REPORT DOCUMENTATION FORM

WATER RESOURCES RESEARCH CENTER
University of Hawaii at Manoa

[1] SERIES NUMBER	Technical Report No. 187	[2] COWRR FIELD-GROUP	02F; 07C
[3] TITLE Aquifer identification and classification for Molokai: Groundwater protection strategy for Hawaii		[4] REPORT DATE	October 1992
		[5] NO. OF PAGES	viii + 31
		[6] NO. OF TABLES	1
		[7] NO. OF FIGURES	7
[8] AUTHORS John F. Mink L. Stephen Lau		[9] GRANT AGENCY State of Hawaii Department of Health	
		[10] CONTRACT NUMBER	91-330

[11] DESCRIPTORS: *aquifers, *aquifer characteristics, *aquifer systems, groundwater

IDENTIFIERS: *aquifer classification, *Aquifer Code, *groundwater protection strategy, Class I groundwaters, Molokai, Hawaii

[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 fourth report provides Aquifer Codes and Status Codes for the island of Molokai. 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 Molokai classification includes 4 Aquifer Sectors, 16 Aquifer Systems, and 40 Aquifer Types.

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NOTE: Please indicate **TR 187** on check or money order for our reference.

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

John F. Mink
L. Stephen Lau

Technical Report No. 187

October 1992

Project Completion Report
for
Identification of Class I: Special Groundwaters
Highly Vulnerable to Contamination, Moloka'i

Contract No.: 91-330

Principal Investigator: L. Stephen Lau

Project Period: 15 March 1991–30 September 1992

Funding Agency: Department of Health, State of Hawaii

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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 fourth report provides Aquifer Codes and Status Codes for the island of Moloka'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 Moloka'i classification includes 4 Aquifer Sectors, 16 Aquifer Systems, and 40 Aquifer Codes.

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INTRODUCTION

The aquifer classification protocol was invented to provide a framework within which to identify and describe groundwater resources throughout the state of Hawaii. The framework is necessary because a standard locational and descriptive nomenclature has not been uniformly applied by investigators when referring to groundwater resources. The classification allows hydrologists, engineers, decision makers and laymen to avoid misunderstandings and confusion by using a common reference.

The intent of the classification is to simplify groundwater hydrology so that discussion at all levels of scientific-engineering comprehension can take place. It is designed for practical application, and therefore boundaries for the subdivisions must be drawn, even though the boundaries are not exact because conditions of actual groundwater occurrence and behavior are generally only poorly understood. For example, where hydrogeological conditions have not been unravelled, boundaries are drawn along topographic divides to encompass whole drainage areas even though these divides most often are weak expressions of subsurface hydrogeology. Virtually all boundaries for the classification in Moloka'i 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 Moloka'i. Classification is based on 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. Not identified but following Type in the hierarchy is the Aquifer Unit, which is defined as an identifiable unit within an Aquifer Type.

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.

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, 4 03 01 111, 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 in 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 Moloka‘i is

4	Moloka‘i (Island)
02	Central (Aquifer Sector)
01	Ho‘olehua (Aquifer System)
111	Basal, unconfined; flank (Aquifer Type)

The Aquifer Code for the above is 4 02 01 111. There can be no repetition elsewhere in the state.

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.

A total of 40 Aquifer Codes has been assigned to the island: 4 in West Moloka‘i, 5 in Central Moloka‘i, 13 in Southeast Moloka‘i, and 18 in Northeast Moloka‘i (Fig. 1 and appendix figures).

Table 1 lists the Aquifer Codes for the island of Moloka‘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.

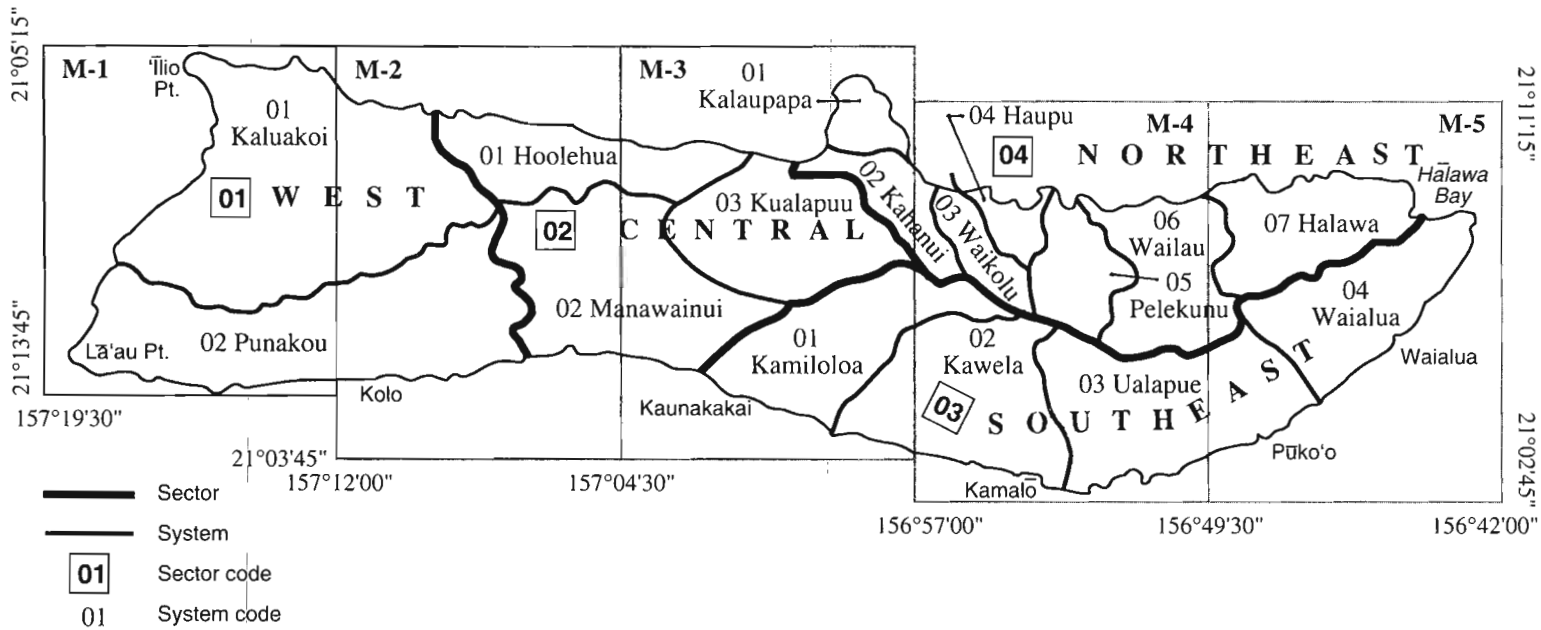

Figure 1. Aquifer codification by Sector and System for Moloka'i, Hawai'i

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

Moloka'i Is.	Aquifer Sector		Aquifer System		Aquifer Type	Aquifer Code	Status Code	Quadrangle No.
4	01	West	01	Kaluakoi	111	40101111	33321	1
					112	40101112	33321	1, 2
			02	Punakou	111	40102111	33321	1
					112	40102112	33321	1, 2
	02	Central	01	Hoolehua	111	40201111	21211	2, 3
			02	Manawainui	111	40202111	21211	2, 3
					116/111	40202116/40202111	12211/21212	2, 3
			03	Kualapuu	214/112	40203214/40203112	11111/11111	3
					214/212	40203214/40203212	11111/11111	3, 4
	03	Southeast	01	Kamiloloa	214/212	40301214/40301212	21111/21111	3, 4
					111	40301111	11111	3, 4
					116/111	40301116/40301111	11111/11111	3
			02	Kawela	214/212	40302214/40302212	22111/21111	4
					214/111	40302214/40302111	21111/11111	3, 4
					116/111	40302116/40302111	11111/11111	3, 4
			03	Ualapue	214/212	40303214/40303212	22111/21111	4
					212	40303212	21111	4, 5
					111	40303111	11111	4, 5
					116/111	40303116/40303111	11111/11111	4, 5
			04	Waialua	214/212	40304214/40304212	22111/21111	5
					111	40304111	11111	5
					116/111	40304116/40304111	11111/11111	5
	04	Northeast	01	Kalaupapa	111	40401111	21211	3
			02	Kahanui	112	40402112	11111	3, 4
					214/212	40402214/40402212	21111/21111	3, 4
			03	Waikolu	112	40403112	21111	4
					212	40403212	11111	4
					214/212	40403214/40403212	22111/11111	4
			04	Haupu	212	40404212	21111	4

TABLE 1.—*Continued*

Moloka'i Is.	Aquifer Sector	Aquifer System	Aquifer Type	Aquifer Code	Status Code	Quadrangle No.
4	04 Northeast	05 Pelekunu	212	40405212	21111	4
			116 / 212	40405116 / 40405212	22111 / 21111	4
		06 Wailau	212	40406212	21111	4, 5
			214 / 212	40406214 / 40406212	22111 / 21111	4
			112	40406112	21111	4, 5
			116 / 112	40406116 / 40406112	22111 / 21111	4
		07 Halawa	214 / 212	40407214 / 40407212	22111 / 21111	5
			214 / 112	40407214 / 40407112	22111 / 21111	5
			112	40407112	21111	4, 5
			111	40407111	21111	5
			116 / 111	40407116 / 40407111	22111 / 21111	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/1 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 to 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 Hawai'i 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 Island 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 employing 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.

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 40301111 (11111) defines an aquifer in Moloka'i, Southeast Sector, Kamiloloa System, in which the groundwater is basal and unconfined in flank lavas. The last five digits within parentheses tell that the aquifer is currently used to supply drinking water having less than 250 mg/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 groundwaters in Moloka'i have 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 Moloka'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 Moloka'i

The elemental identification and description of the geology and hydrology of the island of Moloka'i is the work of Stearns and Macdonald (1947). Subsequent geological studies have concentrated on the basic characteristics of the rocks with some attention given to regional geological features. Since the initial hydrological discussions, a large quantity of data relating to stream flow and groundwater occurrence has accumulated, and revised rainfall maps of the island have been drawn.

The bulk of Moloka'i was formed by the coalescence of two volcanic shields, the larger in the east and the smaller in the west. Both volcanoes were active simultaneously, but the West Molokai volcano became extinct before the East Molokai volcano, allowing for the emplacement of East Molokai lavas on eastern slope of the West Molokai shield. Kalaupapa is a small, separate volcano that erupted long after the main volcanism.

The West Molokai volcanics consist of a single formation predominantly consisting of the primitive basalts and olivine basalts that constitute the main shield of all Hawaiian volcanoes. The East Molokai volcanics are divided into two members, the Lower member composed of primitive shield-building basalts and the Upper member consisting of alkalic basalts transitional from the tholeiitic primitive basalts. The alkalic basalts form a relatively thin carapace on the early basalts but do not constitute significant aquifers. They are less permeable than the primitive basalts and often contain layers on which groundwater perches.

West Moloka'i

West Moloka'i covers about one third of the island's present land mass. The presumed center of volcanic activity was around Mauna Loa where a gravity high has been mapped and thermal groundwater has been encountered.

The West Molokai volcanics erupted mainly along a major westerly to southwesterly rift zone and minor northwesterly rift. The result is two broad structural arches congruent with rift zones. The division between the two Aquifer Systems comprising the West Aquifer Sector follows the axis of the southwesterly rift zone.

Eruptions of tholeiitic basalts covered by a thin cap of alkalic olivine basalt constitute the shield. Associated with the northwesterly rift zone are 16 cinder and spatter cones. Dikes are exposed along the northern coast. A dike swarm parallel to the southwesterly rift is visible at the head of Waiahewahewa Gulch.

Erosion of West Moloka'i is muted because of low elevation and sparse rainfall. Most gulches are shallow and narrow. A 500 ft (152.4 m) high sea cliff forms much of the north coast, but the south coast has not been steepened by wave erosion.

Sediments consist chiefly of calcareous sand along the coasts. Strong trade winds have created large dunes in the Kaluakoi Aquifer system downwind of Mo'omomi Beach. Some of these dunes are 60 ft (18.3 km) high and half a mile (0.8 km) wide. The sand deposits extend as far as 4 miles (6.4 km) inland.

Streams are active only during intense rain showers and often discharge sediment-laden waters into the sea. All of the groundwater is nonpotable. With care, some may be recoverable for use in irrigation.

East Moloka'i

East Moloka'i, encompassing about two thirds of the island, is a volcanic pile which progressed through the shield-building and caldera-filling stages of development before undergoing a period of quiescence and renewed post-shield volcanic activity.

East Moloka'i was formed along two principal rift zones extending from the caldera in Pelekunu and Wailau valleys. One rift strikes west-northwest through Waikolu Valley on to the north coast at Kalaupapa, while the other strikes eastward toward Halawa Valley. The original caldera was large, about 4.5 miles (7.2 km) by 1.5 miles (2.4 km). Massive lava flows, pyroclastics and other poorly permeable deposits associated with the caldera perch groundwater which drains as springs, especially in Pelekunu. Abundant rainfall supports perennial streams that have carved the great windward valleys perpendicular to the dike complex of the caldera.

The Lower member of the East Molokai volcanics is composed of thousands of layers of basalt. This formation on a regional scale is highly permeable and in it the principal aquifers are found. The Upper member is also basaltic but less permeable. Although forming an extensive cap on the Lower member, it is not deep enough to carry regional aquifers.

The south side of East Moloka'i is the eroded remnant of the lava pile that formed the original flank of the volcano. Gulches have cut deep into the Upper member to expose the basement consisting of the Lower member.

The Upper member is the terminal formation that accompanied the main volcanic activity and is not separated from the Lower member by a significant unconformity. Following dormancy of the original volcano, the volcanic dome was deeply eroded and the island subsided. The Kalaupapa volcano erupted about a million years after the main activity ceased.

The windward valleys of East Moloka'i are alluviated with boulders and cobbles of basalt. The beaches tend to be formed of boulders and basaltic sand.

On the lee side, soil washed from volcanic slopes has produced extensive mud flats. Deposition of mud was greatly accelerated by the introduction of hooved animals and the subsequent destruction of upland forests.

The great valleys of windward East Moloka'i are rich in high-level groundwater resources. Streams are perennial because they drain the high-level aquifers. In leeward East Moloka'i high-level groundwater occurs near the crest of the mountain range and basal groundwater toward the coast. Although the Kualapuu aquifer in the Kualapuu Aquifer System of Central Moloka'i is the most critical potable water resource at this time because of its accessibility, the bulk of the potable resources of the island occur in high-level and basal aquifers of East Moloka'i.

AQUIFER SECTOR: WEST (401)

Aquifer System: Kaluakoi (40101)

BOUNDARIES. The System covers the northern two thirds of the extreme western portion of the island. Total area is 44.6 miles^2 (115.5 km^2). The eastern boundary follows the trace of the East Molokai volcanics resting on West Molokai volcanics. The south boundary is the topographic divide along the axis of the southwest rift zone. The northern and western boundaries are the sea.

GEOLOGY. All of the rocks except for hydrogeologically unimportant patches of sediment belong to the West Molokai volcanics. Dikes visible along the north coast suggest that most of the System is in a rift zone. The dune sands blown inland from the north coast are not a significant control on hydrology.

HYDROLOGY. The region is arid, suffering an average annual rainfall of less than 22 in. (558.8 mm). No streams are perennial, and the shallow gulches carry water only during heavy rain showers.

GROUNDWATER. Groundwater is predominantly basal and occurs in both flank lavas and dike compartments. To date no fresh groundwater has been discovered, and it is improbable that domestic quality water is developable. Brackish water permeates the entire region, most of it having salinity in excess of 1000 mg/l chloride. Test borings have been drilled, but groundwater is not yet being developed.

ENVIRONMENT. At one time pineapple was grown, but today some diversified agriculture is pursued. Ranching continues. A tourist resort is located along the western shore. Small trees and large shrubs grow in the gulches, but the higher land supports only coarse grass and shrubs.

Aquifer System: Punakou (40102)

BOUNDARIES. Total area is 35.2 miles^2 (91.2 km^2). On the east the boundary follows the contact between the East Molokai and the West Molokai volcanics. The boundary separating Punakou from the Kaluakoi Aquifer System is the axis of the southwest rift zone. The south and western boundaries is the sea.

GEOLOGY. The southwest rift zone constitutes the System. The dike complex is exposed at the head of Waiahewahewa Gulch. A narrow rim of sediments lines the coast but does not behave as a caprock.

HYDROLOGY. Average annual rainfall is small and concentrated in the winter months. At other times the climate is arid. No streams are perennial. The gulches are water courses only during winter rains. Average annual rainfall is only 17 in. (431.8 mm).

GROUNDWATER. Basal groundwater, none of it potable, saturates dike compartments and perhaps flank lavas nearer the coast. None is currently being developed. A small amount may be useful for irrigation.

ENVIRONMENT. Grasses and shrubs cover those areas that are not barren. A tourist destination has been proposed in the western portion of the System, but access to a water supply is a serious problem. At one time sand mined from the beaches of western Moloka‘i and local cinder were exported to O‘ahu for construction purposes.

AQUIFER SECTOR: CENTRAL (402)

Aquifer System: Hoolehua (40201)

BOUNDARIES. The System consists of about 14 miles^2 (36.3 km^2) of the Ho‘olehua Plain that drains to the north. To the west is the Kaluakoi Aquifer System and to the east the

Kualapuu Aquifer System. The topographic divide of the Ho'olehua Plain is the southern boundary.

GEOLOGY. The basement rock is the basaltic Lower member of the East Molokai volcanics, but much of the region is covered by the andesitic rocks of the Upper member. Flank lava flows predominate. The western reach of the coastline has spotty calcareous sand deposits while toward the east the high cliffs of the north Moloka'i coast appear.

HYDROLOGY. Average annual rainfall is 29 in. (736.6 mm). The region is semi-arid and does not include any perennial streams. Gulches are shallow.

GROUNDWATER. The System is underlain by moderately brackish groundwater in a basal lens. Its quality is good for most agriculture but cost of development would be high. At present no groundwater is being developed.

ENVIRONMENT. Some of the level land is used for farming, replacing pineapple that once covered the area.

Aquifer System: Manawainui (40202)

BOUNDARIES. The southern draining portion of the Ho'olehua Plain is the Manawainui Aquifer System. On the west is the Punakou Aquifer System, and on the east both the Kualapuu and Kamiloloa Aquifer Systems. The southern boundary is the sea. Total area is 25 miles^2 (64.75 km^2).

GEOLOGY. Like the Hoolehua Aquifer System, Manawainui includes the Upper and Lower members of the East Molokai volcanics. The lower member forms the surface in the western quadrant inland of a large sedimentary coastal plain. The Upper member forms a relatively thin cover elsewhere. Manawainui Gulch cuts through the Upper member to expose the Lower member. The coastal plain of sediments, as much as half a mile wide, is a partially effective caprock.

HYDROLOGY. Manawainui is the largest and deepest gulch in the System. It rises in the highlands bordering the west divide of Waikolu Valley. At its headwaters it may be weakly perennial, but downstream it is dry except during rain showers. Other gulches are shallow and non-perennial. Average annual rainfall in the System is 18 in. (457.2 mm), resulting in semi-arid conditions.

GROUNDWATER. A basal lens in flank lavas underlies the System. Low salinity groundwater, though not potable by Hawai'i standards, occurs near the boundary with the Kualapuu Aquifer System. Underflow from Kualapuu, where the head is 5 ft (1.52 m) higher than in Manawainui, spills into the System and eventually discharges along the south coast as springs and where dug wells exploit it. The maximum basal head in Manawainui is about 5 ft.

Irrigation and aquaculture quality water is developable. Wells yielding brackish water have been drilled and are in use.

ENVIRONMENT. Pineapple once covered the region. Large-scale farming is now practiced. Aquaculture takes advantage of easily developable groundwater along the coast.

Aquifer System: Kualapuu (40203)

BOUNDARIES. The boundaries of the Kualapuu Aquifer System attempt to define the aquifer having a head of more than 10 ft (3 m) lying to the east of the Kualapuu volcanic cone. Where possible the boundaries reflect data from drilled wells. Total area in the System is about 18 miles^2 (46.6 km^2). On the east the System reaches to the Kahanui watershed. The southern and western boundaries connect the outermost significant volcanic vents aligned in a east-west direction. On the north are cliffs fronting the sea.

GEOLOGY. The Lower member of the East Molokai volcanics is exposed in valleys but the Upper andesitic member covers the interfluves. Numerous volcanic vents suggest that the East Moloka‘i rift zone, highly visible in Waikolu Valley, continues as a marginal dike zone as far west as Kualapu‘u.

HYDROLOGY. Near the Kahanui boundary in the mountainous area where average annual rainfall is nearly 60 in. (1 524 mm) some streams are weakly perennial. Perched water in the Upper member drains as springs, a few of which are useful. No perennial flows reach the main region toward the town of Kualapu‘u in the west. For the entire System, average annual rainfall is 39 in. (990.6 mm).

GROUNDWATER. The System is the furthest extension westward from the wet northeast of groundwater meeting potability standards. At the moment the Kualapuu aquifer is the most important in Moloka‘i because of its central location and accessibility. The aquifer is basal but groundwater occurrence is controlled by dikes extending westward from the major rift zone in the northeast. Heads are too high to be attributable to basal water in an uninterrupted flank lava aquifer. High-level dike water, on the other hand, probably occurs in the mountainous region near the Kahanui drainage basin. Successful potable water wells have been drilled in the basal sector and their use has been vital to the domestic water supply of central and western Moloka‘i. More wells have been proposed.

ENVIRONMENT. At one time pineapple was the principal agricultural activity. To some extent diversified farming has replaced it. The region is semi-humid and probably would have been covered with trees under natural conditions. Forests cover the uplands. Tourist developments have been planned.

AQUIFER SECTOR: SOUTHEAST (403)

Aquifer System: Kamiloloa (40301)

BOUNDARIES. The System falls between Kaunakakai and Ōnini gulches on the lee side of Eastern Moloka'i. Total area is about 17 miles^2 (44 km^2).

GEOLOGY. Most of the surface is covered by the Upper member of the East Molokai volcanics. The Lower member, however, constitutes the important aquifers. A narrow coastal plain of sediments behaves as a weak caprock. In the mountains where the System meets Waikolu and Kahanui, dikes of the rift zone may be present at depth.

HYDROLOGY. Streams are not perennial in their lower reaches but probably carry water most of the time in the wet mountains. Rainfall for the entire System averages 35 in. (889 mm) per year.

GROUNDWATER. High-level dike water likely occurs in the most inland part of the System but the water table nevertheless would be very deep below the ground surface. Most of the System is underlain with a basal lens in flank lavas. Potable water is developable inland, and high quality irrigation water nearer the coast. Numerous dug wells extract useable groundwater on and at the edge of the coastal plain.

ENVIRONMENT. The System includes Kaunakakai, the population center of the island. Farming and ranching are practiced. Dry-land growth covers the lower slopes and a wet forest the higher mountainous region.

Aquifer System: Kawela (40302)

BOUNDARIES. Between Ōnini and Kamalō gulches the System embraces about 24 miles^2 (62.2 km^2), reaching from the coast to the upper margin of Waikolu Valley.

GEOLOGY. Except where deep gulches expose basalts of the Lower member of the East Molokai volcanics, the surface of the System consists of andesites of the Upper member. Except near the coast, however, the contact between the two members lies above sea level, and the Lower member as a result carries the principal aquifer. Near the most inland boundary, dikes associated with the caldera across the mountain rim in Pelekunu may occur. Along the coast a narrow band of sediments occurs.

HYDROLOGY. In the wet mountains, streams may have weak perennial flows, but toward the coast they dry up except during rainy periods. Rainfall averages 48 in. (1 219.2 mm) per year.

GROUNDWATER: Basal groundwater exists in flank lavas except in the most inland sector where dike compartments may hold high level water. Potable basal water can be developed

perhaps a mile (1.6 km) and beyond inland. Good irrigation quality water in available in the coastal region.

ENVIRONMENT: Residences are scattered along the coast. Some farming and aquaculture is practiced. The slopes are range land for ranching. Far inland a wet forest grows.

Aquifer System: Ualapue (40303)

BOUNDARIES. The System extends eastward from Kamalō Gulch for about 7 miles (11.3 km) to Kawaikapu Gulch at Pauwela. Total area is about 18 miles^2 (46.6 km^2). The inland boundary is the top of the pali which plunges into Pelekunu and Wailau valleys.

GEOLOGY. The cap of the Upper member is not as continuous as in the Kamiloloa and Kawela Aquifer Systems. The Lower member is exposed on interfluves as well as in deep gulches. Tongues of alluvium reach upstream in the deeper gulches from the sedimentary coastal plain. A few scattered dikes were mapped near the Wailau boundary.

HYDROLOGY. The environment is semi-humid to humid, having average annual rainfall of 69 in. (1 752.6 mm). Streams are not perennial.

GROUNDWATER. Ualapue includes mostly basal water in flank lavas but may contain a few square miles of high-level water in dike compartments. Good quality basal water discharges near the coast behind a rampart of weak sedimentary caprock. Potable basal water can be developed.

ENVIRONMENT. Ranching, small-scale farming and some aquaculture are the main economic activities.

Aquifer System: Waialua (40304)

BOUNDARIES. The most easterly System in the Southeast Sector, Waialua reaches from Pauwalu to Cape Hālawa south of the Hālawa valley divide. Total area is about 15 miles^2 (39 km^2).

GEOLOGY. Inland a thin section of the Upper member covers the Lower member, but the coastal half of the System is dominated by exposed Lower member basalts. The entire System is composed of flank lavas but near the Wailau boundary a few dikes may occur at depth. Scattered patches of alluvium fill the lower reaches of the deeper gulches. A continuous sedimentary coastal plain does not exist.

HYDROLOGY. The average annual rainfall in the System is 75 in. (1 905 mm). No streams are perennial.

GROUNDWATER. Basal groundwater in flank lavas is the chief water resource. A square mile or so of high-level water may exist where the System meets the Wailau pali and the headwaters

of Hālawa Stream. Potable water is developable, but near the coast the basal water is brackish. Groundwater is not being developed.

ENVIRONMENT. Ranching is an important activity. Few people live in the region.

AQUIFER SECTOR: NORTHEAST (404)

Aquifer System: Kalaupapa (40401)

BOUNDARIES. The System is restricted to the Kalaupapa Peninsula which consists of the Kalaupapa volcanics. Total area is only 4.5 miles^2 (11.7 km^2).

GEOLOGY. The Kalaupapa volcanics erupted a long time after erosion of the original East Molokai volcano had taken place. A band of colluvium at the base of cliffs made up of the Lower member of the East Molokai volcanics connects the peninsula with the main land mass. Basaltic lavas of the Kalaupapa volcanics spread radially from the small Kahauko Crater on the peninsula. Coastal sediments are virtually absent.

HYDROLOGY. Rainfall averages 45 in. (1 143 mm) per year. The surface rocks are highly permeable and have not been incised with a strong drainage network.

GROUNDWATER. Basal groundwater saturates the basalt to several feet above sea level. The water is not potable.

ENVIRONMENT. Kalaupapa Peninsula has been the home of Hansen's disease patients for more than a century. It continues to house the remaining patients, but in addition has been declared a National Historical Park.

Aquifer System: Kahanui (40402)

BOUNDARIES. The System covers about 5.5 miles^2 (14.2 km^2). It embraces the north flowing drainages between Waikolu on the east, Kamiloloa on the south and the headwater tributaries of Manawainui on the west. Its northern boundary is along the contact between Kalaupapa Peninsula and the cliffs of the Moloka'i mainland.

GEOLOGY. The rift zone of the East Molokai volcano reaches into Kahanui. The lavas of the Upper member cover the rift zone of the Lower member. Alluvium occurs as wedges at the mouths of the main streams, Waihānau and Wai'ale'ia.

HYDROLOGY. Waihānau and Wai'ale'ia are perennial where they drain high-level water but lose flow downstream. Average annual rainfall is 60 in. (1 524 mm).

GROUNDWATER. Groundwater occurs in the rift zone as high-level water in the interior and as basal water near the coast. The main aquifers are in the Lower member and consist of dike compartments. Perched high-level water drains from the andesite of the Upper member at the

inland margin of the drainage basin. Two wells have been drilled in lower Waihānau Valley to serve the Kalaupapa settlement.

ENVIRONMENT. The area mostly is in a natural state without significant human activity.

Aquifer System: Waikolu (40403)

BOUNDARIES. The System consists solely of the drainage basin of Waikolu Stream. Total area is about 4.5 miles^2 (11.7 km^2).

GEOLOGY. Waikolu is part of the rift zone striking northwest from Pelekunu Valley. The eastern part of the drainage is a small tableland covered by the Upper member of the East Molokai volcanics. In the valley the Lower member is exposed. A tongue of alluvium in the valley reaches inland a mile from the coast.

HYDROLOGY. Waikolu is perennial because it drains high level dike aquifers. Rainfall in the System averages annually 85 in. (2 159 mm).

GROUNDWATER. All of the major aquifers are in dike intruded lavas of the Lower member. Except for a narrow band along the coast where basal conditions prevail, the groundwater is high level. Perched water drains from the tableland covered by the andesitic formation. In the upper valley groundwater is captured by means of a tunnel and wells drilled in dike compartments for transfer to central Moloka'i.

ENVIRONMENT. The removal of groundwater from the upper valley has diminished downstream flow. Nevertheless the stream remains perennial. The lower valley diversion which served the drinking water needs of Kalaupapa for decades has been abandoned because of the success of the wells in Waihānau Valley.

Aquifer System: Haupu (40404)

BOUNDARIES. The System is small, about 3.0 miles^2 (8 km^2), encompassing the Haupu drainage only. It is an isolated steep embayment situated between the lower reaches of Waikolu on the west and Pelekunu on the east.

GEOLOGY. The region is part of the East Molokai rift and consists of the Lower member intersected by the dike complex. A portion of the drainage originates on the tableland of the Upper member shared with the Waikolu drainage. The coast is a rugged cliff and is not rimmed with sediments.

HYDROLOGY. The lower reach of the drainage is kept perennial by seepage from high-level groundwater. In non-drought periods the tableland contributes perched water which cascades over a 3500 ft (1 066.8 m) high pali. Average annual rainfall is 83 in. (2 108.2 mm).

GROUNDWATER. High-level groundwater saturates dike compartments and some is perched in the andesitic tableland. The System is inaccessible, beyond the reach of development feasibility.

ENVIRONMENT. Natural conditions have been retained because of the remoteness of the region.

Aquifer System: Pelekunu (40405)

BOUNDARIES. The System is restricted to the drainage basin of Pelekunu Stream. Total area is about 7.4 miles^2 (19.2 km^2). The drainage limit of the basin is the line drawn along the top of the encircling palis.

GEOLOGY. Pelekunu drains the fossil caldera of the East Molokai volcano and its associated dike complex. All of the rocks belong to the Lower member. The dominant dike trend is to the northwest. An alluvium apron lies at the mouth of the valley, and from it a tongue reaches about two miles up the valley.

HYDROLOGY. Pelekunu and its tributaries are perennial because they drain high-level dike aquifers. Minor aquifers perched on ash beds also add to flow. Average annual rainfall in the System is about 100 in. (2 540 mm).

GROUNDWATER. A small area at the mouth of Pelekunu may be underlaid by basal water in the dike zone, but otherwise all groundwater is high level, mostly in dike-controlled aquifers. No groundwater development has been attempted, but studies have been made about extending the Waikolu Tunnel into the valley to capture additional water.

ENVIRONMENT. Virtually the entire valley now belongs to the Nature Conservancy who want to retain it in its natural state. The upper valley evidently is nearly pristine.

Aquifer System: Wailau (40406)

BOUNDARIES. Wailau is the largest drainage basin in Moloka‘i. The drainage area, along with a small acreage that drains directly to the sea over cliffs in the west part of the region, constitutes the Wailau Aquifer System. Total area is about 13.3 miles^2 (344.5 km^2).

GEOLOGY. Wailau is a deep canyon incised in the Lower member of the East Moloka‘i volcanics. Its upper half shares the fossil caldera with Pelekunu. Dikes of the rift occur throughout the valley. About a square mile of the Upper member forms a tableland in the west portion of the drainage. The valley bottom is alluviated over a reach of 3 miles (4.8 km) starting with a sediment wedge at the coast.

HYDROLOGY. The stream and its headwaters tributaries are perennial, fed by drainage from high level aquifers. Wailau is the largest stream in Moloka'i. Annual average rainfall is nearly 100 in. (2 540 mm).

GROUNDWATER. The lower portion of the valley, perhaps half a mile to a mile wide parallel to the coast, probably carries basal groundwater in dike aquifers. Inland all groundwater is high level, predominantly in dike aquifers. Perched water drains from the small tableland abutting the Pelekunu drainage. The water resources have not been developed, but because of their magnitude they are attractive to planners.

ENVIRONMENT. The upper valley is in its natural state, while the lower valley has been occasionally used for small scale living adventures.

Aquifer System: Halawa (40407)

BOUNDARIES: The Halawa Aquifer System completes the Northeast Aquifer Sector. On the south the boundary follows the Hālawa Valley divide while it terminates at the coast in the north and east. On the west it abuts Wailau. In addition to the Hālawa Valley drainage, the System includes several much smaller drainages that drain northward. Total area is about 14 miles^2 (36 km^2).

GEOLOGY. Throughout most of the region a cap of the andesitic Upper member forms the surface. The Lower member is exposed in Hālawa Valley and in cliffs along the north shore. The rift zone striking east from Wailau appears to be attenuated such that surface evidence of dikes is absent except at the falls of Hālawa Stream. Lower Hālawa Valley is alluviated over the two miles (3.2 km) from the coast to Hālawa Falls. Patches of sediments occur along the north coast.

HYDROLOGY. Hālawa Stream is perennial, largely because it receives seepage from perched aquifers in the Upper member. Kawainui Stream, draining to the north coast, is also perennial. Rainfall is moderate, annually averaging 66 in. (1 676.4 mm).

GROUNDWATER. Groundwater occurs in a complex geological framework starting with perched water in and on the Upper member, then high-level dike water in the Lower member, basal water in dike aquifers, and finally basal water in flank lavas for considerable distance inland. Sediments are not hydrogeologically important. Groundwater development has not taken place yet.

ENVIRONMENT. The most inland portion of the System includes wetlands sustained by perched groundwater. It is relatively inaccessible. The reach of Hālawa Valley between the falls and the coast is used by campers and hikers. Cattle graze the highland on the south side of Lower Hālawa.

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AQUIFER CLASSIFICATION EXPLANATION

AQUIFER AND STATUS CODES*

Aquifer Code		=	Island
		+	Aquifer Sector
		+	Aquifer System
		+	Aquifer Type
Thus,	40301111	=	Aquifer Code
where	4	=	Molokai
	03	=	Southeast
	01	=	Kamiloloa
	1	=	basal
	1	=	unconfined
	1	=	flank
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	
4	01	West	01	Kaluakoi
			02	Punakou
	02	Central	01	Hoolehua
			02	Manawainui
			03	Kualapuu
	03	Southeast	01	Kamiloloa
			02	Kawela
			03	Ualapue
			04	Waialua
	04	Northeast	01	Kalaupapa
			02	Kahanui
			03	Waikolu
			04	Haupu
			05	Pelekunu
			06	Wailau
			07	Halawa

*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)

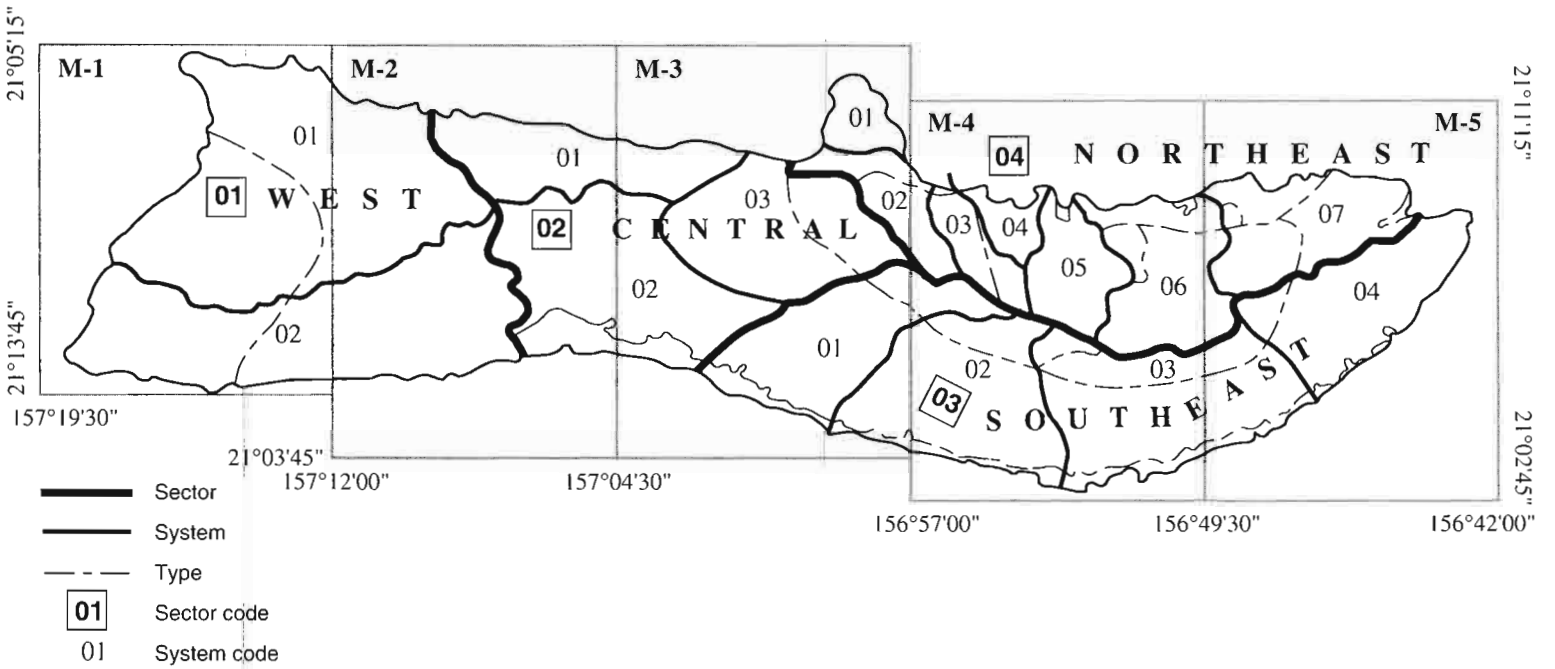
Development Stage
1 Currently used
2 Potential use
3 No potential use

Utility
1 Drinking
2 Ecologically important
3 Neither

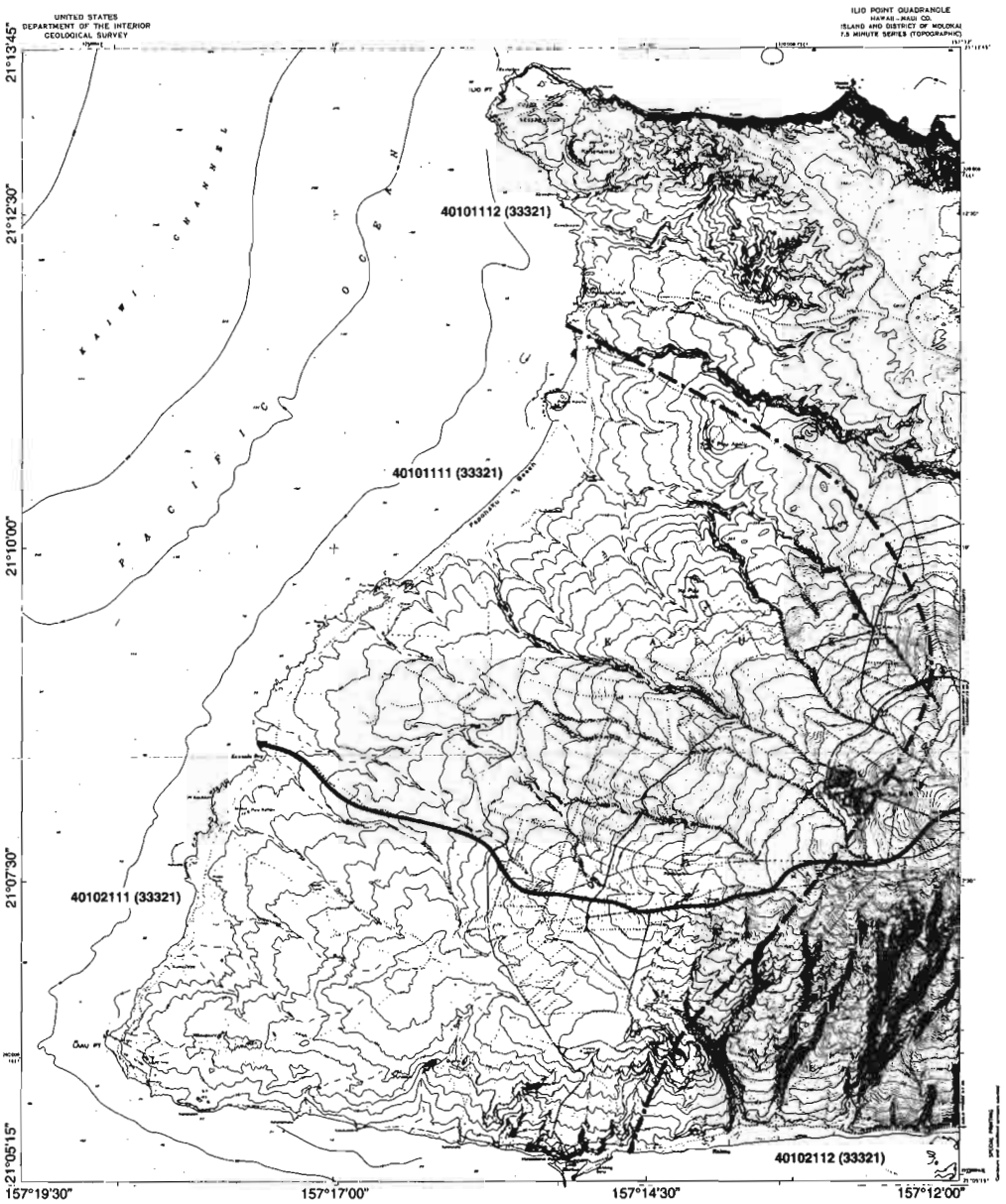
Salinity (mg/l Cl^-)
1 Fresh (<250)
2 Low (250-1000)
3 Moderate (1000-5000)
4 High (5000-15,000)
5 Seawater (>15,000)

Uniqueness
1 Irreplaceable
2 Replaceable

Vulnerability to Contamination
1 High
2 Moderate
3 Low
4 None

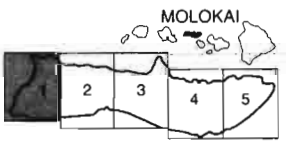


Appendix Figure A.1.0. Layout of Sectors, Systems, and Types for Moloka'i, Hawai'i



Base Map: USGS (1:24,000 series, rev. 1968).

ILIO POINT, MOLOKAI
M-1



Sector
Aquifer System
Aquifer Type
40101111 Aquifer Code
(11111) Status Code

1992

0 1 2 Miles
0 1 2 3 Kilometers

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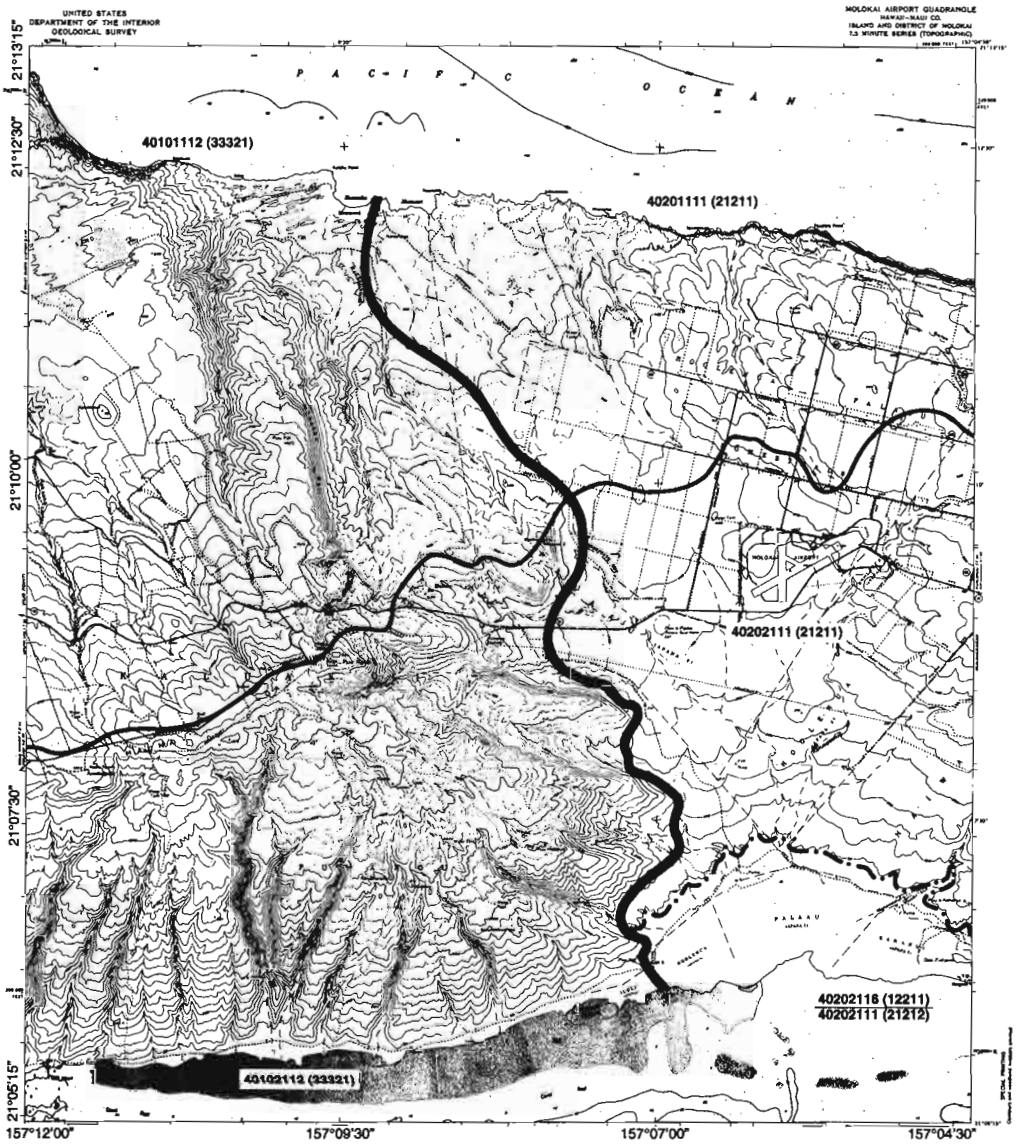
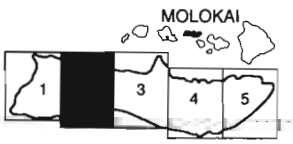
Appendix Figure A.1.1. Aquifer classification map, Ilio Point, Moloka'i, Hawai'i



Base Map: USGS (1:24,000 series, rev. 1968).

MOLOKAI AIRPORT, MOLOKAI
M-2



Sector
Aquifer System
Aquifer Type
40101111 Aquifer Code
(11111) Status Code

1992

0 1 2 Miles
0 1 2 3 Kilometers

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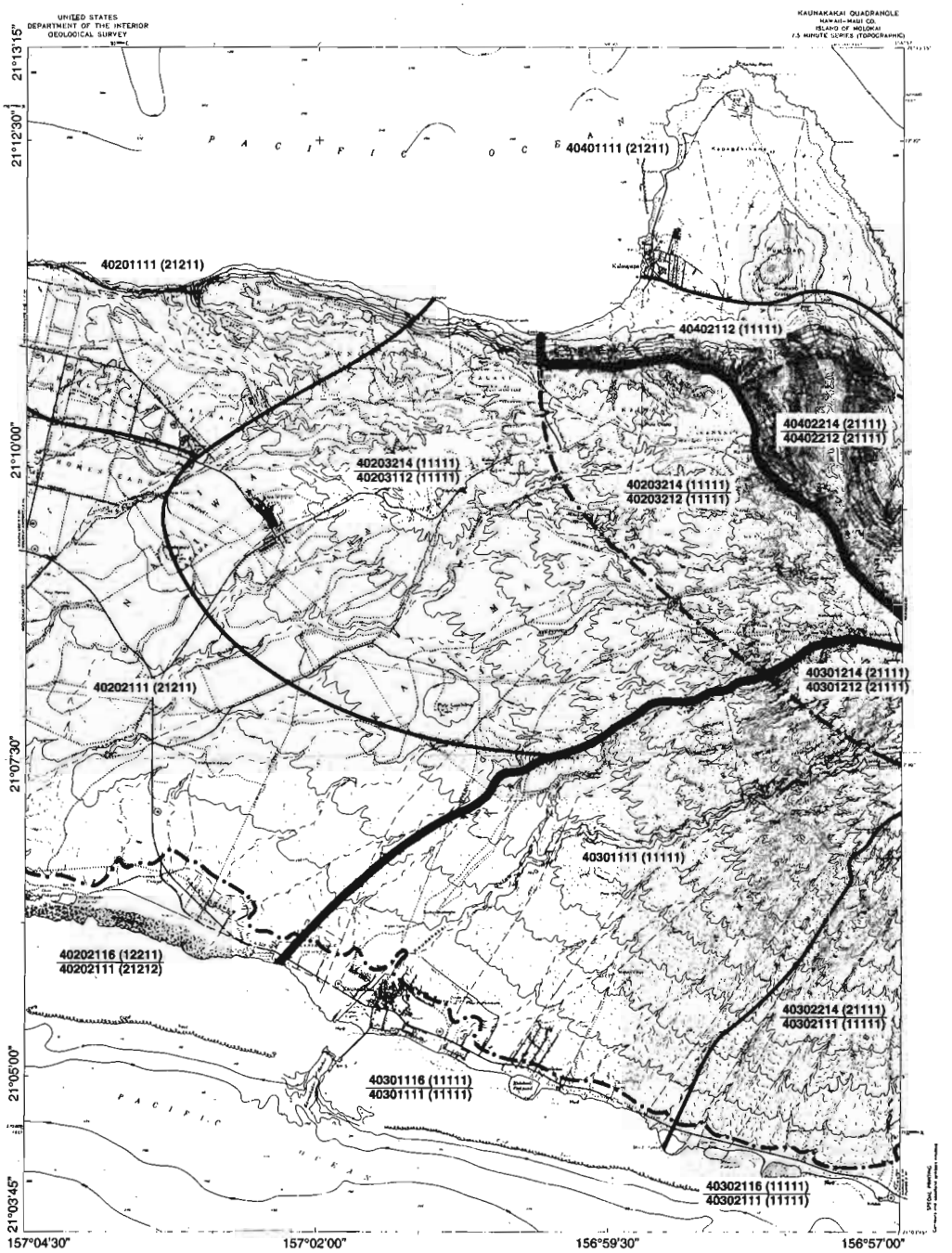
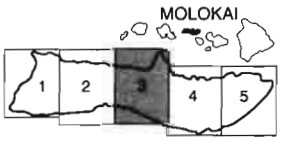
Appendix Figure A.1.2. Aquifer classification map, Molokai Airport, Moloka'i, Hawai'i



Base Map: USGS (1:24,000 series, rev. 1967).

KAUNAKAKAI, MOLOKAI
M-3



Sector
Aquifer System
Aquifer Type
40101111 Aquifer Code
(11111) Status Code

1992

0 1 2 Miles
0 1 2 3 Kilometers

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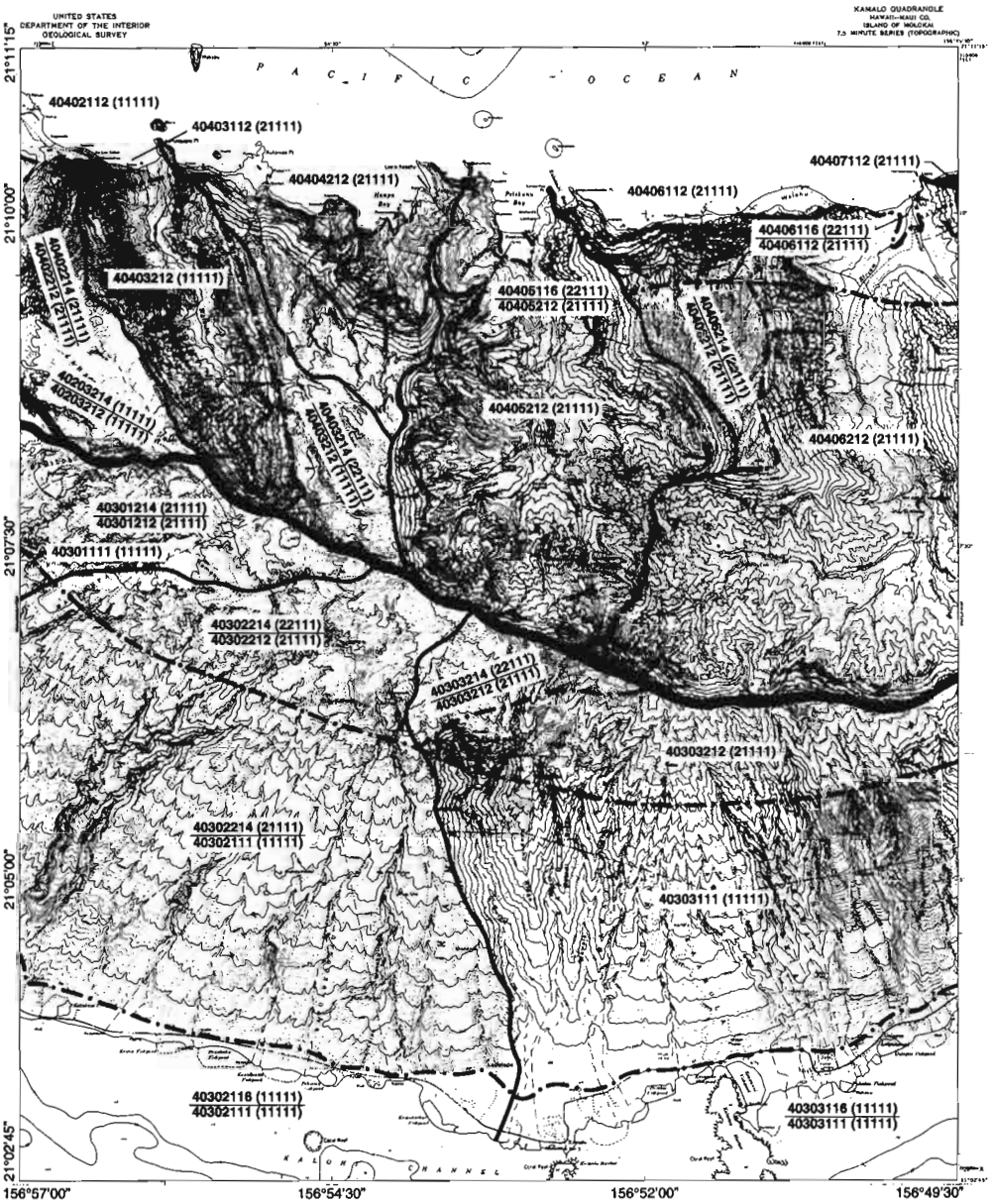
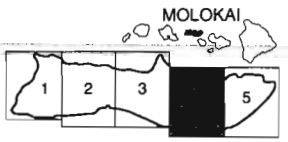
Appendix Figure A.1.3. Aquifer classification map, Kaunakakai, Moloka'i, Hawai'i



Base Map: USGS (1:24,000 series, rev. 1958).

KAMALO, MOLOKAI
M-4



Sector
Aquifer System
Aquifer Type
40101111 Aquifer Code
(11111) Status Code

1992

0 1 2 Miles
0 1 2 3 Kilometers

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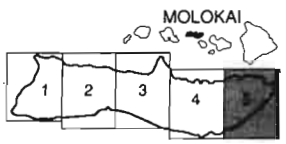
Appendix Figure A.1.4. Aquifer classification map, Kamalo, Moloka'i, Hawai'i

Base Map: USGS (1:24,000 series, rev. 1968).

HALAWA, MOLOKAI
M-5



Sector
Aquifer System
Aquifer Type
40101111 Aquifer Code
(11111) Status Code

1992

0 1 2 Miles
0 1 2 3 Kilometers

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Appendix Figure A.1.5. Aquifer classification map, Halawa, Moloka'i, Hawai'i