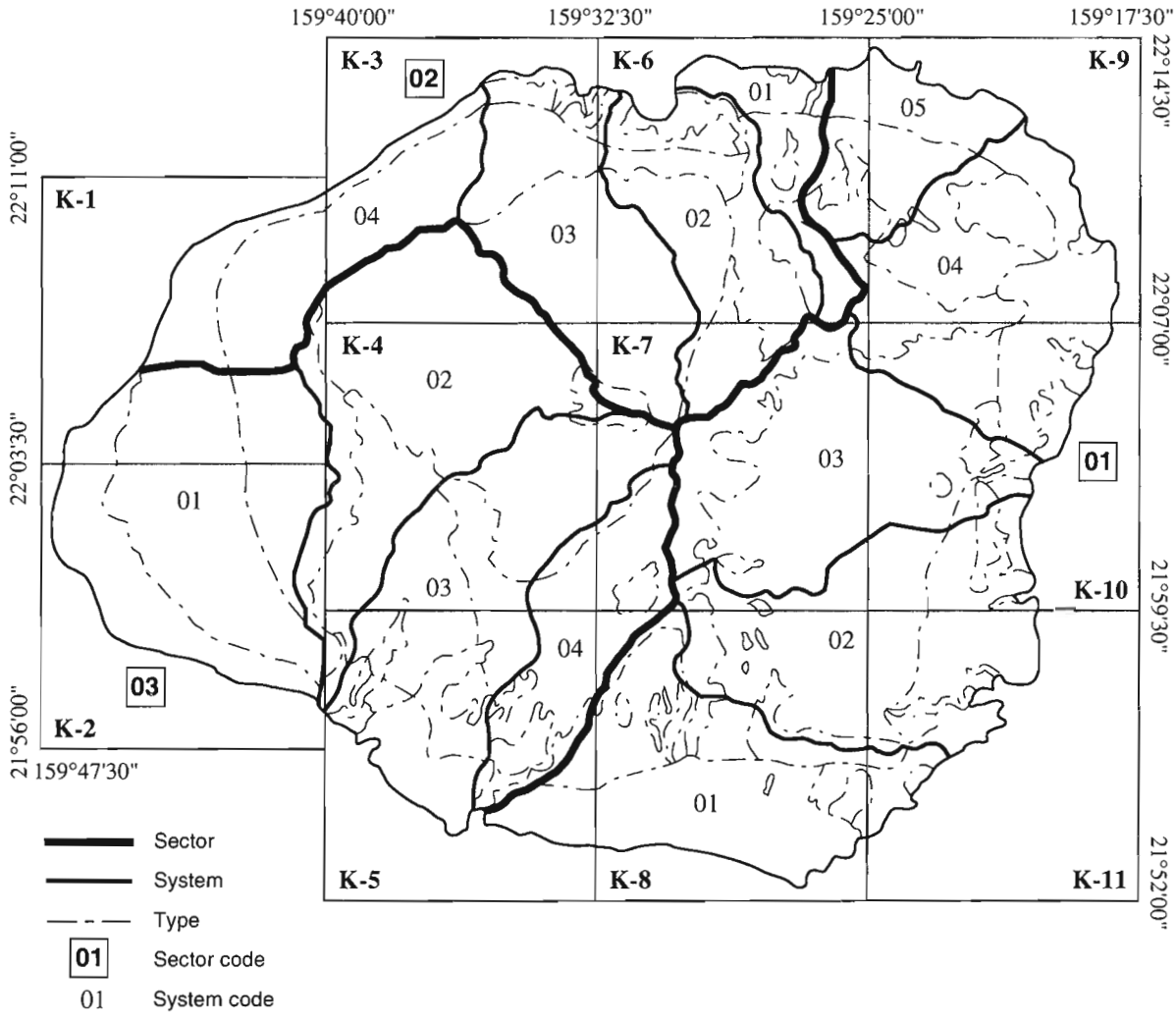
Development Stage
1 Currently used
2 Potential use
3 No potential use

Utility
1 Drinking
2 Ecologically important
3 Neither

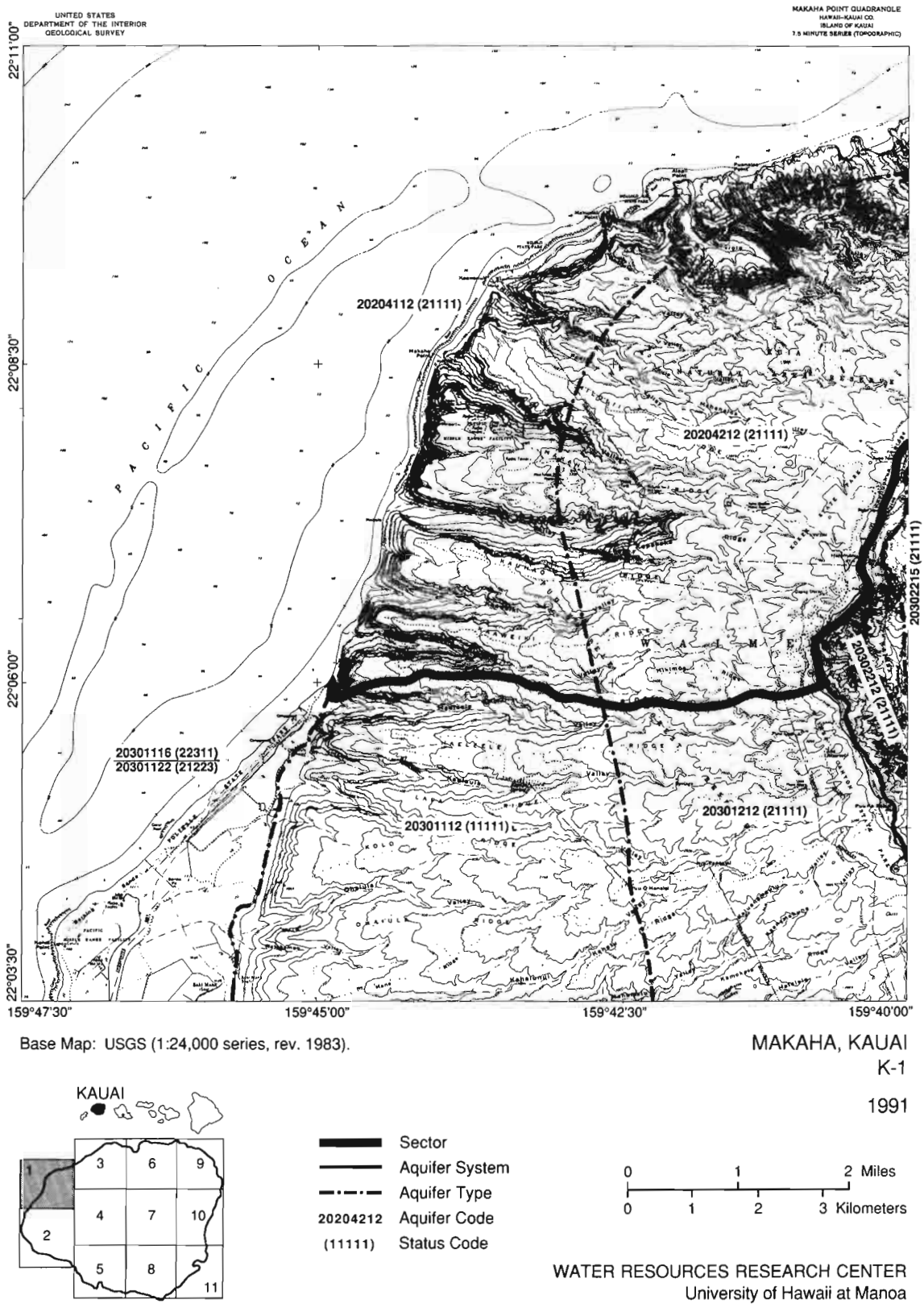
Salinity (mg/l Cl^-)
1 Fresh (<250)
2 Low (250-1000)
3 Moderate (1000-5000)
4 High (5000-15,000)
5 Seawater (>15,000)

Uniqueness
1 Irreplaceable
2 Replaceable

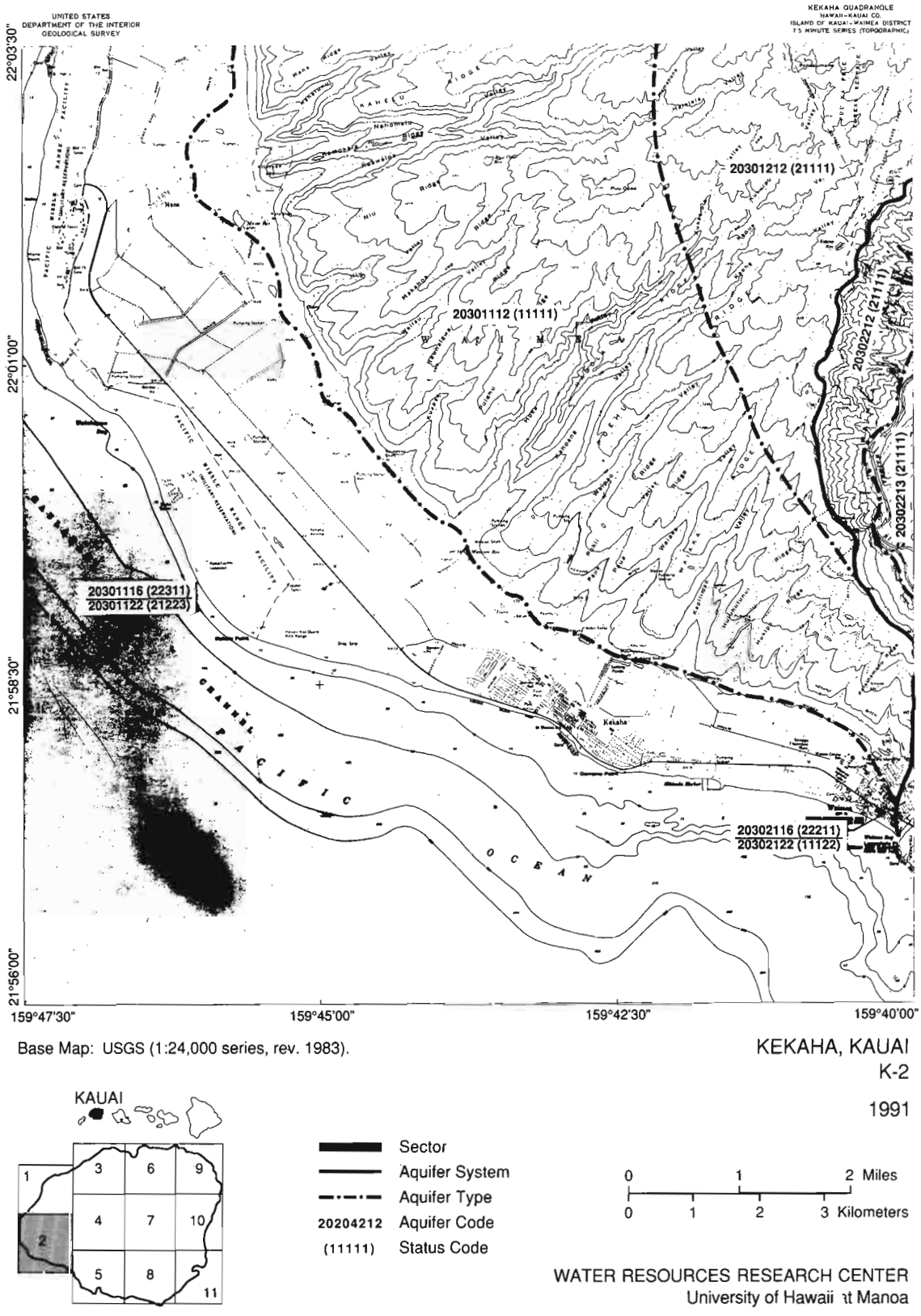
Vulnerability to Contamination
1 High
2 Moderate
3 Low
4 None



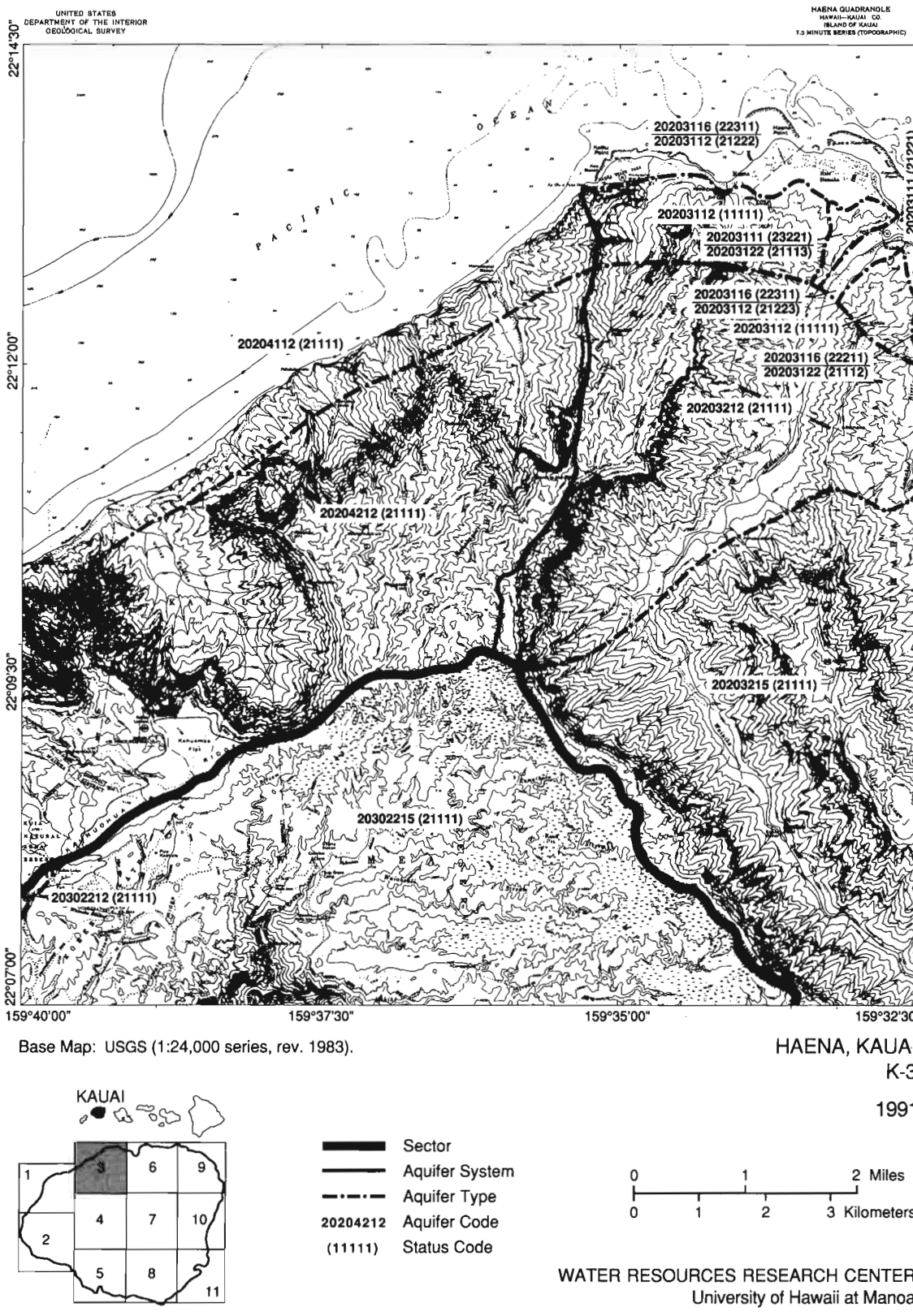
Appendix Figure A.1.0. Layout of Sectors, Systems, and Types for Kaua'i, Hawai'i



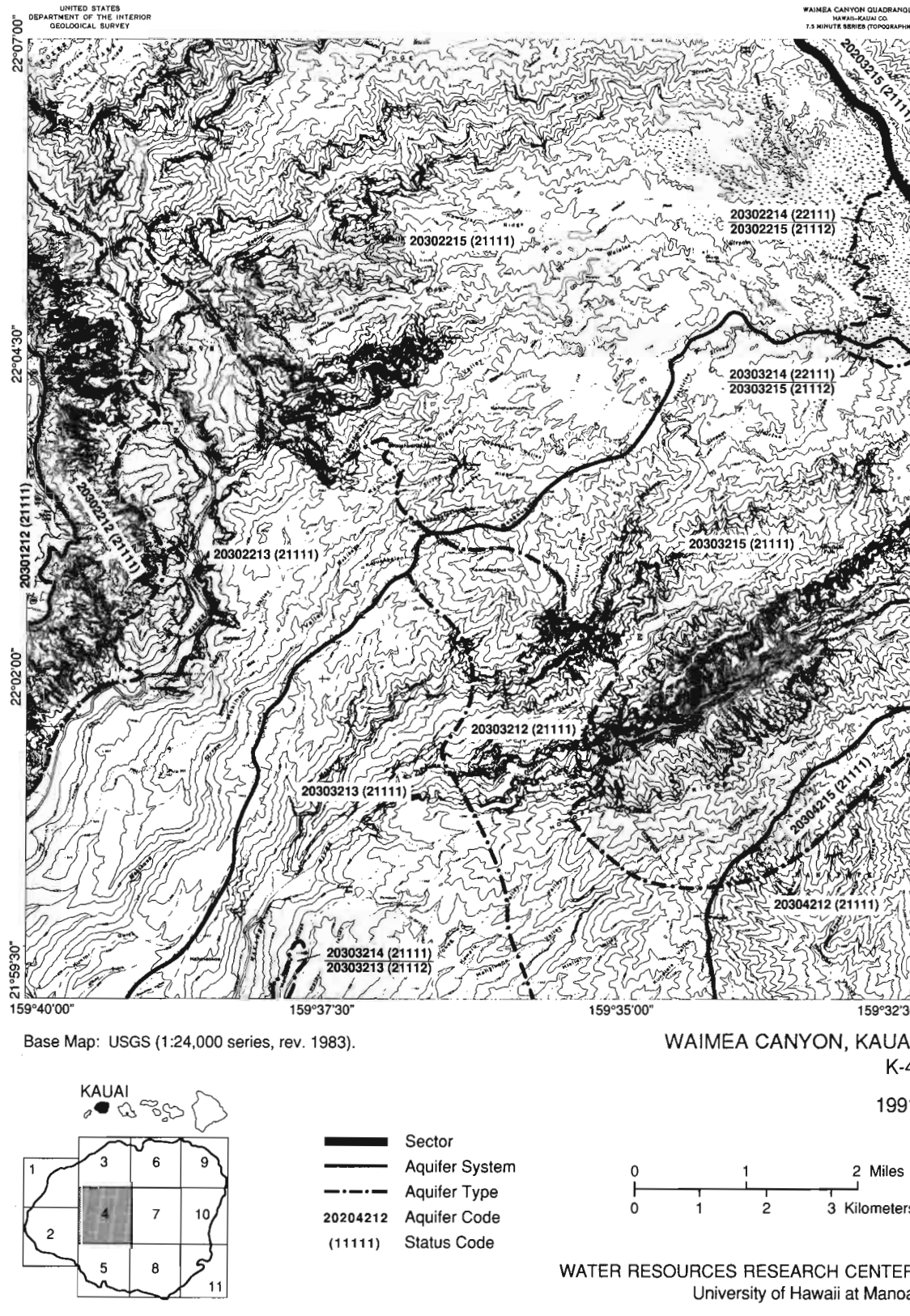
Appendix Figure A.1.1. Aquifer classification map, Makaha Point, Kaua'i, Hawai'i



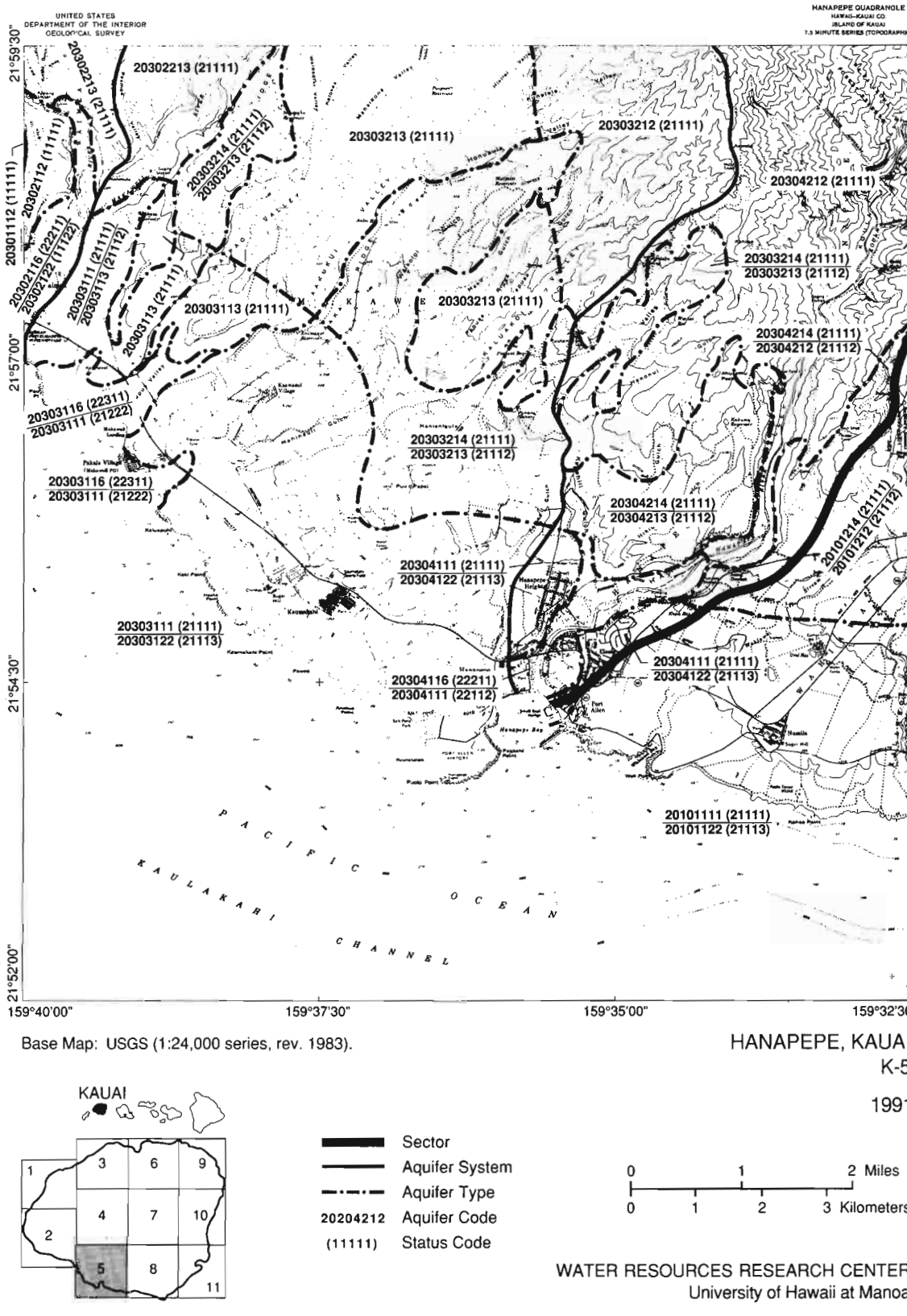
Appendix Figure A.1.2. Aquifer classification map, Kekaha, Kaua'i, Hawai'i



Appendix Figure A.1.3. Aquifer classification map, Haena, Kaua'i, Hawai'i

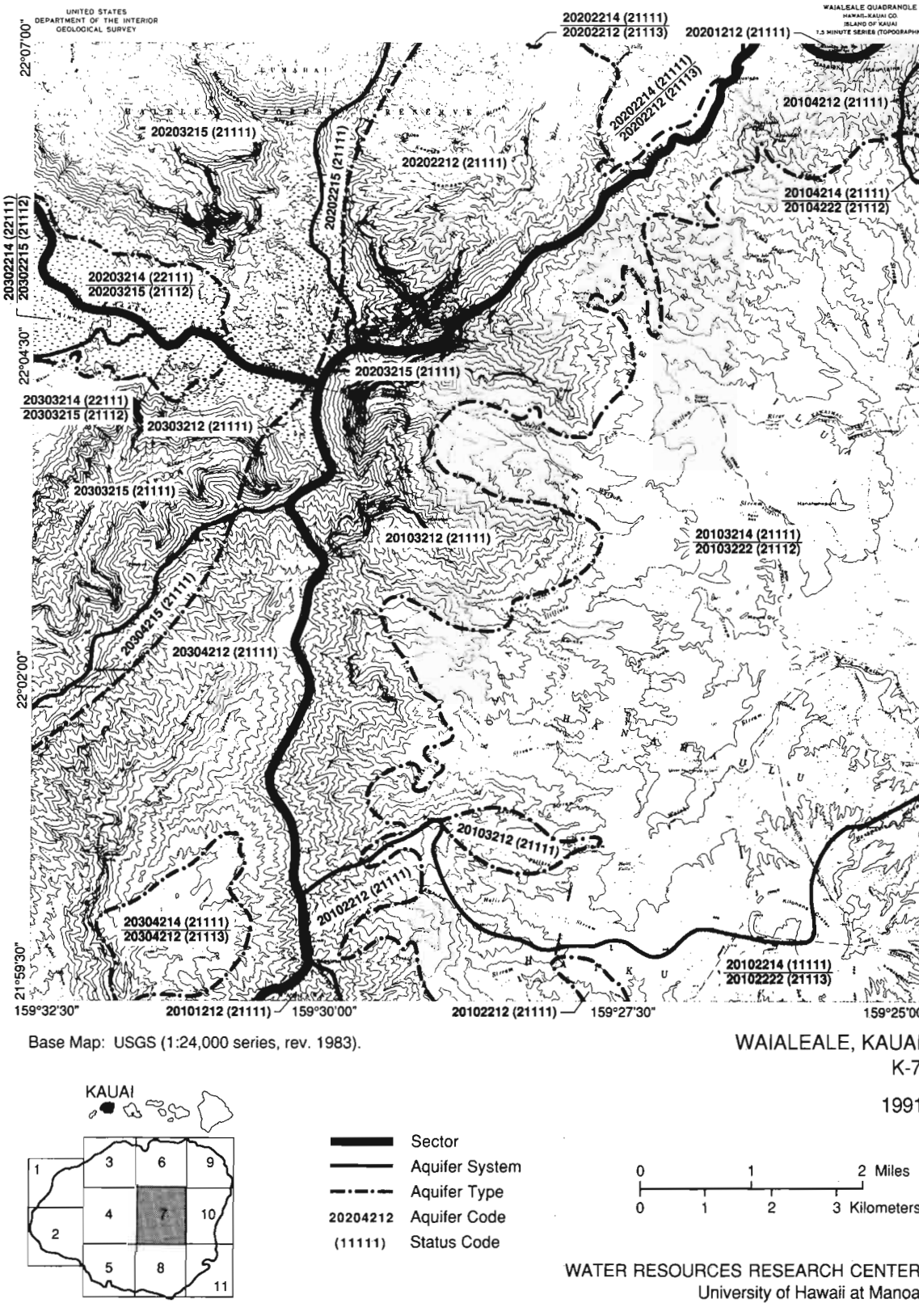


Appendix Figure A.1.4. Aquifer classification map, Waimea Canyon, Kaua'i, Hawai'i



Appendix Figure A.1.5. Aquifer classification map, Hanapepe, Kaua'i, Hawai'i

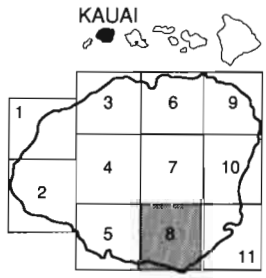
Appendix Figure A.1.6. Aquifer classification map, Hanalei, Kaua'i, Hawai'i



Appendix Figure A.1.7. Aquifer classification map, Waialeale, Kaua'i, Hawai'i

Base Map: USGS (1:24,000 series, rev. 1983).

KOLA, KAUAI
K-8
1991



Sector
Aquifer System
Aquifer Type
20204212 Aquifer Code
(11111) Status Code

0 1 2 Miles
0 1 2 3 Kilometers

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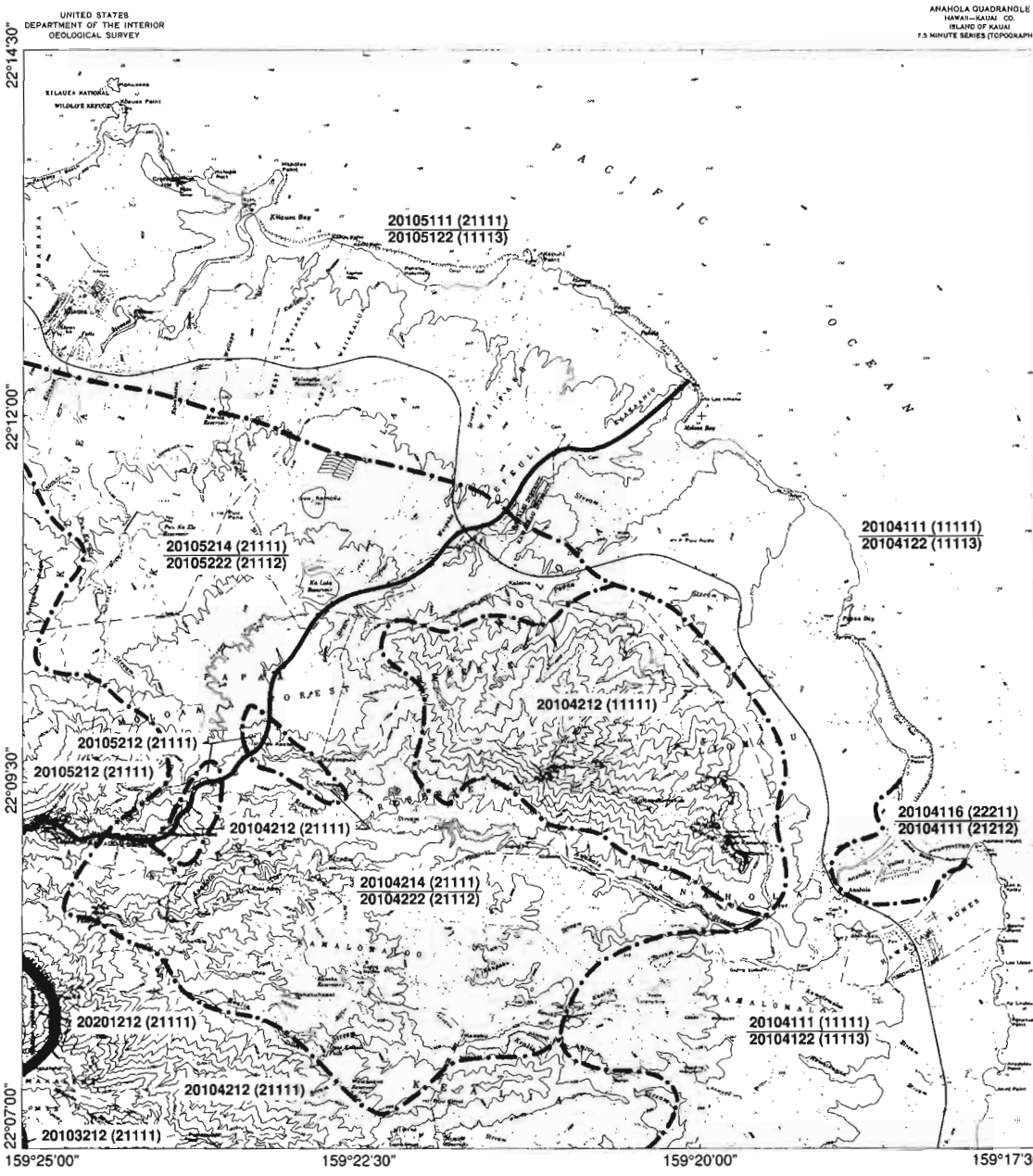
Appendix Figure A.1.8. Aquifer classification map, Koloa, Kaua'i, Hawai'i



Base Map: USGS (1:24,000 series, rev. 1983).

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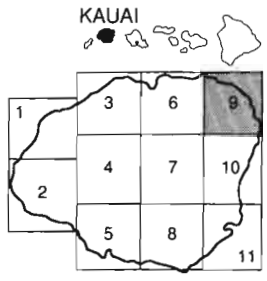
K-9

1991



Sector
Aquifer System
Aquifer Type
20204212 Aquifer Code
(11111) Status Code

0 1 2 Miles
0 1 2 3 Kilometers

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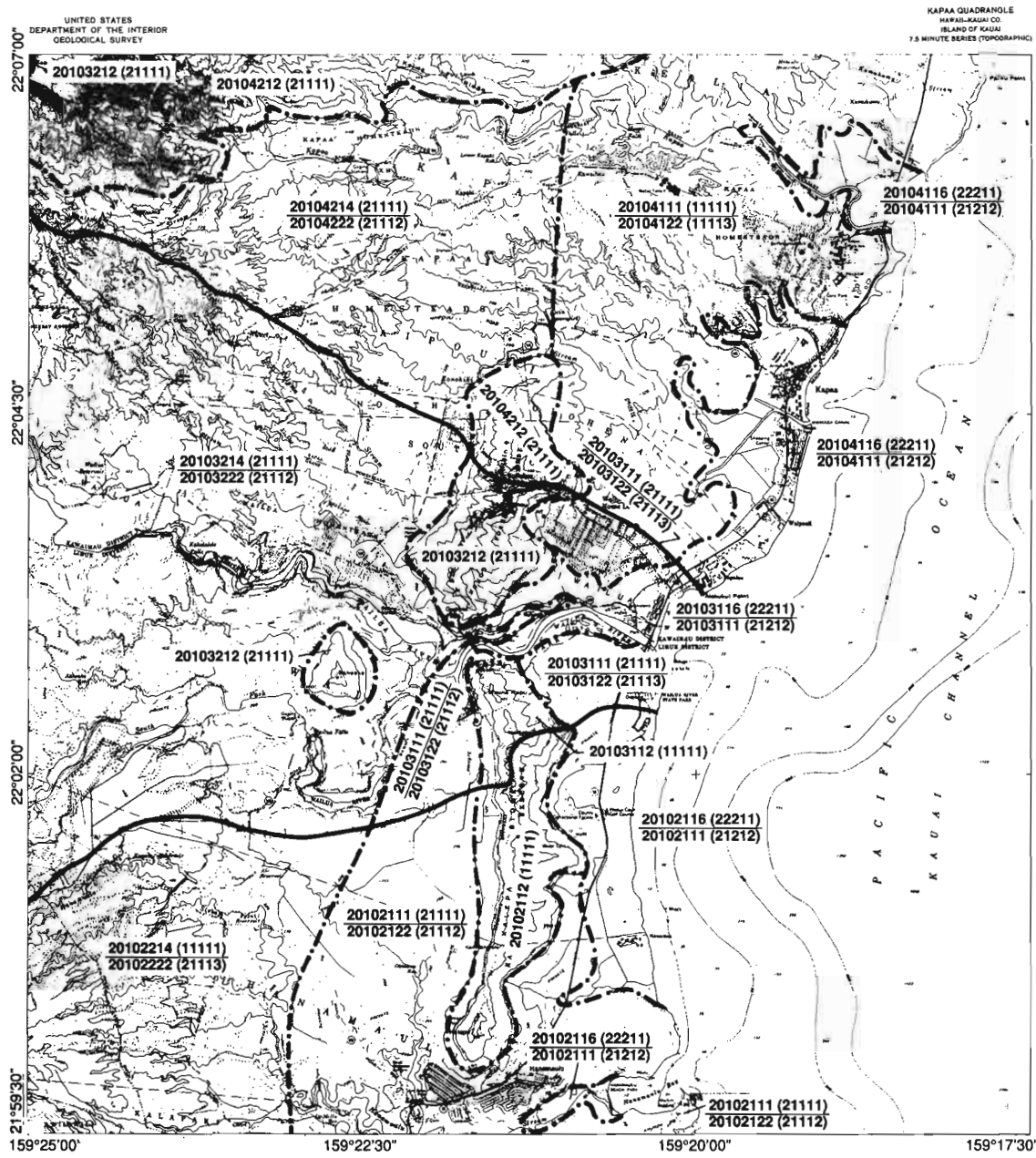
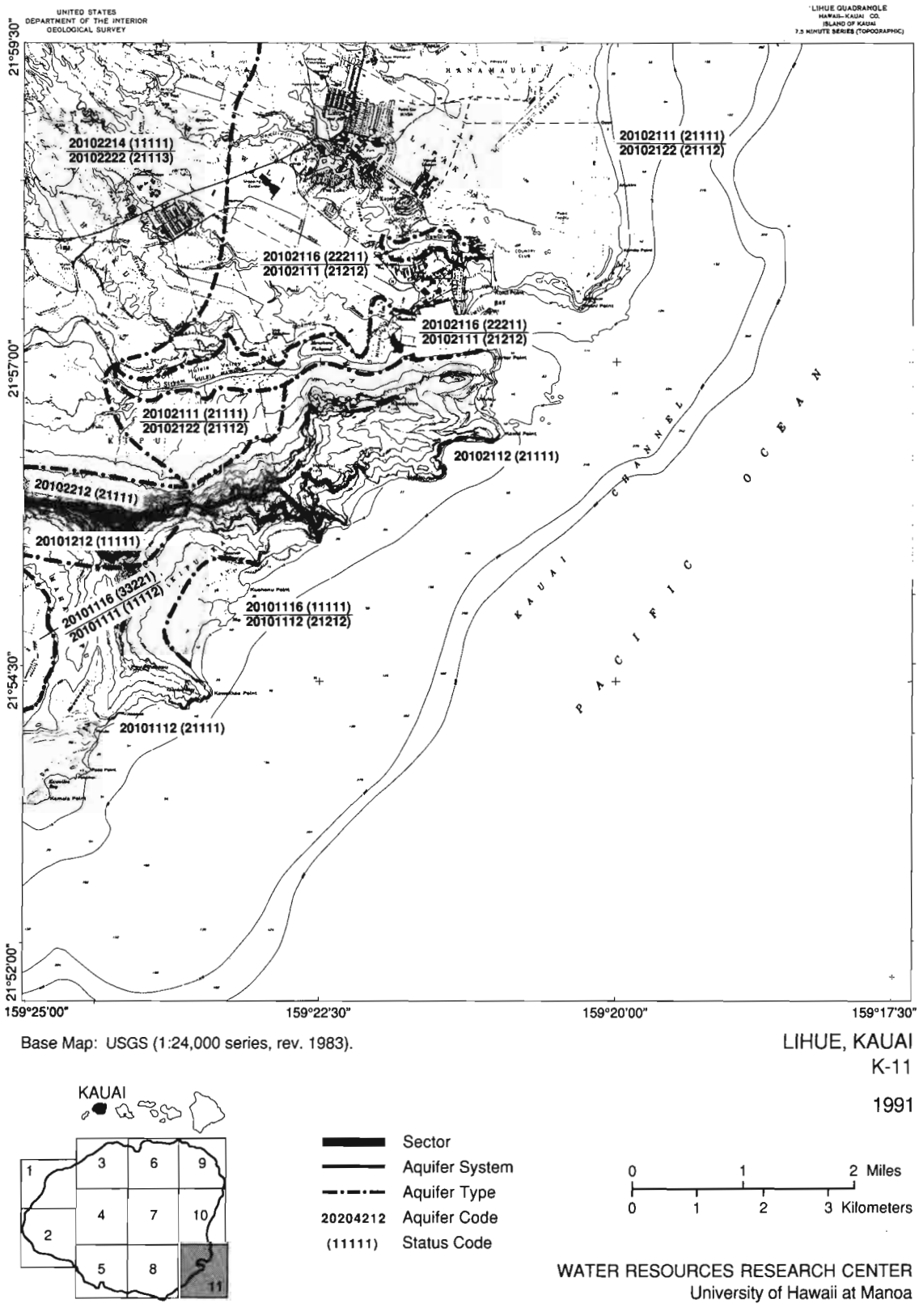
Appendix Figure A.1.9. Aquifer classification map, Anahola, Kaua'i, Hawai'i



Appendix Figure A.1.10. Aquifer classification map, Kapaa, Kaua'i, Hawai'i



Appendix Figure A.1.11. Aquifer classification map, Lihue, Kaua'i, Hawai'i