Section 3

Inventory and Assessment of Resources

3. INVENTORY AND ASSESSMENT OF RESOURCES

The State Water Code mandates that the WRPP include an inventory of water resources statewide. This section provides the resource inventory as well as pertinent supporting information and discussions of issues that contribute to resource assessment and management.

3.1. Managing Hawaii's Water Resources for Sustainability

The movement of water between the atmosphere, the land, and the ocean is described by the hydrologic cycle. In Hawaii, solar energy causes the evaporation of water from the ocean. Clouds form and render their moisture over the islands. This rainfall supports stream flow and replenishes ground water, while a portion evaporates back into the atmosphere. The land-related components of the hydrologic cycle have been impacted over time by human settlement and short- and long-term climate change. For example, early Hawaiians diverted the natural flow patterns of streams through auwais to provide water for agriculture, but much of the water was eventually returned to downstream segments of the stream. Later, as the sugar industry became established in Hawaii, large-scale stream diversions and wells were constructed to support the plantations and the needs of the growing population. Most recently, the decline of plantation agriculture and increasing urbanization have significantly altered drainage patterns and the rate of ground water recharge. The cumulative effects of land use changes and other human activities can shift the natural balance of the hydrologic cycle. Such changes can have profound social, environmental, and economic impacts within our island communities.

To sustainably manage water resources, it is critical to apply an organized program for measuring, assessing, and communicating water-related information to decision makers and to the public. Government agencies, resource managers, private purveyors, and the general public benefit from the continued investigation and study of water resources. The best information available should be applied to explore the processes and resource interdependencies implicit in the water cycle. With increasing insight, better resource management strategies can be developed and implemented to achieve sustainability.

3.1.1. Evolving Issues in Water Resource Management

> *Traditionally, management of water resources has focused on surface water or ground water as if they were separate entities. As development of land and water resources increases, it is apparent that development of either of these resources affects the quantity and quality of the other. Nearly all surface-water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with ground water. These interactions take many forms. In many situations, surface-water bodies gain water and solutes from ground-water systems and in others the surface-water body is a source of ground-water recharge and causes changes in ground-water quality. As a result, withdrawal of water from streams can deplete ground water or conversely, pumpage of ground water can deplete water in streams, lakes, or wetlands. Pollution of surface water can cause degradation of ground-water quality and conversely pollution of ground water can degrade surface water. Thus, effective land and water management requires a clear understanding of the*

> *linkages between ground water and surface water as it applies to any given hydrologic setting.*
>
> *– Robert M. Hirsch, Chief Hydrologist, USGS*[1]

In the above excerpt from the 1998 USGS Circular 1139, author Robert M. Hirsch summarizes the difficulties faced by scientists and water managers in understanding the integrated nature of ground and surface water systems. From a government perspective, the typical administrative separation of ground and surface water management creates additional challenges for most water managers, especially as research efforts constantly reveal new aspects and venues by which ground and surface water systems are interdependent. The intent of USGS Circular 1139 is to help Federal, State and local agencies construct a scientific base for the development of policies governing the management and protection of aquifers and watersheds.

The author further asserts that, "Effective policies and management practices must be built on a foundation that recognizes that surface water and ground water are simply two manifestations of a single integrated resource." The document emphasizes that management of one component of the hydrologic system, such as a stream or an aquifer, tends to be only partly effective because each hydrologic component is in continuous interaction with other components. Concerns related to water supply, water quality, and degradation of aquatic environments are frequently at the forefront of water management issues, and the interaction of ground water and surface water has been, and continues to be, a significant area of focus and deliberation. Hirsch provides an example where contaminated aquifers that discharge to streams can result in long-term contamination of surface water and, conversely, streams can be a major source of contamination to aquifers. Although this scenario may be more common throughout the Continental US, this could also occur in Hawaii, where the implications and impacts of cross-contamination may be devastating to our limited water resources, population, and environment.

Although surface water typically has a hydraulic connection to ground water, according to Hirsch, the interactions are difficult to observe and measure and "commonly have been ignored in water-management considerations and policies." The limited understanding of ground and surface water interactions makes it difficult to characterize the processes.

In Hawaii, water managers, government agencies, and hydrologists struggle with ground and surface water interactions, as most dramatically demonstrated by high-profile water disputes in East Maui, in the Wailuku area on Maui (Iao Aquifer System Area), and in Windward Oahu (Waiahole Ditch System). Due to the volcanically-formed aquifers, island topography, and tropical climate, surface water and ground water interactions are most likely unique in comparison with the larger-scale river basin watersheds and expansive sedimentary aquifer systems typical of mainland US areas. Nevertheless, the large-scale concepts, themes, issues, and investigations related to ground and surface water interaction remain pertinent to Hawaii in that they provide insight for consideration and adaptation for island systems. The following examples of common water-resource issues, as adapted from Hirsch, are provided to demonstrate how understanding the interconnections between ground water and surface water is "fundamental to development of effective water-resource management and policy."

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[1] *USGS Circular 1139: Ground Water and Surface Water: A Single Resource,* http://water.usgs.gov/ogw/gwsw.html.

Water Supply

- It has become difficult in recent years to construct reservoirs for surface storage of water because of environmental concerns and because of the difficulty in locating suitable sites. An alternative, which can reduce or eliminate the necessity for surface storage, is to use an aquifer system for temporary storage of water. For example, water stored underground during times of high streamflow can be withdrawn during times of low streamflow. The characteristics and extent of the interactions of ground water and surface water affects the success of such conjunctive-use projects.

- Methods of accounting for water rights of streams invariably account for surface water diversions and surface water return flows. Increasingly, the diversions from a stream that result from ground water withdrawals are considered in accounting for water rights as are ground water return flows from irrigation and other applications of water to the land surface. Accounting for these ground water components can be difficult and controversial. Another form of water-rights accounting involves the trading of ground water rights and surface water rights. This has been proposed as a water management tool where rights to the total water resource can be shared. It is an example of the growing realization that ground water and surface water can essentially be one resource in many suituations.

- In some regions, the water released from reservoirs decreases in volume, or is delayed significantly, as it moves downstream because some of the released water seeps into the stream-banks. These losses of water and delays in travel time can be significant, depending on antecedent ground water and stream flow conditions as well as on other factors such as the condition of the channel and the presence of aquatic and riparian vegetation.

- Storage of water in streambanks, on flood plains, and in wetlands along streams reduces flooding downstream. Modifications of the natural interaction between ground water and surface water along streams, such as drainage of wetlands and construction of levees, can remove some of this natural attenuation of floods. Unfortunately, present knowledge is limited with respect to the effects of land-surface modifications in river valleys on floods and on the natural interaction of ground water and surface water in reducing potential flooding.

Water Quality

- Much of the ground water contamination in the United States is in shallow aquifers that are directly connected to surface water. In some settings where this is the case, ground water can be a major and potentially long-term contributor to contamination of surface water. Determining the contributions of ground water to contamination of streams and lakes is a critical step in developing effective water management practices.

- A focus on watershed planning and management is increasing among government agencies responsible for managing water quality as well as broader aspects of the environment. The watershed approach recognizes the interactions between ground and surface water. Integrating ground water into this “systems” approach is essential, but challenging, because of limitations in knowledge of the interactions of ground water and surface water. These difficulties are further complicated by the fact that surface water watersheds and ground water watersheds may not coincide.

- To meet water quality standards and criteria, States and local agencies need to determine the amount of contaminant movement (wasteload) to surface waters so they can issue permits and control discharges of waste. Typically, ground water inputs are not included in estimates of wasteload; yet, in some cases, water-quality standards and criteria cannot be met without reducing contaminant loads from ground water discharges to streams.

- It is generally assumed that ground water is safe for consumption without treatment. Concerns about the quality of ground water from wells near streams, where contaminated surface water might be part of the source of water to the well, have led to increasing interest in identifying when filtration or treatment of ground water is needed.

- Wetlands, marshes, and wooded areas along streams (riparian zones) are protected in some areas to help maintain wildlife habitat and the quality of nearby surface water. Greater knowledge of the water-quality functions of riparian zones and of the pathways of exchange between shallow ground water and surface water bodies is necessary to properly evaluate the effects of riparian zones on water quality.

Characteristics of Aquatic Environments

- Mixing of ground water with surface water can have major effects on aquatic environments if factors such as acidity, temperature, chlorides, and dissolved oxygen are altered. Thus, changes in the natural interaction of ground water and surface water caused by human activities can potentially have a significant effect on aquatic environments.

- The flow between surface water and ground water creates a dynamic habitat for aquatic fauna near the interface. These organisms are part of a food chain that sustains a diverse ecological community. Studies indicate that these organisms may provide important indications of water quality as well as of adverse changes in aquatic environments.

- Many wetlands are dependent on a relatively stable influx of ground water throughout changing seasonal and annual weather patterns. Wetlands can be highly sensitive to the effects of ground water development and to land-use changes that modify the ground water flow regime of a wetland area. Understanding wetlands in the context of their associated ground water flow systems is essential to assessing the cumulative effects of wetlands on water quality, ground water flow, and stream-flow in large areas.

- The success of efforts to construct new wetlands that replicate those that have been destroyed depends on the extent to which the replacement wetland is hydrologically similar to the destroyed wetland. For example, the replacement of a wetland that is dependent on ground water for its water and chemical input needs to be located in a similar ground water discharge area if the new wetland is to replicate the original. Although a replacement wetland may have a water depth similar to the original, the communities that populate the replacement wetland may be completely different from communities that were present in the original wetland because of differences in hydrogeologic setting.

3.1.2. Applying the “Systems” Approach to Water Resource Management

The WRPP encourages effective ground and surface water management through the application of a hydrologic unit systems approach that focuses on the interaction and feedback that occurs between ground and surface water systems and management decisions. Management practices, including infrastructure, economic, and political factors represent stresses to the ground water system. The physical ground water system (geologic framework, hydraulic properties and boundary conditions) demonstrates environmental effects and responses due to the imposed stresses, which are initially observed in ground water levels, discharge rates, and water-quality conditions. The cumulative effects are sometimes observed in streamflow rates, aquatic habitats, and other environmental conditions. Observing these initial and long-term cumulative effects helps in understanding the properties and processes of ground water systems and the environmental effects and other consequences that result from management decisions.

This section of the WRPP provides information on the nature and occurrence of water resources in the State of Hawaii, as well as discussions on the human impacts to those resources and the issues, challenges, and opportunities for improving management and protection practices. The goals and objectives of this section embrace the “systems” approach to water resource management, recognizing the connections between ground and surface water resources. CWRM encourages the exploration and application of this approach through the information presented herein and through State actions to support sustainable management of water resources.

The remaining sections are generally organized as follows:

- **Goals and Objectives:** This section describes general goals and objectives for resource inventory efforts and tracking to support water planning and management. Also listed are items specifically applicable to ground water and surface water inventory and assessment.

- **Nature and Occurrence of Ground Water:** Information on ground water occurrence and aquifer settings is followed by an explanation of the ground water hydrologic units as delineated by CWRM and how ground water availability is quantified and assessed. Finally, an inventory of aquifer system areas and aquifer system sustainable yields are presented with additional supporting information incorporated by reference.

- **Nature and Occurrence of Surface Water:** Similar to the previous section on ground water, surface water occurrence and settings are described and followed by an explanation of the surface -water hydrologic units delineated by CWRM. Information of the quantification of stream flow is accompanied by a summary of issues associated with quantification and assessment of resources. The section on surface water concludes with an inventory of surface water hydrologic units with information on instream flow standards as determined thus far.

3.2. Goals for Water Resource Inventory and Assessment

The following CWRM goals are intended to guide and influence water resource inventory and assessment efforts in support of sustainable water planning and management activities.

- Study and inventory the water resources of the State to protect resource viability and to provide the maximum beneficial use of water by present and future generations.

- Promote the administrative use of management boundaries designated by CWRM to define the extent of ground water and surface water hydrologic units and ensure the consistent application of these boundaries throughout the State and across State and county jurisdictions.

- Commit to long-term, reliable data collection programs and use of improved methods of analyses; use data to develop improved management decisions through a continuing iterative approach of data collection and analysis, including the use of models to evaluate alternatives in development, management, and decision making.

- Develop the best available information on the occurrence, location, extent, and behavior of water resources to support resource management, policy and regulatory decisions, and planning efforts.

- Catalog and maintain hydrologic data, geologic data, and topographic surveys and apply data to the enhancement and improvement of current stream protection and ground water protection programs wherever appropriate and beneficial.

- Apply inventory information to manage the conservation, protection, and use of the State’s water resources for social, economic, and environmental needs as mandated by the State Water Code.

- Apply inventory and assessment information to the exploration of managed conjunctive use of combined ground water and surface water supplies, as well as the artificial recharge of ground water systems; address both challenges and opportunities through the application of best science practices, improved understanding of resources, and informed consensus of stakeholders.

- Use iterative scientific investigation practices to support the improved understanding of emerging issues and practices in the management of water resources; resource management should address the interaction between management decisions, the dynamic nature of ground and surface water systems, and the consequences that result from management actions.

- Promote effective coordination between land use planning and water availability in the interest of addressing carrying capacity issues, competing values, and urban expansion.

3.3. Nature and Occurrence of Ground Water

Much research and study has been devoted to the nature and occurrence of ground water in Hawaii. Over the past century, various private, federal, State, county and university ground water investigations have helped scientists understand the unique and complex nature of the nature of Hawaii's ground water resources. An Internet search for ground water hydrology of the Hawaiian Islands will return over 162,000 articles related to this subject.

To help communicate Hawaii ground water concepts to the public, the USGS and CWRM cooperatively developed and published in 2000 the reference brochure entitled *Ground Water in Hawaii*. The document contains descriptions of Hawaii's hydrologic settings and hydrogeology. The Honolulu BWS, in consultation with CWRM, has also developed descriptions of Hawaii's ground water settings for inclusion in the BWS's *Koolau Loa Watershed Management Plan* and *Waianae Watershed Management Plan*. The information in the following sections adapts CWRM's collaborative work with the USGS and BWS to provide a basic overview of the nature and occurrence of ground water in the State.

3.3.1. The Hydrologic Cycle

The hydrologic cycle refers to the constant movement of water between the ocean, the atmosphere, and the Earth's surface. A continuous cycle of water can be easily traced on small oceanic islands like Hawaii. Solar energy drives the hydrologic cycle by causing evapotranspiration**.** Evapotranspiration is the loss of water from soils and open water bodies through evaporation and the transfer of water from plants to the air through transpiration. Moisture in the air is carried by trade winds up mountain sides, where it cools and condenses, and finally falls to the land surface as rain or fog drip. Plants immediately absorb and use some of the rain and fog drip, but the remaining volume of water infiltrates through the ground surface, runs off to the ocean or streams, or evaporates into the atmosphere.

The three main elements of the hydrologic cycle are: 1) precipitation; 2) infiltration and recharge; 3) runoff; and 4) evapotranspiration. These can be summarized in the equation:

$$R = P - RO - ET$$

where "R" is natural recharge due to infiltration and subsequent deep percolation, "P" is precipitation, "RO" is runoff, and "ET" is evapotranspiration.

Infiltration is key to sustaining ground water resources. Human activities, especially agricultural and urban activities, alter infiltration and runoff patterns, affecting the components of the hydrologic cycle. As rainwater wets the land surface, shallow infiltration saturates the uppermost soil layer and replaces soil moisture used by plants. Thereafter, excess water percolates slowly downward and to recharge ground water bodies and support stream flow in perennial sections. One factor that affects the rate of infiltration is the permeability of the ground surface. Permeability describes the ease with which water travels through a substance. Ground surfaces with high permeability allow rapid infiltration of rainfall. Conversely, low-permeability surfaces like concrete and asphault inhibit infiltration, causing water to pond or flow across the surface as runoff. Therefore, different land uses can encourage or inhibit infiltration depending on the built environment.

3.3.2. Ground Water Occurrence

The State Water Code defines ground water as “any water found beneath the surface of the earth, whether in perched supply, dike-confined, flowing, or percolating in underground channels or streams, under artesian pressure or not, or otherwise.” Water beneath the ground surface occurs in two principle zones: the unsaturated zone and the saturated zone. In the unsaturated zone, the pore spaces in soils and rocks contain both air and water, whereas in the saturated zone, the pore spaces are entirely filled with water.

Ground water occurs within portions of geologic formations that are favorable for receiving, storing, and transporting water. These subsurface formations are called aquifers. The USGS defines an aquifer as follows:

> *Aquifer - a geologic formation(s) that is water bearing. A geological formation or structure that stores and/or transmits water, such as to wells and springs. Use of the term is usually restricted to those water-bearing formations capable of yielding water in sufficient quantity to constitute a usable supply for people's uses.*
>
> \- USGS Water Science Glossary of Terms
> http://ga.water.usgs.gov/edu/dictionary.html

Lava erupted during the principal growth stage, or shield building stage, of a volcano tends to form the most extensive and productive aquifers throughout the Hawaiian islands. Lava from the shield building stage consists of basalts that characteristically form thin flows ranging in thickness from a few feet to a few tens of feet. The shield stage is the most voluminous phase of eruptive activity during which 95 to 98 percent of the volcano is formed. Lava flows erupt from the central caldera and rift zones. Intrusive dikes fed by rising magma extend down the rift zones and may erupt if they reach the surface. Some volcanoes have a postshield-stage during which younger lava flows form over the shield-stage basalts. The postshield-stage lava flows are marked by a change in lava chemistry and character that commonly leads to the formation of massive lava flows that can be many tens of feet thick. After a period of volcanic inactivity, lava might issue from isolated vents on the volcano during a final rejuvenated stage.

Permeability refers to the ease with which fluids can move through rock. The permeability of volcanic rocks is variable and depends of the mode of emplacement, amount of weathering, and thickness of the rocks. The three main groups of volcanic rocks (lava flows, intrusive dikes, and pyroclastic deposits) are formed by different modes of emplacement. Weathering reduces the permeability of all types of volcanic rocks. The thickness of a lava flow can depend of the lava chemistry and the topography over which it cooled. Thicker flows generally are less permeable and form from lava accumulating on flat topography or in depressions.

Lava flows are mainly composed of two lava morphologies: pahoehoe and aa. Pahoehoe flows are thinner and form from more fluid lava. Pahoehoe flows have smooth, undulating surfaces, and commonly exhibit ropy textures. Aa flows have coarse surfaces of rubble, or clinker, and thick interior sections composed of massive rock. A typical geologic profile will show a sequence of both aa and pahoehoe flows. The interconnected void spaces in a sequence of pahoehoe flows may lead to high permeability. The layers of clinker at the top and bottom of aa flows also impart high permeability (similar to that of coarse-grained gravel) to volcanic-rock aquifers. However, the lava in the core of an aa flow typically cools as a massive body of rock with much lower permeability. The most productive and most widespread aquifers consist of thick sequences of numerous thin lava flows, however, ground water occurs in a variety of geologic settings in Hawaii, as described in the sections below.

3.3.2.1. Basal Water

The freshwater lenses in basal aquifers, the most important sources of freshwater supply in Hawaii, occur in dike-free volcanic rocks and in sedimentary deposits. Basal waters can be either confined or unconfined. Unconfined aquifers are where the upper surface of the saturated aquifer is not bounded. Confined is where the aquifer is bounded by low permeability formations or poorly permeable formations.

In some coastal areas there is a sediment sequence of low permeability commonly called "caprock." This caprock barrier tends to restrict the seaward flow of freshwater and causes the thickness of the freshwater lens to be greater than it would if the caprock was absent. Depending upon the effectiveness of the caprock, the resulting lens could range from local thickening of a relatively thin lens of a hundred feet to over 1800 feet. The amount of water stored in basal lens is significant. Water is withdrawn from the basal aquifer for various uses; basal aquifers provide the primary source for municipal water in Hawaii.

The thickness of the freshwater basal lens can be estimated using the Ghyben-Herzberg formula, which assumes a hypothetical sharp interface between freshwater and seawater, and states that every foot of freshwater above mean sea level indicates 40 feet of freshwater below mean sea level. For example, if freshwater is known to occur at an elevation 20 feet above mean sea level, it can be reasonably estimated that the hypothetical sharp interface would be approximately 800 feet below sea level.

The Ghyben-Herzberg formula provides a reasonable estimate of the freshwater basal lens thickness; however, in actuality, the interface between freshwater and seawater occurs as a brackish transition zone, rather than a sharp interface, with salinity gradually increasing with depth. Therefore, the Ghyben-Herzberg formula is used to estimate the midpoint of the transition zone, which is 50% seawater and

50% freshwater. The thickness of transition zone depends on various chemical and physical parameters including, but not limited to, advection and dispersion, mechanical mixing, physical properties of the aquifer, tidal fluctuation, and atmospheric pressure variation. The movement of the brackish transition zone, both horizontally inland from the seacoast and vertically upward, presents a constant potential danger of saline contamination to the freshwater portion of the system.

3.3.2.2. Dike Water

Water impounded behind dikes in the mountains is called "dike-impounded water," or "high-level water." Dikes are low permeability magmatic intrusions that typically consist of nearly vertical slabs of dense, massive rock, generally a few feet thick, which can extend for considerable distances and cut across existing older lava flows. High-level water impounded in permeable lavas occurring between dikes in the interior portions of the islands is usually of excellent quality due to the elevation of dike impounded aquifers, the low permeability of dike structures, and the distance from the ocean, which prevents sea water instrusion. Tunnels and shafts have been drilled through multiple dike compartments to develop this water source.

Some water leakage occurs across dike boundaries, and this water flows to down-gradient dike compartments or to the basal aquifer. However, the interaction between these dike-confined and basal aquifers is not well understood and is difficult to quantify.

Dike-impounded water may overflow directly to a stream at the ground surface where stream erosion has breached dike compartments. Once breached to the water table, the percentage of overall contribution to total stream flow depends on the head of the stored water, how deep the stream has cut into the high level reservoir, the permeability of the lavas between dikes, the size of the compartments as well as connections to other compartments, and the amount of recharge into the breached compartment.

3.3.2.3. Perched Water

Water in perched aquifers is also classified as high-level water. In this type of system, water is "perched" on top of layers of low permeability material such as dense volcanic rock, weathered and solidified ash, or clay-bearing sediments. Discharge of perched water sometimes occurs as springs where the water table has been breached by erosion. Perched water supplies can be developed by tunnels or by constructing masonry chambers around spring orifices to collect flow and to prevent surface contamination. This type of water is of excellent mineral quality, and like most dike water, is free from seawater encroachment.

Perched water can also be found in alluvial deposits. Alluvial water is found in the more recent alluvial layers and remains perched because of older compacted alluvial layers below. Sometimes small wells can be productive in this area but generally the alluvium provides small amounts of water.

3.3.2.4. Caprock Water

Caprock units found in Hawaiian aquifer system are generally composed of sedimentary formation, and commonly seen in oceanic islands with emergent shorelines. It bears evidences of sedimentation in shallow marine and littoral environments that are shown by the dominant presence of reefal limestone members consist of fringing coralline build-up and associated calcareous sediments with overprinting of fine-grained alluvial sedimentation. Having formed in submarine conditions and with high clay content, young calcareous sedimentary units may preserve the brackish or saline caprock water as interstitial fluid or as perched water within the formation. Moreover, intertidal fluctuation and sea level rise allows sea water intrusion into the caprock units, creating a broad transition zone of brackish water along coastal areas. Recharge from surface flows, local rainfall, return irrigation water, and leakage from confined basal water could result into a potential resource of caprock water, but maybe of limited direct use due to its saline quality. Caprock water occurs, and perhaps is fairly common around older emergent Hawaiian islands, such as Oahu. A good example of an extensive caprock formation is the Ewa Caprock, where brackish water has been pumped and utilized.

3.3.2.5. Brackish Water

Water occurring in the caprock, in a transition zone, and in some basal springs comprises a large resource that is presently unused for municipal supplies due to excessive chlorides (salt) content. Chlorides range from just above recommended drinking water limits to that nearly of seawater. With respect to its potential as an alternative source of water supply, brackish water desalination is generally more cost-effective and environmental-friendly than seawater desalination.

Utilization of brackish water sources for municipal supplies requires the reduction of chloride concentration through blending and/or demineralization. Water exhibiting chloride concentrations greater than 250 milligrams per liter (mg/L) is generally considered unacceptable for drinking purposes. The county water departments generally limit chloride levels of water within their municipal system to less than 160 ppm.

Future updates of this plan may include discussions of other geologic settings where ground water occurs.

3.3.3. Ground Water Hydrologic Units

Ground water hydrologic units have been established by the Commission on Water Resource Management to provide a consistent basis for managing ground water resources. An aquifer coding system is used to reference and describe the ground water hydrologic units delineated by CWRM. This section describes the aquifer coding system and lists all ground water hydrologic units by island. Maps illustrating the hydrologic unit boundaries are included in Section 3.3.3.3.

3.3.3.1. Purpose of Aquifer Coding

As described earlier in section 3.3.2, ground water occurs in variable settings throughout the State of Hawaii. The aquifer coding system described herein was established to provide a consistent method by which to reference and describe ground water resources and to assist in various water planning efforts. The coding system encourages public understanding of ground water hydrology by delineating areas that are related and exhibit similar characteristics.

The primary objective of the coding system is to provide standard aquifer delineations for the coordination of data, information, and resource management practices. The aquifer coding system provides the following benefits:

- Establishment of a consistent and uniform aquifer coding system and a reference for statewide planning, surveying, and regulatory purposes.

- Facilitation of consistent collection and sharing of ground water information amongst CWRM, community organizations, private and public entities, and other agencies;

- Facilitation of public and private implementation of resource protection measures. Such measures include, but are not limited to, permitting, monitoring, best management practices, and etc;

- Effective coordination of monitoring, data collection, and data interpretation.

3.3.3.2. Basis for Ground Water Hydrologic Unit Delineations

In general, each island is divided into regions that reflect broad hydrogeological similarities while maintaining hydrographic, topographic, and historical boundaries where possible. These divisions are known as Aquifer Sector Areas. Smaller sub-regions are then delineated within Aquifer Sector Areas based on hydraulic continuity and related characteristics. These sub-regions are called Aquifer System Areas. In general, these units allow for optimized spreading of island-wide pumpage on an aquifer-system-area scale.

It is important to recognize that Aquifer Sector Area and Aquifer System Area boundary lines were based largely on observable surface conditions (i.e. topography, drainage basins and streams, and surface geology). In general, only limited subsurface information (i.e. well logs and well cores) is availabe. Hydrogeologic features and conditions at the surface may not adequately or accurately reflect subsurface conditions that directly affect groundwater flow. As a result, the Aquifer Sector Area and Aquifer System Area boundary lines should be recognized as management lines and not as hydrologic boundaries. Communication of groundwater between Aquifer Sector Areas and between Aquifer System Areas is known to occur.

The aquifer coding system was first initiated by the State Department of Health in response to directives from the U.S. Environmental Protection Agency. Since then, boundary delineations of ground water hydrologic units were manually drawn or re-traced by the DLNR Division of Water and Land Development (DOWALD) General Flood Control Plan of Hawaii (1983), the State Department of Health (1987), and the Commission on Water Resource Management (1990).

The naming convention for ground water hydrologic units indicates regional and sub-regional divisions as follows:

Island division = Island
Regional division = Aquifer Sector Area
Sub-regional division = Aquifer System Area

3.3.3.3. Aquifer Coding System

The aquifer coding system is based on a hierarchy in which the island is the largest component, followed by the Aquifer Sector Area as the regional component, and the Aquifer System Area as the sub-regional component. The island is identified by a single-digit number in conformance with the first digit of the Hawaii State well numbering system, derived from the U.S. Geological Survey (1976). Each Aquifer Sector Area is identified by a two-digit number and a Hawaiian geographic name or a geographic term such as Windward. Finally, the Aquifer System Area is identified by a two-digit number. Therefore, ground water hydrologic units are assigned a unique code in the five-digit format as follows:

0	**00**	**00**
Island	Aquifer Sector Area	Aquifer System Area

The individual components of the aquifer system area code are described below.

Island **0**0000

The island code component identifies the major Hawaiian island by a unique number assigned by USGS and DLNR. Each island is considered by the USGS to be a distinctive hydrologic unit.

Aquifer Sector Area 0**00**00

The Aquifer Sector Area code component identifies regional hydrologic units within each island. These Aquifer Sector Areas represent large regions with hydrogeological similarities.

Aquifer System Area 000**00**

The Aquifer System Area code component identifies sub-regional hydrologic units within each Aquifer Sector Area. Aquifer System Areas represent aquifers that exhibit hydrogeological continuity.

There are a total of 113 Ground Water Hydrologic Units delineated across the islands of Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii. Tables 3-1 to 3-6 below list all units by island and are accompanied by Figures 3-1 to 3-6 showing the unit boundaries.

Table 3-1:
Kauai (2) Ground Water Hydrologic Units

Lihue Aquifer Sector Area (01)	
20101	Koloa
20102	Hanamaulu
20103	Wailua
20104	Anahola
20105	Kilauea
Hanalei Aquifer Sector Area (02)	
20201	Kalihiwai
20202	Hanalei
20203	Wainiha
20204	Napali
Waimea Aquifer Sector Area (03)	
20301	Kekaha
20302	Waimea
20303	Makaweli
20304	Hanapepe

Table 3-2: Oahu (3) Ground Water Hydrologic Units	
Honolulu Aquifer Sector Area (01)	
30101	Palolo
30102	Nuuanu
30103	Kalihi
30104	Moanalua
30105	Waialae-West
30106	Waialae-East
Pearl Harbor Aquifer Sector Area (02)	
30201	Waimalu
30203	Waipahu-Waiawa
30204	Ewa-Kunia
30205	Makaiwa
30207	Ewa Caprock - Malakole
30208	Ewa Caprock - Kapolei
30209	Ewa Caprock - Puuloa
Waianae Aquifer Sector Area (03)	
30301	Nanakuli
30302	Lualualei
30303	Waianae
30304	Makaha
30305	Keaau
North Aquifer Sector Area (04)	
30401	Mokuleia
30402	Waialua
30403	Kawailoa
Central Aquifer Sector Area (05)	
30501	Wahiawa
Windward Aquifer Sector Area (06)	
30601	Koolauloa
30602	Kahana
30603	Koolaupoko
30604	Waimanalo

Table 3-3: Molokai (4) Ground Water Hydrologic Units	
West Aquifer Sector Area (01)	
40101	Kaluakoi
40102	Punakou
Central Aquifer Sector Area (01)	
40201	Hoolehua
40202	Manawainui
40203	Kualapuu
Southeast Aquifer Sector Area (01)	
40301	Kamiloloa
40302	Kawela
40303	Ualapue
40304	Waialua
Northeast Aquifer Sector Area (01)	
40401	Kalaupapa
40402	Kahanui
40403	Waikolu
40404	Haupu
40405	Pelekunu
40406	Wailau
40407	Halawa

Table 3-4: Lanai (5) Ground Water Hydrologic Units	
Central Aquifer Sector Area (01)	
50101	Windward
50102	Leeward
Mahana Aquifer Sector Area (02)	
50201	Hauola
50202	Maunalei
50203	Paomai
Kaa Aquifer Sector Area (03)	
50301	Honopu
50302	Kaumalapau
Kamao Aquifer Sector Area (04)	
50401	Kealia
50402	Manele

Table 3-5: Maui (6) Ground Water Hydrologic Units	
Wailuku Aquifer Sector Area (01)	
60101	Waikapu
60102	Iao
60103	Waihee
60104	Kahakuloa
Lahaina Aquifer Sector Area (02)	
60201	Honokohau
60202	Honolua
60203	Honokowai
60204	Launipoko
60205	Olowalu
60206	Ukumehame
Central Aquifer Sector Area (03)	
60301	Kahului
60302	Paia
60303	Makawao
60304	Kamaole
Koolau Aquifer Sector Area (04)	
60401	Haiku
60402	Honopou
60403	Waikamoi
60404	Keanae
Hana Aquifer Sector Area (05)	
60501	Kuhiwa
60502	Kawaipapa
60503	Waihoi
60504	Kipahulu
Kahikinui Aquifer Sector Area (06)	
60601	Kaupo
60602	Nakula
60603	Lualailua

Table 3-6:
Hawaii (8) Ground Water Hydrologic Units

Kohala Aquifer Sector Area (01)	
80101	Hawi
80102	Waimanu
80103	Mahukona
East Mauna Kea Aquifer Sector Area (02)	
80201	Honokaa
80202	Paauilo
80203	Hakalau
80204	Onomea
West Mauna Kea Aquifer Sector Area (03)	
80301	Waimea
Northeast Mauna Loa Aquifer Sector Area (04)	
80401	Hilo
80402	Keaau
Southeast Mauna Loa Aquifer Sector Area (05)	
80501	Olaa
80502	Kapapala
80503	Naalehu
80504	Ka Lae
Southwest Mauna Loa Aquifer Sector Area (06)	
80601	Manuka
80602	Kaapuna
80603	Kealakekua
Northwest Mauna Loa Aquifer Sector Area (07)	
80701	Anaehoomalu
Kilauea Aquifer Sector Area (08)	
80801	Pahoa
80802	Kalapana
80803	Hilina
80804	Keaiwa
Hualalai Aquifer Sector Area (09)	
80901	Keauhou
80902	Kiholo

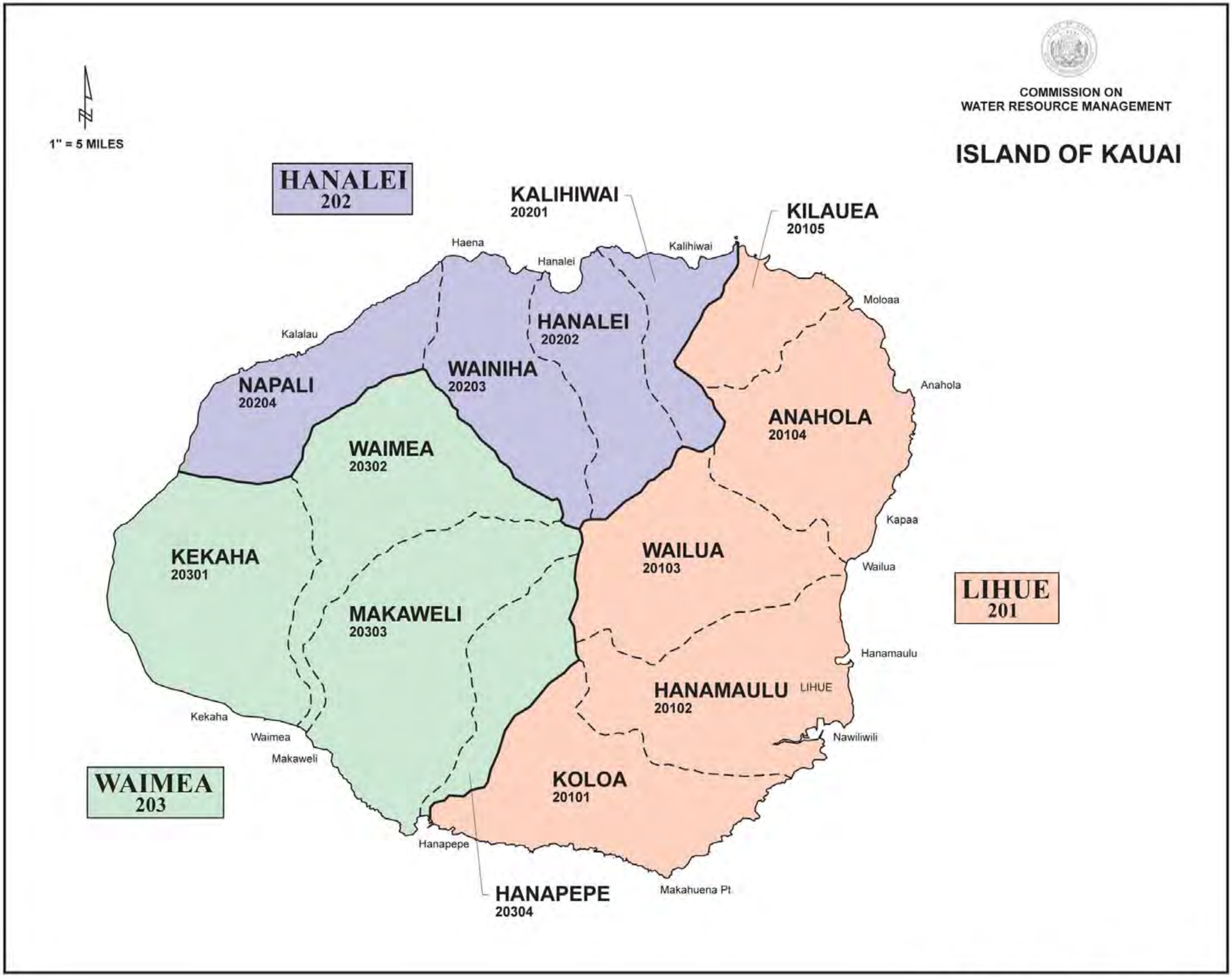

Figure 3-1. Island of Kauai Ground-Water Hydrologic Units

Map Projection: Universal Transverse Mercator

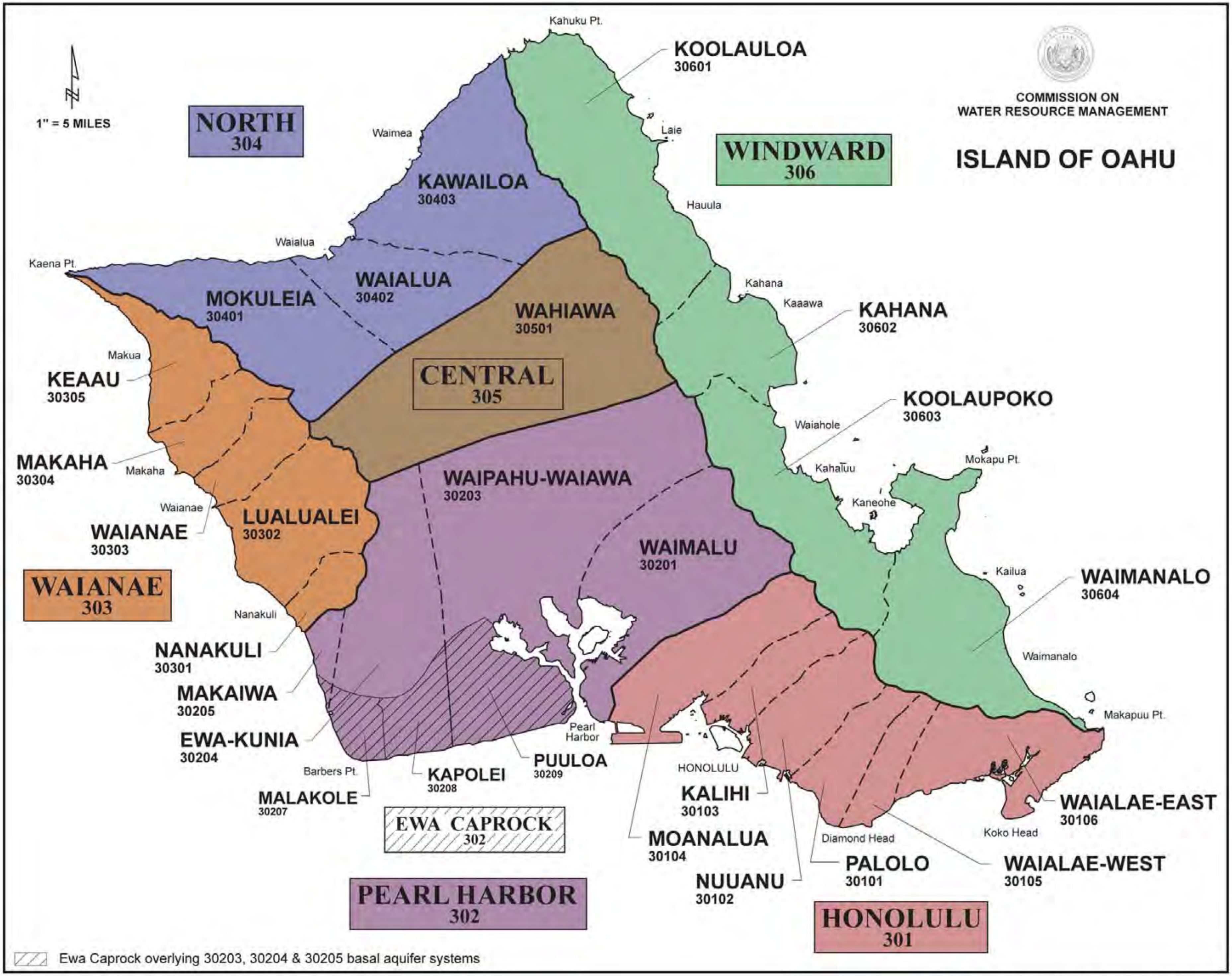

Figure 3-2. Island of Oahu Ground-Water Hydrologic Units

Map Projection: Universal Transverse Mercator

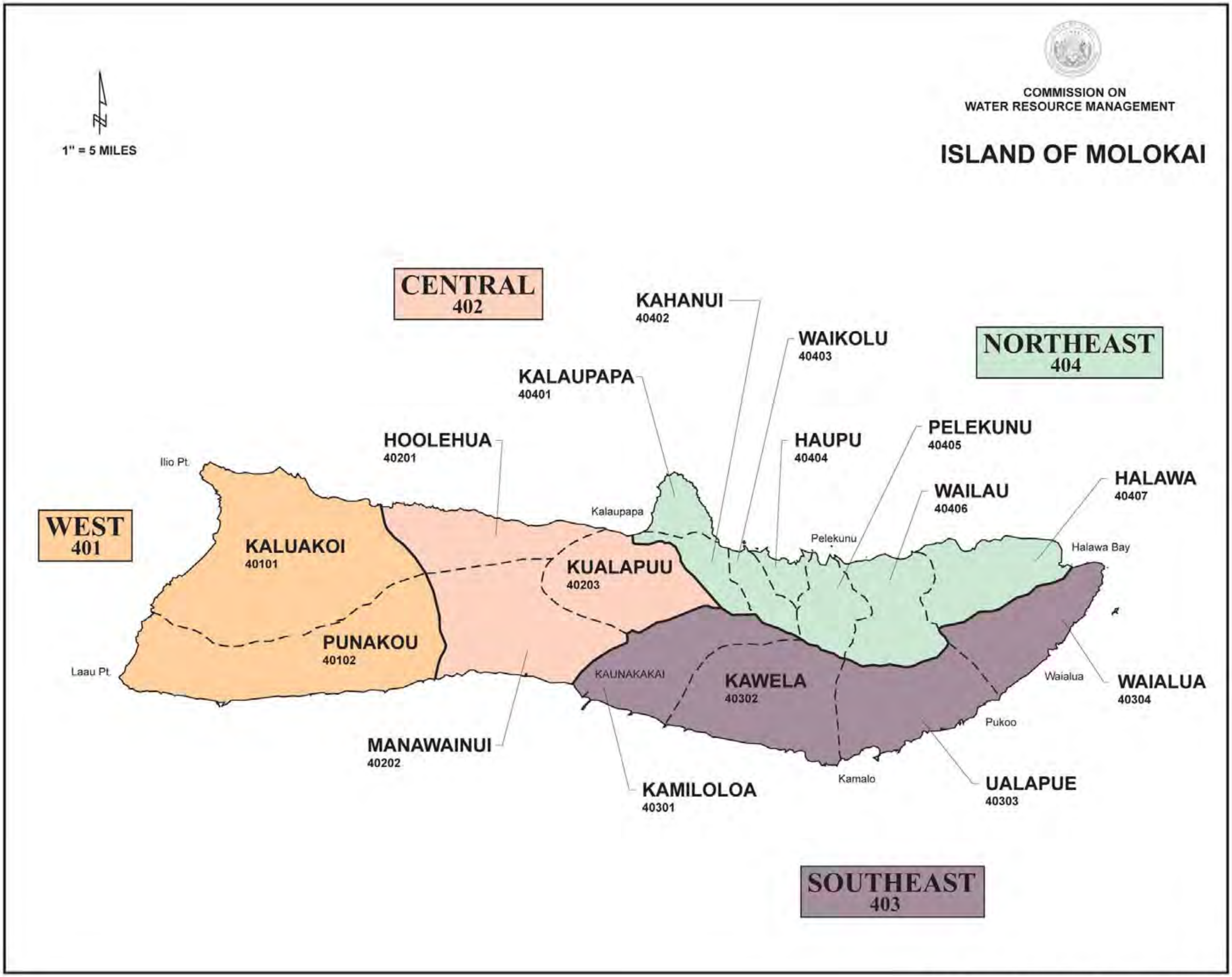

Figure 3-3. Island of Molokai Ground-Water Hydrologic Units

Map Projection: Universal Transverse Mercator

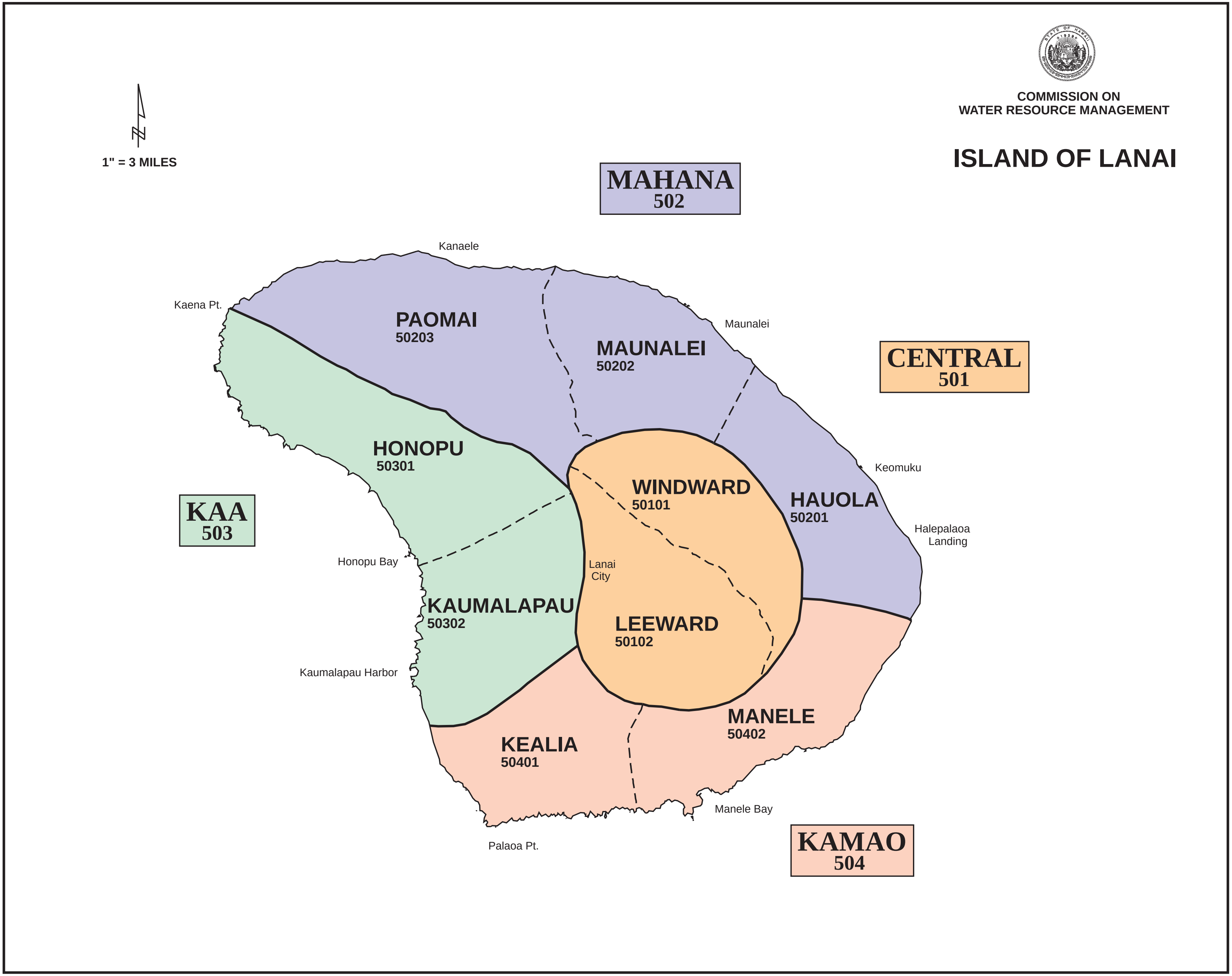

Figure 3-4. Island of Lanai Ground Water Hydrologic Units

Map Projection: Universal Transverse Mercator

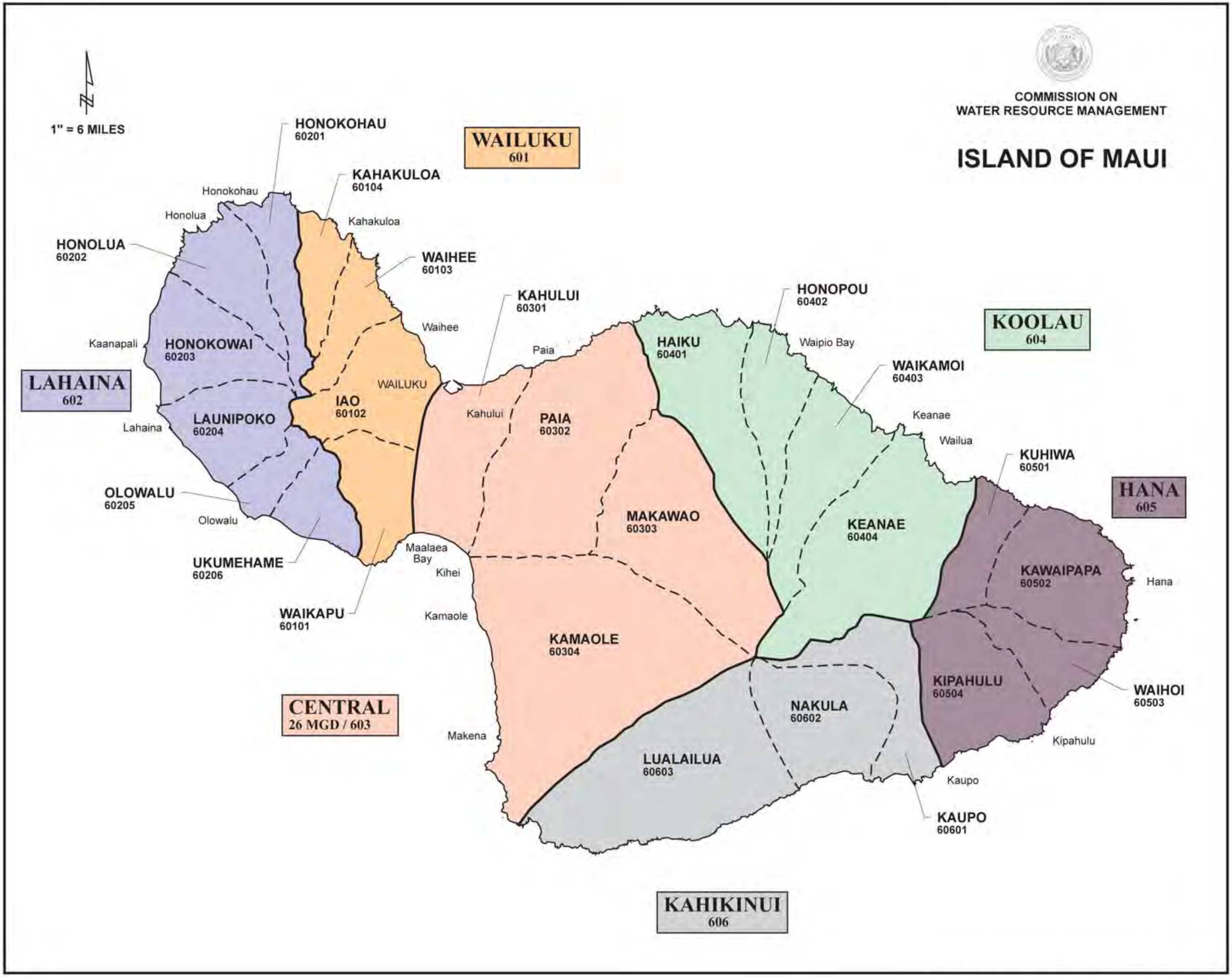

Figure 3-5. Island of Maui Ground-Water Hydrologic Units

Map Projection: Universal Transverse Mercator

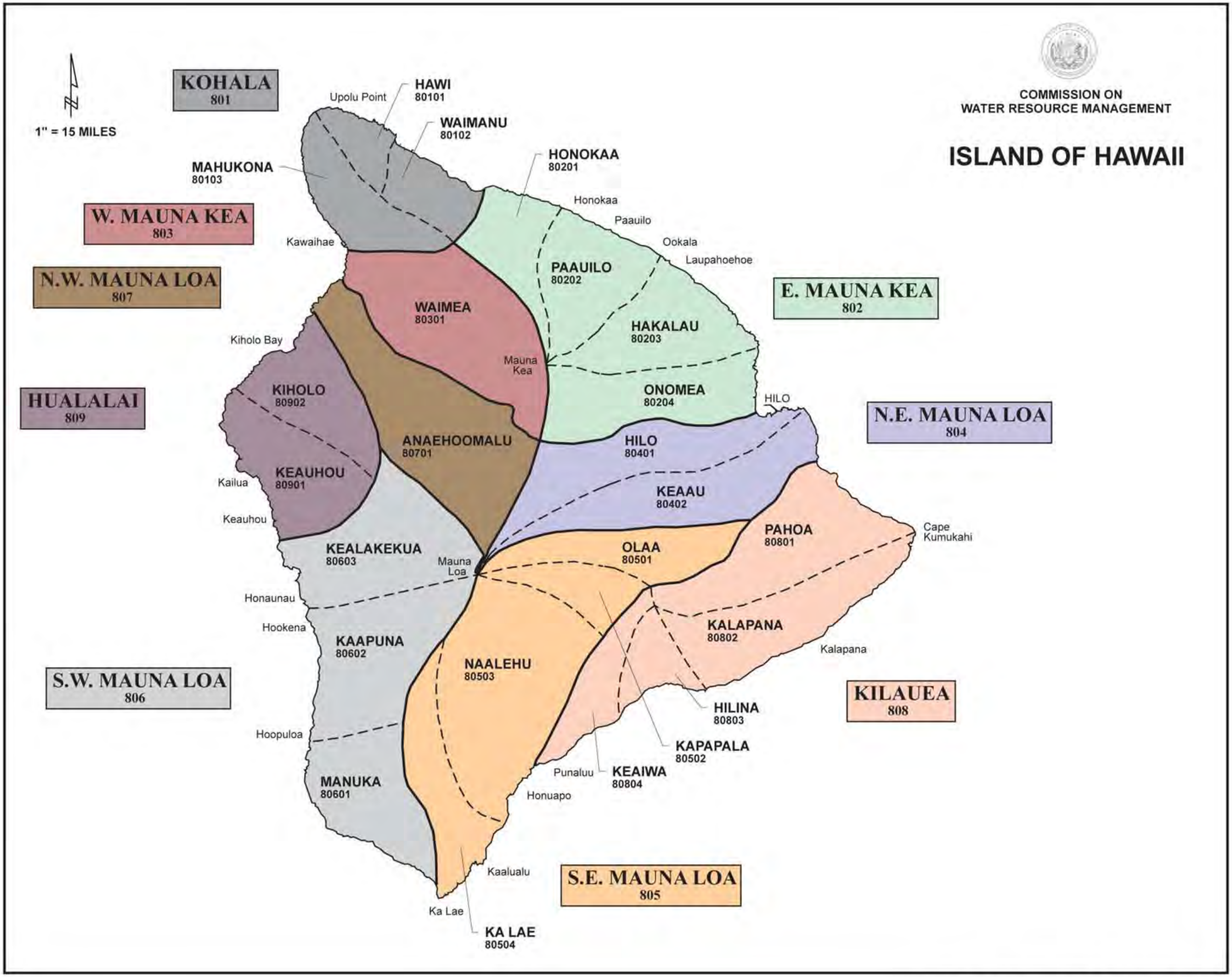

Figure 3-6. Island of Hawaii Ground-Water Hydrologic Units

Map Projection: Universal Transverse Mercator

3.3.4. Determining the Availability of Ground Water Resources: Assessing Recharge, Ground Water/Surface Water Interactions, and Sustainable Yields

Ground water flow patterns and chemical transport processes within that flow can be difficult to understand because they occur below the ground surface. Therefore, scientists must often infer and interpolate the status and characteristics of ground water resources from limited data and modeling tools. Use of these tools requires the establishment of certain assumptions and inputs, which inherently possess varying degrees of uncertainty. The following sections provide an overview of the primary issues related to the quantification of recharge, ground and surface water interaction, and sustainable yield. These issues contribute to uncertainties in the estimation of available ground water resources.

3.3.4.1. Assessing Ground Water Recharge

Ground water recharge is the replenishment of fresh ground water and depends on many natural and human-related factors. Recharge can change over time and in response to changes and events in climatological trends and land use. Ultimately, the goal of water-budget and recharge analysis is to quantify how much and where fresh water eventually reaches and becomes part of a saturated ground water aquifer.

Estimating Recharge

The ground water recharge equation (or ‘soil-moisture water-budget’ or ‘mass-balance’ equation) considered in this plan to estimate ground water recharge over a specified area is:

$$R = RF + FD + IR - DRO - \Delta SMS - ET$$

where:

R = Recharge
RF = Rainfall
FD = Fog drip
IR = Irrigation
DRO = Direct surface runoff
ΔSMS = Change in soil-moisture storage
ET = Evapotranspiration

Various methods have been derived using the above equation in varying levels of complexity and analysis to estimate ground water recharge. Each of the components within this equation have their own ‘best estimate’ quantification issues. Some of these major issues regarding the application of this equation are:

- Spatial Data Coverage
- Time Steps
- Direct Runoff Estimation; and
- Soil-Moisture Storage/ Evapotranspiration Interaction

These are discussed in more detail in the subsections below.

Spatial Data Coverage. The number and location of rainfall, fog-drip, evaporation, streamflow, irrigation return flow, soils, and land use cover data collection and analysis affect the estimation of recharge. There are three entities that maintain major climatological networks: the USGS; the U.S. Department of Commerce, National Oceanic & Atmospheric Adiministration (NOAA), National Weather Service (NWS), and the University of Hawaii - State Climate Office (SCO). The SCO is currently updating the statewide rainfall station index.

Many investigations rely on the DLNR's *Rainfall Atlas*, R76, 1986, which has been used as the standard long-term baseline monthly rainfall average and median throughout the state. Likewise, the DLNR *Pan Evaporation: State of Hawaii 1894-1983*, R74, 1986 provides the best long-term statewide annual estimate of pan evaporation. The best spatial soil coverage is the United States Department of Agriculture Soil Conservation Service's *Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii*, 1972-73. Another source of significant historic and spatial climactic and irrigation data is the Hawaii Agricultural Research Center (formerly the Hawaii Sugar Planters Association and the Pineapple Research Institute of Hawaii), which compiles data collected by sugar plantations for irrigation activities.

Spatial data coverage density varies for both rainfall and streamflow data collection and return irrigation areas such that some areas will have higher density of data compared to others. The most current land cover data is compiled through the Gap Analysis Program (GAP) run by the United States Geological Survey that maps, in part, the land cover of the dominant plant species. This mapping of land use cover will greatly enhance potential evapotranspiration spatial coverage data. Lastly, spatial data coverage differences can be best represented in recharge analysis through the use of Geographic Information Systems (GIS) and preferably on a basin wide scale, coincident with aquifer system area boundaries.

Time Steps. Time steps are periods over which data is available and comparable to each other. Time steps can be annual, monthly, daily, or even hourly. In ground water management, annual recharge is the most conservative approach (monthly or daily recharge data is only needed for detailed modeling analysis). Usually, annual time-step water budget averages are more conservative estimates than monthly, daily, or hourly water budget averages because 'spikes' in precipitation and evaporation intensities and effects of soil-moisture storage are attenuated and significant inputs to recharge can be lost.

Annual water budgets were used in the 1990 WRPP assessment of recharge and are therefore considered reasonably conservative. However, the recharge water budget equation above works best with shorter time steps, with daily time-steps being the most realistically achievable data set. Unfortunately, it is also difficult for all data points to have daily time steps over the same period of analysis. For example, daily readings for rainfall are readily available whereas pan evaporation daily data is much more limited.

Precipitation and evaporation intensities as well as soil-moisture storage vary significantly between and during the wet and dry seasons and have a significant effect on seasonal recharge rates. For numerical ground water modeling, monthly and daily time-steps provide a better way to look at transitory behavior of an aquifer and should provide a better calibration opportunity than annual time-steps. Further, if sufficient data is available, daily time-steps is preferable to monthly time steps.

Total Direct Runoff Estimation. Total direct runoff for an entire drainage basin is difficult to measure. Estimates of total direct runoff do not account for the amount of overland flow to the ocean (which does not contribute to stream flow). Soil properties and land use also change and affect this component. If adequate rainfall and streamflow data is available, direct runoff-to-rainfall ratios can be computed on a basin-wide scale.

Soil-Moisture Storage/Evapotranspiration Interaction. Another critical consideration is when to subtract ET in the water budget. Past recharge studies using the above recharge equation, which includes soil-moisture storage considerations, have used the following two methods:

1. ET is subtracted before soil-moisture storage capacity considerations. Any water left over then goes to soil storage and any water in excess of soil storage then goes to recharge.
2. ET is subtracted only after soil-moisture storage capacity considerations and any recharge has occurred. In other words, ET potential is limited by soil-moisture storage capacities.

Method 1 is considered to be more realistic and conservative than method 2, especially for daily recharge calculations. Method 2 has been used for monthly recharge estimates when daily calculations are not possible, or Method 1 seemed to unreasonably underestimate monthly recharge. The best GIS based soil datasets are available from the U.S. Department of Agriculture’s Natural Resources Conservation Service, Soil Survey Geographic Database.

Simplified Ground Water Recharge Calculation: The 1990 WRPP

The June 1990 WRPP used a simplified version of the recharge calculation to determine recharge and is the statewide standard under that portion of the HWP. It can be generally represented as follows:

$$R = RF - DRO - ET$$

where:

R = Recharge
RF = Rainfall
DRO = Direct runoff (surface water flows)
ET = Evapotranspiration

all values are in average annual values (inches/year)

Fog drip, irrigation, and changes in soil-moisture storage, were generally not considered. In some well-studied areas, such as the Pearl Harbor area on Oahu, irrigation return contributions were considered in calculating net draft or pumping rate, which is the actual pumping rate minus the rate of irrigation return flow. In general, though, the 1990 WRPP plainly states that no adjustments to the statewide water budgets were made to account for return irrigation and sought to reflect pre-agricultural and pre-urbanization conditions.

Estimates for rainfall, direct runoff, and evapotranspiration were based on simple but reasonable methods for estimating these recharge parameters at the time. Weighted annual averages for rainfall, direct runoff and evapotranspiration in inches per year (in/yr) over aquifer system areas, based on DLNR rainfall maps[2], were used. Direct runoff calculations were based on empirical correlations between annual average rainfall and runoff based on the following empirical equation:

$$DRO = aRF^n$$

where:

DRO = Direct runoff (surface water flows)
RF = Rainfall
a = empirical constant
n = empirical constant

The 1990 WRPP states these are not very good estimators for direct runoff compared to actual streamflow data but are reasonable estimators at the system area scale where actual data is lacking and provided a simple consistent method for statewide application. Lastly, pan evaporation maps from DLNR pan evaporation maps[3] were not used directly to estimate evapotranspiration. Instead, where rainfall exceeded 55 in/yr, evapotranspiration was assigned as 40 in/yr while in areas where rainfall was less than 55 in/yr evapotranspiration was assigned to be 73% of rainfall.

The differences imparted by seasonal variations and the order in which to subtract evapotranspiration from its relationship with soil-moisture storage were not addressed in the 1990 WRPP. Other soil characteristics available in terms of direct runoff/rainfall ratios available were not considered in detail either.

Though the 1990 WRPP did not consider all of the generally accepted recharge considerations (it did not recognize soil-moisture storage for example), it was a reasonable first cut that could be quickly applied statewide to estimate recharge, especially in areas with little or no data. Future investigations may yield more accurate recharge estimations. These studies should include the additional contributions of fog drip and return irrigation, the effects of soil characteristics on

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[2] Giambelluca, T.W., Nullet, M.A., and Schroeder, T.A., 1986, Rainfall Atlas of Hawaii, Report R76, Deptartment of Land and Natural Resources, Division of Water and Land Development, State of Hawaii, 267 p.

[3] Ekern, P.C., and Chang, J.H., 1985, Pan Evaporation: State of Hawaii, 1894-1983, Report R74, Deptartment of Land and Natural Resources, Division of Water and Land Development, State of Hawaii, 172 p.

direct runoff, soil-moisture storage, and shorter time-steps (month-to-month or day-to-day).

Ground Water Recharge Studies in Hawaii since the 1990 WRPP

Since the publication of the June 1990 WRPP, there have been many ground water recharge related studies published for various locations within the state that use the more generalized recharge calculation rather than the 1990 WRPP simplified version. There have also been unpublished private reports that are purported to use the more generalized ground water recharge calculation recognized as the minimal standard by this update of the WRPP.

Further investigation is needed to refine estimates of natural recharge rates. At this time, there are significant variations between reported values of natural recharge to Hawaii basal aquifers. For example, the rate of natural recharge in the Iao Aquifer System Area on Maui was estimated by CWRM in 1990 at 15 mgd (based on a 17.81 square mile recharge area) and by Engott in 2007 at 42 mgd[4] (based on a 18.12 square mile recharge area). These reported values were both derived by hydrologic balance analysis, but Engott's method also included fog drip, daily (instead of annual) time steps, and areal issues with valley fill, caprock, and irrigation return scenarios. According to the principle of hydrology balance, natural recharge equals precipitation minus the total of surface runoff and evapotranspiration. Therefore, more accurate estimation of the rate of natural recharge can only be achieved with an improved understanding of precipitation, including fog drip and rainwater, surface runoff, and evapotranspiration.

Recommendations for Recharge Assessment

- Achieve more accurate estimation of the rate of natural recharge through further study of relevant hydrologic processes such as precipitation (including canopy throughfall of fog water and rainwater), surface runoff, and evapotranspiration.

- Identify the rainfall isohyets described in DLNR's *Rainfall Atlas*, R76, 1986 as the minimum standard to be used in estimating ground water recharge.

- Update recharge estimates statewide for complete island coverage using the general ground water recharge equation in its entirety.

- Review ground water recharge components with other state and federal agencies and produce GIS coverage formats for various time-steps (annual, monthly, and if feasible, daily) and update where feasible.

- Consider exclusion of basal recharge from caprock and valley fill geology.

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[4] Engott, John A., and Vana, Thomas T. 2007, Effects of agricultural land-use changes and rainfall on ground-water recharge in central and west Maui, Hawaii, 1926-2004: U.S. Geological Survey Scientific Investigations Report 2007-5103, 56 p. Available online at http://pubs.usgs.gov/sir/2007/5103.

- Consider current and future land use (urban vs. rural vs. agriculture) impacts to water budget component processes.

- Provide recharge updates in GIS coverage format to be placed on the State GIS system.

3.3.4.2. Assessing Ground and Surface Water Interactions

In Hawaii, ground water and surface water interactions may occur under the following conditions:

- High-level water seeps into stream channels to provide baseflow to streams;

- Basal water in coastal areas flows into stream channels to provide baseflow; and

- Stream water between marginal dike zones and coastal areas infiltrates into ground water, as evidenced by losing stream reaches in these areas.

- Basal water discharges through basal and/or caprock springs to provide water to wetlands and ponds.

Author Gordon A. Macdonald and Agatin T. Abbott, in their 1970 book entitled *Volcanoes in the Sea, The Geology of Hawaii*, describe the close interrelationship between surface water and ground water in many of Hawaii's watersheds. The discharge of excess water stored in high-level aquifers provides "a significant portion of the low water flow of many Hawaiian streams." In the following statement, the authors accurately anticipate that controversy over ground water development impacts to streamflow would soon manifest:

> *This is certain to become a source of major conflict in future years, not only on Oahu but also on the neighbor islands, because increasing groundwater development from the headwater areas of the stream basins will surely reduce down-stream supplies for irrigation as well as water for other instream uses such as wildlife habitats and recreation and aesthetic enjoyment.*

In more recent publications, ground and surface water interactions are discussed in the context of the contested case hearing over the Waiahole Ditch irrigation system, located in Windward Oahu. The system provides an example of how the development of water tunnels and stream diversions can impact the base flow (flow supplied by ground water discharge to the stream) of diverted streams as well as the recharge of the basal lens. In his 2002 book Hawaiian Natural History, Ecology, and Evolution, Alan C. Ziegler wrote of the Waiahole Ditch System and its water resource impacts as follows:

> *The entire Waiahole Ditch System is approximately 43.5 km (27 miles) long, and since its opening in 1916 has had an average water flow of over 1.4 m^3/s (32 mg/d). Of the average flow over the life of the project, 1.2 m^3/s (27 mg/d) is estimated to have been groundwater. The average amount of surface water the system collected from streams and perched springs might thus seem to be 0.2 m^3/s (4.5 mg/d). Because the withdrawal of high-level groundwater caused less to seep out to these surface water sources, however, the reduction from predevelopment Windward surface water flow was substantially greater than this amount, conceivably at least twice as much, although no exact figures are available.*[5]

Surface and ground water relationships are further complicated by human impacts and infrastructure installed to transport water between different hydrologic units. The built environment can create artificial relationships between surface and ground water resources, and these situations can be difficult to manage. In his book Water and the Law in Hawaii, published in 2004, Lawrence H. Miike notes that the laws regulating surface and ground water resources have developed separately, although natural and man-made interaction exists. An example of this is the artificial relationship between Windward Oahu surface water and Leeward ground water created by the Waiahole Ditch System. Miike further notes that, as a result of the 2000 Waiahole Ditch Contested Case, where there exists an undisputed interrelationship between surface and ground water, the State’s water use permitting authority extends to both ground and surface water withdrawals if there is a designation of either a ground or surface water management area (see Section 5 for discussion on water management areas and CWRM’s regulatory programs).

From a regulatory perspective, the Commission on Water Resource Management is primarily concerned with ground and surface water interaction issues as they affect surface water resources and estimates of ground water availability. Where ground water aquifers contribute to streamflow, well withdrawals from the contributing aquifer may cause depletion in stream base flow. This is a concern, as adequate stream flow must be maintained to support instream uses. In the interest of responsible management and protection of surface water resources, CWRM assesses ground and surface water relationships during staff evaluations of well permit applications. CWRM also must consider such relationships in the evaluation of sustainable yield estimates where aquifers are hydraulically connected to streams. The following sections provide examples of different types of interactions, information on methods for assessing ground and surface water interaction, and recommendations for improving monitoring and assessment.

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[5] Estimates for natural flow in streams affected by the Waiahole Ditch System can be found in the USGS Scientific Investigations Report 2006-5285, available online at http://pubs.usgs.gov/sir/2006/5285. (Yeung, C.W., and Fontaine, R.A., 2007, Natural and diverted low-flow duration discharges for streams affected by the Waiahole Ditch System, windward Oahu, Hawaii: U.S. Geological Survey Scientific Investigations Report 2006-5285.)

Ground Water Contributions to Stream Flow

Ground water can provide a significant contribution to stream flow. Most perennial stream segments in Hawaii rely on input from dike-impounded ground water or basal water contributions at the coast. Figure 3-7 provides a schematic cross section of a dike-impounded ground water system along the length of a stream.

The upper reaches of many Hawaiian streams are within or near the area where volcanic dikes (near-vertical sheets of massive, low-permeability rock that cut through older rocks) impound ground water to high levels. Streams that intersect the water table of the dike-impounded ground water body are commonly perennial because they are continually recharged by the ground water body.[6] A stream that receives ground water discharge is called a “gaining” stream. In general, the flow increases as one moves downstream within dike zones. The development of a system to capture dike-impounded ground water can affect natural springs and reduce the amount of springflow that feeds the perennial streams in the upper reaches, resulting in diminished streamflows. An example of where such streamflow impacts have occurred is in the windward Oahu watersheds affected by the Waiahole Ditch system of tunnels and ditches.[7]

At low altitudes, water levels in streams and ground water bodies may be affected by ocean tides. Thus, streams in coastal areas may either gain or lose water during the day depending on the relative effects of the ocean tide on streams and ground water levels. Streams may also flow perennially in areas where dikes are not present. For example, in southern Oahu, ground water discharges to streams from a thin freshwater-lens system in permeable rocks at altitudes less than a few tens of feet.[8] Another example can be seen in eastern Kauai, where ground water discharges to streams from a vertically extensive freshwater-lens system in low-permeability rocks at altitudes of several hundred feet.[9]

Stream Flow Contributions to Ground Water

Some streams run dry at lower reaches because water infiltrates into the streambed before reaching the coast. Depending on the local geology and soils, there are stream segments, or reaches, where water seeps down through the stream bed into ground water bodies. These reaches are referred to as “losing” stream reaches because stream flow is lost to ground water recharge. Figure 3-7 illustrates both gaining and losing stream reaches.

Water can move from the stream into the ground if the water table is at a lower elevation than the streamflow level. Losing stream conditions can occur if a rainfall

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[6] Oki, D.S., 2003, Surface Water in Hawaii: U.S. Geological Survey Fact Sheet 045-03, 6 p.

[7] Hirashima, G.T., 1971, Tunnels and dikes of the Koolau Range, Oahu, Hawaii, and their effect on storage depletion and movement of ground water: U.S. Geological Survey Water-Supply Paper 1999-M, 21 p.

[8] Oki, D.S., 2003, Surface Water in Hawaii: U.S. Geological Survey Fact Sheet 045-03, 6 p.

[9] Izuka, S.K., and Gingerich, S.B., 1998, Ground water in the southern Lihue Basin, Kauai, Hawaii: U.S. Geological Survey Water-Resources Investigations Report 98-4031, 71 p.

event in the upper reaches, or a water diversion causes an increased stream discharge, bulking up the flow to a height above the water table, and subsequently forcing the stream water into the ground water system. Another example of losing stream conditions is where an active water supply well lowers the local water table and attracts the stream water towards the pumping well.

Where ground water development has occurred in areas known to be subject to ground water/surface water interaction, the volume of surface water loss attributable to well pumping is usually not equal to the volume of ground water withdrawal. In rare cases, there is a direct and equal relationship between ground water withdrawals and stream flow depletion. However, this type of relationship depends on many factors, such as a well's proximity to a stream, well depth, and surrounding geology. Figure 3-8 illustrates how well pumping can affect the interaction between a ground water system and a stream. Therefore, it is important to have methods to assess the extent of ground and surface water interaction and the degree to which water development may influence stream discharge.

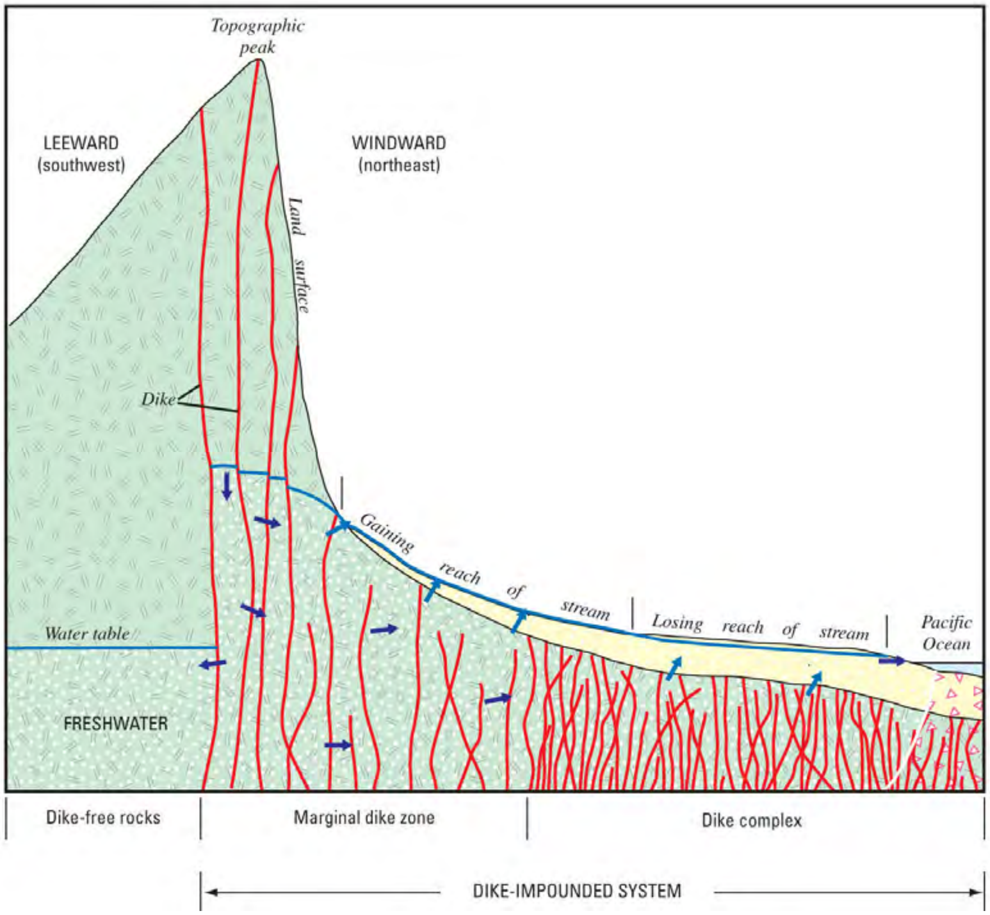

Figure 3-7. Schematic cross section showing a dike-impounded system (adapted from Oki and Brasher, 2003[10])

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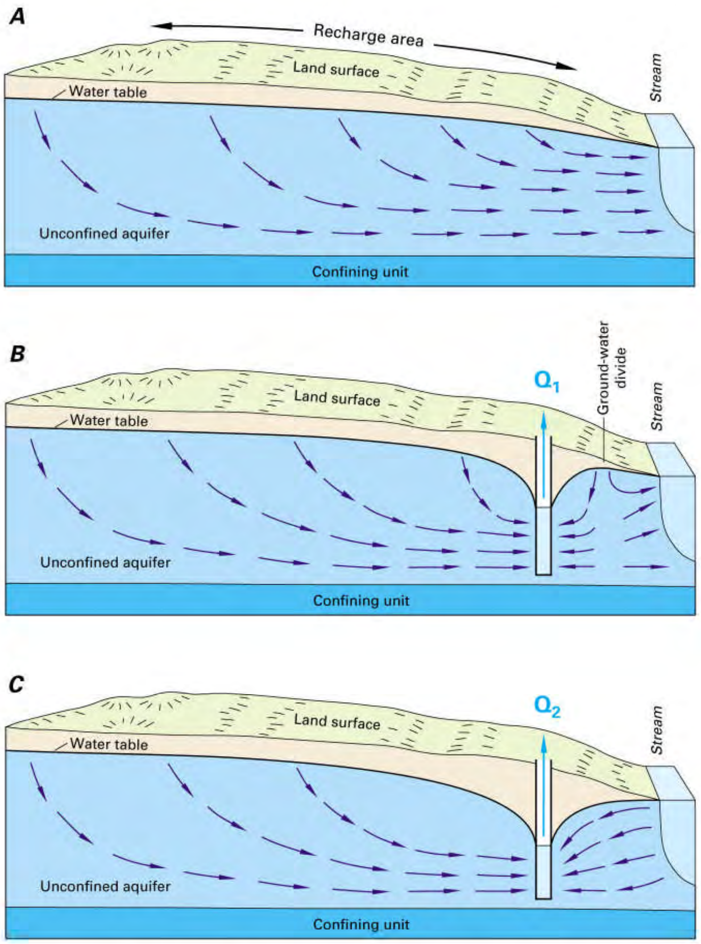
[10] Oki, Delwyn S. and Anne M.D. Brasher, 2003, Environmental Setting and the Effects of Natural and Human-Related Factors on Water Quality and Aquatic Biota, Oahu, Hawaii: U.S. Geological



Under natural conditions (A), recharge at the water table is equal to ground-water discharge to the stream. Assume a well is installed and is pumped continuously at a rate, Q_1, as in (B). After a new state of dynamic equilibrium is achieved, inflow to the ground-water system from recharge will equal outflow to the stream plus the withdrawal from the well. In this new equilibrium, some of the ground water that would have discharged to the stream is intercepted by the well, and a ground-water divide, which is a line separating directions of flow, is established locally between the well and the stream. If the well is pumped at a higher rate, Q_2, a different equilibrium is reached, as shown in (C). Under this condition, the ground-water divide between the well and the stream is no longer present, and withdrawals from the well induce movement of water from the stream into the aquifer. Thus, pumping reverses the hydrologic condition of the stream in this reach from ground-water discharge to ground-water recharge. Note that in the hydrologic system depicted in (A) and (B), the quality of the stream water generally will have little effect on the quality of ground water. In the case of the well pumping at the higher rate in (C), however, the quality of the stream water can affect the quality of ground water between the well and the stream, as well as the quality of the water withdrawn from the well. Although a stream is used in this example, the general concepts apply to all surface-water bodies, including lakes, reservoirs, wetlands, and estuaries.

Figure 3-8. Effects of pumping from a hypothetical ground water system that discharges to a stream (Adapted from Alley and others, 1999[11]).

Survey Water-Resources Investigatons Report 03-4156, 98 p. Available online at http://pubs.usgs.gov/wri/wri034156.

[11] Alley, W.M., T.E. Reilly, and O.L. Franke, 1999, Sustainability of Ground-Water Resources: U.S. Geological Survey Circular 1186, 79 p. Available online at http://pubs.usgs.gov/circ/circ1186/html/gw_effect.html.

Methods to Assess Ground Water/Surface Water Interaction

Direct Measurement Within the Stream Channel. Base flow is the volume of water in a stream due solely to ground water input. It may be possible to directly measure the interaction of ground and surface water within a stream channel, although such efforts may not be feasible across the vast majority of the State because the investigations are field intensive, time consuming, and very costly. According to the USGS, "Future goals associated with the issue of ground water/surface water interaction can only be minimally addressed with the existing surface water data-collection program (continuous recording, low-flow partial record stations, and crest-stage gages). The current program is structured primarily to provide streamflow data at specific points. Streamflow data that describe the magnitude of changes in base flow (flow supplied by ground water discharge to the stream) or data from seepage runs along stream reaches are required to address the issue of ground water/surface water interaction."[12] Data sets that indicate changes in base-flow characteristics (e.g. changes in low-flow discharge) are generally not available for most areas of the State. Therefore, the wide application of these investigations may not be practicably implemented.

A series of continuously recording stream gages on a stream can provide long-term flow data for analyses using the base-flow index (BFI) or flow duration curves. Such analyses can be used to separate out gains or losses of base flow between the gages. A pumping well can change the quantity of water naturally discharging to a stream, as well as the direction of ground water flux to a stream under different pumping rates.[13] The closer the well is to a stream, the more likely measurable affects will occur. Moreover, the greater the long-term pumping rate, the greater the likelihood that the stream will be affected. In cases where a gaged stream is influenced by the presence of a well, it may be possible to observe and directly measure streamflow losses due to pumping withdrawals. The effects of well withdrawals could be observed at one or multiple stream gages, along the stream reach adjacent to the well, depending on the distance between the well and the stream. Procedures for utilizing continuous gaging techniques have been published by the USGS and are available through the USGS website, "Techniques of Water-Resources Investigations Reports" (http://pubs.usgs.gov/twri/). Continuous gaging is discussed in "Techniques of Water-Resources Investigations Reports Book 3, Chapter A6, General procedure for gaging streams.[14]

A seepage run is a direct way to accurately measure gains and losses of stream discharge. The process is an intensive data collection effort where discharge measurements are made at several locations along a stream reach. The time

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[12] Fontaine, R. A., 1996, Evaluation of the surface-water quantity, surface-water quality, and rainfall data-collection programs in Hawaii, 1994: U. S. Geological Survey, Water-Resources Investigations Report 95-4212, prepared in cooperation with the Commission on Water Resource Management, Dept. of Land and Natural Resources, State of Hawaii, 125 p.

[13] Alley, W. M., Reilly, T. E., and Franke, O. L., 1999, Sustainability of ground-water resources: U. S. Geological Survey Circular 1186, 86 p.

[14] Carter, R.W. and Davidian, J., 1968, Chapter A6, General procedure for gaging streams, Book 3, Applications of Hydraulics, Techniques of Water Resources Investigations of the U.S. Geological Survey. Available online at http://pubs.usgs.gov/twri/twri3-A6/html/pdf.html.

between the first and last discharge measurement is minimized to reduce the effects of temporal variability. Ideally, a seepage run would be performed on a day where stream discharge is stable, during base-flow or low-flow conditions. A current meter is used to measure flow velocities in designated subsection areas across the stream channel. The product of the subsection areas and velocities (perpendicular to flow direction) are summed to provide the total flow for that stream section. Procedures used in measuring stream discharge across a section have been outlined, and the following formula[15] represents how stream discharge is computed at a specific section:

$$Q = \sum (a\ v)$$

Where: Q = total cross-sectional discharge
a = individual subsection area
v = mean velocity normal to the subsection

The accuracy of the current-meter measurements depends upon choosing good cross-sections with little or no turbulent flow. These are referred to as synoptic streamflow measurements since they were performed on the same day and under the same flow conditions.[16] In some studies, seepage runs are repeated several times over a period of time (using the same measuring sites) to provide an accurate assessment of a stream's gains and losses. Seepage run data may be supplemented by concurrent measurements of specific conductance and temperature, which can aid in the interpretation of the data.

Seepage runs have been used in various stream scenarios to study such parameters as gains to stream base-flow discharge, streamflow losses to the basal lens and coastal sediments, and the impacts of surface water diversions and ground water pumpage.[17] Ideally, prior to conducting a pump test on a well that may affect streamflow, baseline discharge data should be collected along the stream reach most likely to experience impacts. A detailed survey of the stream reach should be conducted before the pump test to determine any obvious changes in flow (gains or losses). Discharge measuring sites should then be established to monitor flow before, during, and after the test. There should be one or more upstream monitoring sites, one or more monitoring sites adjacent to the well, and one or more monitoring sites downstream of the well. Monitoring can be done by direct flow measurements using a flow meter, or by installing temporary weirs and/or partial flumes. Pressure transducers can be used to measure changes in stream stage upstream of the weir or flume before, during, and after the test. Procedures for

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[15] Rantz, S. E. and others, 1982, Measurement and computation of streamflow: volume 1. measurement of stage and discharge: U. S. Geological Survey Water-Supply Paper 2175, 284 p.

[16] Fontaine, 1996.

[17] Takasaki, K. J., Hirashima, G. T., and Lubke, E. R., 1969, Water resources of windward Oahu, Hawaii: U. S. Geological Survey, Water-Supply Paper 1894, prepared in cooperation with Dept. of Land and Natural Resource, State of Hawaii, 119 p.; Izuka, S. K., 1992, Geology and stream infiltration of North Halawa Valley, Oahu, Hawaii: U. S. Geological Survey Water Resources Investigations Report 91-4197, prepared in cooperation with the Dept. of Transportation, State of Hawaii, 21 p.; Oki, D. S., Wolff, R. H., and Perreault, J. A., 2006, Effects of surface-diversion and ground-water withdrawal on streamflow and habitat, Punaluu Stream, Oahu, Hawaii: U. S. Geological Survey Scientific Investigations Report 2006-5153, prepared in cooperation with the Honolulu Board of Water Supply, 104 p.

utilizing seepage run techniques are available from the USGS “Techniques of Water-Resources Investigations Reports” website (http://pubs.usgs.gov/twri/) and are discussed in “Techniques of Water-Resources Investigations Reports Book 4, Chapter B1, Low-flow investigations.[18]

There are situations where direct stream monitoring will not provide definitive results as to the effects of pumping on stream discharge. Observed geohydrological conditions may result from a complex mix of geologic formations, aquifers, and streams. Also, human errors in data collection and/or recording can occur during streamflow measurements using flow meters and stream gages (assumed to be about 5 percent). Natural events, of course, can also affect data quality. Rainfall events during pump tests can skew data such that any pumping-induced losses to streamflow are masked by gains to stream discharge caused by runoff and infiltration. Also, the lag time between pumping and the observation of surface water impacts may vary. In some cases, a pump test that lasts for 120 hours (5 days) may not be long enough to show depletions in streamflow, although continued monitoring after the test may display changes in low-flow characteristics.

Indirect Methods for Assessing Ground Water/Surface Water Interaction. Although it is ideal to assess ground water/surface water interaction through the analysis of measurements taken in the field, the logistics and costs associated with direct measurement methods are often prohibitive. Thus, investigators employ various indirect methods to assess the interaction of ground and surface water resources. Indirect assessment methods include numerical ground water models and analytical methods.

Numerical models are generally considered superior to analytical models. However, numerical models require detailed data inputs for multiple variables and such data is not available for most areas of the State. In addition, to date, no numerical models designed for Hawaii aquifers have been designed to account for ground water/surface water interaction. Therefore, ground water/surface water interaction in Hawaii is primarily assessed through the use of analytical models, which are simpler, require fewer data inputs, and are more easily applied than numerical models.

CWRM is primarily concerned with ground water/surface water interaction with respect to potential well impacts on surface water resources. These issues typically arise when a well is proposed near a stream. A variety of methods may be used to estimate the degree to which a proposed well may impact stream flow. Historically, CWRM has used two methods to estimate stream flow impacts: (1) estimating ground water drawdown based on the Theis equation and (2) estimating stream loss utilizing a stream depletion equation based on work by Sophocleous and others. In the first method, the hydraulic conductivity of the aquifer is determined from pump test data. This hydraulic conductivity is then input into the Theis equation to calculate drawdown of the water table at a given distance from the pumping well (e.g. distance to the stream). Potential impacts to the stream are then assessed

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[18] Riggs, H.C., 1972, Chapter B1, Low-Flow Investigations, Book 4, Hydrologic Analysis and Interpretation, Techniques of Water Resources Investigations of the U.S. Geological Survey. Available online at http://pubs.usgs.gov/twri/twri4b1/pdf/twri_4-B1_a.pdf.

based on this predicted drawdown. For method two, the hydraulic conductivity of the aquifer is determined from pump test data. This hydraulic conductivity is then input into a stream depletion equation to calculate stream loss, for a given stream reach, as a percentage of the pumping rate of the well.

As a part of the well permit application process, CWRM requires a pump test to be performed for all new wells with a proposed pumping rate greater than 50 gpm. Data from these tests are used for an initial determination on the potential for the well to impact nearby streams, marshes, or other surface water bodies. If it is determined that a new well is likely to adversely impact a surface water body, CWRM may take several actions, including, but not limited to: (1) requiring additional testing and monitoring activities prior to, or as a condition of, permit application approval, (2) submission of an instream flow standard amendment application, (3) approval of the well permit at a reduced pumping rate if it is a requirement of the instream flow standard amendment or if subsequent pumping tests indicate that operation of the well at a lower pump rate will not impact any surface water bodies, or (4) denial of the permit application.

Examples of Ground Water/Surface Water Interaction

Basal Ground Water as Spring Discharge in Pearl Harbor. As mentioned above, many streams are intermittent in their middle reaches and become perennial in their lower reaches due to their intersection of a basal lens. This is particularly the case in Pearl Harbor. Waikele and Waiawa springs are located in the Pearl Harbor Aquifer Sector Area and offer the best examples of surface water where base-flow discharge is dependent upon head.[19]

Oki[20] in the CENCOR numerical model (see Section 3.3.4.3), used the head-discharge relationship at Kalauao Springs in Pearl Harbor to analyze the effects of pumpage to discharge. The base-case was the Visher and Mink[21] condition when agricultural recharge and pumpage was at steady-state or 1950’s conditions. For future pumpage scenarios, Oki used the 1967-90 measured head-discharge relationships when agricultural activities ceased as a base-case. The future pumpage scenarios provide an estimate on the loss of basal discharge at one of the Pearl Harbor springs. Future numerical model simulations can calibrate to other Pearl Harbor springs’ head-discharge relationships to deduce the amount of discharge reduction throughout the Pearl Harbor area for different pumpage scenarios.

A part of the cooperative agreement between CWRM and the USGS is to directly measure flow and sample the Pearl Harbor springs on a biannual basis. These data

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[19] Visher, F. N. and Mink, J. F., 1964, Ground-water resources in Southern Oahu, Hawaii: U. S. Geological Survey Water-Supply Paper 1778, prepared in cooperation with the Division of Land and Water Development, Dept. of Land and Natural Resources, State of Hawaii, 133 p.

[20] Oki, D. S., 1998, Geohydrology of the Central Oahu, Hawaii, ground-water flow system and numerical simulation of the effects of additional pumpage: U. S. Geological Survey Water-Resources Investigations Report 97-4276, prepared in cooperation with the Honolulu Board of Water Supply, 132 p.

[21] Visher and Mink, 1964.

can be directly correlated to water levels in monitor wells and correlated to actual pumpage in the region.

Basal Ground Water as Leakage into Marshes. Basal water also discharges through the caprock and from basal and/or caprock springs in low-lying areas forming marshes and anchialine ponds. Basal water leakage is predominant in the Kahuku area where Punamano and Kii marsh and pond complexes are formed from rainfall, runoff, diffuse leakage of ground water, and from two known springs.[22] In addition there are several flowing artesian wells which supply water to James Campbell Wildlife Refuge at Kii Marsh. The sediments forming the caprock that underlies the marshes, create a semi-confined Koolau basal aquifer. With the basal aquifer having a potentiometric head of about 15 feet above sea level and the elevation of the marsh is only a few feet above sea level, there is ground water leakage through the sediments. Any reduction in the potentiometric head by pumping basal ground water will reduce the amount of leakage through the caprock. The actual amount of leakage cannot be measured directly, but up-gradient increases in basal ground water pumpage will reduce the leakage into the marsh by the same amount.

Kaloko-Honokohau National Historical Park, located on the Kona coast of the Island of Hawaii, is an example of an area where anchialine ponds are present. However, anchialine ponds with greater biodiversity can be found in other areas of the state.

Development of High-Level Ground Water and Impacts to Streams. The development of ground water resources in Hawaii has historically been driven by municipal and agricultural demands. Horizontal tunnels, large shafts, and traditional wells have been constructed to yield water from both basal aquifers and high-level aquifers. The development of high-level aquifers in some areas has been observed to impact stream flow where surface water discharge was dependent upon dike compartment stores.

Between 1900 and 1950, many high-level water sources were developed to supplement plantation irrigation systems. The plantations drilled horizontal tunnels to tap dike impounded water, which was then gravity-fed to irrigation ditches and distribution systems. Tunnels were developed in mountain areas where high spring and stream discharge provided good surface indicators of ground water accumulated in dike compartments. Spring discharge and streamflow, however, was observed to decrease after tunnel development, as the tunnels effectively captured ground water flows before the water could issue forth from springs and seeps.

An example of an area where tunnels impact surface water resources can be found in Windward Oahu, where the Waiahole Ditch system tunnels capture water from numerous dike-impounded reservoirs. Over time, dike-impounded water was

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[22] Hunt, C. D., and DeCarlo, E. H., 2000, Hydrology and water and sediment quality at James Campbell National Wildlife Refuge near Kahuku, Island of Oahu, Hawaii: U. S. Geological Survey Water-Resources Investigations Report 99-4171, prepared in cooperation with the U. S. Fish and Wildlife Service, Dept. of Interior, 85 p.

depleted as it discharged through the tunnels. Meanwhile, stream flow diminished as the dike water no longer contributed to flow.

As awareness of surface water impacts increased, water development efforts began to modify tunnel construction. Engineers introduced concrete bulkheads in tunnels to simulate dike boundaries, control water discharge, and to allow ground water to rebuild as storage. The success of bulkheading varies from site to site, and many questions remain as to the effectiveness of such installations in facilitating storage recovery.

Wells have also used to develop high-level aquifers, and well withdrawals have been observed to impact vicinity surface water resources. In 1963, the Honolulu Board of Water Supply drilled two exploratory wells in Waihee Valley, Oahu (T-114 and T-115 wells 2751-02, 03, respectively). A temporary weir was constructed downstream from the wells to measure changes in stream discharge the five-day well pump testing. Measurements at the weir during testing indicated that well withdrawals resulted in loss of stream flow and that there are also some alluvial contributions to ground water. Pumping of these wells has been restricted by court order[23] such that at least 2.78 mgd of water must be allowed to flow downstream.

Examples Where Surface and Ground Water Do Not Interact. There are cases where pumping wells located near streams have been determined not to affect proximal streamflow. When the streambed is higher than the ground water table, well withdrawals typically do not impact streams. For example, wells (e.g. Mokuhau wells) in Wailuku, Maui, which pump ground water from 10 feet above sea level, do not impact the nearby Iao Stream, which is located several hundred feet above sea level. A similar condition exists with the North Waihee Wells located in the neighboring Waihee Aquifer System Area. Water levels are approximately 8 feet above sea level and the Waihee River streambed invert elevation is much higher.

Well pumping tends not to impact streams where the streambed is separated from the ground water table by perching members. In the Honolulu area, the Board of Water Supply has drilled wells into the basal aquifer (e.g., Nuuanu, Manoa, and Palolo) that do not affect vicinity streams. In these instances, streams are not affected by wells because streamflow is dependent upon shallow alluvial aquifers that are not connected to basal ground water aquifers.

Recommendations for Assessing Ground and Surface Water Interaction

The following recommendations are intended to guide future CWRM efforts to improve the assessment of ground and surface water interaction:

- Identify sites statewide where it would be appropriate to conduct seepage runs and incorporate seepage run data collection into the monitoring program.

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[23] Reppun v. Board of Water Supply, 1982, 65 Haw. 531, 656 P.d 57, cert. denied, 471 U.S. 014, 105 S. Ct 2016, 85 L Ed 2d 298 (1985).

- Ensure adequate coverage of long-term stream gage sites and identify appropriate low-flow partial record sites.

- Ensure adequate baseline data collection prior to new source development. Coordinate data collection based upon long-range county plans for water development.

- Establish a statewide hydrologic monitoring netwok which will provide a basis for calibrating and validating numerical models of ground water/surface water interaction.

- Promote and encourage the use of calibrated local-scale numerical model of ground water flow in basal aquifers to assess ground water/surface water interaction as part of the well permitting process. In the modeling area, the ground water head and stream base flow are influenced by the proposed pumping.

3.3.4.3. Assessing Aquifer Sustainable Yield

Natural resources are commonly classified as either renewable: capable of being replenished as rapidly as they are used; or non-renewable: a result of accumulation over a long period of geologic time. Ground water, replenished by rainfall recharge, is universally classified as a renewable resource. However, the amount of ground water that can be developed in any Hawaii aquifer is limited by the amount of natural recharge. Additionally, not all natural recharge an aquifer receives can be developed. Some aquifer outflow or leakage must be maintained to prevent seawater intrusion or to maintain some perennial streamflow. Therefore, the sustainable yield of an aquifer normally represents a percentage of the natural recharge. Ideally, this percentage is determined by considering all relevant aquifer hydrogeologic properties and their effects on temporal and spatial variation in flow, hydraulic head, and storage. However, the State Water Code provides CWRM some flexibility in using other methods to define sustainable yield as provided by HRS §174C-3: "'Sustainable yield' means the maximum rate at which water may be withdrawn from a water source without impairing the utility or quality of the water source as determined by the commission."

The basic question that must be addressed to successfully manage Hawaii's ground water resources is: "what is the acceptable minimum storage?" This question can also be stated as: "what is the acceptable rate of forced draft?" The acceptable rate of forced draft from an aquifer is formally defined as the sustainable yield.

Ground water models are used as tools in ground water management. This section provides a general summary of ground water modeling efforts as they have been applied in Hawaii to evaluate aquifer sustainable yield. As background to support the modeling discussion, a brief explanation of ground water storage and movement parameters is provided.

Ground Water Storage and Movement

According to the mass conservation principle, the total storage in an aquifer changes when its inflow is not balanced by its outflow. Under natural conditions, the aquifer is in a hydrologic balance such that the inflow, or the rate of natural rainfall recharge, equals the outflow or the coastal leakage. Thus, the volume of aquifer storage remains constant.

Hydraulic head, or the water level as it relates to water pressure, is an important variable. The spatial distribution of the hydraulic head or gradient determines the speed of water movement. The hydraulic head also determines the storage of an aquifer. The hydraulic head of a basal aquifer is the highest at the inland boundary and gradually reduces toward the coastline. This spatial variation of the hydraulic head induces ground water flow from mountain areas toward the ocean (see Figure 3-9).

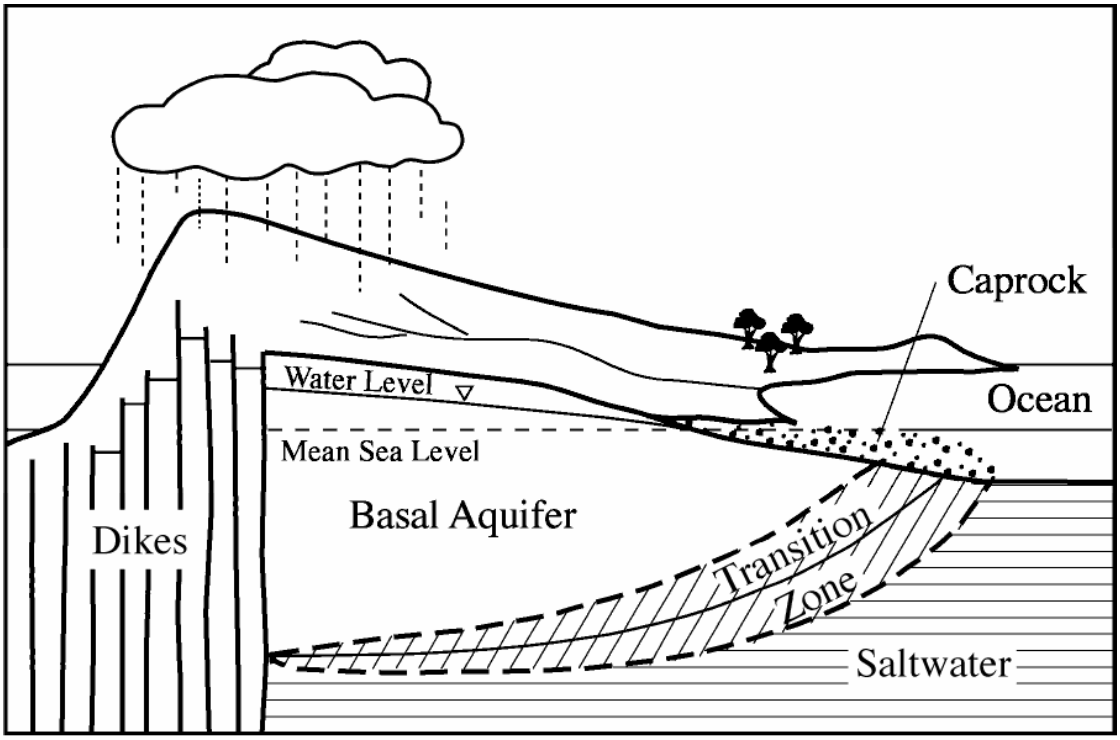

Figure 3-9. Hydrogeologic feature of a typical Hawaiian basal aquifer.

Forced draft or pumping has disrupted the natural balance of Hawaii aquifers. This is evident in the decline of hydraulic head and the reduction of storage. If the rate of forced draft from an aquifer remains constant, the aquifer would eventually reach a new hydrologic balance with a smaller storage. In principle, if the rate of forced draft equals the rate of natural recharge, there will be no leakage outflow and no storage. The hydraulic head or aquifer storage would be reduced to zero. This is not an acceptable scenario. As aquifer storage is reduced, the transition zone would grow to occupy the entire aquifer, gradually replacing all freshwater with brackish or saltwater. Therefore, as a practical matter, it is not possible to create a well network that will capture all recharge.

An aquifer's value as a source of freshwater can be evaluated in terms of hydrogeologic properties that dictate ground water storage and ground water movement. These properties are measured in terms of porosity, storage coefficient, hydraulic conductivity, and transmissivity.

An aquifer's ability to store ground water is determined by porosity and the storage coefficient. Porosity is the ratio of the aquifer's void volume to the total volume of rock material. The void volume of an aquifer is the volume occupied entirely by water. Thus, porosity indicates the maximum amount of water that an aquifer can contain. Generally, only a portion of this water can be developed and extracted for water supply; this is referred to as specific yield. The remaining volume of water is retained as a film on rock surfaces.

The volume of water stored in an aquifer changes in response to hydraulic pressure. The storage coefficient is defined as the volume released from or taken into storage per unit area of the aquifer per unit change in hydraulic head. The typical Hawaiian basal aquifer is unconfined, where the water table comprises the upper boundary (see Figure 3-9). In an unconfined aquifer, the effective porosity or specific yield is equal to the storage coefficient.

Ground water movement through an aquifer can be measured in terms of hydraulic conductivity or transmissivity. Hydraulic conductivity can be decribed as the ease with which water moves through the aquifer. Transmissivity is the product of hydraulic conductivity and the depth of flow.

Ground water supplies may be vulnerable to contamination due to human-induced and natural conditions. The impacts of contamination can be amplified and facilitated by ground water movement. Chemical leaching and seawater intrusion are two common sources of contamination. Chemical leaching occurs when residual pesticides, petrochemicals, or other contaminants percolate down from upper soil layers into the fresh water lens. Saltwater intrusion occurs when increasingly brackish water infiltrates into the freshwater lens. This can occur due to (1) improper pumping of a production well, or (2) over pumping of the aquifer, or (3) migration of the transition zone inland and/or vertically upward.

The susceptibility of an aquifer to contamination can be measured by evaluating advection and dispersion. Advection is the transport of contaminants, as water carries impurites in the direction of flow. Dispersion includes: 1) microscopic mechanical mixing due to varying pore spaces through which water flows and 2) molecular diffusion. Diffusion is defined by Fick's law as the movement of a fluid from an area of higher concentration to an area of lower concentration. Advection and the mechanical mixing portion of dispersion constitututes the majority of contaminant movement within an aquifer while the diffusion component of dispersion usually has much less effect in the spreading of contaminants.

As described earlier, storage and movement of groundwater in basal aquifers is also influenced by the Ghyben-Herzberg equilibrium formula. However, though this formula gives satisfactory results where ground water flow is horizontal, in cases where vertical flow is encountered there may be significant deviation from the 1 to 40 relationship. Vertical flow can be encountered near the coastline and in instances where there is vertical flow in monitoring wells that penetrate differing layers of geologic and aquifer formations.

Laboratory or field tests can be used to assess the parameters described above. Laboratory tests are less reliable, as only a limited portion of the rock matrix can be evaluated. Hawaii aquifers are highly heterogeneous and, at this time, only statistically describable aquifer parameters can be assigned to Hawaii aquifers on a large scale.[24] Field tests can provide effective values appropriate for regional studies, however, site-specific pumping tests should be conducted to evaluate local conditions.

Ground Water Management Model Development and Application

Many types of models have been developed and applied in the U.S. and elsewhere for simulating ground water flow and solute transport. These models help to address sustainability issues. The early simulation attempts used analog models such as sand boxes, electrical conductivity sheets, and resistance-capacitance networks. Analytical models such as RAM have been and continue to be used in Hawaii with limited ground water data to estimate sustainable yields. More recently, mathematical models have been developed that take full advantage of the rapid advancement of numerical methods and computer technology through what is commonly refered to as numerical models. Finite-difference, finite-element, and other boundary-integral numerical modeling techniques are important tools that should be used to aid in the management of well infrastructure and other ground water management problems where sufficient data and monitoring exist.

Mathematical models of ground water flow are formulated by combining the mass conservation principle and Darcy’s law of ground water movement. Darcy’s law states that the ground water flow rate can be calculated if the hydraulic head gradient and hydraulic conductivity is known. A conceptual ground water flow model can simulate a basal aquifer when the width of the transition zone is small relative to the thickness of the aquifer. In this case, the freshwater and salt water are considered to be immiscible fluids separated by a sharp interface. This type of sharp interface model is adequate if the purpose of modeling analysis is to determine the general position, shape, and behavior of the interface; water levels; and flow directions in response to climatic and pumping stresses .

The conceptual sharp interface model may be further divided into two categories: freshwater flow models, and coupled freshwater-saltwater flow models. The freshwater flow models are formulated by assuming the saltwater is stationary. The lower boundary of the freshwater model or the sharp interface can then be located by the Ghyben-Herzberg formula.[25] Coupled freshwater-saltwater models are

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[24] Lau, L. Stephen and Mink, J.F., *Hydrology of the Hawaiian Islands*, University of Hawaii Press: Honolulu, 2006.

[25] Liu, C.C.K., Lau, L.S. and Mink, J.F., 1983, Groundwater Model for a Thick Freshwater Lens, *Ground Water*, 21(3):293-300.

formulated by assuming both freshwater and underlying saltwater are moving. The sharp interface of a coupled freshwater-saltwater flow model can be located based on Hubbert formula.[26]

Mathematical models of ground water solute transport, the movement of solutes in ground water systems, are formulated by combining the mass conservation principle and Fick's law of dispersion. Fick's law states that the mixing of a solute in an aquifer can be calculated if the solute concentration gradient and dispersion coefficient are known. For modeling reactive chemicals, additional mathematical terms representing relevant reaction kinetics must also be included in the transport model formulation.

Because the solution of a transport model requires prior knowledge of flow velocity, solute transport modeling must be conducted following a flow simulation. The flow simulation calculates the flow velocity distribution in the aquifer, which is subsequently applied in transport simulation to calculate the salinity distribution. In modeling seawater intrusion, salinity re-distribution may cause appreciable change in water density, which is a flow model variable. Therefore, a comprehensive ground water model must combine both flow and transport simulation. The flow simulation is first conducted to calculate velocity distribution. The velocity distribution is then used by the transport model to calculate salinity distribution. The density change caused by the new salinity distribution is then determined and used to re-calculate the velocity distribution. The process must continue until stable velocity and salinity distributions are established. SUTRA, a numerical ground water model developed by the US Geological Survey, solved coupled flow and solute transport equations.[27]

Formerly, simple analytical ground water models were developed and tested in aquifers with reasonably defined geological structures and hydrology. Mathematical modeling using simple analytical models highlights the relative importance of aquifer hydrogeologic properties. With the increasing power of computers, the accessibility to and use of more complex numerical ground water models and computer codes has increasely become more important.. However, before a numerical ground water model can be soley relied upon for prediction and management decisions, a rigorous process of model calibration and verification must be completed. The general procedure in model calibration and verification is to estimate a range of values for the ground water flow and the solute transport parameters, then test the model by comparing the calculated hydraulic head and salinity distribution to the observed values. The results of an adequately-calibrated model will reasonably emulate the observed results of historical events that provide the basis for estimated parameters. Anderson provides a very good detailed explanation of numerical

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[26] Liu, et al.1983; Essaid, H. I., 1986, A comparison of the coupled fresh water-salt water flow and the Ghyben-Herzberg sharp interface approaches to modeling of transient behavior in coastal aquifer systems, *Journal of Hydrology,* 86:169–193.

[27] Voss, C.J., 1984, A finite-element Simulation Model for Saturated-unsaturated, Fluid-density-dependent Groundwater Flow and Transport Flow with Energy Transport or Chemically Reactive Single-species Solute Transport, *U.S. Geological Survey Water Resources Investigation Report* 84-4369.

model development.[28] Additionally, the CWRM has provided a Guide for Documentation for Ground Water Modelling Reports since 1994.

A comprehensive numerical ground water model contains many model parameters. It may also consist of a huge numerical network with up to one million nodes or computational units. In principle, each node may have different model parameters to address the real world heterogeneity of an aquifer. Therefore, a very close match of calculated and observed head and salinity distribution data is difficult but may be achieved by the simultaneous manipulation of several model parameters.

Inaccurate model calibrations can be corrected by model verification. A model is considered verified if calculated results can reasonably emulate a historical event, or reasonably predict the behavior of water levels under changing circumstances based on an actual data set. New pumpage distribution patterns or changes in recharge due to reduced irrigation are typical examples of changing circumstances. Ideally, some judgment of the values of model parameters should be practiced. In model calibration and verification, it is advantageous for the investigators who developed the model and those who have gathered field data to participate in the calibration and verification process.

Numerical Ground Water Modeling Efforts in Hawaii

Table 3-7 is a listing of numerical modeling efforts in Hawaii that have been reviewed by the CWRM. This is not an exhaustive listing, as there are other private and public reports available that have not been reviewed in depth by the CWRM. As reports come to the attention and are reviewed by the CWRM these documents are compiled in the digital library of the Water Commission for public information. In addition, public and private reports exist which have valuable hydrologic information but are not ground water flow models (e.g., recharge studies).

Table 3-7
Summary of Mathematical Ground Water Flow Models Reports in Hawaii

YEAR	MODEL	APPLICATION	REFERENCES
1974	GE-TEMPO	Long-term head variability in Palolo aquifer, Oahu	Meyers, C.K., Kleinecke, D.C., Todd, D.K., and Ewing, L.E., 1974
1980	Robust Analytical Model (RAM)	Analytical model to assess sustainable yields of Southern Oahu	Mink, J.F., WRRC prepared for Honolulu BWS
1981	2-D Flow Model	Ground water head variability in Pearl Harbor aquifer, Oahu	Liu, C.C.K., Lau, L.S. and Mink, J.F., WRRC TR 139
Early to Mid-80s	Methods of Characteristics (MOC)	2-D/3-D finite difference model of ground water and chemical transport of pesticide residuals in Pearl Harbor aquifer	Konikow, L.F., and Bredehoeft, J.D., 1978 Orr, Shlomo, and Lau, L.S., 1987

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[28] Anderson, M.P., Woessner, W.W., 1992, Applied Groundwater Modeling – Simulation of Flow and Advective Transport, 381 p.

Table 3-7 (continued)
Summary of Mathematical Ground Water Flow Models Reports in Hawaii

YEAR	MODEL	APPLICATION	REFERENCES
1985	AQUIFEM-Salt	2-D finite element to water systems in Southeast Oahu	Eyre, P., Ewart, C., Shade, P. USGS WRIR 85-4270
1990	RAM	Analytical ground water model for estimating sustainable yield values in 1990 WRPP	Mink, J.F. Mink & Yuen, prepared for the Water Commission
1993 to 1994	DYNSYSTEM	3-D finite element to study ewa marina construction effects on ewa caprock	Camp Dresser & McKee, 4 Volumes, prepared for HASEKO (Ewa) Inc., CCH-OA96-1
1995	AQUIFEM-Salt	2-D finite element to study water level changes due to increased pumping in Hawi, Big Island.	Underwood, M., Meyer, W. Souza, W. USGS WRIR 95-4113
1995	AQUIFEM-Salt	2-D finite element to study water level changes due to increased pumping from Barbers Point Shaft on Waianae Aquifer.	Souza, W., Meyer, W. USGS WRIR 95-4206
1996	Modular Finite Difference Flow (MODFLOW)	2-D finite difference to study the effects of pumpage on water levels for the entire island of Lanai	Hardy, R. CWRM R-1
1996	MODFLOW	2-D finite difference to study connection between caprock and basal aquifers	Willis, R., prepared for The Hawai'i-La'ieikawai Assoc. Inc., CCH-OA96-02
1996	Saturated-Unsaturated Transport (SUTRA)	2-D finite element to study pumpage impacts to water levels on cross-section of Ewa Caprock	Oki, D., Souza, W., Bolke, E.,Bauer. G USGS OFR 96-442
1997	AQUIFEM-Salt	2-D finite element to study pumpage impacts to water levels and coastal leakage for entire island of Molokai	Oki, D. USGS WRIR 97-4176
1998	SHARP	Quasi 3-D finite difference to study pumpage impacts to water levels in Central Oahu	Oki, D. USGS WRIR 97-4276
1998	SHARP	Quasi 3-D finite difference to study pumpage impacts to water levels in Lihue Kauai	Izuka, S. Gingerich, S. WRIR 98-4031
1998	RAM	Study on sustainable yield for Waipahu, Waiawa and Waimalu Aquifer Systems	Mink, J.F. Mink & Yuen prepared for LURF
1998	RAM	Study on sustainable yield of Ewa-Kunia Aquifer System	Mink, J.F. Mink & Yuen prepared for Estate of James Campbell
1998	FEMWATER	3-D finite element coupled flow and transport to model the Ewa Plain	Woodward Clyde, prepared for C&C of Honolulu
1999	SHARP	Quasi 3-D finite difference to study water levels and coastal leakage at Kaloko-Honokohau National Park	Oki, D., Tribble, G., Souza, W., Bolke, E. USGS WRIR 99-4073
2001	RAM	Comparison between RAM and numerical model results	Oki, D., Meyer. W. USGS WRIR 00-4244

Table 3-7 (continued)
Summary of Mathematical Ground Water Flow Models Reports in Hawaii

YEAR	MODEL	APPLICATION	REFERENCES
2001	SHARP	Quasi 3-D finite difference to study water levels, transition zone, and surface water impacts	Izuka, S., Oki, D. USGS WRIR 01-4200
2002	AQUIFEM-Salt	2-D finite element ground water flow model to study Hawi area on big island	Oki, D. 2002, USGS WRIR 02-4006
2005	FEFLOW	3-D finite element simulation to study transition zone movement due to pumping on the Honolulu aquifer.	Todd Engineers, prepared for BWS 2005
2005	SUTRA	2-D finite element to effects of Honolulu Valley fills	Oki D. USGS SIR 2005-5253
2006	MODFLOW	3-D finite difference study of the Mahukona Aquifer System	Spengler, S., Pacific Hydrogeologic, LLC
2006	AQUIFEM-Salt	2-D finite element simulation to study impacts of future pumpage on water levels and coastal leakage on Molokai	Oki, D. USGS SIR 2006-5177
2006	MODFLOW	3-D finite difference study for DOH SWAP program to identify well capture zones	Whitttier, R, El-Kadi, A., et. al. WRRC prepared for State of Hawaii DOH
2007	AQUIFEM-Salt	2-D finite element simulation to study impacts of pumpage on water levels and coastal leakage on Kaunakakai Stream Molokai	Oki, D. USGS SIR 2007-5128
2007	RAM2	Modified RAM that includes deep monitor well salinity profile data for estimating sustainable yield values in 2008 WRPP	Liu, C.C.K., 2007.WRRC PR-2008-06

Analytical Ground Water Modeling Efforts in Hawaii

Table 3-7 also lists analytical modeling efforts that have been reviewed by the CWRM. This is not an exhaustive listing as there are other private and public reports available. In addition, public and private reports exist which have valuable hydrologic information but are not ground water flow models (e.g., recharge studies).

An analytical model for a particular ground water system can be formulated using simplifying assumptions for system boundaries, flow, and transport processes. With these simplifying assumptions, theoretical or mathematically derived solutions of the model governing equations can be obtained.

Analytical ground water models are used extensively in ground water management for the following reasons:

- Analytical models are essential for the design of field experiments and subsequent data interpretation to estimate aquifer flow and transport parameters;

- Analytical models are useful modeling tools for preliminary ground water investigations; and

- Analytical models can be used to test comprehensive numerical models through comparison of modeling results for simplified conditions and scenarios.

Analytical Ground Water Flow Model RAM

In Hawaii, the most commonly used analytical ground water model is the robust analytical model (RAM) [29] derived by Mink. Sustainable yield values of Hawaii basal aquifers were estimated by RAM and included in the 1990 WRPP.

In RAM, a basal aquifer is represented conceptually by two completely stirred tank reactors (CSTRs) separated by a sharp interface (see Figure 3-10). The freshwater in the upper CSTR flows at a constant rate of $L = I - D$, where L is the coastal leakage; I is the natural rainfall recharge, a constant; and D is the pumping rate, or pumping minus irrigation return flow. The saltwater in the lower CSTR is stationary. RAM calculates the variations over time of the hydraulic head (h) in a basal aquifer in response to pumping stress. The steady-state solution of RAM indicates a simple relationship between the hydraulic head and the pumping rate. This relationship is presented graphically in Figure 3-11.

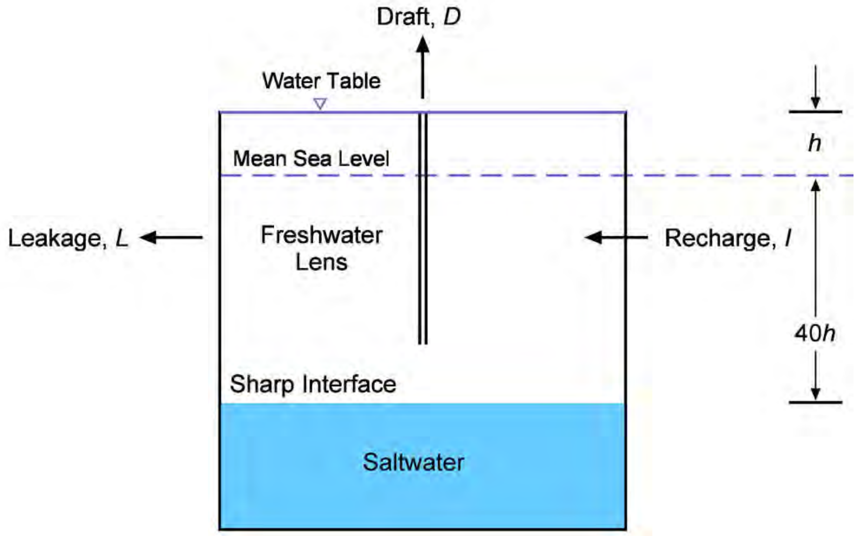

Figure 3-10. Conceptual formulation of the basal aquifer in the robust analytical model (RAM).

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[29] Mink, 1980; Mink, J.F., 1981, Determination of Sustainable Yields in Basal Aquifer, in: *Groundwater in Hawaii-A Century of Progress,* Book published by the Water Resources Research Center, University of Hawaii at Manoa, pp.101-116.

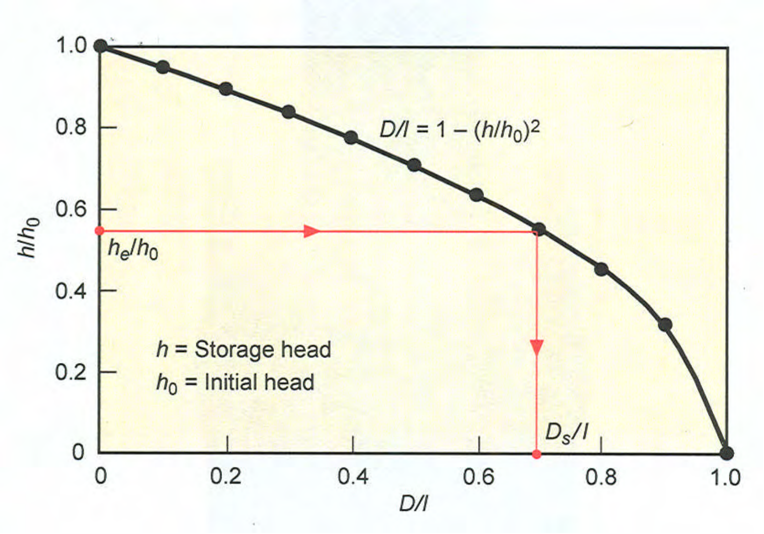

Figure 3-11. Basal aquifer head-draft curve derived by RAM.

Key assumptions of RAM include the following:

- Fresh water occurs as a basal lens floating on top of sea water;
- A sharp interface exists between the fresh and sea water;
- The aquifer is unconfined, its properties are homogeneous and isotropic, and its thickness is constant;
- Groundwater flow is uniform and laminar;
- Head is equivalent to Storage Head; and
- Wells are optimally placed throughout the aquifer system area.

Important limitations of RAM include the following:

- RAM ignores the spatial distribution of (1) recharge, (2) actual well placement, and (3) actual well pumpage;
- Many of the “initial heads” used the in RAM calculation were estimated due to the absence of pre-development groundwater data;
- The “minimum equilibrium head” used in the RAM equation is an estimate based on empirical relationships. It cannot be determined analytically.;
- RAM does not account for (1) convection and dispersion, (2) variability in the transition zone, (3) flow between aquifer system areas, and (4) aquifer system area boundary conditions (such as caprock); and
- RAM does not model ground water flow in three-dimensions.

Analytical Ground Water Flow and Transport Model RAM2

The modified RAM (or RAM2,) consists of two submodels. The flow submodel takes the form of RAM. The transport submodel simulates the variation of salinity over time in the transition zone of a basal aquifer in response to pumping stress. In RAM2, a basal aquifer is represented conceptually as two completely stirred tank reactors (CSTRs) separated by a transition zone of varying salinity (see Figure 3-12).

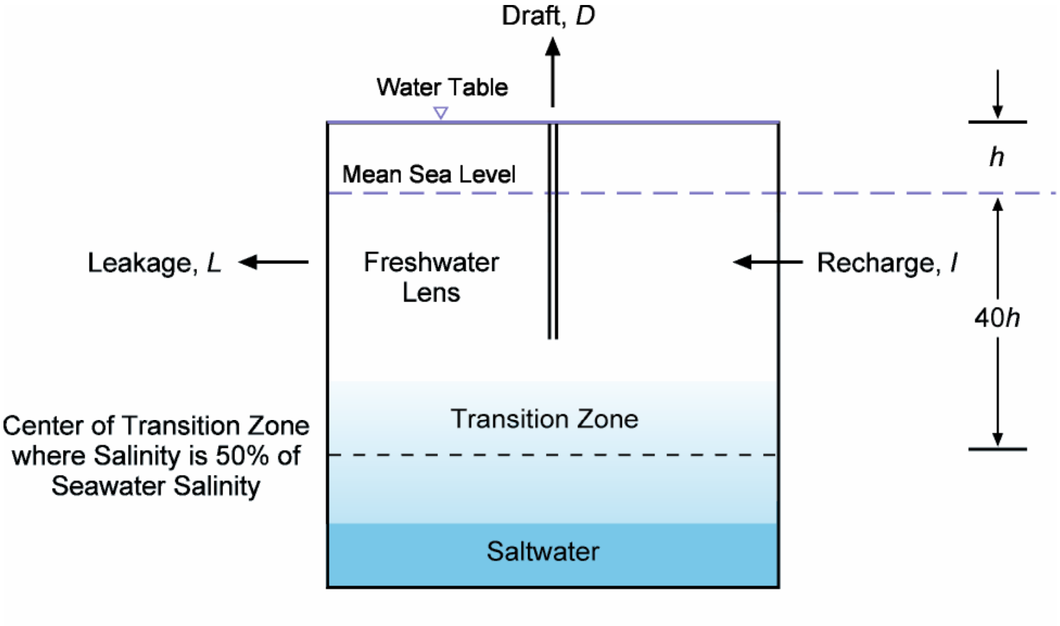

Figure 3-12. Conceptual formulation of the basal aquifer model RAM2.

Assessing Sustainable Yield of the Hawaiian Basal Aquifers by RAM and RAM2

Ideally, the sustainable yield of a basal aquifer would be determined through a numerical simulation using a comprehensive three-dimensional flow and transport model. However, the application of a comprehensive model for this purpose requires significant time and money to produce and is difficult to use. Comprehensive numerical model parameters are very complex and are difficult to quantify. Simple analytical models such as RAM and RAM2 are currently more readily applied to estimate sustainable yields for water planning purposes, especially given the complexities of estimating recharge alone.

According to RAM, a parabolic relationship of hydraulic head and draft rate exists when a basal aquifer is at a steady state, or when recharge to the aquifer equals leakage plus pumping or forced draft. Figure 3-11 shows a plot of head vs. draft in terms of dimensionless variables. The ordinate is a dimensionless variable of head, or h/h_0, where h_0 is constant initial head. The abscissa is a dimensionless variable of draft rate, or D/I.

According to RAM, the sustainable yield of a basal aquifer relates directly to its minimum equilibrium head. Mink stated that “the clearest expression of sustainable yield is that of allowable net draft for a selected (minimum) equilibrium head.”[30] Sustainable yield represents the maximum amount of water that can be withdrawn before a given equilibrium head is compromised.

The response of a basal aquifer to pumping stress can be measured in terms of hydraulic head decline and the expansion and upward movement of the transition zone. This expansion and upward movement is a prelude to seawater intrusion. Acceptable source-water salinity in Hawaii is 250 mg/L chlorides or less . Seawater intrusion occurs when water with salinity higher than 250 mg/L chlorides reaches the bottom of a pumping well. Therefore, the minimum equilibrium hydraulic head can generally be defined as the hydraulic head that must be maintained to prevent seawater intrusion into a particular well.

The minimum equilibrium head of a well cannot be determined analytically by solving the governing flow equation of RAM as it does not consider salt water movement or well upconing issues for the spatial distribution of actual wells. Therefore, RAM estimates sustainable yield by establishing a minimum equilibrium head based on selected important well depth within an aquifer or, in the absence of a selected well site, it relies on a relationship for selecting minimum equilibrium head, as suggested by CWRM in the 1990 WRPP (see Table 3-8). In this WRPP update, the CWRM generally used the table to reassess sustainable yields rather than rely on a single important well site.

After an equilibrium head (h_e) and thus (h_e/ h_0) is selected, this value is inserted into Figure 3-11 to obtain the dimensionless variable of draft or D_s/I. Multiplying this value by the known recharge rate gives the sustainable yield

Table 3-8. Relationships between initial head and minimum equilibrium head of Hawaii basal aquifers.[31]

The range of initial head, h_0 (ft)	Ratio of minimum equilibrium head and initial head (h_e/h_0)	D/I or SY = %of Recharge
4 – 10	0.75	0.44
11 – 15	0.70	0.51
16 – 20	0.65	0.58
21 – 25	0.60	0.64
> 26 and High-Level	0.50	0.75

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[30] Mink, 1980.

[31] State of Hawaii Department of Land and Natural Resources, Commission on Water Resource Management, 1990, *Hawaii Water Plan, Water Resources Protection Plan:* Honolulu, Hawaii.

The sustainable yield of Hawaii basal aquifers can be determined by the integrated application of both the flow and transport submodels of RAM2. The modeling procedure, as shown in Figure 3-13, consists of the following steps:

1. Use hydraulic heads and salinity profiles from deep monitoring wells and previous studies to estimate the transport parameter values (i.e., dispersion coefficient and mean hydraulic resident time);
2. Use the transport submodel to calculate the minimum equilibrium hydraulic head; and
3. Use the flow submodel to determine the sustainable yield.

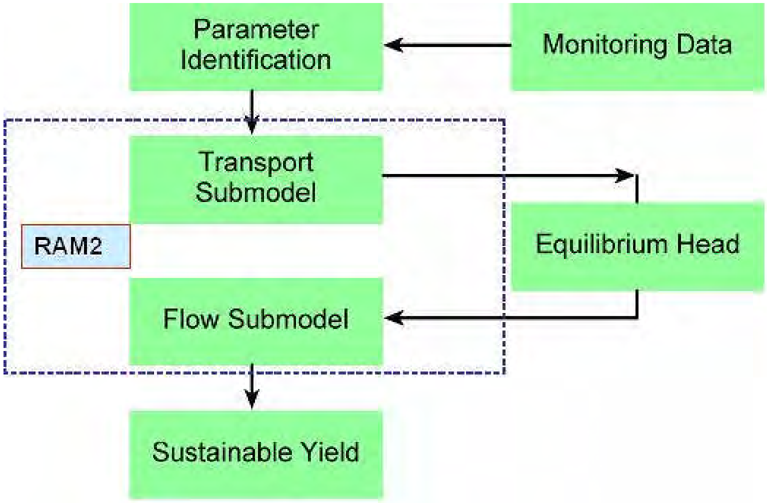

Figure 3-13. RAM2 modeling procedure.

RAM2 was used by two recent studies[32] to re-evaluate the sustainable yield of a few selected Hawaii basal aquifers. Table 3-9 summarizes the results of sustainable yield estimation by both RAM and RAM2.

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[32] Liu, 2006; Liu, 2007.

Table 3-9. Sustainable yield estimation of selected Hawaii basal aquifers

Aquifer	Areas (mi^2)	Natural Recharge (in.)	Estimated Sustainable Yield (mgd)	
			RAM	RAM2
Oahu				
Ewa-Kunia	28.1	24.0	11.0	19.4
Waipahu-Waiawa	60.7	136.3	102.0	110.3
Waimalu	32.1	59.7	45.0	48.3
Moanalua	10.9	24.0	18.0	15.8
Kalihi	6.3	12.0	9.0	8.7
Beretania	8.6	20.0	15.0	13.9
Kaimuki	14.4	8.7	--	6.5
Maui				
Iao	24.7	28.0	20.0	18.5
Molokai				
Kualapuu	13.0	9.0	7.0	5.0

Note: According to CWRM, area of Iao is 17.81 mi^2 and area of Kualapuu is 18.2 mi^2

Production Wells in Hawaii Basal Aquifers: Operation and Safe Yield

The sustainable yield of Hawaii basal aquifers represents the maximum aquifer pumping rate (i.e. allowable draft) assuming optimal placement of wells. In principle, if optimally distributed, each of production well in a basal aquifer can be assigned an allowable draft such that the total draft from the aquifer is equal to or less than the sustainable yield. However, the safe yield of an individual production well is also limited by the localized ground water behavior near the well in response to its pumpage. Specific yields, upconing, and pump intake altitudes can severly limit the safe yield of an individual well while the aquifer as a whole is not threatened. Examples of this are wells drilled too deep, too shallow, or are located in very tight (low permeability) formations. The safe yield of an individual production well may be less than the allowable draft based on any model prediction because of localized operational limitations. Safe yield can be optimized in a production well with proper well design, location, and operation. Further, safe yield of an aquifer based on well infrastructure is best esimated utilizing a calibrated and validated numerical model based on sufficient hydrologic data.

Decline in Specific Capacity

Sustainable yield is evaluated assuming an aquifer is experiencing steady state conditions. It should be noted that this assumption does not account for operational conditions at a given production well. A basal aquifer's transient response to pumping stress, in the vicinity of a well, may include a decline in specific capacity and/or upconing.

The safe yield of an individual production well is partly controlled by the specific capacity the available drawdown of that well. When a well is pumped, water is removed from the aquifer surrounding the well, and the water level or hydraulic head is lowered. The drawdown is defined as the vertical distance the water level within the well bore is lowered from the original static (non-pumping) water level. The specific capacity of a production well is its yield per unit drawdown. Available drawdown is the difference between the static head and the lowest practical head, which is normally determined at the time of well construction.

Decline in the specific capacity of a well is measured in terms of operating head. The operating head indicates the transient response of an aquifer to pumping stress. This is usually measured in the field while the aquifer is being pumped. The hydraulic head of a basal aquifer is governed by the Ghyben–Herzberg formula and is called the storage head. The storage head of a large aquifer declines slowly in response to pumping stress. For example, the average decline of the storage head of the Pearl Harbor aquifer was less than 0.25 ft/yr during the last 100 years[33]; during the same period, the measured seasonal changes of the operating head near a pumping well in the Pearl Harbor aquifer fluctuated as much as 10 feet. At pumping wells, operating heads are less than storage heads due to turbulent flow into the well. Therefore, operating heads reflect both well inefficiancies and aquifer storage heads.

In Hawaii, the ground water is often pumped from several production wells in a well field. The drawdown at a given well field is equal to the superposition sum of the individual well drawdowns. In general, wells in a well field should be spaced as far apart as possible to minimize well interference. However, economic factors including the cost and availability of land may dictate the implementation of a least-cost well layout, which results in some interference. Both the specific capacity and the available drawdown for each well in a well field must be closely monitored to achieve for satisfactory well operation.

Deterioration in Water Quality (Saltwater intrusion)

When water from a basal aquifer is pumped through a well, pumping stress causes a localized rising of the underlying saltwater. This phenomenon is called upconing.[34] Most past upconing studies and ground water flow models assumed the existence of a sharp interface between freshwater and the underlying salt water. However, in real-world basal aquifers a gradual transition zone exists between the freshwater and the underlying saltwater (see Figure 3-9), which appear to differ between aquifer system areas based on deep monitor well data. Also, the near-shore toe of the basal aquifer will shift inland as cumulative pumpage is increased and captures leakage to the ocean. These are significant issues regarding well susceptibility to salt water intrusion. Mathematical models can and have been used by the CWRM to estimate upconing and saltwater intrusion, but the dynamics of the transition zone are not well understood.

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[33] Mink, 1980.
[34] Todd, D.K., 1980. Groundwater Hydrology, John Wiley & Sons: New York.

Upconing can be minimized through the proper design and operation of production wells. Generally, wells should have the maximum possible vertical separation from the salt water zone. This is why in the *Hawaii Well Construction Standards* the depths of all new basal well depths are limited the top ¼ the thickness of the basal lens encountered during construction. This will reduce the capacity of an individual well but provides a method to optimize the resource and protect future constructed well infrastructure. Wells should also be pumped at a low, uniform rate. The total number of production wells in a well field, well spacing, and pumping rates can be optimized using numerical modeling analyses.

Recommendations for Assessing Sustainable Yield

Ground water can be managed through an understanding of sustainable yield, which is defined as the maximum amount of water that may normally be withdrawn from a source without significantly impairing the source. This definition gives CWRM flexibility to consider and redefine sustainable yields with time and based on case-by-case circumstances. At this time, the sustainable yield of the Hawaii basal aquifers is being evaluated by using analytical ground water models such as the robust analytical model (RAM) and the modified RAM, or RAM2. However, in some areas, including Honolulu, Pearl Harbor, Lanai, Molokai, and (soon) West Maui numerical ground water models have been used to help assess the sustainability of the ground water and refine the uncertainty of analytical ground water models. Additionally, the Ewa Caprock area has used a general chloride limit for wells to establish overall aquifer area sustainable yield.

The most immediate area that requires further investigation is the rate of natural recharge. Reported values of natural recharge vary significantly. These values have been derived from various past studies using differing hydrologic balance analyses. Climate change and data from the last 25 years should also be included into recharge analysis. Recharge should also be standardized such that model studies are comparable. Critical issues for recharge include:

- Estimation of runoff;
- Soil-moisture storage and its relationship to evapotranspiration;
- Assesment of fog drip on precipitation;
- Time steps (daily vs. monthly vs. annual);
- Land use (urban vs. rural vs. agriculture); and
- Results attributed to CWRM formal aquifer system areas.

A second area that requires further investigation is the interaction between ground water and streamflow. In cases where a stream is hydraulically connected to an aquifer, well withdrawals from the aquifer may cause depletion in the base flow of the stream. This is a concern, as adequate stream flow must be maintained to support instream uses. CWRM must consider ground water/streamflow interactions in its evaluation of sustainable yield and in its review of well-permit applications. Also, numerical models must include the baseflow of streams as part of their calibration analysis.

A third area that requires further study is the salinity transport in the transition zone of basal aquifers. This transport is driven by ground water flow and solute dispersion. Additionally, the effects of bore hole flow in deep monitor wells can introduce complexity in salinity profiles. A recently developed field tracer method by a research team at the University of Hawaii estimates the value of the dispersion coefficient of a basal aquifer by using the salinity profiles observed at deep monitoring wells. The success of this method depends on: how accurately the salinity profile is measured at a deep monitoring well; and how accurately the travel time to the monitoring well is determined. More accurate estimates of the dispersion coefficient can be achieved by establishing ground water monitoring well networks, and by mathematical simulations of the head and velocity distributions.

A fourth area that requires further study is impacts of reducing coastal leakage through pumping and how this might be factored in to sustainable yield estimates. Though §174C-4, HRS of the Water Code states nothing under the chapter of the Code shall apply to coastal waters, this is becoming an increasingly important issue raised through public comments received by the CWRM through its processing of other Code responsibilities.

Fifth, more study on spatially detailed analysis of safe yield or well infrastructure along with water use and development plan scenarios is required. Though RAM has its idealized optimization assumptions and RAM2 is formulated by including salinity transport considerations, these models do not simulate the spatial variations of ground water flow and solute transport. Though more spatially detailed analysis can be achieved through monitoring of field data and, if sufficient data exists, numerical ground water models, these approaches must consider clearly defined future land development and pumpage scenarios. Before these comprehensive models can be applied, careful model calibration and verification must be conducted based on adequate field data to ensure that the comprehensive model is a viable management tool. Comprehensive local-scale models may be used for the design and operation of well fields where model parameters can be readily estimated based on sufficient hydrologic data and site-specific field aquifer tests.

Sixth, in the interest of responsible management and protection of water resources and environmental quality, CWRM should expand and improve its hydrologic monitoring network and water use reporting to achieve statewide coverage and to better assses sustainable yields based on actual data. Also, CWRM should integrate its future activities to re-evaluate sustainable yield with the State GIS system, which may allow efficient data storage, retrieval, and model application.

Lastly, the CWRM should consider adaptive management concepts to link the preceeding recommendations, which span both science and societal values. CWRM should explore how adaptive management concepts can be applied to the estimation of sustainable yields. The CWRM permit process applies adaptive management concepts and considers other other factors, such as rights that affect individual well owners. However, the potential application and incorporation of adaptive management concepts in the estimation of aquifer sustainable yield has yet to be evaluated.

3.3.5. Establishment of the 1990 Sustainable Yield Estimates and Subsequent Updates

In 1980, the Honolulu BWS commissioned hydrologists at the University of Hawaii to develop a model to determine sustainable yields for ground water aquifers in Hawaii. The result was the analytical model known as RAM. Sustainable yield estimates derived via RAM reflect the maximum sustainable average-daily-pumpage rates over an entire aquifer system area, assuming wells are spaced optimally throughout the system. These RAM-derived sustainable yield estimates were incorporated into the 1990 WRPP. In cases where RAM-predicted sustainable yield did not correlate with actual observed conditions in an aquifer system area, CWRM evaluated irrigation practices, historical aquifer pumpage, and other data to refine the RAM estimate. This refined estimate was adopted by CWRM, rather than the strict RAM derived valued. A complete list of the 1990 sustainable yield estimates are presented in Table 3-10.

In 1993, CWRM adopted an Aquifer System Area approach to organize and manage ground water resources. This superceded the previous method of managing aquifers by larger Sector area boundaries. The Aquifer System Area approach allows for better optimization of well placement and is a better indicator of where water is located within a Sector area. It is the simplest method for optimizing development of the island’s ground water resources while ensuring long-term sustainability from the planning and regulatory perspective. As a result of the new management approach, some aquifer system areas were subdivided into multiple systems and others were consolidated into single systems. This resulted in significant changes in the distribution of sustainable yields amongst affected aquifer system areas. Identification of the aquifers systems that were affected and descriptions of the changes that took place are provided in Comment 6 of Table 3-10.

In 1997, CWRM recognized and adopted the first caprock aquifer sector. The Ewa Caprock Aquifer Sector includes three aquifer system areas. Because the Ewa Caprock Aquifer System Areas overlie basal ground water bodies of other aquifer sectors and systems, and because the dynamics of ground water communication between the caprock and basal aquifers is unclear, CWRM established sustainable yields for the Ewa Caprock Aquifer Aystem Areas based on the chloride content of ground water in individual wells rather than on average-daily-pumping rates across the aquifer system area, as was done for the basal aquifers. A sustainable yield of less than 1,000mg/L chloride was adopted for all three Ewa Caprock Aquifer System Areas (see Table 3-12).

Revisions of individual aquifer system area sustainable yields have also occurred on a case-by-case basis in response to the availability of new data. Sustainable yield estimates have been revised based on recharge studies, groundwater models, other hydrogeologic studies, pumpage and deep monitor well data, and the identification of errors in previous models or studies. All revisions to the sustainable yields have taken place in accordance with statutory requirements and revised sustainable yield estimates adopted by CWRM are official and are used for regulatory and planning purposes.

3.3.5.1. Selection of the 2008 Sustainable Yields

As part of the update to the Hawaii Water Plan, CWRM inventoried all ground water hydrologic units and conducted an evaluation of sustainable yield estimates for all aquifers system areas. The evaluation entailed the following steps:

1. Review of sustainable yield calculation models, recharge calculations, deep monitoring well data, historical pumping data, numerical models for predicting infrastructure safe yields, and other hydrogeologic data and studies;

2. Comparison of the previously adopted sustainable yields (those in effect as of December 31, 2006) against those predicted by other models; and

3. Identification of the most appropriate sustainable yield for each aquifer based on conclusions drawn from steps 1 and 2.

CWRM considered three sustainable yield data sets in its evaluation: RAM (2008), RAM + Updated Recharge, and RAM2. RAM (2008) is a recalculation of sustainable yield using the RAM and the reported original 1990 input values. The recalculation was conducted when errors were found in the original 1990 calculations. RAM + Updated Recharge consists of sustainable yield estimates resulting from the input of updated recharge estimates into the RAM. RAM2 consists of sustainable yield estimates predicted by the RAM2.

Sustainable yield estimates by models other than RAM or RAM2 were available for some areas; however, because the areas modeled did not match the aquifer system area boundaries, the values could not practically be compared to existing sustainable yield values. Similar issues were encountered with some recent recharge studies. Therefore, these models and studies were eliminated from consideration.

The sustainable yields for the three data sets considered are listed in Table 3-10. In addition to these three data sets, the CWRM considered the Previously Adopted SY (2007) when the value originated from a commission action or a numerical ground water model study. The original 1990 RAM sustainable yield numbers are shown in the table for reference; however, they were not considered in the selection process as they were superceded by the RAM (2008) numbers which correct known math errors. The comments in Table 3-10 also provide historical background on changes to aquifer system area boundaries and changes to sustainable yield values.

For a given aquifer system area, the range of sustainable yield estimates shown in Table 3-10 demonstrates that the estimation of aquifer sustainable yields is not an exact science. Insufficient hydrologic, geologic, and meteorological data require the estimation of critical input parameters in any sustainable yield model. Differences in estimates of these input parameters, and in how they are incorporated in a model, can produce a wide range in predicted sustainable yield values for a given aquifer.

Given the range of predicted sustainable yields for each aquifer, and the inherent uncertainty in each prediction, CWRM has applied the *precautionary principle* in selecting sustainable yields for adoption in this update to the WRPP. Application of the precautionary principle is appropriate in light of CWRM's role as a trustee of Hawaii's water resources.

In general, the lowest predicted sustainable yield for an aquifer system area, as shown in Table 3-10, was selected as the 2008 Sustainable Yield. Exceptions to this rule were recognized on a case-by-case basis and alternative sustainable yields were selected depending on the following:

For Aquifer Systems with predominantly basal resources:

- Presence of an operational deep monitor well and other publicly available hydrologeologic data, such as:
    - Recharge studies that follow the convention of section 3.3.4.1;
    - Complete and significant record of historical pumpage, chloride, and water-level data;
    - Numerical model studies for establishing infrastructure safe yields; or
    - Other hydrologic and geologic studies reviewed and accepted by CWRM staff.

- Ground water inputs from adjacent aquifers.

- Post-1990 WRPP CWRM actions.

- Errors in mathematical calculations.

- Clerical errors.

For Aquifer Systems with predominantly high-level resources:

- Presence of an operational ground water-level monitoring network and a stream monitoring network, where applicable, to ensure compliance with instream flow standards, and other publicly available hydrogeologic data, such as:
    - - Recharge studies that follow the convention of section 3.3.4.1;
    - - Complete and significant record of historical pumpage, chloride, and water-level data;
    - - Numerical model studies for establishing infrastructure safe yields; or
    - - Other hydrologic and geologic studies reviewed and accepted by CWRM staff.

- Errors in mathematical calculations.

For basal aquifer dominated aquifer system areas, the existence of an operational deep monitor well is critical in determining the location and characteristics of the transition zone and provides an early warning system on the sustainability of the resource. In high-level aquifer dominated aquifer system areas, a robust operational ground water-level monitoring network provides more valuable information than deep monitor wells to assess the sustainability of the resource. In addition, in high-level aquifer systems where existing pumping wells have the potential to impact perennial stream flows, a stream monitoring network provides essential sustainability data.

When monitoring data (well and/or stream) coupled with other scientifically sound, public, and CWRM-vetted aquifer-specific hydrologic, geologic, or other studies strongly suggested that the lowest predicted sustainable yield in Table 3-10 underestimated the sustainable yield, then selection of an alternatively higher sustainable yield was justified. In cases where an alternate sustainable yield was selected, the basis for the selection is called out in Table 3-10 in the Alternate 2008 SY Selection Criteria column and additional information is provided in the table comments.

Table 3-11 lists the 2008 Sustainable Yields for basal and high-level aquifers along with planning comments and a confidence ranking for each sustainable yield estimate. Figure 3-14 illustrates sustainable yield confidence rankings by island and aquifer system area. Table 3-12 lists the 2008 Sustainable Yields for caprock aquifers. Maps illustrating the ground water hydrologic unit boundaries and the 2008 sustainable yield for each aquifer system area are included as Figures 3-15 to 3-20.

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Table 3-10
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Aquifer Sector	Aquifer System	RAM (1990)	RAM (2008)	RAM + Updated Recharge	RAM 2	*SY Range*[(1)]	Previously Adopted SY (2007)[(2)]	Sustainable Yield (2008)	Alternate 2008 SY Selection Criteria
Hawaii									
Kohala	Hawi	27	27	13/29	~	*13-29*	27	**13**	
Kohala	Waimanu	110	110	~	~	*110*	110	**110**	
Kohala	Mahukona	17	17	~	~	*17*	17	**17**	
E. Mauna Kea	Honokaa	31	31	~	~	*31*	31	**31**	
E. Mauna Kea	Paauilo	60	60	~	~	*60*	60	**60**	
E. Mauna Kea	Hakalau	150	150	~	~	*150*	150	**150**	
E. Mauna Kea	Onomea	147	147	~	~	*147*	147	**147**	
W. Mauna Kea	Waimea	24	24	~	~	*24*	24	**24**	
NE. Mauna Loa	Hilo	347	349	~	~	*349*	347	**349**	
NE. Mauna Loa	Keaau	393	395	~	~	*395*	393	**395**	
SE. Mauna Loa	Olaa	124	125	~	~	*125*	124	**125**	
SE. Mauna Loa	Kapapala	19	19	~	~	*19*	19	**19**	
SE. Mauna Loa	Naalehu	117	118	~	~	*118*	117	**118**	
SE. Mauna Loa	Ka Lae	31	31	~	~	*31*	31	**31**	
SW. Mauna Loa	Manuka	42	42	25	~	*25-42*	42	**25**	
SW. Mauna Loa	Kaapuna	50	51	58	~	*51-58*	50	**51**	
SW. Mauna Loa	Kealakekua	38	38	38	~	*38*	38	**38**	

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Aquifer Sector	Aquifer System	RAM (1990)	RAM (2008)	RAM + Updated Recharge	RAM 2	*SY Range[(1)]*	Previously Adopted SY (2007)[(2)]	Sustainable Yield (2008)	Alternate 2008 SY Selection Criteria
Hawaii (continued)									
NW. Mauna Loa	Anaehoomalu	30	30	~	~	*30*	30	**30**	
Kilauea	Pahoa	435	437	~	~	*437*	435	**437**	
Kilauea	Kalapana	157	158	~	~	*158*	157	**158**	
Kilauea	Hilina	9	9	~	~	*9*	9	**9**	
Kilauea	Keaiwa	17	17	~	~	*17*	17	**17**	
Hualalai	Keauhou	38	38	38	~	*38*	38	**38**	
Hualalai	Kiholo	18	18	~	~	*18*	18	**18**	
Kauai									
Lihue	Koloa	30	30	34	~	*30-34*	30	**30**	
Lihue	Hanamaulu	40	40	36	~	*36-40*	40	**36**	
Lihue	Wailua	60	60	43	~	*43-60*	60	**43**	
Lihue	Anahola	36	36	17	~	*17-36*	36	**17**	
Lihue	Kilauea	17	17	5	~	*5-17*	17	**5**	
Hanalei	Kalihiwai	16	22	11	~	*11-22*	16	**11**	
Hanalei	Hanalei	35	35	34	~	*34-35*	35	**34**	
Hanalei	Wainiha	24	24	61	~	*24-61*	24	**24**	
Hanalei	Napali	20	20	17	~	*17-20*	20	**17**	
Waimea	Kekaha	12	10	12	~	*10-12*	12	**10**	
Waimea	Waimea	42	37	55	~	*37-55*	42	**37**	
Waimea	Makaweli	30	26	33	~	*26-33*	30	**26**	
Waimea	Hanapepe	26	22	24	~	*22-24*	26	**22**	

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Aquifer Sector	Aquifer System	RAM (1990)	RAM (2008)	RAM + Updated Recharge	RAM 2	*SY Range*(1)	Previously Adopted SY (2007)(2)	Sustainable Yield (2008)	Alternate 2008 SY Selection Criteria
Lanai									
Central	Windward	3(3)	3	5	~	*3-5*	3	**3**	
Central	Leeward	3(3)	3	5	~	*3-5*	3	**3**	
Mahana Sector	Hauola	~	~	~	~	~	0	~	
Mahana Sector	Maunalei	~	~	~	~	~	0	~	
Mahana Sector	Paomai	~	~	~	~	~	0	~	
Kaa	Honopu	~	~	~	~	~	0	~	
Kaa	Kaumalapau	~	~	~	~	~	0	~	
Kamao	Kealia	~	~	~	~	~	0	~	
Kamao	Manele	~	~	~	~	~	0	~	
Maui									
Wailuku	Waikapu	2	3	6	~	*3-6*	2	**3**	
Wailuku	Iao	20(4)	11	31	19	*11-31*	20	**20**(14)	8a-c, 10
Wailuku	Waihee	8	6	15	~	*6-15*	8	**8**(15)	8a, 8c
Wailuku	Kahakuloa	8	5	8	~	*5-8*	8	**5**	
Lahaina	Honokohau	10	9	17	~	*9-17*	10	**9**	
Lahaina	Honolua	8	8	10	~	*8-10*	8	**8**	
Lahaina	Honokowai	8	6	11	~	*6-11*	8	**6**	
Lahaina	Launiupoko	8	7	14	~	*7-14*	8	**7**	
Lahaina	Olowalu	3	2	7	~	*2-7*	3	**2**	
Lahaina	Ukumehame	3	2	6	~	*2-6*	3	**2**	

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Aquifer Sector	Aquifer System	RAM (1990)	RAM (2008)	RAM + Updated Recharge	RAM 2	*SY Range[(1)]*	Previously Adopted SY (2007)[(2)]	Sustainable Yield (2008)	Alternate 2008 SY Selection Criteria
Maui (continued)									
Central	Kahului	1	1	1	~	*1*	1	**1**	
Central	Paia	8	7	8	~	*7-8*	8	**7**	
Central	Makawao	7	7	20	~	*7-20*	7	**7**	
Central	Kamaole	11	11	16	~	*11-16*	11	**11**	
Koolau	Haiku	31	27	27	~	*27*	31	**27**	
Koolau	Honopou	29	25	26	~	*25-26*	29	**25**	
Koolau	Waikamoi	46	40	40	~	*40*	46	**40**	
Koolau	Keanae	96	83	83	~	*83*	96	**83**	
Hana	Kuhiwa	16	14	14	~	*14*	16	**14**	
Hana	Kawaipapa	48	48	48	~	*48*	48	**48**	
Hana	Waihoi	20	18	21	~	*18-21*	20	**18**	
Hana	Kipahulu	49	42	42	~	*42*	49	**42**	
Kahikinui	Kaupo	18	16	16	~	*16*	18	**16**	
Kahikinui	Nakula	7	7	7	~	*7*	7	**7**	
Kahikinui	Lualailua	11	11	11	~	*11*	11	**11**	
Molokai									
West	Kaluakoi	2	2	4	~	*2-4*	2	**2**	
West	Punakou	2	2	3	~	*2-3*	2	**2**	
Central	Hoolehua	2	2	2	~	*2*	2	**2**	
Central	Manawainui	2	2	3	~	*2-3*	2	**2**	
Central	Kualapuu	7	4	6	5	*4-6*	5[(5)]	**5**[(16)]	8a, 8c-d, 9
Southeast	Kamiloloa	3	3	5	~	*3-5*	3	**3**	

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Aquifer Sector	Aquifer System	RAM (1990)	RAM (2008)	RAM + Updated Recharge	RAM 2	*SY Range[(1)]*	Previously Adopted SY (2007)[(2)]	Sustainable Yield (2008)	Alternate 2008 SY Selection Criteria
Molokai									
Southeast	Kawela	5	5	10	~	*5-10*	5	**5**	
Southeast	Ualapue	8	8	8	~	*8*	8	**8**	
Southeast	Waialua	8	8	6	~	*6-8*	8	**6**	
Northeast	Kalaupapa	2	2	4	~	*2-4*	2	**2**	
Northeast	Kahanui	3	3	8	~	*3-8*	3	**3**	
Northeast	Waikolu	5	5	8	~	*5-8*	5	**5**	
Northeast	Haupu	2	2	5	~	*2-5*	2	**2**	
Northeast	Pelekunu	9	9	12	~	*9-12*	9	**9**	
Northeast	Wailau	15	15	23	~	*15-23*	15	**15**	
Northeast	Halawa	8	8	11	~	*8-11*	8	**8**	
Oahu									
Honolulu	Palolo	5	5	8	6	*5-8*	5	**5**	
Honolulu	Nuuanu	15	15	19	14	*14-19*	15	**14**	
Honolulu	Kalihi	9	9	12	9	*9-12*	9	**9**	
Honolulu	Moanalua	18	18	19	16	*16-19*	18	**16**	
Honolulu	Waialae(6a)	3	3	~	~	~	~	~	
Honolulu	Waialae-West(6a)	~	~	4	~	*4*	4(6a)	**4**(17)	10
Honolulu	Waialae-East(6a)	~	~	10	~	*10*	2(6a)	**2**(18)	10

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Aquifer Sector	Aquifer System	RAM (1990)	RAM (2008)	RAM + Updated Recharge	RAM 2	*SY Range(1)*	Previously Adopted SY (2007)(2)	Sustainable Yield (2008)	Alternate 2008 SY Selection Criteria
Oahu (continued)									
Pearl Harbor	Waimalu	45	47	77	48	*47-77*	45	**45**(19)	8a-c
Pearl Harbor	Waiawa(6c)	52	52	~	See Waipahu-Waiawa	~	~	~	
Pearl Harbor	Waipahu(6c)	50	50	~	See Waipahu-Waiawa	~	~	~	
Pearl Harbor	Waipahu-Waiawa(6c)	~	~	117	110	*110-117*	104(7)	**104**(20)	8a-c, 9, 10
Pearl Harbor	Ewa(6d)	3	3	~	See Ewa-Kunia	~	~	~	
Pearl Harbor	Kunia(6d)	8	10	~	See Ewa-Kunia	~	~	~	
Pearl Harbor	Ewa-Kunia(6d)	~	~	10	19	*10-19*	16(7)	**16**(21)	8a-c, 9, 10
Pearl Harbor	Makaiwa(6e)	~	~	0	~	*0*	0	~	
Central	Wahiawa(6b)	104	104	141	~	*104-141*	23(6b)	**23**(22)	10
Waianae	Nanakuli	1	2	2	~	*2*	1	**2**	
Waianae	Lualualei	4	4	9	~	*4-9*	3(6f)	**4**	
Waianae	Waianae	2	2	4	~	*2-4*	3(6f)	**3**(23)	13a-b
Waianae	Makaha	3	3	4	~	*3-4*	4(6f)	**3**	
Waianae	Keaau	4	4	10	~	*4-10*	4	**4**	

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Aquifer Sector	Aquifer System	RAM (1990)	RAM (2008)	RAM + Updated Recharge	RAM 2	*SY Range[(1)]*	Previously Adopted SY (2007)[(2)]	Sustainable Yield (2008)	Alternate 2008 SY Selection Criteria
Oahu (continued)									
North	Mokuleia	9	8	16	~	*8-16*	12(6g)	**8**	
North	Waialua	5	4	12	~	*4-12*	40(6g)	**25(24)**	9
North	Kawailoa	32	29	31	~	*29-31*	39(6g)	**29**	
Windward	Koolauloa	42	36	41	~	*36-41*	35(6h)	**36**	
Windward	Kahana	15	15	23	~	*15-23*	13(6h)	**15**	
Windward	Koolaupoko	30	30	46	~	*30-46*	43(6h)	**30**	
Windward	Waimanalo	13	13	10	~	*10-13*	8(6h)	**10**	

Notes:

~	Sustainable Yield Not Calculated
CWRM	Commission on Water Resource Management
RAM	Robust Analytical Model
SY	Sustainable Yield
WRPP	Water Resources Protection Plan

General Comments & Historical Background on Changes to Aquifer System Boundaries and Sustainable Yield Values

(1) SY Range - Ranges listed in this colum do not incorporate the RAM (1990) values as some of the numbers were found to be incorrect due to mathematical errors (see RAM 2008 below). The bounds of the sustainable yield range were set based on numbers in the RAM 2008, RAM + Updated Recharge, and RAM 2 columns.

(2) Previously Adopted Sustainable Yield (2007) - Sustainable Yields in effect as of December 2007. These values include updates made to the RAM (1990) SY values based on the results of hydrologic studies or actions of the CWRM.

(3) The Sustainable Yield values for the Windward and Leeward Aquifer System areas were calculated in 1990 but were accidentally omitted from the Water Resources Protection Plan.

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

General Comments & Historical Background on Changes to Aquifer System Boundaries and Sustainable Yield Values (cont.)

(4) The 20 mgd sustainable yield number is based on a higher recharge value than that reported in the 1990 WRPP. This higher recharge value, along with a slightly modified version of the RAM equation into which it was input, were believed by John F. Mink (developer of the RAM) to more accurately reflect conditions in the Iao Aquifer System Area. *Reference: Mink, John.F, 1995, Sustainable Yields Maui and Molokai, Letter to the CWRM from Mink & Yuen Inc., dated September 9, 1995.*

(5) In 1993, a mathematical error was discovered in the calculation of the 1990 sustainable yield for the Kualapuu Aquifer System Area. A recalculation of the sutainable yield by John F. Mink in 1995 resulted in a revised recommendation of 5 mgd for the sustainable yield. This number was based on (1) revised estiamtes for direct runoff and evapotranspiration, (2) a modified RAM calculation for sustainable yield, and (3) the presumption of additional recharge to the system from Waikolu Valley. *Reference: Mink, John.F, 1995, Sustainable Yields Maui and Molokai, Letter to the CWRM from Mink & Yuen Inc., dated September 9, 1995.*

(6) In 1993, the CWRM adopted an aquifer system areas approach to managing ground water resources in Hawaii. This approach is considered the best method for optimizing development of an aquifer while ensuring long-term stability of the water resource. As a result, some aquifer system areas were divided into multiple systems, some aquifer system areas were consolidated into a single system, and new aquifer system areas were created. In addition, revised sustainable yields were proposed for several systems. Specific changes in aquifer system area management and sustainable yields are discussed below:

> (a) The Waialae Aquifer System Area was subdivided into two separate aquifer system areas due to the presence of a hydrologic boundary at Waialae Iki Ridge. This boundary results in a siginificant hydrologic head difference between the Waialae East and Waialae West Aquifer System Areas. The 6 mgd sustainable yield for the original combined aquifer system was redistributed, based on the best available hydrogeologic information, with two-thirds (4mgd) going to Waialae West and one-third (2mgd) going to Waialae East.
>
> (b) The Central Aquifer Sector (Wahiawa Aquifer System) was separated out from the Pearl Harbor and North Aquifer Sectors because the water is high-level rather than basal. The exisiting pumping withdrawal from the system, which totalled 23 mgd, was set as the sustainable yield to maintain spillover of ground water into the Pearl Harbor and North Sectors, thus ensuring sufficient ground water availability in these Sectors to meet demand. The spillover was variably redistributed between the Pearl Harbor and North Aquifer Sectors based on the best available hydrogeologic information.
>
> (c) The Waipahu and Waiawa Aquifer System Areas were combined to allow for more flexibility in pumping. The original subdivision of the aquifer system area was not based on hydrogeologic properties. The combined Waipahu-Waiawa Aquifer System Area was assigned the aquifer code (30203).

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

General Comments & Historical Background on Changes to Aquifer System Boundaries and Sustainable Yield Values (cont.)

– In addition, the sustainable yield for the combined aquifer system area was raised for two reasons. (1) To account for 62 mgd of additional recharge via groundwater spillover from the Wahiawa Aquifer System Area (see comment 6b above) and (2) because historic pumping above the 1990 sustainable yields did not adversely affect properly installed wells, indicating that the true sustainable yield of the aquifer system area was greater than that predicted by the RAM.

(d) The Ewa & Kunia Aquifer System Areas were combined to manage the aquifer as a whole. The original division of the aquifer was based on the irrigation source (well water versus ditch water) and not hydrologeologic properties. The combined Ewa-Kunia Aquifer System Area was assigned the aquifer code (30204).

– In addition, the sustainable yield for the combined aquifer system area was raised to account for 14 mgd of additional recharge via groundwater spillover from the Wahiawa Aquifer System Area (see comment 6b above).

(e) The Makaiwa Aquifer System Area was separated out from the Waianae Aquifer System Area due to a difference in ground water behavior in the two aquifer systems. No sustainable yield was established for this system. The Makaiwa Aquifer System Area was assigned the aquifer code (30205), which was previously assigned to the Kunia Aquifer System Area.

(f) Revised sustainable yields were proposed for the Lualualei, Waianae, and Makaha Aquifer System Areas of the Waianae Sector. The basis for the revised numbers was not documented.

(g) Revised sustainable yields were proposed for all North Sector aquifer system areas to account for groundwater spillover from the Central Sector (see comment 6b above). The additional recharge was variably applied to the North Sector systems; however, the exact amount and distribution of the recharge was not documented. The revised sustainable yields also likely account for significant return irrigation from large-scale sugar cultivation. For the Waialua Aquifer System Area, the sutainable yield number also likely considers the historic pumpage (several decades) of groundwater above 50 mgd without noticeable impacts to the aquifer system area, indicating that the true sustainable yield is significantly higher than the RAM predicted sustainable yield of 4 mgd.

(h) Revised sustainable yields were proposed for all Windward Sector aquifer system areas. The basis for the revised numbers was not documented.

Reference: Hawaii Department of Land and Natural Resources - Commission on Water Resource Management, 1993, Commission Meeting Submittal - Boundary Reclassifications within the Honolulu, Pearl Harbor, and Waialua Ground Water Management Areas, dated March 3, 1993.

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

General Comments & Historical Background on Changes to Aquifer System Boundaries and Sustainable Yield Values (cont.)

(7) Sustainable Yield adopted by the CWRM in 2000 based on a review of three ground water models: RAM (analytical), RASA (numerical), CENCOR (numerical). The impetus for the reassessment of the sustainable yields was the demise of large-scale agriculture in the area and the resultant loss of significant volumes of return irrigation recharge to the aquifer systems. The three models assumed significant ground water spillover was occuring from the Central Sector into the Pearl Harbor Sector and reflected various pumping scenarios designed to protect existing infrastructure. The sustainable yield values calculated by the models provided a range of sustainable yield estimates for the Ewa-Kunia and Waipahu-Waiawa Aquifer System Areas. The adopted sustainable yields of 16 mgd for Ewa-Kunia and 104 mgd for Waipahu-Waiawa reflect the high end of the range for each system. The middle and lower range values were adopted as regulatory action milestones. *Reference: Hawaii Department of Land and Natural Resources - Commission on Water Resource Management, 2000, Commission Meeting Submittal - Request for Approval to Adopt New Sustainable Yields for Ewa-Kunia and Waipahu-Waiawa Aquifer Systems, Pearl Harbor Aquifer Sector, Oahu, dated March 15, 2000.*

Alternate Sustainable Yield Selection Criteria

In general, the lowest predicted sustainable yield for an aquifer system area was selected as the 2008 Sustainable Yield. Exceptions to this rule were recognized on a case-by-case basis and alternative sustainable yields were selected based on the following:

Basal Ground Water Source

8 - Presence of an operational deep monitor well AND other publicly available hydrogeologic data, such as:
    8a - Recharge studies that follow the convention of section 3.3.4.1 of the WRPP;
    8b - Complete and significant record of historical pumpage, chloride, and water-level data;
    8c - Numerical model studies for establishing infrastructure safe yields;
    8d - Other hydrologic and geologic studies reviewed and accepted by CWRM Staff; or
9 - Ground water inputs from adjacent aquifers;
10 - Post 1990 WRPP CWRM actions;
11 - Errors in mathematical calculations; or
12 - Clerical errors.

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Alternate Sustainable Yield Selection Criteria (continued)
High-Level Ground Water Source
13 - Presence of an operational ground water-level monitoring network and a stream monitoring network, where applicable, to ensure compliance with instream flow standards, AND other publicly available hydrogeologic data, such as: 13a - Recharge studies that follow the convention of section 3.3.4.1 of the WRPP 13b - Complete and significant record of historical pumpage, chloride, and water-level data; 13c - Numerical model studies for establishing infrastructure safe yields; 13d - Other hydrologic and geologic studies reviewed and accepted by CWRM Staff.

Sustainable Yield (2008) Comments
(14) The sustainable yield for the Iao Aquifer System Area was maintained at 20 mgd as this is believed to be the best estimate to date. This 1995 estimate (see comment 4 above) falls within the range of predicted sustainable yields for the system. In addition, numerical models, deep monitor well data, and historical pumpage records all suggest a sustainable yield within the middle of the predicted range. *Reference: Hawaii Department of Land and Natural Resources - Commission on Water Resource Management, 2002, Waihee Aquifer Systems State Aquifer Codes 60102 and 60103 Ground-Water Management Area Designation Findings of Fact, dated November 11, 2002.*
(15) RAM (2008) revealed an error in the calculation of the original RAM (1990) sustainable yield for the Waihee Aquifer System Area. The 1990 value is 8 mgd. The correct value is 6 mgd. However, based on (1) current groundwater demands within the system, (2) the fact that the 8 mgd falls within the predicted range of sustainable yields for the aquifer system, and (3) the presence of a deep monitor well within the system that will allow for long-term monitoring of the transition zone, the CWRM elected to maintain the sustainable yield at 8 mgd. *Reference: Hawaii Department of Land and Natural Resources - Commission on Water Resource Management, 2002, Waihee Aquifer Systems State Aquifer Codes 60102 and 60103 Ground-Water Management Area Designation Findings of Fact, dated November 11, 2002.*
(16) The Previously Adopted SY (2007) for the Kualapuu Aquifer System Area dates to a 1996 recalculation of sustainable yield based on a revised recharge number and modified RAM calculation (see comment 5 above). Based on (1) current groundwater demands within the system, (2) the fact that the 5 mgd falls within the predicted range of sustainable yields for the aquifer system, (3) the presence of a deep monitor well within the system that will allow for long-term monitoring of the transition zone, and (4) the existence of groundwater models for the system, the CWRM elected to maintain the sustainable yield at 5 mgd.
(17) Updated recharge data suggest a sustainable yield of the Waialae East Aquifer System Area equivalent to the Previously Adopted SY (2007). The CWRM maintained the sustainable yield at 4 mgd.

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

Sustainable Yield (2008) Comments (continued)
(18) Updated recharge data suggest that the sustainable yield of the Waialae West Aquifer System Area may be higher than the Previously Adopted SY (2007). However, in the absence of a deep monitor well or groundwater model, the CWRM elected to maintain the sustainable yield at the more conservative 1996 number. See comment 6a above.
(19) RAM (2008) revealed an error in the calculation of the original RAM (1990) sustainable yield for the Waimalu Aquifer System Area. The 1990 value is 45. The correct value is 47 mgd. However, due to exisiting salinity issues in wells in this aquifer system, the CWRM elected to maintain the sustainable yield at 45 mgd. A higher sustainable yield may be possible if well placement and pumping are optimized.
(20) The sustainable yield for the Waipahu-Waiawa Aquifer System Area was maintained at 104 mgd as this is believed to be the best estimate to date. The number is based on the analysis and comparison of three groundwater models for this aquifer system area. See comment 7 above.
(21) The sustainable yield for the Ewa-Kunia Aquifer System Area was maintained at 16 mgd as this is believed to be the best estimate to date. The number is based on the analysis and comparison of three groundwater models for this aquifer system area. See comment 7 above.
(22) The sustainable yield for the Wahaiwa Aquifer System Area was held at 23 mgd to ensure sufficient ground water spillover into the Pearl Harbor and North Sectors to meet demands. See Comment 6b above.
(23) RAM (2008) revealed an error in the calculation of the original RAM (1990) sustainable yield for the Waianae Aquifer System Area. The 1990 value is 3 mgd. The correct value is 2 mgd. However, based on (1) current groundwater demands within the system, (2) the fact that the 3 mgd falls within the predicted range of sustainable yields for the aquifer system, (3) the presence of a ground water monitoring network, and (4) a complete and significant record of historical pumpage, chloride, and water-level data, the CWRM elected to maintain the sustainable yield at 3 mgd.
(24) The 2008 sustainable yield for Wailua Aquifer System Area was derived by assuming that 38% of the reserved recharge from the Central Sector spills over into the Waialua Aquifer System (see comment 6b above). This conforms to the North Sector and Pearl Harbor Sector spillover allocation defined in the CENCOR model (see comment 7 above). The reserved recharge is the difference between the actual recharge to the Wahiawa Aquifer System Area (which yields a sustainable yield of 104 mgd) and the recharge necessary to yield the adopted sustainable yield of 23 mgd (see comment 1f above). Thirty-eight percent (38%) of the reserved recharge was added to the recharge for the Wailua Aquifer System Area and the resulting total recharge value was plugged into the RAM, resulting in a predicted sustainable yield of 25 mgd. Though some ground water spillover does occur from the Central Sector into the other North Sector Aquifer Systems, based on the hydrogeology of the region, the volume is believed to be small relative to that flowing into the Waialua Aquifer System Area. Therefore the entire 38% of Central Sector reserved recharge was applied to the Waialua Aquifer System Area.

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

References	
RAM (1990)	Sustainable Yield Values calculated using the 1990 Robust Analytical Model. *Source: Hawaii Department of Land and Natural Resources - Commission on Water Resource Management, 1990, Water Resources Protection Plan, 127pp.*
RAM (2008)	Sustainable Yield Values recalculated by the CWRM in 2008 using the 1990 Robust Analytical Model and reported original input values. SY values were recalculated after mathematical errors were discovered in calculations for some aquifer systems. Ram (2008) values supercede RAM (1990) values.
RAM + Updated Recharge	Sustainable Yield Values calculated by inputting updated recharge values into the 1990 Robust Analytical Model. Sources of the update recharge values are provided below by island:
Hawaii	*Oki, D.S., 2002, Reassessment of ground-water recharge and Simulated ground-water availability for the Hawi Area of North Kohala, Hawaii:.U.S. Geological Survey Water-Resources Investigations Report 02-4006, 62pp. (Hawi)*
	Oki, D.S., 1999, Geohydrology and numerical simulation of the ground-water flow system of Kona, Island of Hawaii: U.S. Geological Survey Water-Resources Investigations Report 99-4073, 70pp. (Manuka, Kaapuna, Kealakekua, Keauhou)
Kauai	*Shade, P.J., 1995, Water Budget for the Island of Kauai, Hawaii: U.S. Geological Survey Water-Resources Investigations Report 95-4128, 25pp.*
Lanai	*Hardy, W.R., 1996, A numerical ground-water model for the Island of Lanai, Hawaii: Commission on Water Resource Management, Department of Land and Natural Resources, State of Hawaii, 126pp.*
Maui	*Engott, J.A., 2007, Effects of agricultural land-use changes and rainfall on ground-water recharge in Central and West Maui, Hawaii, 1926-2004: U.S. Geological Survey Scientific Investigations Report 2007-5103, 56pp. (Scenario 'C' Waikapu through Ukumehame; Scenario 'D' Kahului through Kamaole)*
	Shade, P.J., 1999, Water budget of East Maui, Hawaii: U.S. Geological Survey Water-Resources Investigations Report 97-4159, 36pp. (Haiku through Lualailua)
Molokai	*Shade, P.J., 1997, Water budget for the Island of Molokai, Hawaii: U.S. Geologic Survey Water-Resources Investigations Report 97-4155, 20pp.*
Oahu	*Shade, P.J., and W.D. Nichols, 1996, Water budget and the effects of land-use changes on ground-water recharge, Oahu, Hawaii: U.S. Geological Survey Professional Paper 1412-C, 38pp.*

Table 3-10 (continued)
Comparison of Predicted Sustainable Yields Considered by the CWRM
Sustainable Yield (SY) in Million Gallons Per Day (mgd)

References (continued)	
RAM 2	Sustainable Yield values calculated using the Robust Analytical Model 2. Sources by Aquifer System are provided below: *Liu,C.C.K., 2006, Analytical Groundwater Flow and Transport Modeling For the Estimation of the Sustainable Yield of Pearl Harbor Aquifer: University of Hawaii Water Resources Research Center, Project Report PR-2006-06, 53pp. (Waimalu, Waipahu-Waiawa, Ewa-Kunia)*
	Liu, C.C.K., 2007, RAM2 Modeling and the Determination of Sustainable Yields of Hawaii Basal Aquifers: University of Hawaii Water Resources Research Center, Project Report PR-2008-06, 81pp. (Maui-Iao, Molokai-Kualapuu; Oahu-Palolo, Nuuanu, Kalihi, Moanalua)

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Hawaii					
Kohala	Hawi	80101	**13**	The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	2
Kohala	Waimanu	80102	**110**		3
Kohala	Mahukona	80103	**17**		2
E. Mauna Kea	Honokaa	80201	**31**		3
E. Mauna Kea	Paauilo	80202	**60**		3
E. Mauna Kea	Hakalau	80203	**150**		3
E. Mauna Kea	Onomea	80204	**147**		3
W. Mauna Kea	Waimea	80301	**24**		2
NE. Mauna Loa	Hilo	80401	**349**		3
NE. Mauna Loa	Keaau	80402	**395**		3
SE. Mauna Loa	Olaa	80501	**125**	Predominantly high-level ground water	3
SE. Mauna Loa	Kapapala	80502	**19**	Predominantly high-level ground water	3
SE. Mauna Loa	Naalehu	80503	**118**		3
SE. Mauna Loa	Ka Lae	80504	**31**		3
SW. Mauna Loa	Manuka	80601	**25**		2
SW. Mauna Loa	Kaapuna	80602	**51**		2

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Hawaii (continued)					
SW. Mauna Loa	Kealakekua	80603	**38**		2
NW. Mauna Loa	Anaehoomalu	80701	**30**	Assumes all recharge discharges at the coast between Anaehoomalu and Puako. Possible significant underflow of ground water out of Anaehoomalu into adjacent aquifer system areas was not accounted for in the recharge estimate used to calculate the sustainable yield. Accounting for such underflows may yield a much lower sustainable yield for Anaehoomalu.	3
Kilauea	Pahoa	80801	**437**		3
Kilauea	Kalapana	80802	**158**		3
Kilauea	Hilina	80803	**9**		3
Kilauea	Keaiwa	80804	**17**		3
Hualalai	Keauhou	80901	**38**		2
Hualalai	Kiholo	80902	**18**		3
Kauai					
Lihue	Koloa	20101	**30**	(1) Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood. (2) The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	3
Lihue	Hanamaulu	20102	**36**	(1) Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood. (2) The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	2

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Kauai (continued)					
Lihue	Wailua	20103	**43**	(1) Predominantly high-level ground water. (2) Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood. (3) The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	2
Lihue	Anahola	20104	**17**	(1) Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood. (2) The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	2
Lihue	Kilauea	20105	**5**	(1) Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood. (2) The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	3
Hanalei	Kalihiwai	20201	**11**	(1) Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood. (2) The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	3
Hanalei	Hanalei	20202	**34**	(1) Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood. (2) The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	3
Hanalei	Wainiha	20203	**24**	Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood.	3

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Kauai (continued)					
Hanalei	Napali	20204	**17**	(1) Due to the presence of a discontinuous, unmapped confining layer, the nature and extent of the basal ground water lens is not well understood. (2) Predominantly Basal Ground Water. (3) The recharge value used to calculate the Sustainable Yield INCLUDES return irrigation inputs to ground water.	3
Waimea	Kekaha	20301	**10**	Predominantly Basal Ground Water.	3
Waimea	Waimea	20302	**37**		3
Waimea	Makaweli	20303	**26**		3
Waimea	Hanapepe	20304	**22**		3
Lanai					
Central	Windward	50101	**3**	Only high-level ground water.	1
Central	Leeward	50102	**3**	(1) Only high-level ground water. (2) Ground water may be brackish in the Palawai Basin area.	1
Mahana Sector	Hauola	50201	**~**	(1) Sustainable Yield has not been calculated due to a lack of recharge data for this aquifer system area. (2) Ground water is brackish	~
Mahana Sector	Maunalei	50202	**~**	(1) Sustainable Yield has not been calculated due to a lack of recharge data for this aquifer system area. (2) Ground water is brackish	~
Mahana Sector	Paomai	50203	**~**	(1) Sustainable Yield has not been calculated due to a lack of recharge data for this aquifer system area. (2) Ground water is brackish	~

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Lanai (continued)					
Kaa	Honopu	50301	~	(1) Sustainable Yield has not been calculated due to a lack of recharge data for this aquifer system area. (2) Ground water is brackish	~
Kaa	Kaumalapau	50302	~	(1) Sustainable Yield has not been calculated due to a lack of recharge data for this aquifer system area. (2) Ground water is brackish	~
Kamao	kealia	50401	~	(1) Sustainable Yield has not been calculated due to a lack of recharge data for this aquifer system area. (2) Ground water is brackish	~
Kamao	Manele	50402	~	(1) Sustainable Yield has not been calculated due to a lack of recharge data for this aquifer system area. (2) Ground water is brackish	~
Maui					
Wailuku	Waikapu	60101	**3**		2
Wailuku	Iao	60102	**20**		1
Wailuku	Waihee	60103	**8**		2
Wailuku	Kahakuloa	60104	**5**		2
Lahaina	Honokohau	60201	**9**		2
Lahaina	Honolua	60202	**8**		2
Lahaina	Honokowai	60203	**6**		2
Lahaina	Launiupoko	60204	**7**		2
Lahaina	Olowalu	60205	**2**		2
Lahaina	Ukumehame	60206	**2**		2

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Maui (continued)					
Central	Kahului	60301	**1**	(1) Only basal ground water. (2) Sustainable Yield ignores significant importation of surface water into Kahului from outside the aquifer system area. This explains the ability to withdraw fresh water from the aquifer at significantly higher rates than the sustainable yield without apparent negative impacts (i.e. rising chloride concentrations or decreasing water levels).	2
Central	Paia	60302	**7**	(1) Only basal ground water. (2) Sustainable Yield ignores significant importation of surface water into Paia from outside the aquifer system area. This explains the ability to withdraw fresh water from the aquifer at significantly higher rates than the sustainable yield without apparent negative impacts (i.e. rising chloride concentrations or decreasing water levels).	2
Central	Makawao	60303	**7**	Only basal ground water.	3
Central	Kamaole	60304	**11**		3
Koolau	Haiku	60401	**27**		2
Koolau	Honopou	60402	**25**		3
Koolau	Waikamoi	60403	**40**		3
Koolau	Keanae	60404	**83**		3
Hana	Kuhiwa	60501	**14**		3
Hana	Kawaipapa	60502	**48**		3
Hana	Waihoi	60503	**18**		3
Hana	Kipahulu	60504	**42**		3
Kahikinui	Kaupo	60601	**16**		3
Kahikinui	Nakula	60602	**7**		3
Kahikinui	Lualailua	60603	**11**		3

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Molokai					
West	Kaluakoi	40101	**2**	(1) Predominantly basal ground water. (2) Ground water is brackish.	3
West	Punakou	40102	**2**	(1) Predominantly basal ground water. (2) Ground water is brackish.	3
Central	Hoolehua	40201	**2**	(1) Predominantly basal ground water. (2) Ground water is brackish.	3
Central	Maunawainui	40202	**2**	(1) Predominantly basal ground water. (2) Ground water is brackish.	2
Central	Kualapuu	40203	**5**	Predominantly basal ground water.	1
Southeast	Kamiloloa	40301	**3**		2
Southeast	Kawela	40302	**5**		3
Southeast	Ualapue	40303	**8**		3
Southeast	Waialua	40304	**6**		3
Northeast	Kalaupapa	40401	**2**	Predominantly high-level ground water	3
Northeast	Kahanui	40402	**3**	Predominantly high-level ground water	3
Northeast	Waikolu	40403	**5**	Predominantly high-level ground water	3
Northeast	Haupu	40404	**2**	Predominantly high-level ground water	3
Northeast	Pelekunu	40405	**9**	Predominantly high-level ground water	3
Northeast	Wailau	40406	**15**	Predominantly high-level ground water	3
Northeast	Halawa	40407	**8**		3
Oahu					
Honolulu	Palolo	30101	**5**		2

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Oahu (continued)					
Honolulu	Nuuanu	30102	**14**		2
Honolulu	Kalihi	30103	**9**		2
Honolulu	Moanalua	30104	**16**		2
Honolulu	Waialae-West	30105	**4**		2
Honolulu	Waialae-East	30106	**2**	Ground Water is predominantly brackish.	2
Pearl Harbor	Waimalu	30201	**45**	The lowest model-predicted sustainable yield is 47 mgd. However, due to exisiting salinity issues in wells in this aquifer system, the CWRM elected to maintain the sustainable yield at 45 mgd. A higher sustainable yield may be possible if well placement and pumping are optimized.	2
Pearl Harbor	Waipahu-Waiawa	30203	**104**	The recharge value used in the Sustainable Yield calculation includes spillover of ground water from the Wahiawa Aquifer System Area.	1
Pearl Harbor	Ewa-Kunia	30204	**16**	(1) Predominantly Basal Ground Water. (2) The recharge value used in the Sustainable Yield calculation includes spillover of ground water from the Wahiawa Aquifer System area.	1

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Aquifer Sector	Aquifer System	Aquifer Code	Sustainable Yield (2008)	Comments	Confidence Ranking
Oahu (continued)					
Pearl Harbor	Makaiwa	30205	~	(1) Sustainable Yield has not been calculated due to a lack of recharge data for this aquifer system area. (2) Predominantly Basal Ground Water. (3) Ground Water is Brackish.	~
Central	Wahiawa	30501	**23**	Only high-level ground water.	1
Waianae	Nanakuli	30301	**2**	Predominantly basal ground water	3
Waianae	Lualualei	30302	**4**	Predominantly basal ground water	3
Waianae	Waianae	30303	**3**	Predominantly high-level ground water	1
Waianae	Makaha	30304	**3**	Predominantly high-level ground water	1
Waianae	Keaau	30305	**4**		3
North	Mokuleia	30401	**8**	Predominantly basal ground water	2
North	Waialua	30402	**25**	Predominantly basal ground water	2
North	Kawailoa	30403	**29**	Predominantly basal ground water	2
Windward	Koolauloa	30601	**36**	Predominantly basal ground water	2
Windward	Kahana	30602	**15**	Predominantly high-level ground water	2
Windward	Koolaupoko	30603	**30**	(1) Predominantly high-level ground water. (2) Ground water removed from the aquifer system area by the Waiahole Tunnel was subtracted from the total recharge value used to calculate sustainable yield.	2
Windward	Waimanalo	30604	**10**	Predominantly high-level ground water	3

Notes:

~ Sustainable Yield Not Calculated

Ground water within an aquifer system area is available from both basal and high-level sources, and includes both fresh and brackish water, unless otherwise indicated

The recharge value used in the Sustainable Yield calculation DID NOT incorporate return irrigation inputs to ground water, unless otherwise indicated. For recharge reference citations see Table 3-10.

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Sustainable Yield Confidence Ranking

For reference purposes, the Sustainable Yield values have been ranked according to the degree of confidence that the CWRM places on the number, ranging from (1) most confident to (3) least confident. The degree of confidence is directly related to the type, quality, and quantity of hydrologic data used in the sustainable yield determination. Ranking criteria are as follows:

(1) Most Confident - Significant Hydrologic Data	The CWRM is fairly confident, based on available information, that the adopted sustainable yield does not over estimate the true sustainable yield of the aquifer system area. Given the presence of deep monitor wells in basal ground water systems or a ground water-level and stream monitoring network in high-level ground water systems, long-term monitoring will provide additional information critical to refining the Sustainable Yield range. * The Sustainable Yield is based on deep monitor well data (for basal ground water sources) or ground water-level and stream monitoring network data (for high-level ground water sources, where applicable) AND hydrologic studies, ground water models, and other data sources that are significant to comprehensive in scope and generally conform to section 3.3.4 of the WRPP.
(2) Moderately Confident - Moderate Hydrologic Data	Sufficient data or studies are available to indicate that the adopted Sustainable Yield is not likely to over estimate the true Sustainable Yield of the aquifer system area. However, more detailed studies are required to better refine the potential range of Sustainable Yields. * The Sustainable Yield is based on hydrologic studies or ground water models AND other data sources. The hydrologic studies, ground water models, and data sources range in scope from limited to comprehensive, and may or may not conform to section 3.3.4 of the WRPP. No deep monitor well data is available.

Table 3-11
2008 Sustainable Yields for Hawaii Aquifers (continued)

Sustainable Yield Confidence Ranking (continued)

(3) Least Confident - Limited to No Hydrologic Data	The CWRM recognizes the adopted Sustainable Yield as a reasonable planning Sustainable Yield until more detailed geologic and hydrologic information is available for these aquifer system areas. There is significant uncertainty associated with this Sustainable Yield due to the lack of hydrogeologic and pumpage information.

* The Sustainable Yield is primarily based on an understanding of the general geologic and hydrologic properties of the aquifer and, where available, (1) pumpage, chloride, and water-level data and (2) recharge studies that do not conform to section 3.3.4.1 of the WRPP.

Table 3-12
Sustainable Yield Values for Hawaii Caprock Aquifers

Sustainable Yield = Miligrams Per Liter (mg/L) Sodium

Aquifer Sector Area	Aquifer System Area	Code	Caprock Aquifer
Oahu			
Ewa Caprock	Malakole	30207	1000
Ewa Caprock	Kapolei	30208	1000
Ewa Caprock	Puuloa	30209	1000

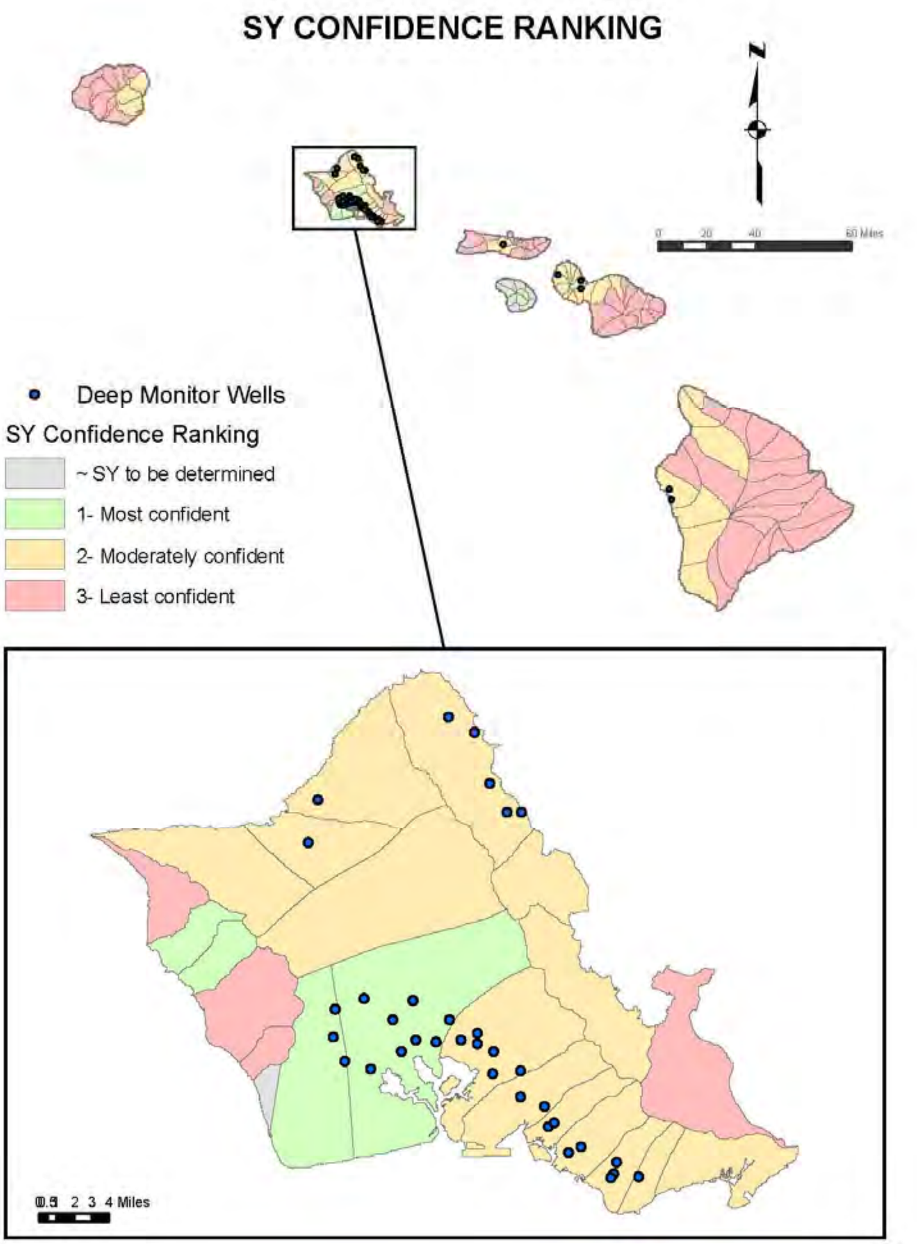

Figure 3-14: Sustainable Yield Confidence Ranking

3.3.5.2 Future Sustainable Yield Selection Criteria

As the WRPP is a living document, sustainable yields will be re-estimated continually based on the best information available as new information is acquired with time. In general, the best information that is scientifically sound and CWRM-vetted for aquifer-specific hydrologic, geologic, or other data will be used for future sustainable yield revisions on case-by-case basis. Revisions shall be consistent with the following criteria:

For Aquifer Systems with predominantly basal resources:

- Presence of an operational deep monitor well and other publicly available hydrogeologic data, such as:
  - Recharge studies that follow the convention of section 3.3.4.1;
  - Complete and significant record of historical pumpage, chloride, and water-level data;
  - Numerical model studies for establishing infrastructure safe yields; or
  - Other hydrologic and geologic studies reviewed and accepted by CWRM staff.
- Ground water inputs from adjacent aquifers.

For Aquifer Systems with predominantly high-level resources:

- Presence of an operational ground water-level monitoring network and a stream monitoring network, where applicable, to ensure compliance with instream flow standards and other publicly available hydrogeologic data, such as:
  - Recharge studies that follow the convention of section 3.3.4.1;
  - Complete and significant record of historical pumpage, chloride, and water-level data;
  - Numerical model studies for establishing infrastructure safe yields; or
  - Other hydrologic and geologic studies reviewed and accepted by CWRM staff.
- Ground-water spill-over from adjacent aquifers.

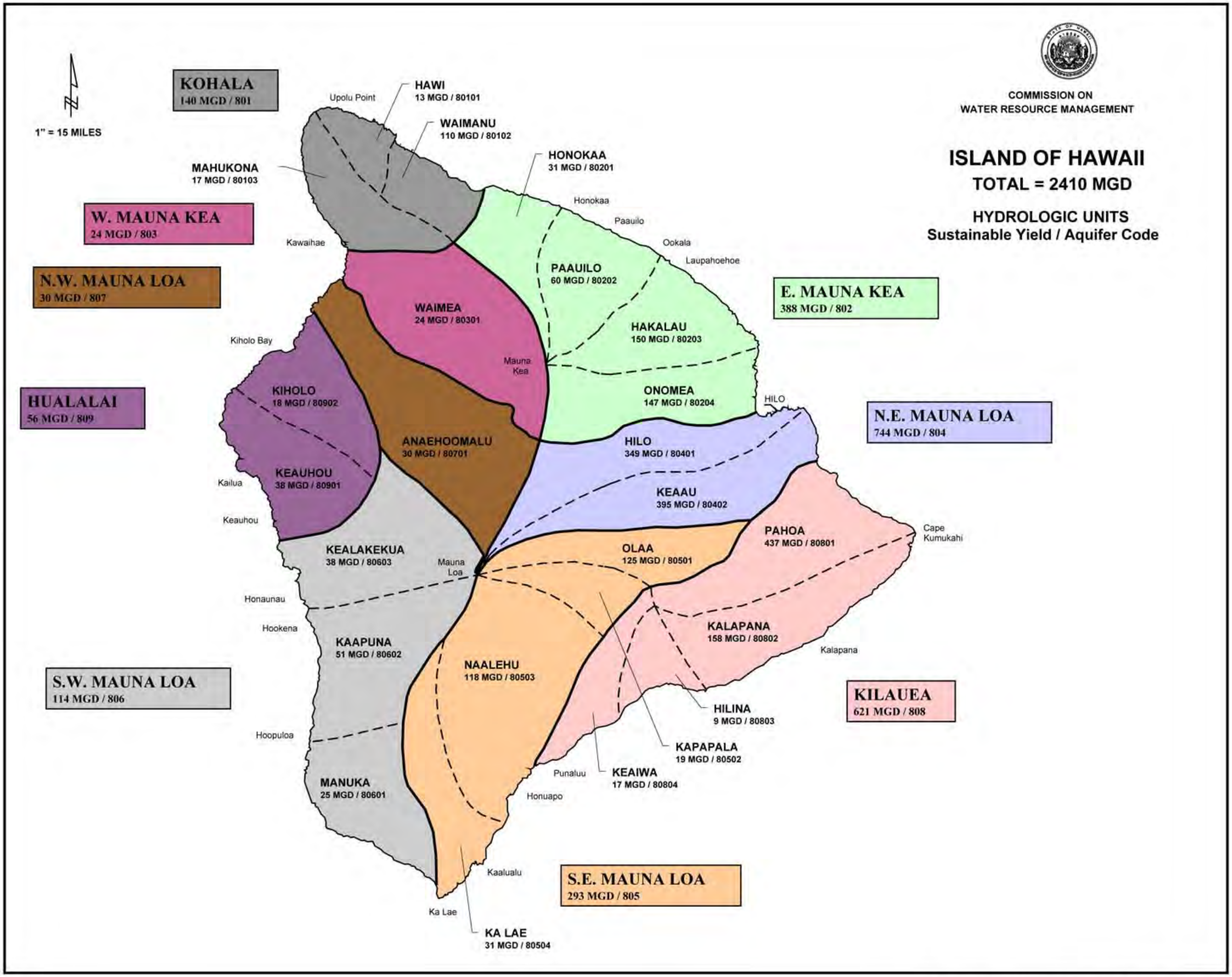

Figure 3-15: Island of Hawaii Ground Water Hydrologic Units and 2008 Sustainable Yields

Map Projection: Universal Transverse Mercator

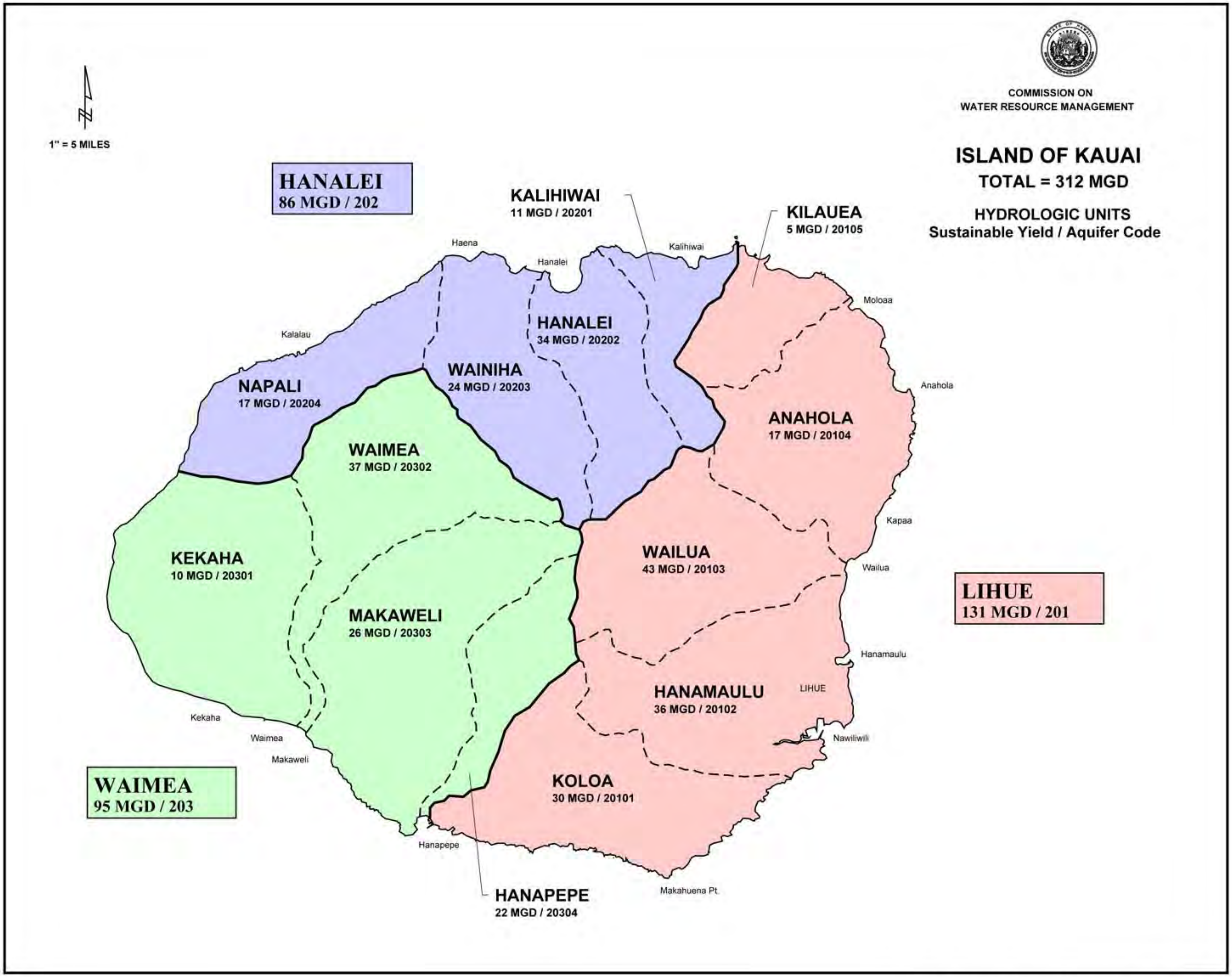

Figure 3-16: Island of Kauai Ground Water Hydrologic Units and 2008 Sustainable Yields

Map Projection: Universal Transverse Mercator

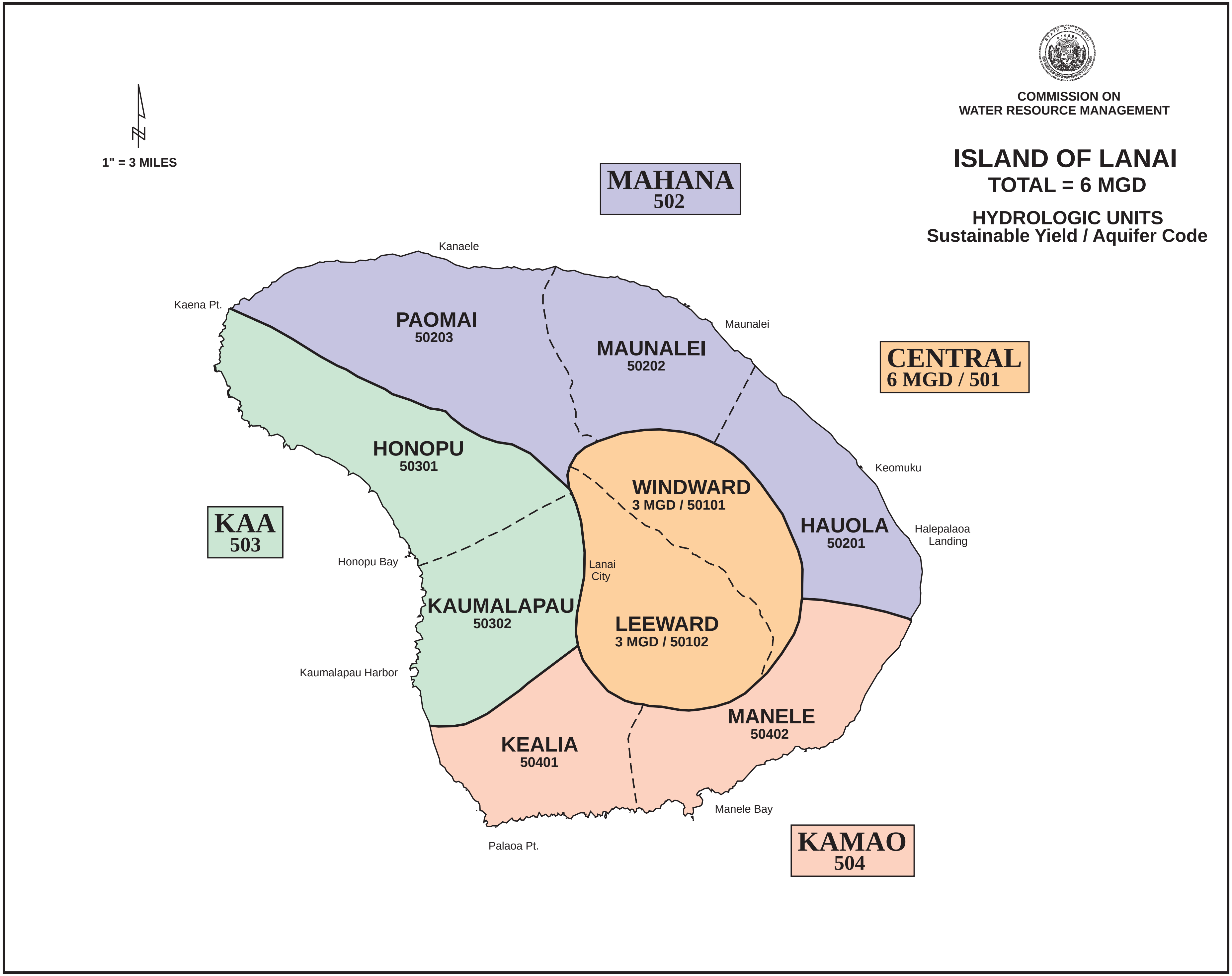

Figure 3-17: Island of Lanai Ground Water Hydrologic Units and 2008 Sustainable Yields

Map Projection: Universal Transverse Mercator

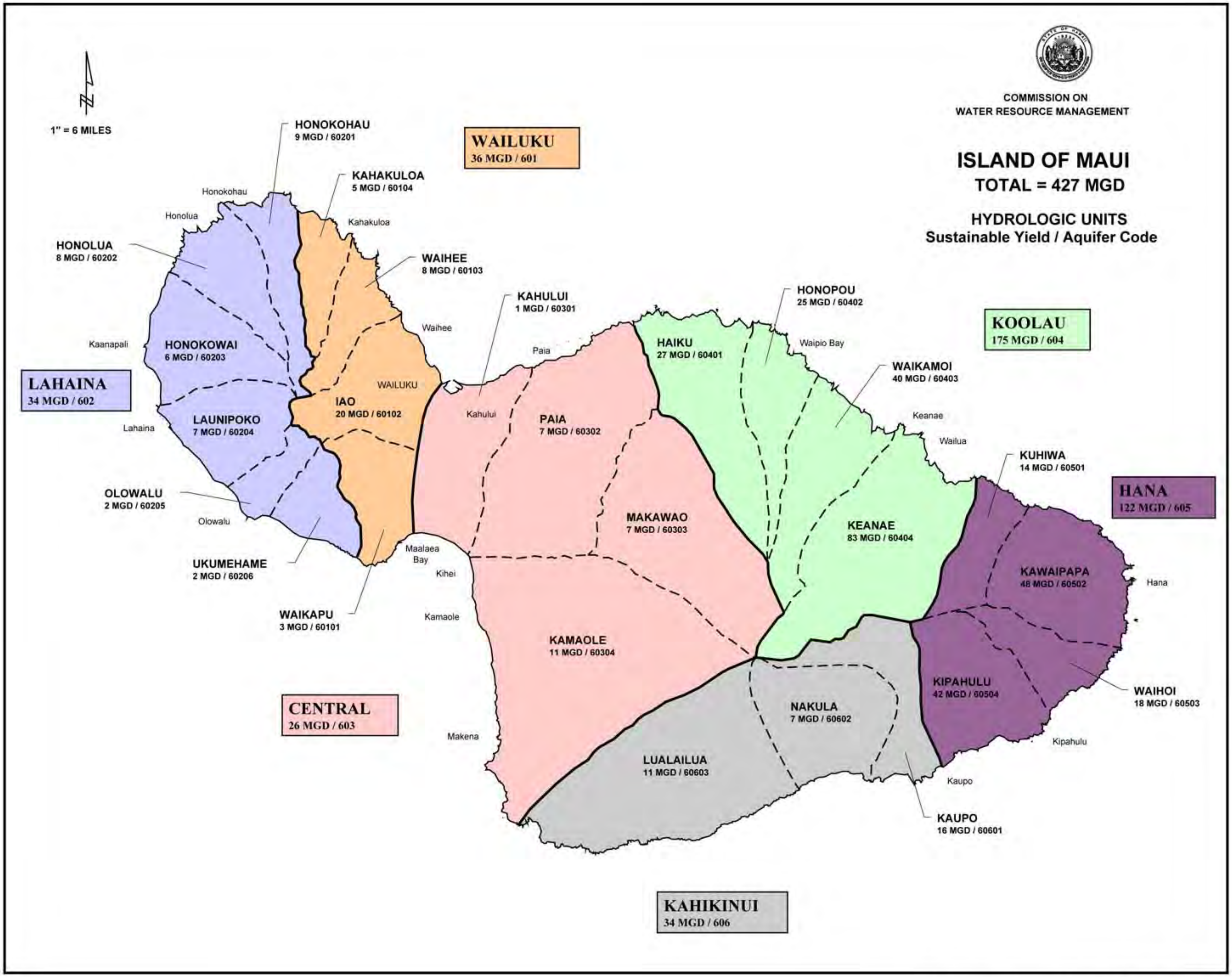

Figure 3-18: Island of Maui Ground Water Hydrologic Units and 2008 Sustainable Yields

Map Projection: Universal Transverse Mercator

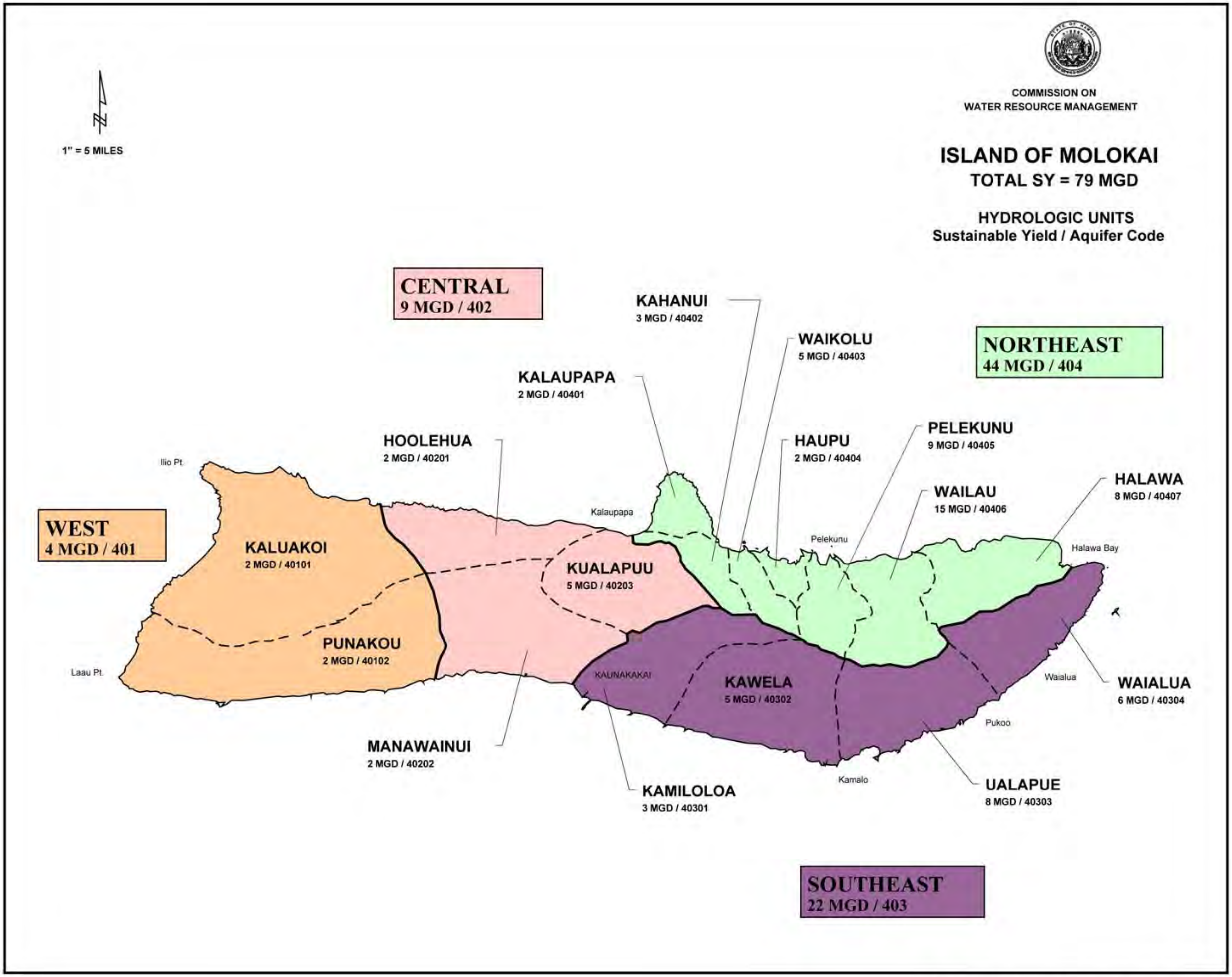

Figure 3-19: Island of Molokai Ground Water Hydrologic Units and 2008 Sustainable Yields

Map Projection: Universal Transverse Mercator

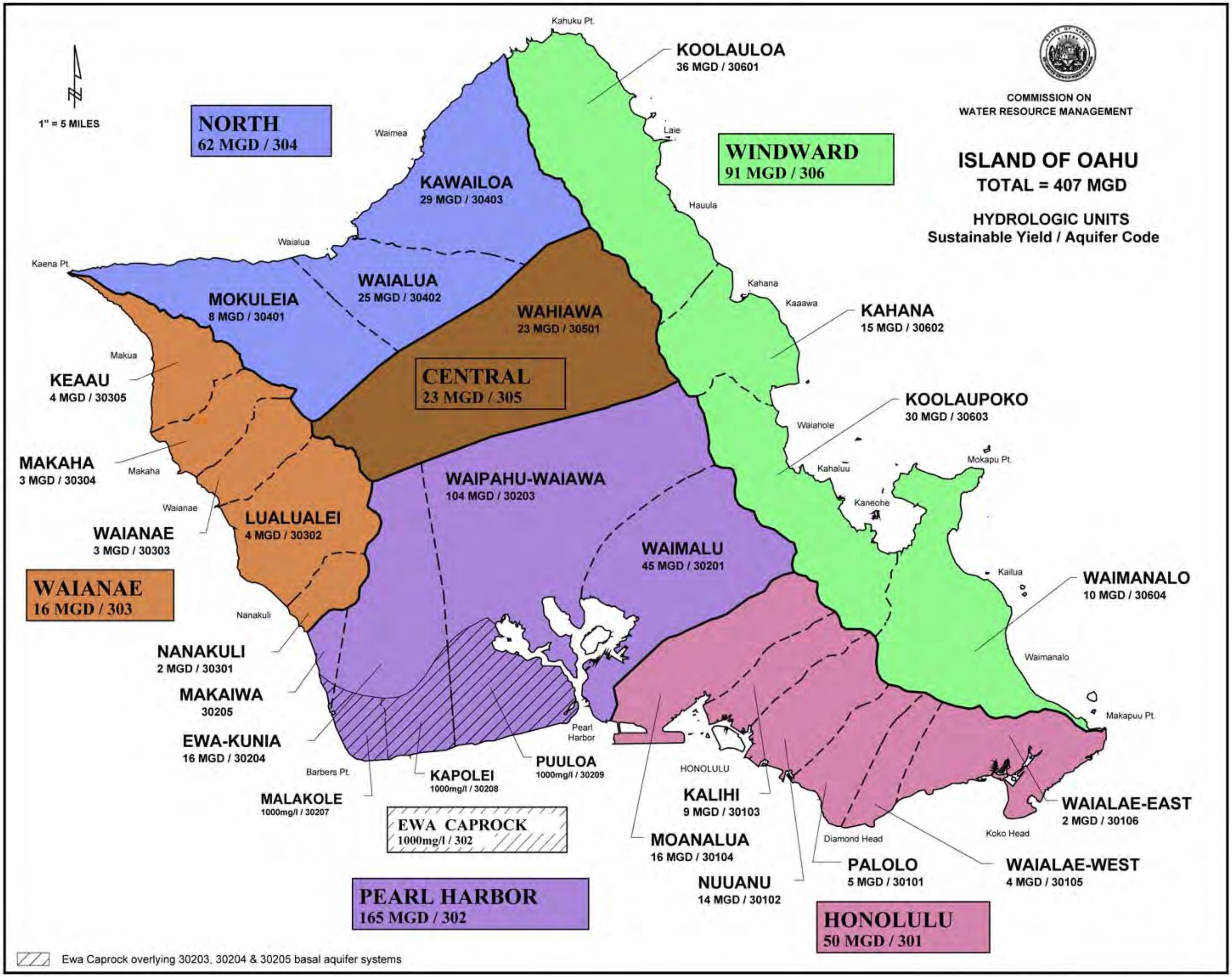

Figure 3-20: Island of Oahu Ground Water Hydrologic Units and 2008 Sustainable Yields

Map Projection: Universal Transverse Mercator

3.4. Nature and Occurrence of Surface Water

Early in its history, CWRM recognized the need for a broad-based collection of existing information on Hawaii's surface water resources to enable sensible water management and decision making. As a result, CWRM and the U.S. National Park Service (USNPS) undertook a cooperative project that produced the 1990 document entitled *Hawaii Stream Assessment: A Preliminary Appraisal of Hawaii's Stream Resources* (HSA). This document continues to serve as a key reference for stream-related research in Hawaii. To provide the general public with an introduction to Hawaii's surface water resources, CWRM and the USGS cooperated to develop the *Surface Water in Hawaii* information brochure published in 2003. The brochure includes information on basic surface water characteristics, system components and behavior, and natural and human-related impacts. The information in this section adapts CWRM's collaborative work with the USNPS and the USGS to provide a basic overview of the nature and occurrence of surface water in Hawaii and implications for surface water management through instream flow standards.

3.4.1. Surface Water Occurrence

The State Water Code defines surface water as consisting of both contained surface water and diffused surface water. Contained surface water exists upon the surface of the earth in naturally or artificially created water bodies such as streams, man-made watercourses, lakes, reservoirs, and coastal waters. Diffused surface water includes all other waters on the surface of the earth that are not contained within waterbodies.

Surface water occurs in areas that, due to topographic slope, contribute to surface water drainage systems that typically manifest as streams or rivers. These drainage areas are confined by topographic divides and are generally referred to as watersheds. Watersheds are sometimes called drainage basins or catchments. Hawaii watersheds are consistently small in comparison to mainland systems, however, watershed profiles vary widely across the main islands. For example, watersheds on the geologically young island of Hawaii tend to be short in length, have fairly shallow channels, exhibit simple stream networks with few tributaries, and may sometimes terminate in a waterfall at the ocean. On the older island of Kauai, watershed systems exhibit eroded features, such as deeper incised channels, complex stream networks with many tributary branches, and large riverine estuaries at the ocean interface.

Watersheds are influenced by human alterations to natural stream systems that affect both surface water hydrology, stream biota, and water quality. Infrastructure significantly changes the path and flow of water. Ditches and canals, even storm drain systems, are built to convey water from one area to another, while reservoirs are used to store water on and off stream systems. Stream channel alterations also influence watershed processes. Channel alterations may include hardened channel linings and embankments, retention basins, culverts, drainage inlets and outlets, and channel realignments.

Within a watershed, surface water resources occur in various settings, both natural and altered. Streams, springs, ditches and canals, and reservoirs are the most common surface water settings in Hawaii. These are described in the sections below.

3.4.1.1. Streams

Streams originating in mauka rainfall belts are the principle drainage features of Hawaii watersheds. The USGS defines the term “stream” as follows:

> *Stream – a general term for a body of flowing water; natural water course containing water at least part of the year. In hydrology, it is generally applied to the water flowing in a natural channel as distinct from a canal.*

Streamflow consists of five components: 1) Direct runoff of rainfall in the form of overland flow and subsurface flow, which rapidly returns infiltrated water to the stream; 2) Water returned from bank storage; 3) Ground water discharge in the form of base flow, where the stream intersects the water table; 4) Rain that falls directly on streams; and 5) any additional water, including excess irrigation water, discharged to the stream by humans[35].

Direct runoff occurs during and immediately following a period of rainfall when the capacity of the soil to accept and store water is exceeded, causing water to runoff in a sheet of overland flow. Water may also enter the stream as subsurface flow when rainfall infiltrates the ground surface and moves laterally in the near-surface soils. Subsurface flow is generally slower and may continue for days after a rainfall event, but may also occur quickly if water is able to move through preferential pathways. Similarly, during a period of high rainfall, water may be absorbed into the banks of the stream as bank storage. This water can be returned to the stream to contribute to total streamflow.

Water that infiltrates the ground surface may also recharge ground water bodies such as perched aquifers or dike compartments, which subsequently discharge water to streams. This ground water discharge to the stream, referred to as base flow, may occur during extended dry periods as well as during rainfall events. Base flow contributions occur where the stream intersects the ground water table and where the ground water body is above the water level in the stream. Since ground water levels vary with time, base flow also varies with time. However, variations in base flow are much smaller than variations in direct runoff.

Perennial Streams: A perennial stream is defined as a stream which flows continuously throughout the year. Some streams flow perennially throughout their entire course, while others flow perennially over parts of their course. Streams in Hawaii are commonly perennial in mountainous interior areas, where streams gain water from dike-impounded ground water systems and where rainfall is persistent. Perennial flow is also common in lower stream reaches near the coast where streams gain water from freshwater-lens systems. Where a vertically extensive freshwater-lens system exists, streams may gain water and flow perennially at higher altitudes inland from the coast[36].

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[35] Oki, D.S., 2004, Trends in Streamflow Characteristics in Hawaii, 1913-2003: U.S. Geological Survey Fact Sheet 2004-3104, 4 p.

[36] Izuka, S.K., and Gingerich, S.B., 1998, Ground water in the southern Lihue basin, Kauai, Hawaii: U.S. Geological Survey Water-Resources Investigations Report 98-4031, 71 p.

The HSA provided a listing of 376 perennial streams which were defined using data from various sources. The authors acknowledged that, although over one third of the streams on the list did not flow continuously from their headwaters to the ocean, these streams have perennial sections. This list of streams is used by CWRM to make preliminary determinations in regulatory permitting, though streams must often be assessed on a case-by-case basis.

Intermittent Streams: A stream or part of a stream is considered intermittent when it only flows at certain times of the year. Flow generally occurs for several weeks or months in response to seasonal precipitation and subsequent ground water discharge. An intermittent stream may also exist where a perched ground water body contributes to streamflow during certain times of the year. Intermittent streams are often able to support small communities of native freshwater species, either due to upstream or downstream perennial reaches or the persistence of pool habitats between flowing stream segments.

Ephemeral Streams: Ephemeral streams usually manifest in dry gulches on the leeward side of mountain ranges, where there is little or no ground water influence. Ephemeral streams only flow in direct response to rainfall, which indicates that the stream channel is not in contact with the water table. In general, flows last but a few hours or days following a single storm event.

3.4.1.2. Springs

Springs occur where ground water discharges naturally from the ground surface at a more or less continuous rate. Springs are largely dependent upon the permeability of rock layers, the position of the water table, and surface topography.

3.4.1.3. Ditches and Canals

The ditches and canals that traverse the Hawaiian landscape are largely a result of the sugar industry’s need to transport water for cane cultivation in the late 1800s. By 1884, there were a total of 90 sugar planters, plantations, and mills. Extensive irrigation systems often consisted of concrete-lined or unlined channels, tunnels, and flumes that moved water from wet, windward areas to arable plains in dry, leeward areas. By 1920, an estimated 800 million gallons of surface water, in addition to almost 400 million gallons of pumped ground water, was consumed by the sugar industry daily.

The demise of the sugar industry towards the end of the 20th Century brought the closure of large-scale plantations and the conversion of plantation fields to diversified agriculture. Associated changes also occurred in irrigation practices and agricultural water consumption. Many of the irrigation systems that once served plantation agriculture still continue to divert water, however, most systems do not function as efficiently as they once did. System maintenance, which was executed by the plantations, is no longer coordinated and many new owners of former plantation lands do not have the means or desire to carry out refurbishment and repair projects. These irrigation systems are significant in that, not only do they contribute to the viability of agriculture, they impact the surface water hydrology of diverted streams; they impact the hydrology of the streams they pass via leakage, overflows, and controlled releases (for maintenance); and they impact the ground water hydrology of the area receiving irrigation.

3.4.1.4. Reservoirs

A reservoir is generally an artificial basin created for the purpose of collecting, storing, and regulating water. Reservoirs are usually created by damming the downstream end of a drainage basin. In Hawaii, there are very few natural lakes, so these man-made reservoirs often serve as recreational boating and fishing lakes. Many of the reservoirs that dot the landscape were constructed to serve the sugar and pineapple industries, while others were built for flood control or as impoundment reservoirs for drinking water prior to treatment. Reservoirs can influence local climatological patterns, habitat conditions for stream organisms, water quality, and ground water infiltration.

3.4.2. Surface Water Hydrologic Units

Surface water hydrologic units have been established by CWRM to provide a consistent basis for managing surface water resources. A surface water hydrologic unit coding system is used to reference and describe the units delineated by CWRM. This section describes the coding system and lists all surface water hydrologic units by island. Maps illustrating the hydrologic unit boundaries are included in Section 3.4.2.3.

3.4.2.1. Purpose of Surface Water Hydrologic Unit Coding

As described earlier in Section 3.4.1, surface water occurs in variable settings throughout Hawaii. The surface water hydrologic unit coding system described herein was established to provide a consistent method by which to reference and describe surface water resources and to assist in various water planning efforts. The coding system is an important first-step towards improving the organization and management of surface water information that CWRM collects and maintains.

The primary goal of the coding system is to provide standard surface water hydrologic unit delineations for the coordination of data, information, and resource management practices. Key objectives of CWRM Surface Water Hydrologic Units include the following:

- Define and delineate unique units that can accommodate the relational requirements in a database environment, while providing a system that can be easily understood by the general public;
- Develop an information management system which utilizes a coding system to relate surface water permits and other resource information to a given unit;
- Define hydrologic units to be considered in the analysis and development of instream flow standards;
- Provide a reference system that promotes better information management of other resource inventories;

- Promote the sharing and collection of surface water resource data between government agencies, the public, private entities, and community organizations; and

- Improve the overall coordination of monitoring, data collection, and field investigation efforts.

3.4.2.2. Basis for Surface Water Hydrologic Unit Delineations

The State Water Code mandates that the WRPP shall include:

> *"…Hydrologic units and their characteristics, including the quantity and quality of available resource, requirements for beneficial instream uses and environmental protection, desirable uses worthy of preservation by permit, and undesirable uses for which permits may be denied."*[37]

The State Water Code defines a hydrologic unit as "[a] surface drainage area or a ground water basin or a combination of the two."[38]

Ground water hydrologic units were established by CWRM under the 1990 WRPP. For surface water units, however, the 1990 WRPP only suggests a complex classification scheme.

In 2005, CWRM adopted surface water hydrologic units and the coding system described below. In developing CWRM Surface Water Hydrologic Units, it was necessary to review the HSA, *State Delineation of Watersheds* (1994), and *Refinement of Hawaii Watershed Delineations* (1999) reports to arrive at a coding system that could meet the requirements for organizing and managing surface water information.

The naming convention for surface water hydrologic units indicates regional and sub-regional divisions as follows:

Island division = Island
Regional division = Surface Water Hydrologic Unit

3.4.2.3. Surface Water Hydrologic Unit Coding System

The surface water hydrologic unit code is a unique combination of four digits. In the *State Definition and Delineation of Watersheds* report, a watershed unit is defined as follows:

> *"A watershed unit is comprised of a drainage basin (or basins) which include both stream and overland flow, whose runoff either enters the ocean along an identified segment of coastline (coastal segment) or enters an internal, landlocked drainage basin. The watershed units for an island are defined so*

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[37] HRS §174C-31(d)(2).
[38] HRS §174C-3.

> *that all segments of coastline are assigned to a unique watershed unit and so that all areas of an island are assigned to one, and only one, watershed unit."*

The surface water hydrologic unit coding system is based on a hierarchy in which the island is the largest component and the surface water hydrologic unit is the regional component. The island is identified by a single-digit number. Each surface water hydrologic unit is identified by a three-digit number and a Hawaiian geographic name or local geographic term.

Therefore, surface water hydrologic units are assigned a unique code in the four-digit format as follows:

0	**000**
Island	Surface Water Hydrologic Unit

The individual components of the coding system are described below.

ISLAND: 0000

The first digit represents the eight main Hawaiian Islands using a unique number assigned by CWRM. The Island Code is the same 1-digit number used in the Hawaii Stream Assessment. The islands of Niihau, Kahoolawe and Lanai did not appear in the HSA database because these islands do not have perennial streams, however they have been included in the coding system as part of a more comprehensive surface water management scheme.

SURFACE WATER HYDROLOGIC UNIT SYSTEM: 0**000**

The last three digits are sequentially assigned, generally beginning in the north and continuing around each island in a clockwise manner. This method is similar to previous coding efforts.

There are a total of 558 Surface Water Hydrologic Units statewide. Tables 3-13 to 3-20 below list all units by island and are accompanied by maps showing the unit boundaries (see Figures 3-21 to 3-28). For the majority of hydrologic units, unit boundaries closely match drainage basin boundaries. Individual stream systems are contained entirely within the hydrologic unit boundaries (from the headwater to the mouth). However, in a few instances, streams were found to cross hydrologic unit boundaries, and in these cases, drainage basins were refined to more accurately determine the natural flow of water based on elevation gradients. In these instances, the hydrologic unit boundaries were evaluated together with the drainage basin and redrawn through on-screen digitizing using ArcGIS software.

Table 3-13:
Niihau (1) Surface Water Hydrologic Units

1001	Kaaukuu	1008	Mauuloa
1002	Kooeaukani	1009	Nonopapa
1003	Kaailana	1010	Puuwai
1004	Nomilu	1011	Kaumuhonu
1005	Kalaoa	1012	Keanauhi
1006	Honuaula	1013	Keawanui
1007	Halaii		

Table 3-14:
Kauai (2) Surface Water Hydrologic Units

2001	Awaawapuhi	2038	Moikeha
2002	Honopu	2039	Waikaea
2003	Nakeikionaiwi	2040	Wailua
2004	Kalalau	2041	Kawailoa
2005	Pohakuao	2042	Hanamaulu
2006	Waiolaa	2043	Lihue Airport
2007	Hanakoa	2044	Nawiliwili
2008	Waiahuakua	2045	Puali
2009	Hoolulu	2046	Huleia
2010	Hanakapiai	2047	Kipu Kai
2011	Maunapuluo	2048	Mahaulepu
2012	Limahuli	2049	Waikomo
2013	Manoa	2050	Aepo
2014	Wainiha	2051	Lawai
2015	Lumahai	2052	Kalaheo
2016	Waikoko	2053	Wahiawa
2017	Waipa	2054	Hanapepe
2018	Waioli	2055	Kukamahu
2019	Hanalei	2056	Kaumakani
2020	Waileia	2057	Mahinauli
2021	Anini	2058	Aakukui
2022	Kalihikai West	2059	Waipao
2023	Kalihikai Center	2060	Waimea
2024	Kalihikai East	2061	Kapilimao
2025	Kalihiwai	2062	Paua
2026	Puukumu	2063	Hoea
2027	Kauapea	2064	Niu
2028	Kilauea	2065	Kaawaloa
2029	Kulihaili	2066	Nahomalu
2030	Pilaa	2067	Kaulaula
2031	Waipake	2068	Haeleele
2032	Moloaa	2069	Hikimoe
2033	Papaa	2070	Kaaweiki
2034	Aliomanu	2071	Kauhao
2035	Anahola	2072	Makaha
2036	Kumukumu	2073	Milolii
2037	Kapaa	2074	Nualolo

Table 3-15:
Oahu (3) Surface Water Hydrologic Units

3001	Kalunawaikaala	3045	Niu
3002	Pakulena	3046	Wailupe
3003	Paumalu	3047	Waialaenui
3004	Kawela	3048	Diamond Head
3005	Oio	3049	Ala Wai
3006	Malaekahana	3050	Nuuanu
3007	Kahawainui	3051	Kapalama
3008	Wailele	3052	Kalihi
3009	Koloa	3053	Moanalua
3010	Kaipapau	3054	Keehi
3011	Maakua	3055	Manuwai
3012	Waipuhi	3056	Salt Lake
3013	Kaluanui	3057	Halawa
3014	Papaakoko	3058	Aiea
3015	Halehaa	3059	Kalauao
3016	Punaluu	3060	Waimalu
3017	Kahana	3061	Waiawa
3018	Makaua	3062	Waipio
3019	Kaaawa	3063	Kapakahi
3020	Kualoa	3064	Waikele
3021	Hakipuu	3065	Honouliuli
3022	Waikane	3066	Kaloi
3023	Waianu	3067	Makaiwa
3024	Waiahole	3068	Nanakuli
3025	Kaalaea	3069	Ulehawa
3026	Haiamoa	3070	Mailiili
3027	Kahaluu	3071	Kaupuni
3028	Heeia	3072	Kamaileunu
3029	Keaahala	3073	Makaha
3030	Kaneohe	3074	Keaau
3031	Kawa	3075	Makua
3032	Puu Hawaiiloa	3076	Kaluakauila
3033	Kawainui	3077	Manini
3034	Kaelepulu	3078	Kawaihapai
3035	Waimanalo	3079	Pahole
3036	Kahawai	3080	Makaleha
3037	Makapuu	3081	Waialua
3038	Koko Crater	3082	Kiikii
3039	Hanauma	3083	Paukauila
3040	Portlock	3084	Anahulu
3041	Kamiloiki	3085	Loko Ea
3042	Kamilonui	3086	Keamanea
3043	Hahaione	3087	Waimea
3044	Kuliouou		

Table 3-16:
Molokai (4) Surface Water Hydrologic Units

4001	Waihanau	4026	Honouliwai
4002	Waialeia	4027	Waialua
4003	Waikolu	4028	Kainalu
4004	Wainene	4029	Honomuni
4005	Anapuhi	4030	Ahaino
4006	Waiohookalo	4031	Mapulehu
4007	Keawanui	4032	Kaluaaha
4008	Kailiili	4033	Kahananui
4009	Pelekunu	4034	Ohia
4010	Waipu	4035	Wawaia
4011	Haloku	4036	Kamalo
4012	Oloupena	4037	Kawela
4013	Puukaoku	4038	Kamiloloa
4014	Wailele	4039	Kaunakakai
4015	Wailau	4040	Kalamaula
4016	Kalaemilo	4041	Manawainui
4017	Waiahookalo	4042	Kaluapeelua
4018	Kahiwa	4043	Waiahewahewa
4019	Kawainui	4044	Kolo
4020	Pipiwai	4045	Hakina
4021	Halawa	4046	Kaunala
4022	Papio	4047	Papohaku
4023	Honowewe	4048	Kaa
4024	Pohakupili	4049	Moomomi
4025	Honoulimaloo	4050	Maneopapa

Table 3-17:
Lanai (5) Surface Water Hydrologic Units

5001	Puumaiekahi	5017	Awehi
5002	Lapaiki	5018	Kapua
5003	Hawaiilanui	5019	Naha
5004	Kahua	5020	Kapoho
5005	Kuahua	5021	Kawaiu
5006	Poaiwa	5022	Mahanalua
5007	Halulu	5023	Manele
5008	Maunalei	5024	Anapuka
5009	Wahane	5025	Palawai Basin
5010	Hauola	5026	Ulaula
5011	Nahoko	5027	Kaumalapau
5012	Kaa	5028	Kalamanui
5013	Haua	5029	Kalamaiki
5014	Waiopa	5030	Paliamano
5015	Kahea	5031	Honopu
5016	Lopa	5032	Kaapahu

Table 3-18:
Maui (6) Surface Water Hydrologic Units

6001	Waikapu	6050	Punalau
6002	Pohakea	6051	Honomanu
6003	Papalaua	6052	Nuaailua
6004	Ukumehame	6053	Piinaau
6005	Olowalu	6054	Ohia
6006	Launiupoko	6055	Waiokamilo
6007	Kauaula	6056	Wailuanui
6008	Kahoma	6057	West Wailuaiki
6009	Wahikuli	6058	East Wailuaiki
6010	Honokowai	6059	Kopiliula
6011	Kahana	6060	Waiohue
6012	Honokahua	6061	Paakea
6013	Honolua	6062	Waiaaka
6014	Honokohau	6063	Kapaula
6015	Anakaluahine	6064	Hanawi
6016	Poelua	6065	Makapipi
6017	Honanana	6066	Kuhiwa
6018	Kahakuloa	6067	Waihole
6019	Waipili	6068	Manawaikeae
6020	Waiolai	6069	Kahawaihapapa
6021	Makamakaole	6070	Keaaiki
6022	Waihee	6071	Waioni
6023	Waiehu	6072	Lanikele
6024	Iao	6073	Heleleikeoha
6025	Kalialinui	6074	Kawakoe
6026	Kailua Gulch	6075	Honomaele
6027	Maliko	6076	Kawaipapa
6028	Kuiaha	6077	Moomoonui
6029	Kaupakulua	6078	Haneoo
6030	Manawaiiao	6079	Kapia
6031	Uaoa	6080	Waiohonu
6032	Kealii	6081	Papahawahawa
6033	Kakipi	6082	Alaalaula
6034	Honopou	6083	Wailua
6035	Hoolawa	6084	Honolewa
6036	Waipio	6085	Waieli
6037	Hanehoi	6086	Kakiweka
6038	Hoalua	6087	Hahalawe
6039	Hanawana	6088	Puaaluu
6040	Kailua	6089	Oheo
6041	Nailiilihaele	6090	Kalena
6042	Puehu	6091	Koukouai
6043	Oopuola	6092	Opelu
6044	Kaaiea	6093	Kukuiula
6045	Punaluu	6094	Kaapahu
6046	Kolea	6095	Lelekea
6047	Waikamoi	6096	Alelele
6048	Puohokamoa	6097	Kalepa
6049	Haipuaena	6098	Nuanuaaloa

Table 3-18: (continued)
Maui (6) Surface Water Hydrologic Units (continued)

6099	Manawainui	6106	Kipapa
6100	Kaupo	6107	Kanaio
6101	Nuu	6108	Ahihi Kinau
6102	Pahihi	6109	Mooloa
6103	Waiopai	6110	Wailea
6104	Poopoo	6111	Hapapa
6105	Manawainui Gulch	6112	Waiakoa

Table 3-19:
Kahoolawe (7) Surface Water Hydrologic Units

7001	Lae Paki	7013	Waaiki
7002	Honokoa	7014	Kealia Luna
7003	Makaakae	7015	Hakioawa
7004	Ahupuiki	7016	Oawawahie
7005	Ahupu	7017	Pali o Kalapakea
7006	Kaukamoku	7018	Kaukamaka
7007	Moaulaiki	7019	Lae o Kaka
7008	Olohia	7020	Kamohio
7009	Kuheeia	7021	Kanaloa
7010	Kaulana	7022	Waikahalulu
7011	Papakanui	7023	Honokanaia
7012	Papakaiki	7024	Wai Honu

Table 3-20:
Hawaii (8) Surface Water Hydrologic Units

8001	Kealahewa	8050	Malanahae
8002	Hualua	8051	Honokaia
8003	Kumakua	8052	Kawela
8004	Kapua	8053	Keaakaukau
8005	Ohanaula	8054	Kainapahoa
8006	Hanaula	8055	Nienie
8007	Hapahapai	8056	Papuaa
8008	Pali Akamoa	8057	Ouhi
8009	Wainaia	8058	Kahaupu
8010	Halelua	8059	Kahawailiili
8011	Halawa	8060	Keahua
8012	Aamakao	8061	Kalopa
8013	Niulii	8062	Waikaalulu
8014	Waikama	8063	Kukuilamalamahii
8015	Pololu	8064	Alilipali
8016	Honokane Nui	8065	Kaumoali
8017	Honokane Iki	8066	Pohakuhaku
8018	Kalele	8067	Waipunahina
8019	Waipahi	8068	Waipunalau
8020	Honokea	8069	Paauilo
8021	Kailikaula	8070	Aamanu

Table 3-20: (continued)
Hawaii (8) Surface Water Hydrologic Units (continued)

8022	Honopue	8071	Koholalele
8023	Kolealiilii	8072	Kalapahapuu
8024	Ohiahuea	8073	Kukaiau
8025	Nakooko	8074	Puumaile
8026	Waiapuka	8075	Kekualele
8027	Waikaloa	8076	Kaala
8028	Waimaile	8077	Kealakaha
8029	Kukui	8078	Keehia
8030	Paopao	8079	Kupapaulua
8031	Waiaalala	8080	Kaiwiki
8032	Punalulu	8081	Kaula
8033	Kaimu	8082	Kaohaoha
8034	Pae	8083	Kaawalii
8035	Waimanu	8084	Waipunalei
8036	Pukoa	8085	Laupahoehoe
8037	Manuwaikaalio	8086	Kilau
8038	Naluea	8087	Manowaiopae
8039	Kahoopuu	8088	Kuwaikahi
8040	Waipahoehoe	8089	Kihalani
8041	Wailoa/Waipio	8090	Kaiwilahilahi
8042	Kaluahine Falls	8091	Haakoa
8043	Waiulili	8092	Pahale
8044	Waikoekoe	8093	Kapehu Camp
8045	Waipunahoe	8094	Paeohe
8046	Waialeale	8095	Maulua
8047	Waikoloa	8096	Pohakupuka
8048	Kapulena	8097	Kulanakii
8049	Kawaikalia	8098	Ahole
8099	Poupou	8133	Paukaa
8100	Manoloa	8134	Honolii
8101	Ninole	8135	Maili
8102	Kaaheiki	8136	Wainaku
8103	Waikolu	8137	Pukihae
8104	Waikaumalo	8138	Wailuku
8105	Waiehu	8139	Wailoa
8106	Nanue	8140	Kaahakini
8107	Opea	8141	Kilauea
8108	Peleau	8142	Keauhou Point
8109	Umauma	8143	Kilauea Crater
8110	Hakalau	8144	Kapapala
8111	Kolekole	8145	Pahala
8112	Paheehee	8146	Hilea
8113	Honomu	8147	Naalehu
8114	Laimi	8148	Kiolakaa
8115	Kapehu	8149	South Point
8116	Makea	8150	Kauna
8117	Alia	8151	Kiilae
8118	Makahanaloa	8152	Kealakekua
8119	Waimaauou	8153	Waiaha
8120	Waiaama	8154	Honokohau

Table 3-20: (continued)
Hawaii (8) Surface Water Hydrologic Units (continued)

8121	Kawainui	8155	Keahole
8122	Onomea	8156	Kiholo
8123	Alakahi	8157	Pohakuloa
8124	Hanawi	8158	Kamakoa
8125	Kalaoa	8159	Haloa
8126	Aleamai	8160	Lamimaumau
8127	Kaieie	8161	Waikoloa
8128	Puuokalepa	8162	Kawaihae
8129	Kaapoko	8163	Honokoa
8130	Papaikou	8164	Keawanui
8131	Kapue	8165	Lapakahi
8132	Pahoehoe	8166	Mahukona

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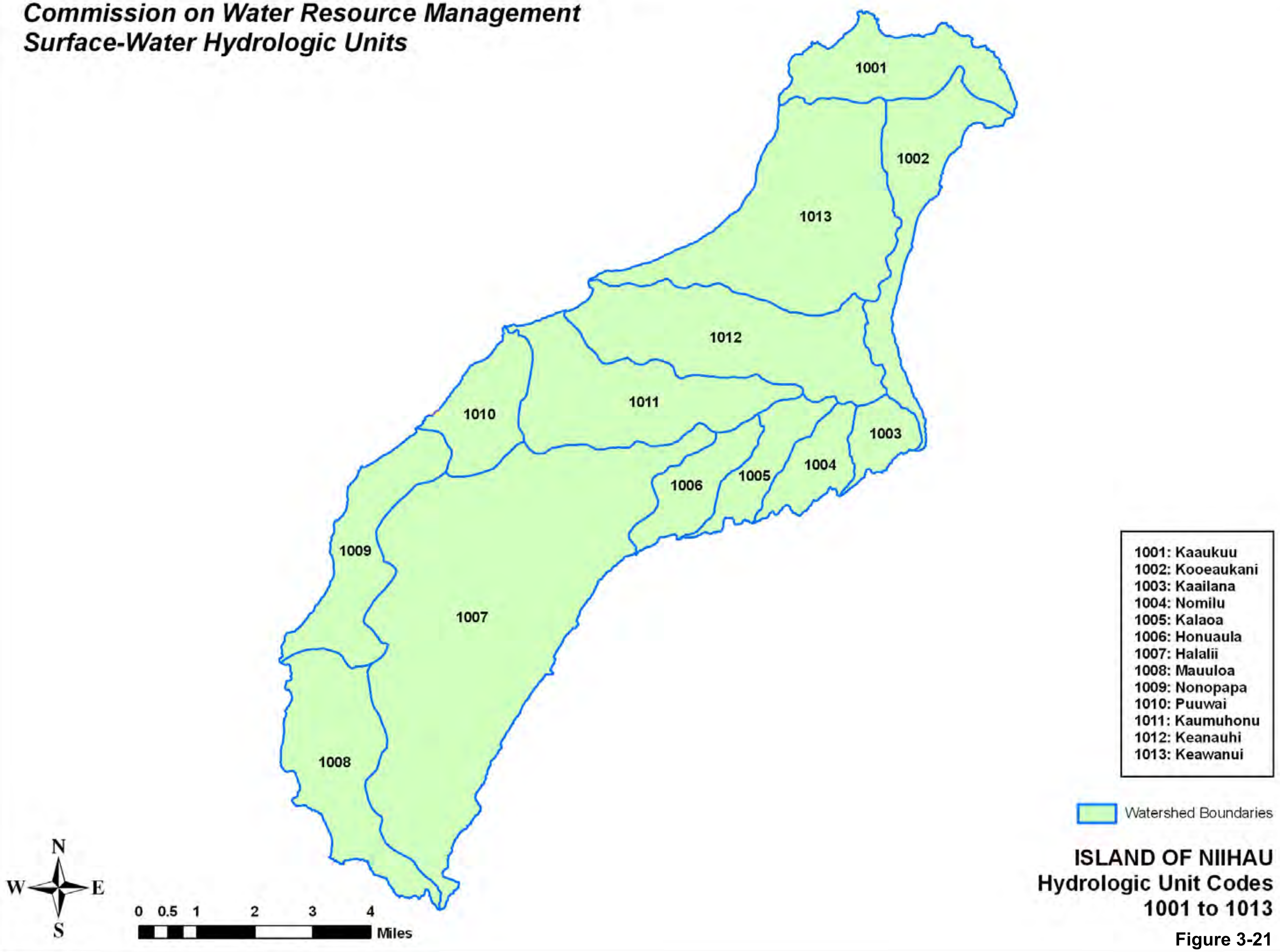
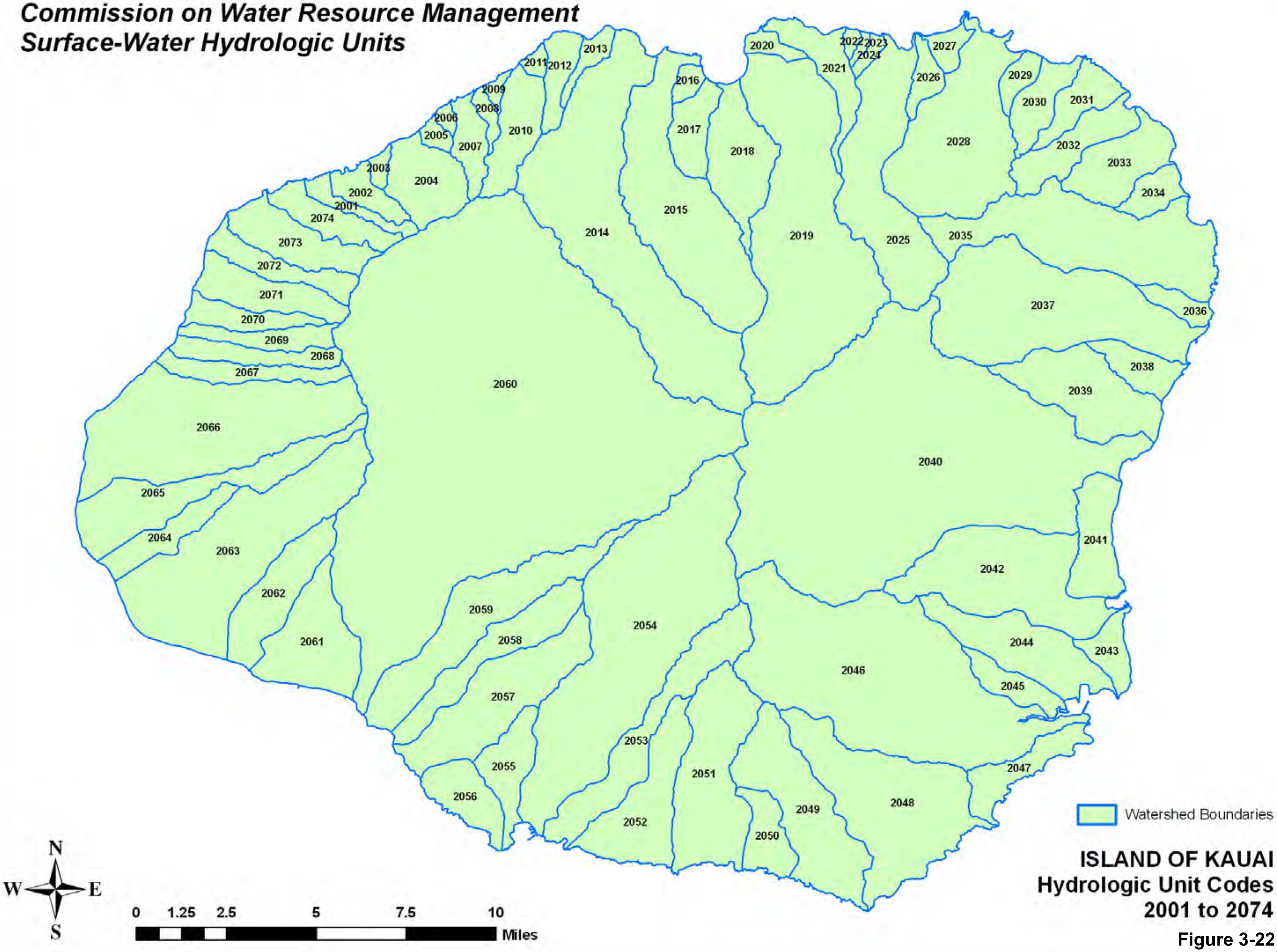
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF NIIHAU
Hydrologic Unit Codes
1001 to 1013

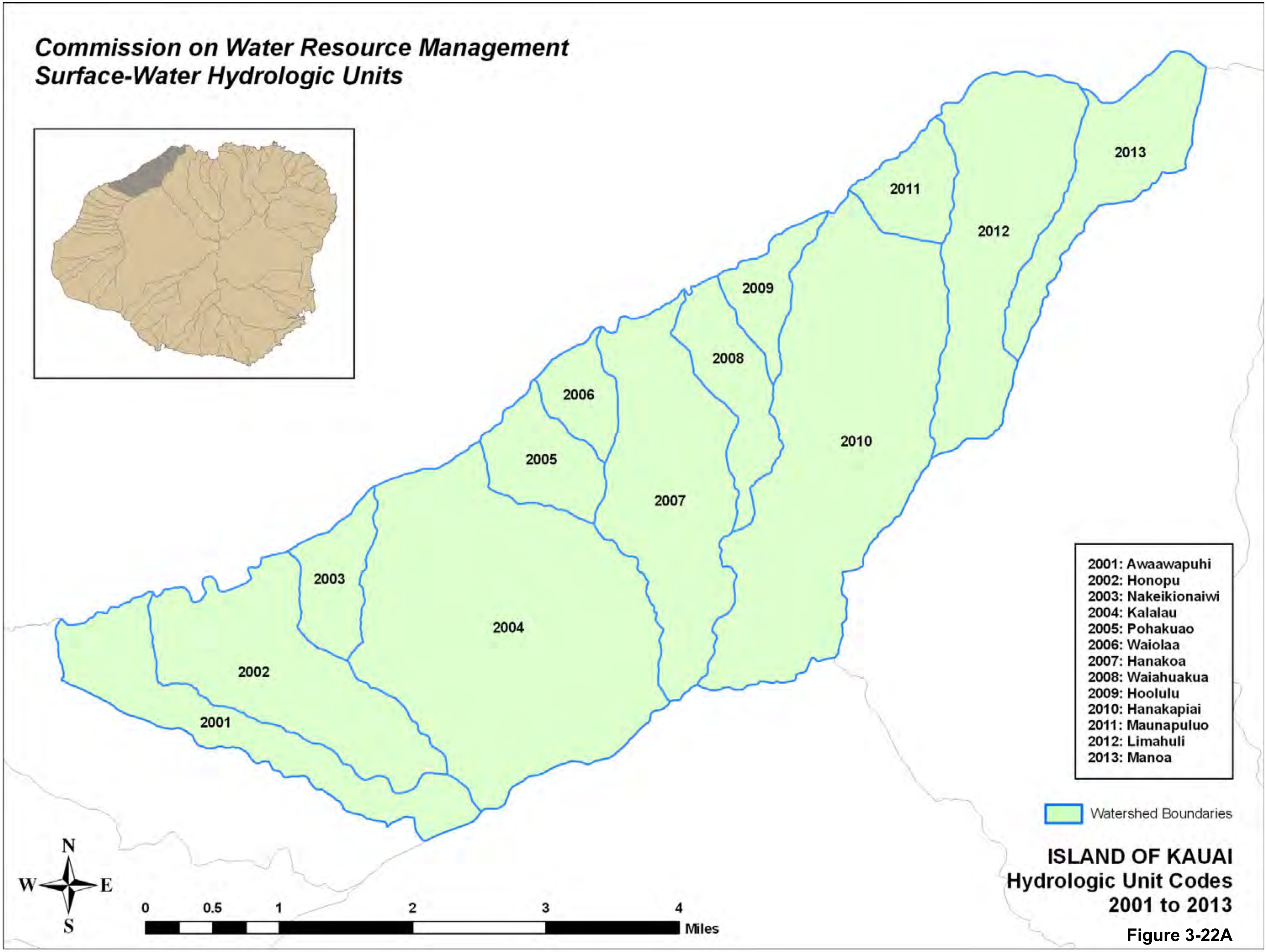
Figure 3-21

Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF KAUAI
Hydrologic Unit Codes
2001 to 2074

Figure 3-22

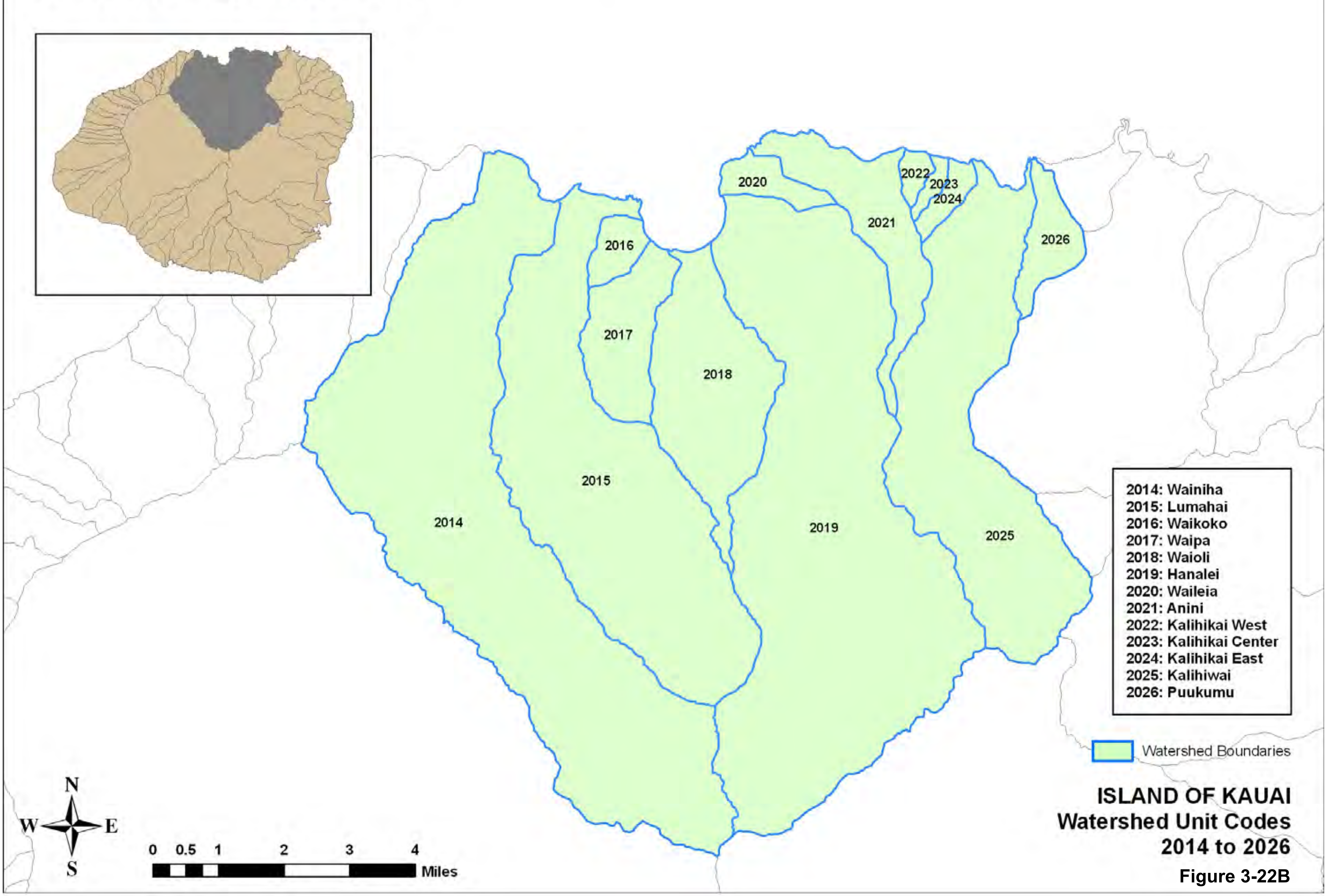


Commission on Water Resource Management
Surface-Water Hydrologic Units

ISLAND OF KAUAI
Hydrologic Unit Codes
2001 to 2013

Figure 3-22A

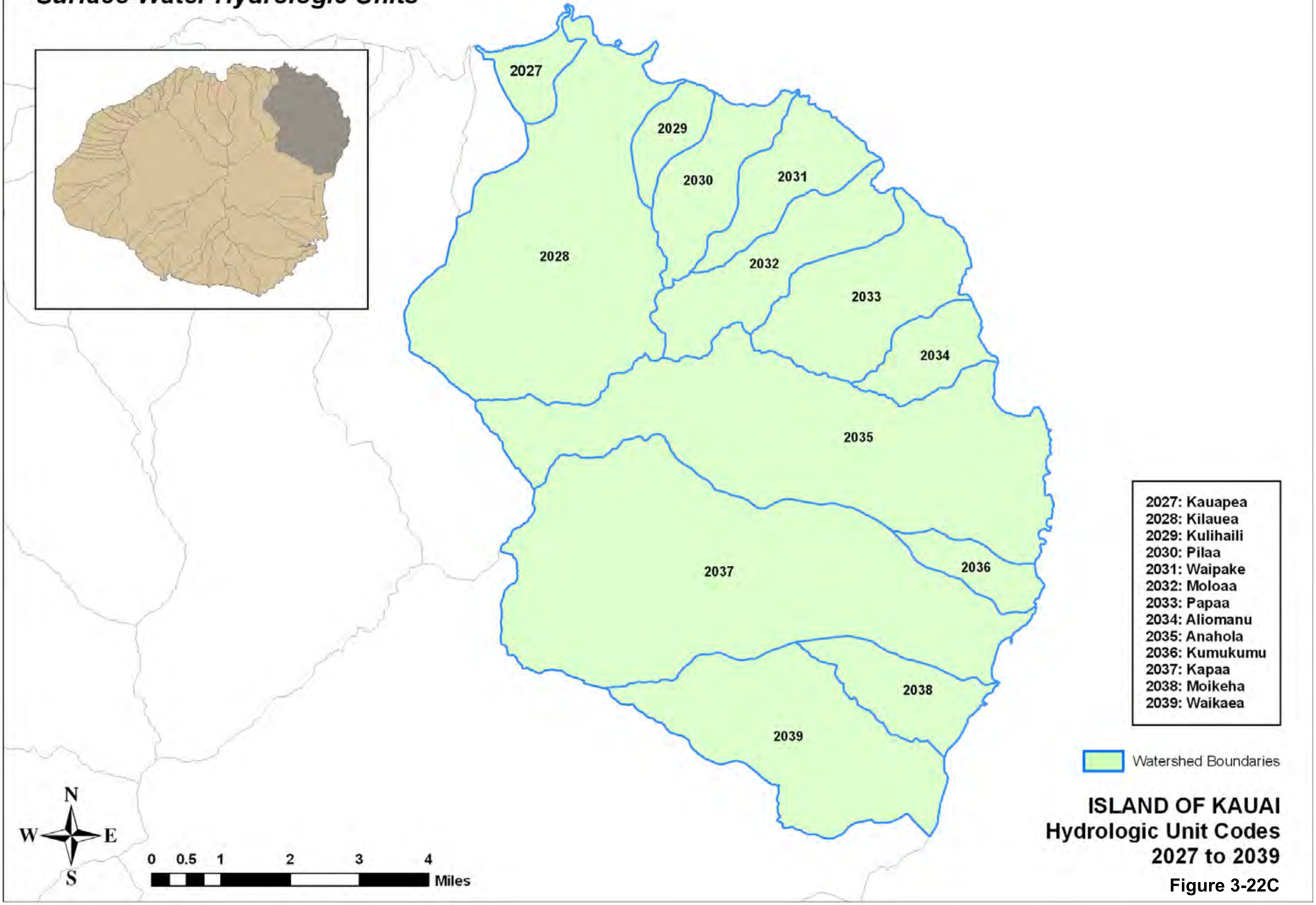
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF KAUAI
Watershed Unit Codes
2014 to 2026

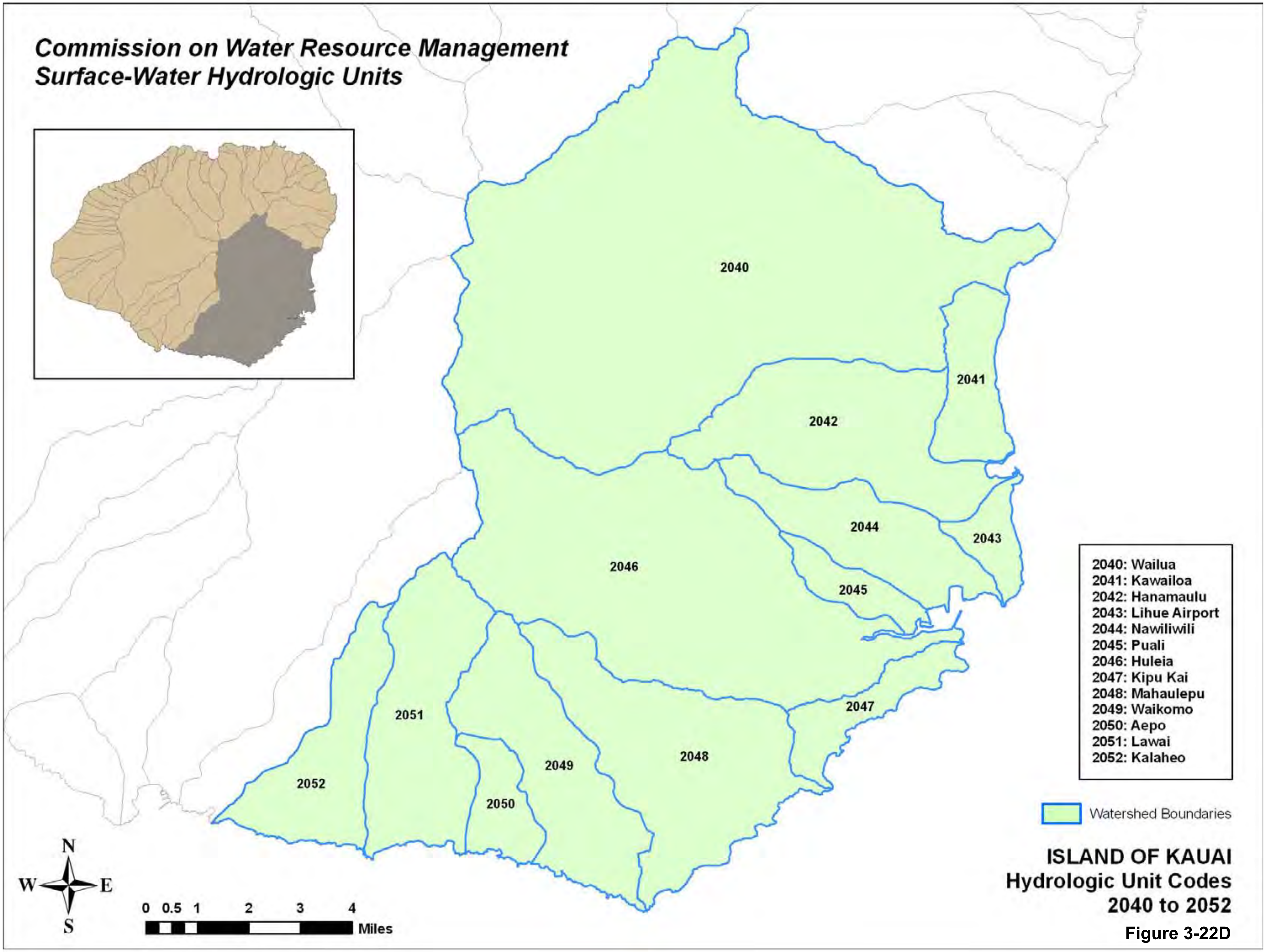
Figure 3-22B

Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF KAUAI
Hydrologic Unit Codes
2027 to 2039

Figure 3-22C



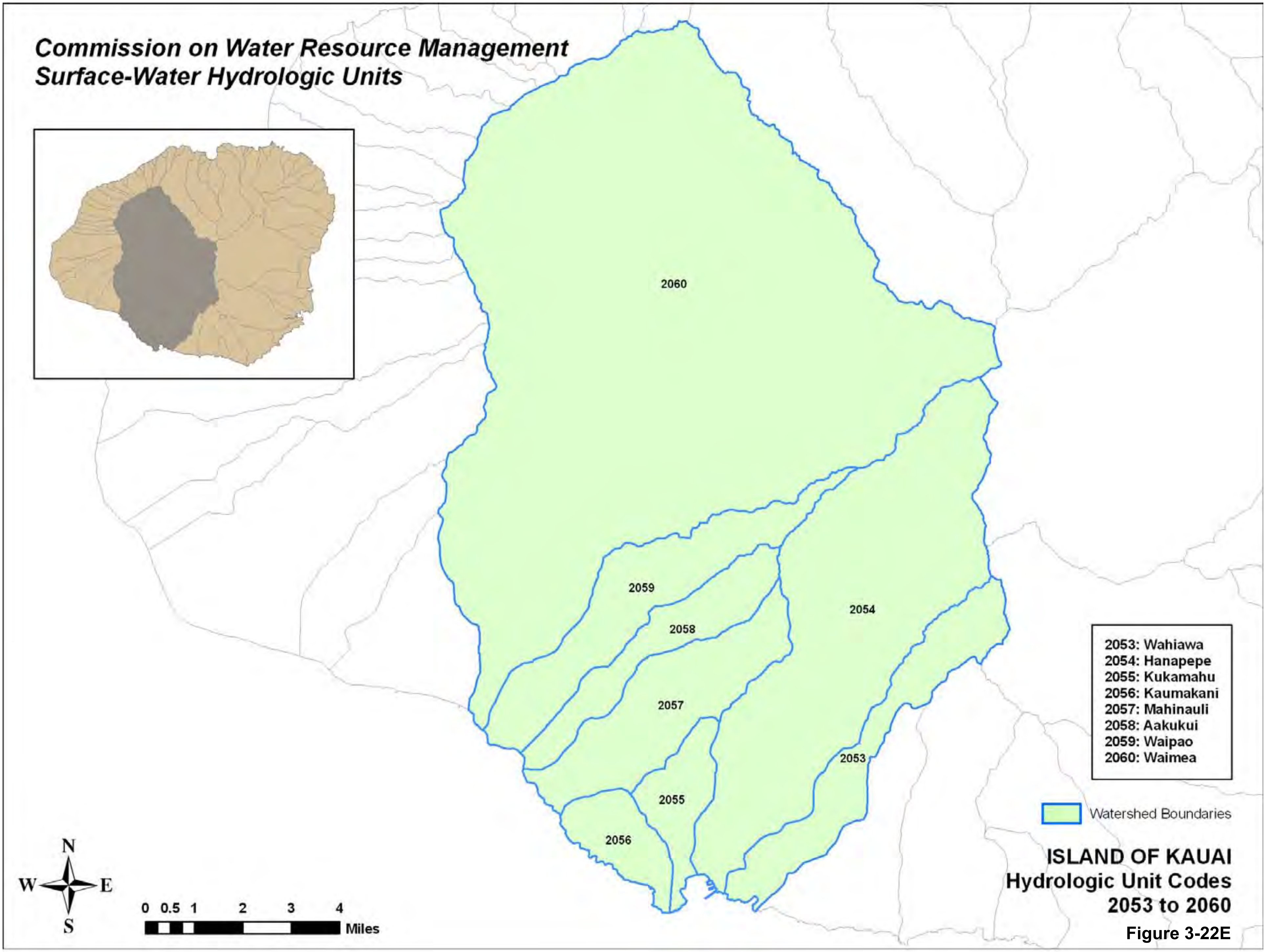
Commission on Water Resource Management
Surface-Water Hydrologic Units

2040: Wailua
2041: Kawailoa
2042: Hanamaulu
2043: Lihue Airport
2044: Nawiliwili
2045: Puali
2046: Huleia
2047: Kipu Kai
2048: Mahaulepu
2049: Waikomo
2050: Aepo
2051: Lawai
2052: Kalaheo

ISLAND OF KAUAI
Hydrologic Unit Codes
2040 to 2052

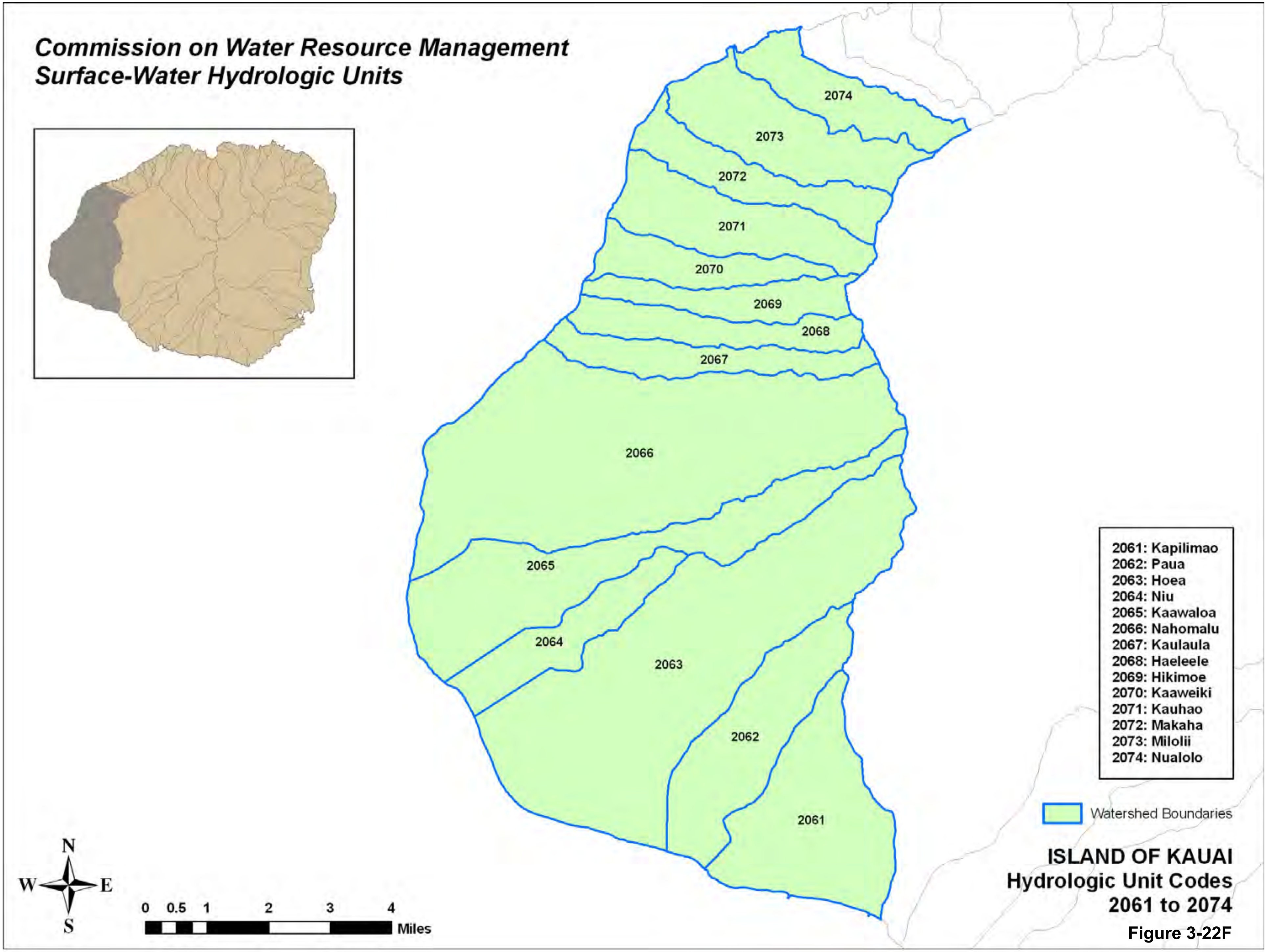
Figure 3-22D

Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF KAUAI
Hydrologic Unit Codes
2053 to 2060

Figure 3-22E



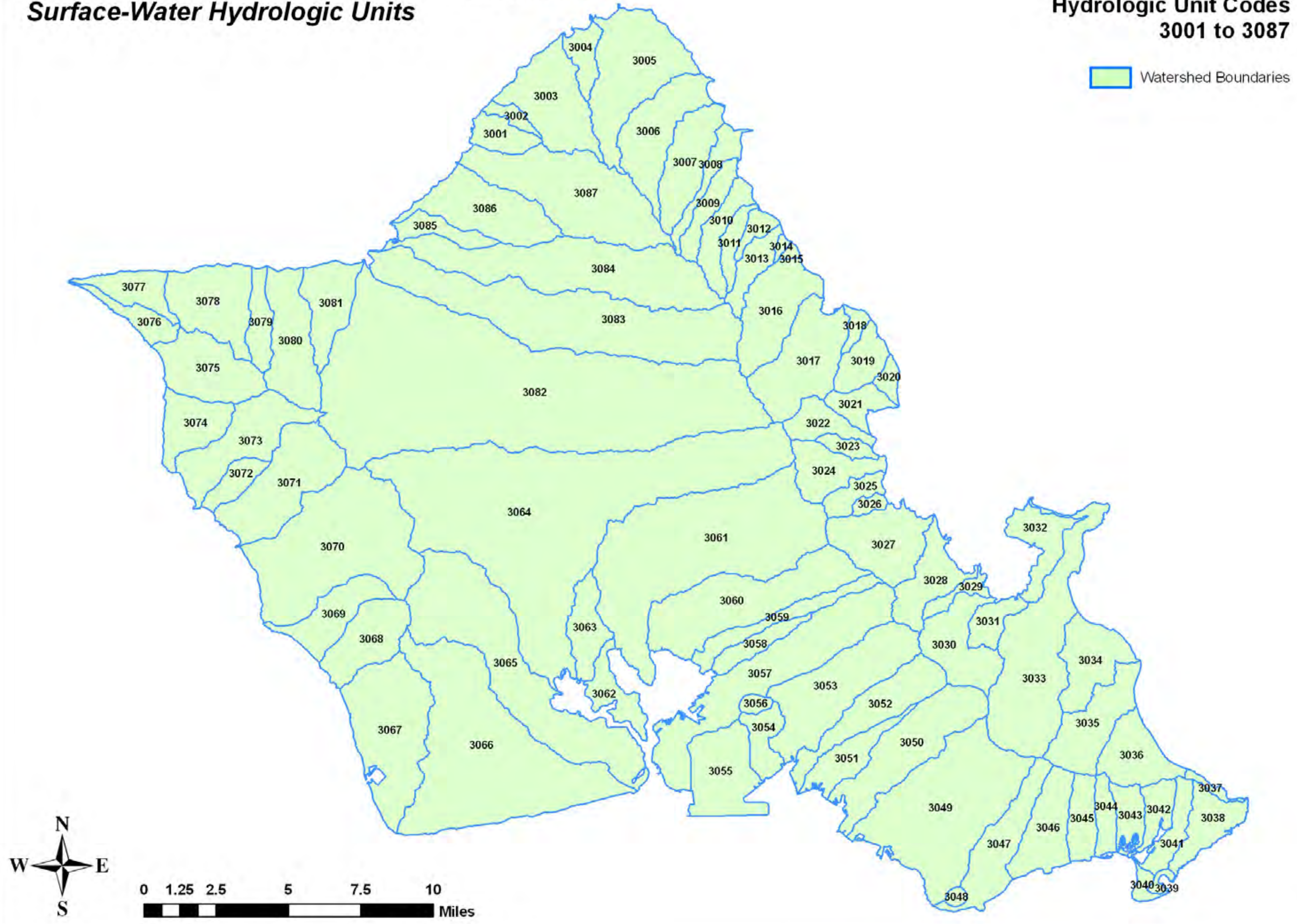
ISLAND OF KAUAI
Hydrologic Unit Codes
2061 to 2074

Figure 3-22F

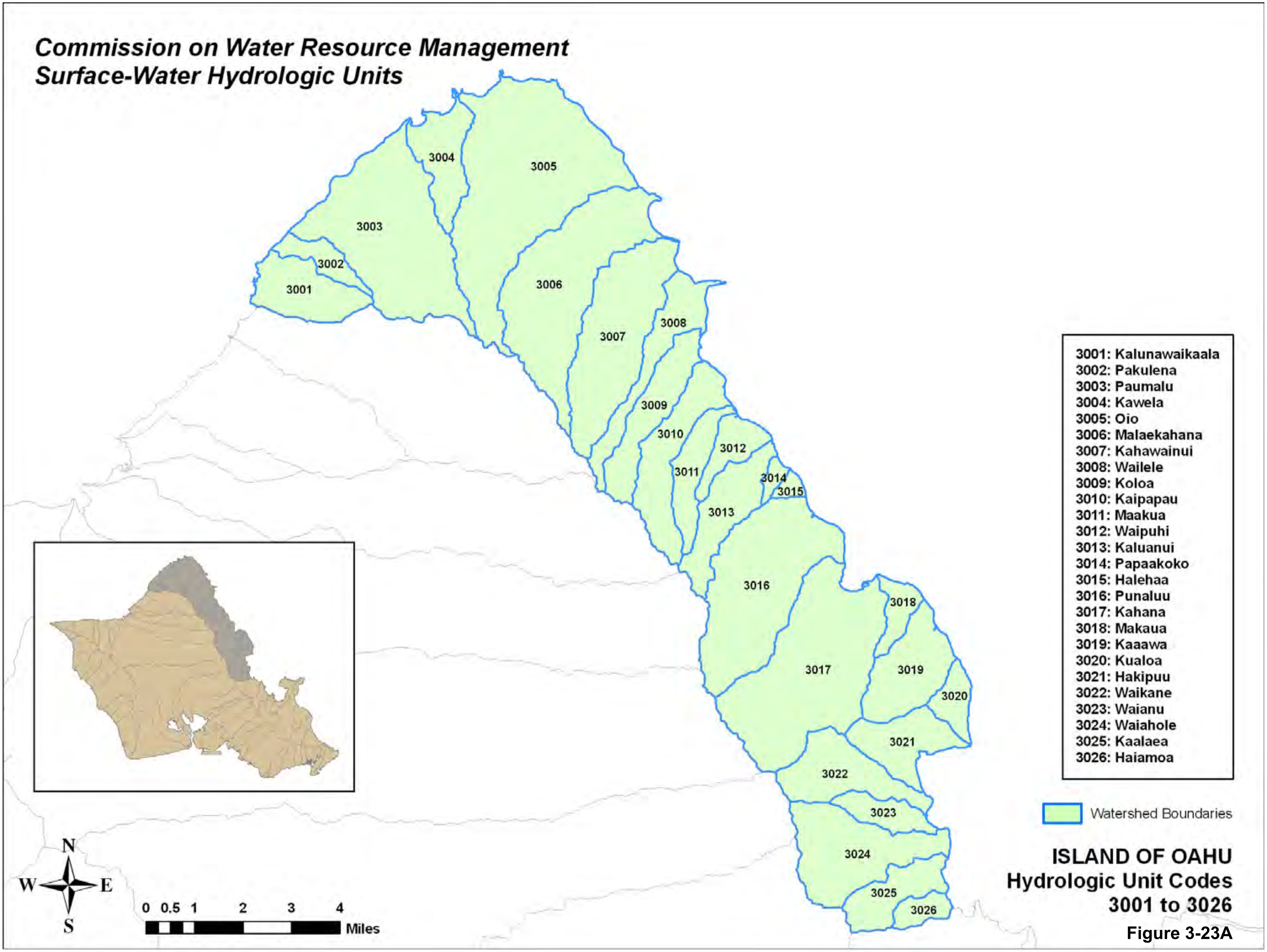
Figure 3-23

ISLAND OF OAHU
Hydrologic Unit Codes
3001 to 3087

Commission on Water Resource Management
Surface-Water Hydrologic Units

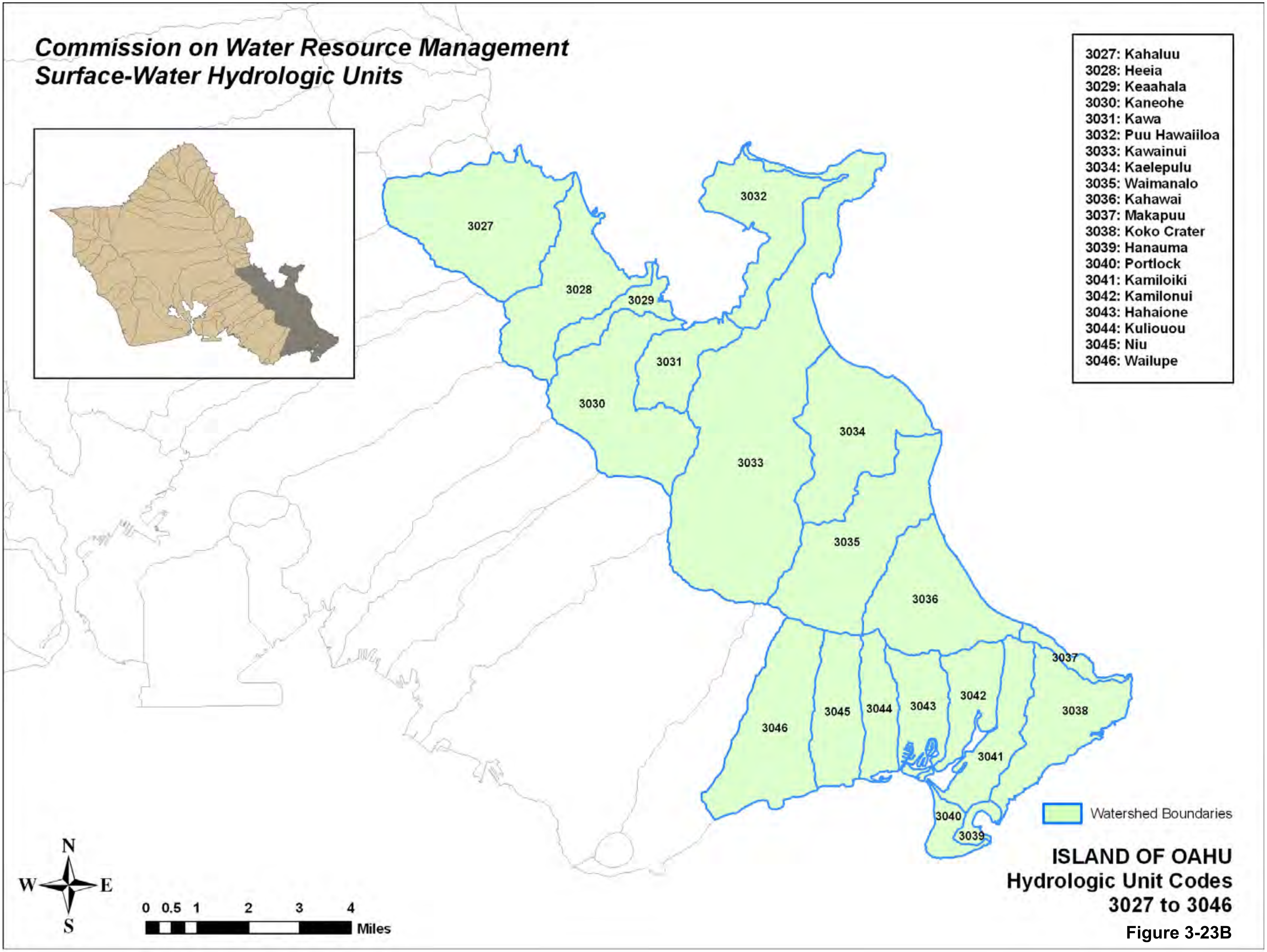


Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF OAHU
Hydrologic Unit Codes
3001 to 3026

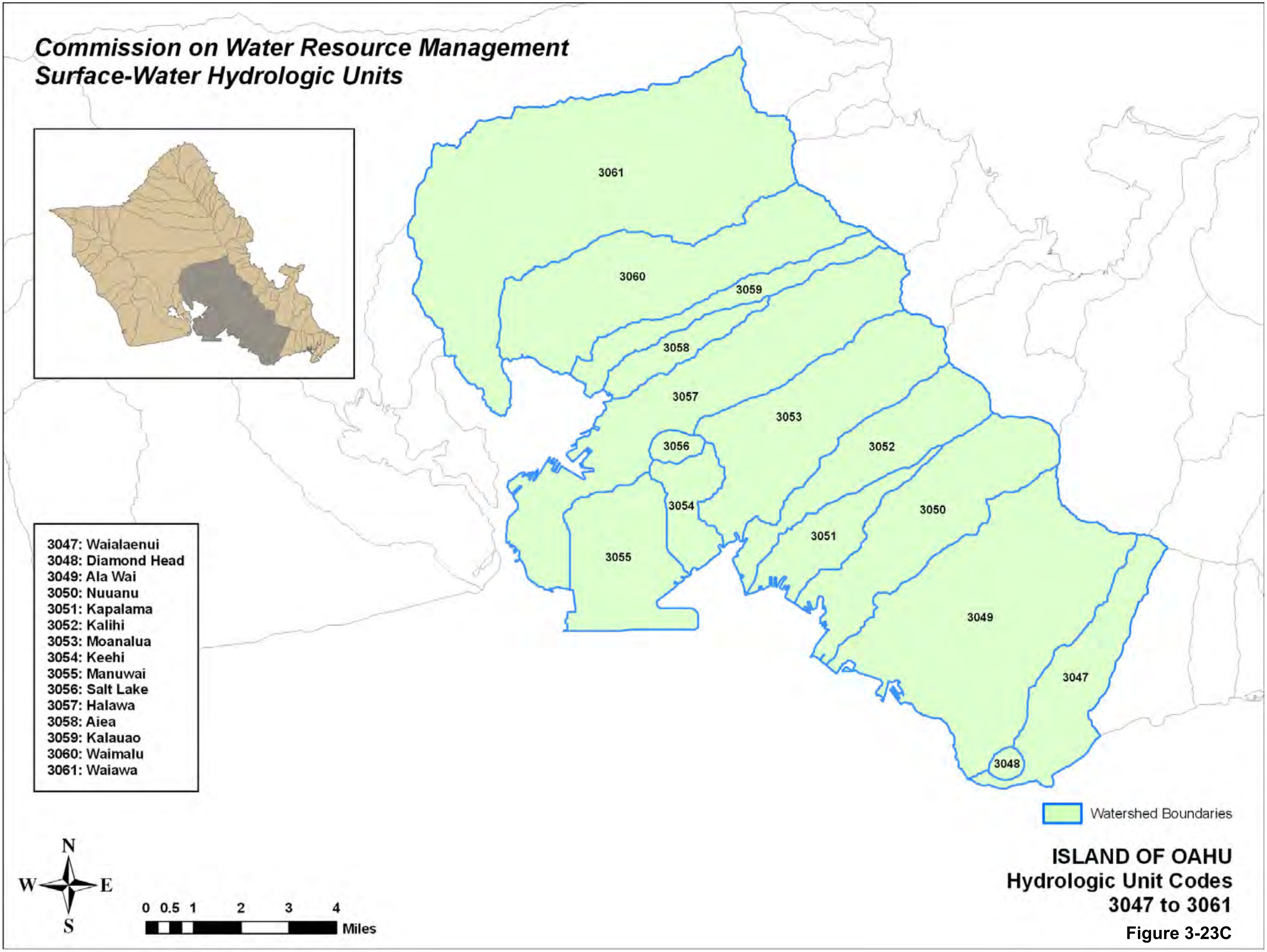
Figure 3-23A



ISLAND OF OAHU
Hydrologic Unit Codes
3027 to 3046

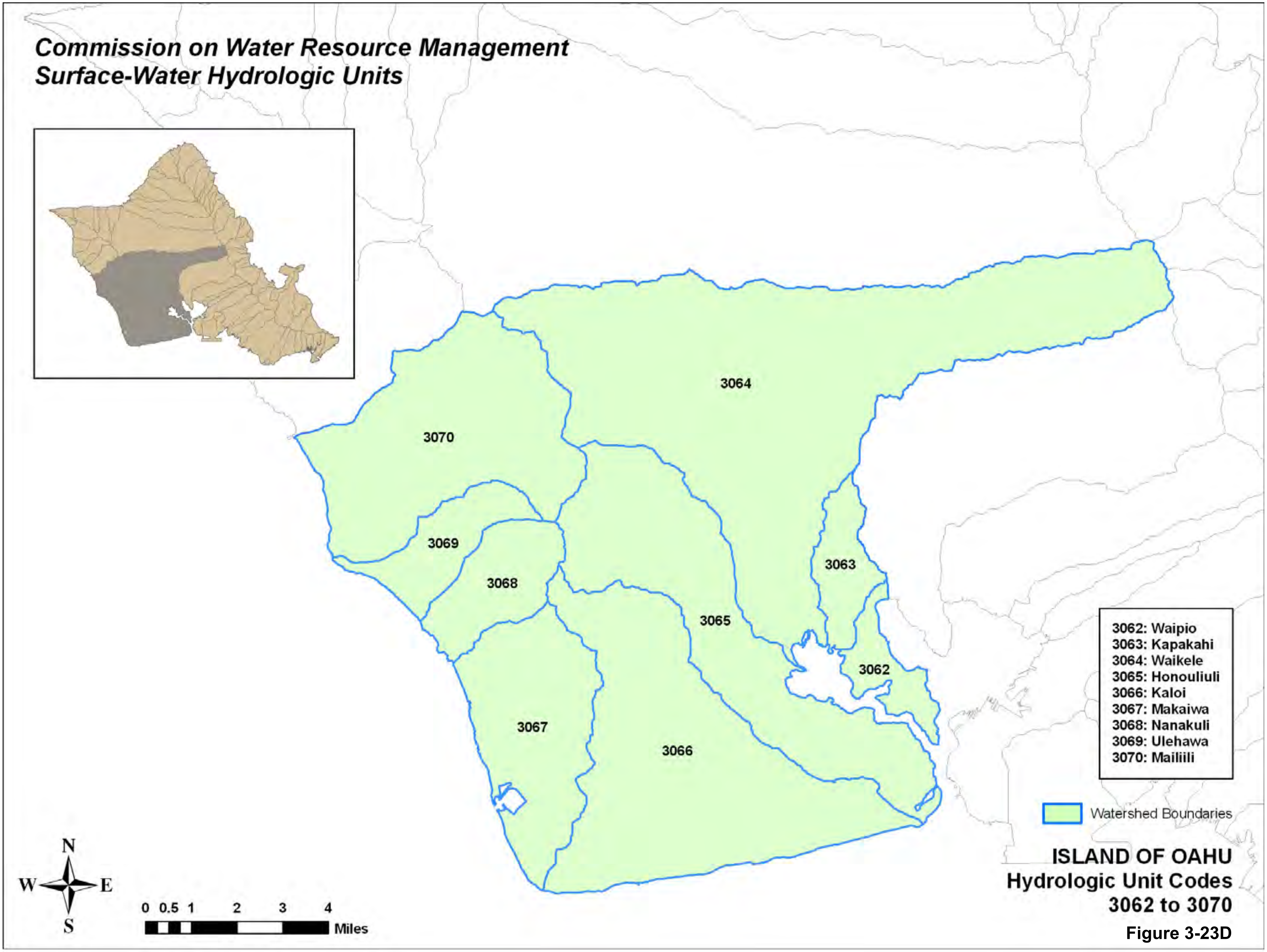
Figure 3-23B

Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF OAHU
Hydrologic Unit Codes
3047 to 3061

Figure 3-23C

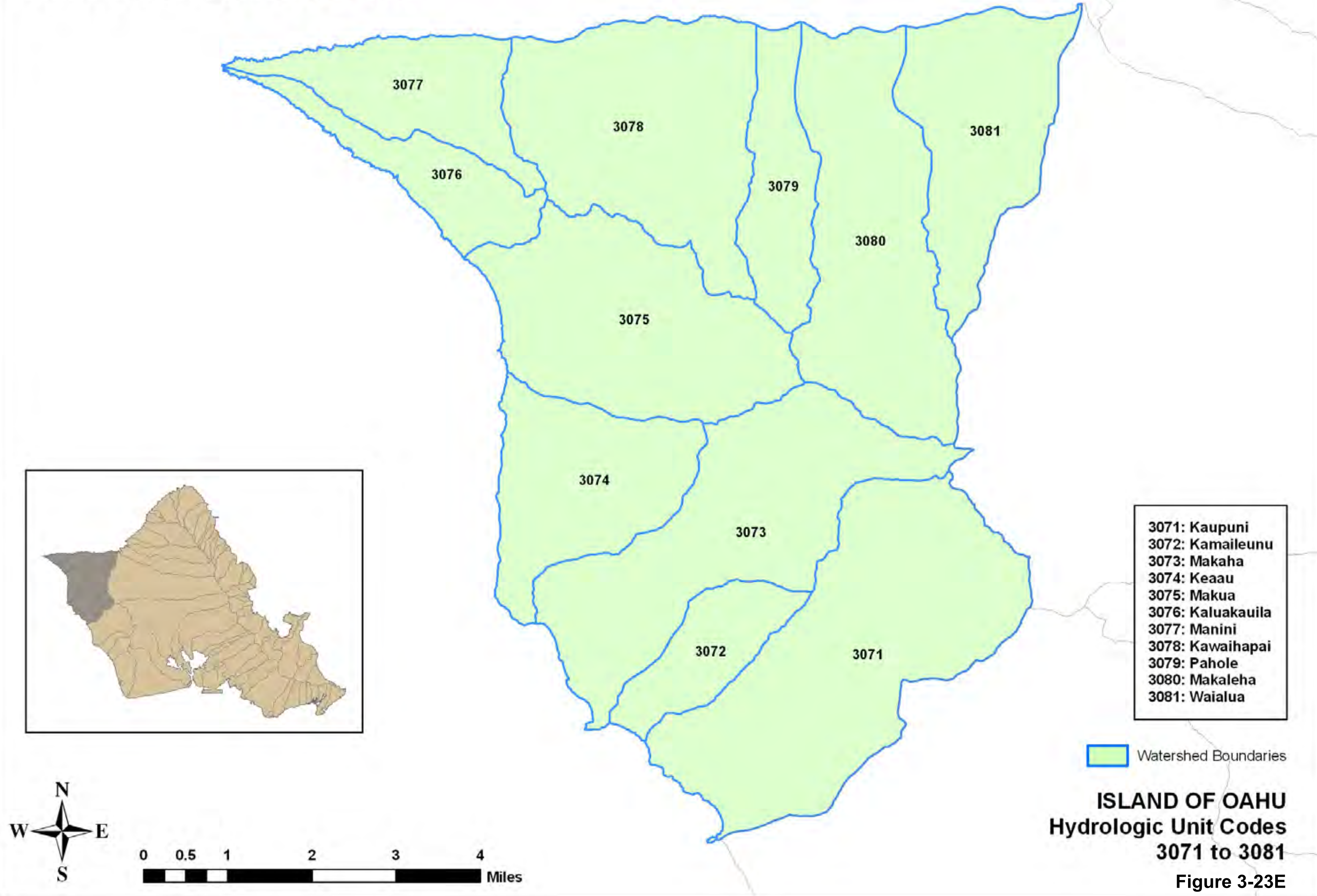


Commission on Water Resource Management
Surface-Water Hydrologic Units

ISLAND OF OAHU
Hydrologic Unit Codes
3062 to 3070

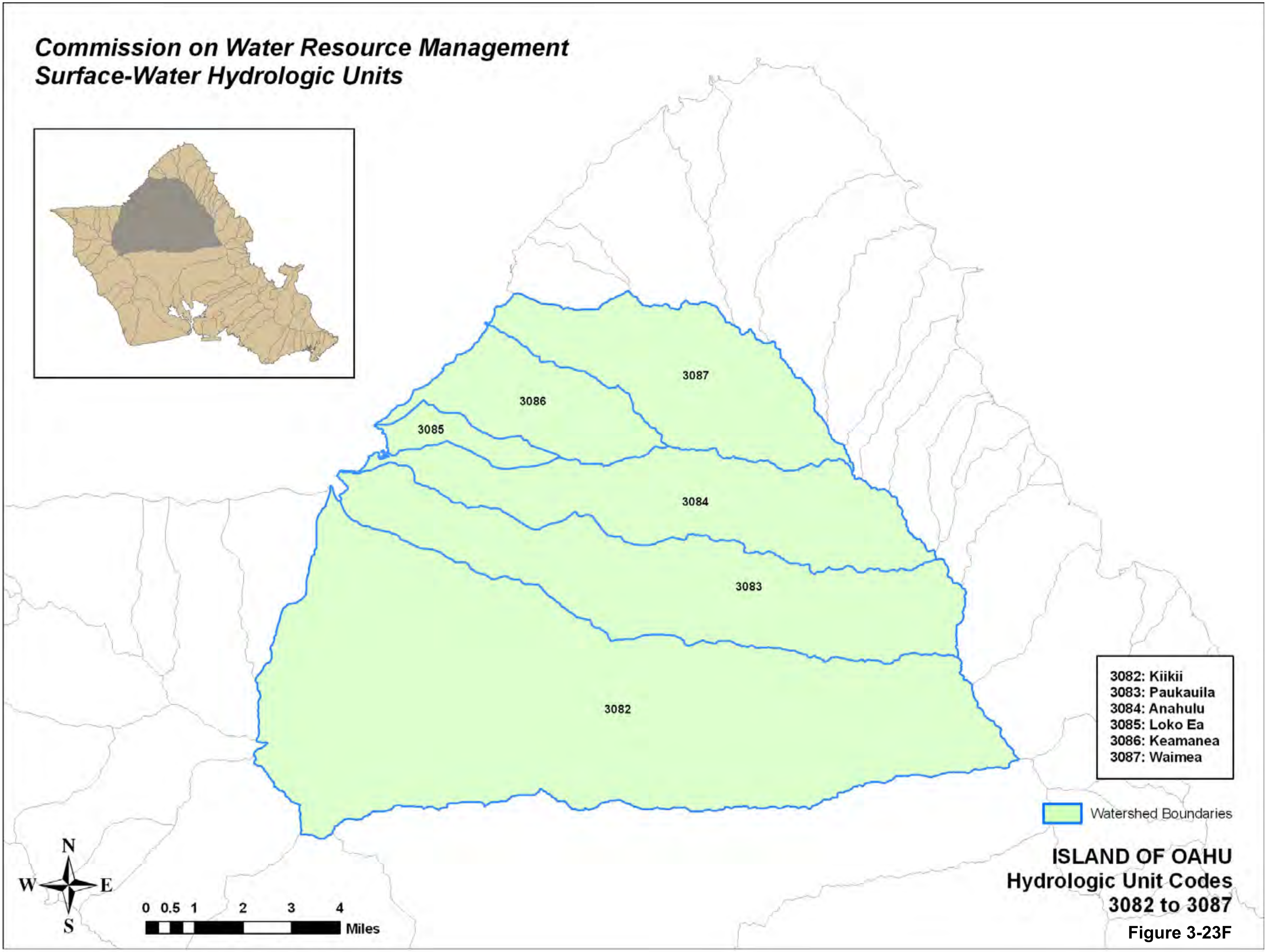
Figure 3-23D

Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF OAHU
Hydrologic Unit Codes
3071 to 3081

Figure 3-23E

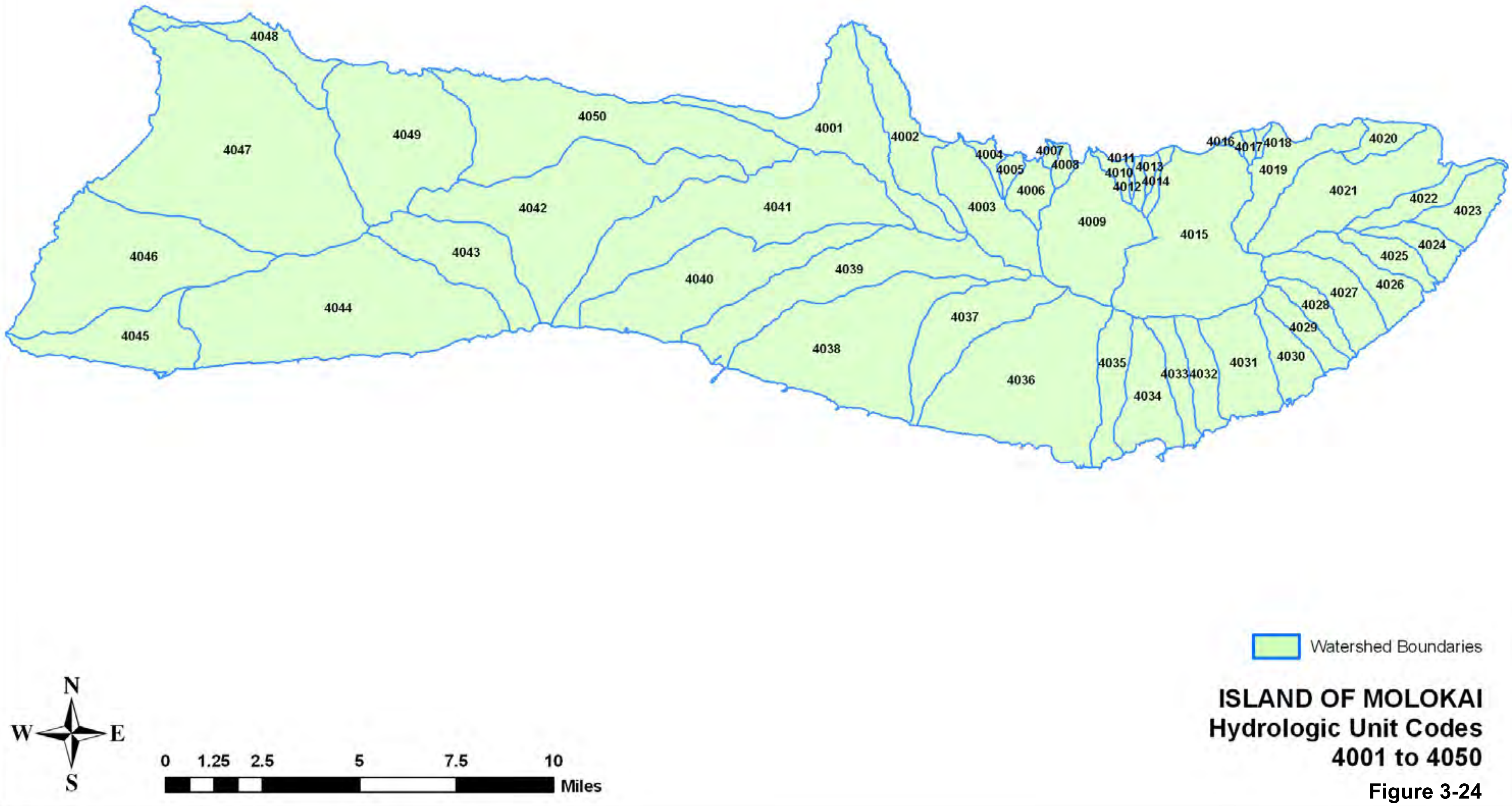


Commission on Water Resource Management
Surface-Water Hydrologic Units

ISLAND OF OAHU
Hydrologic Unit Codes
3082 to 3087

Figure 3-23F

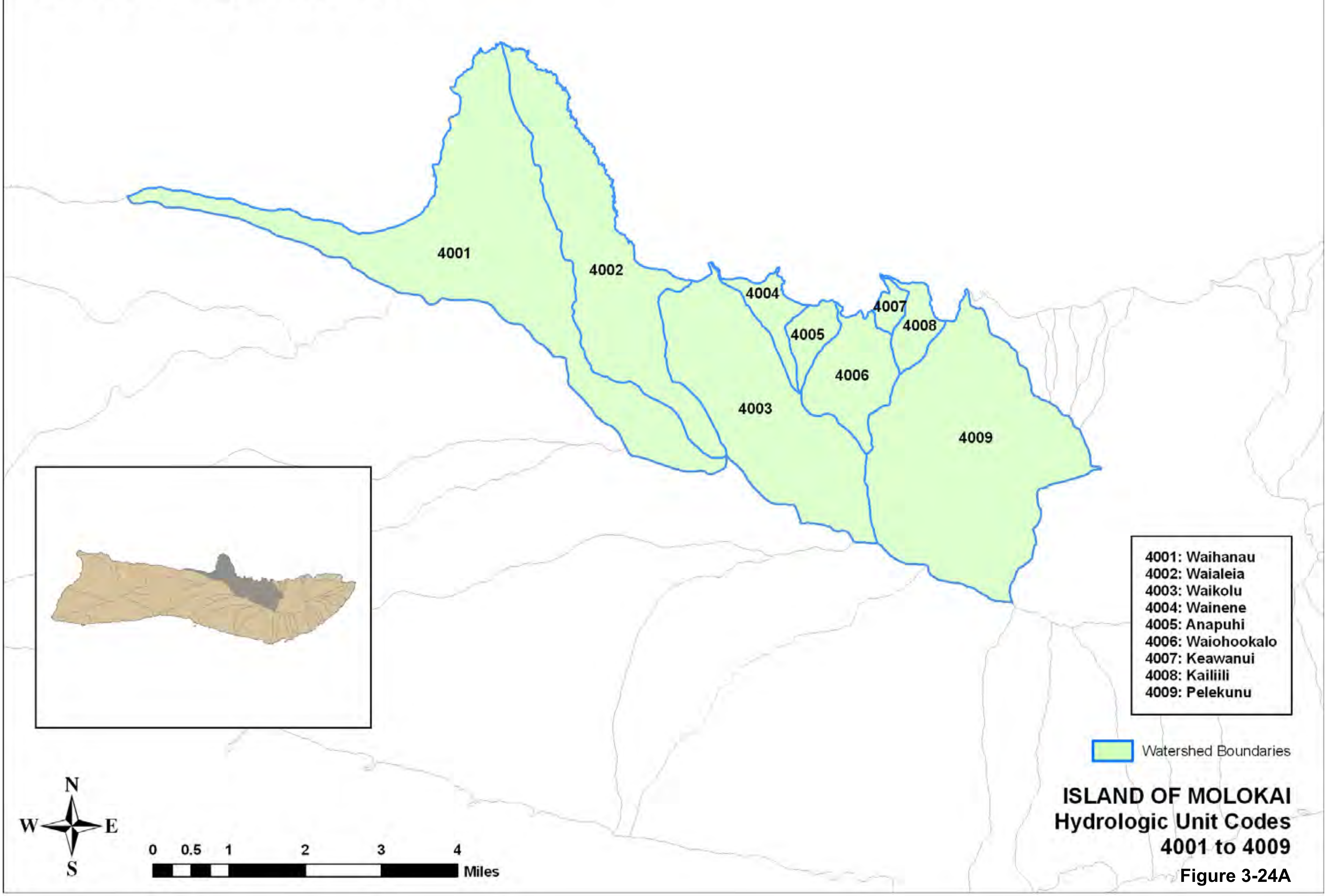
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF MOLOKAI
Hydrologic Unit Codes
4001 to 4050

Figure 3-24

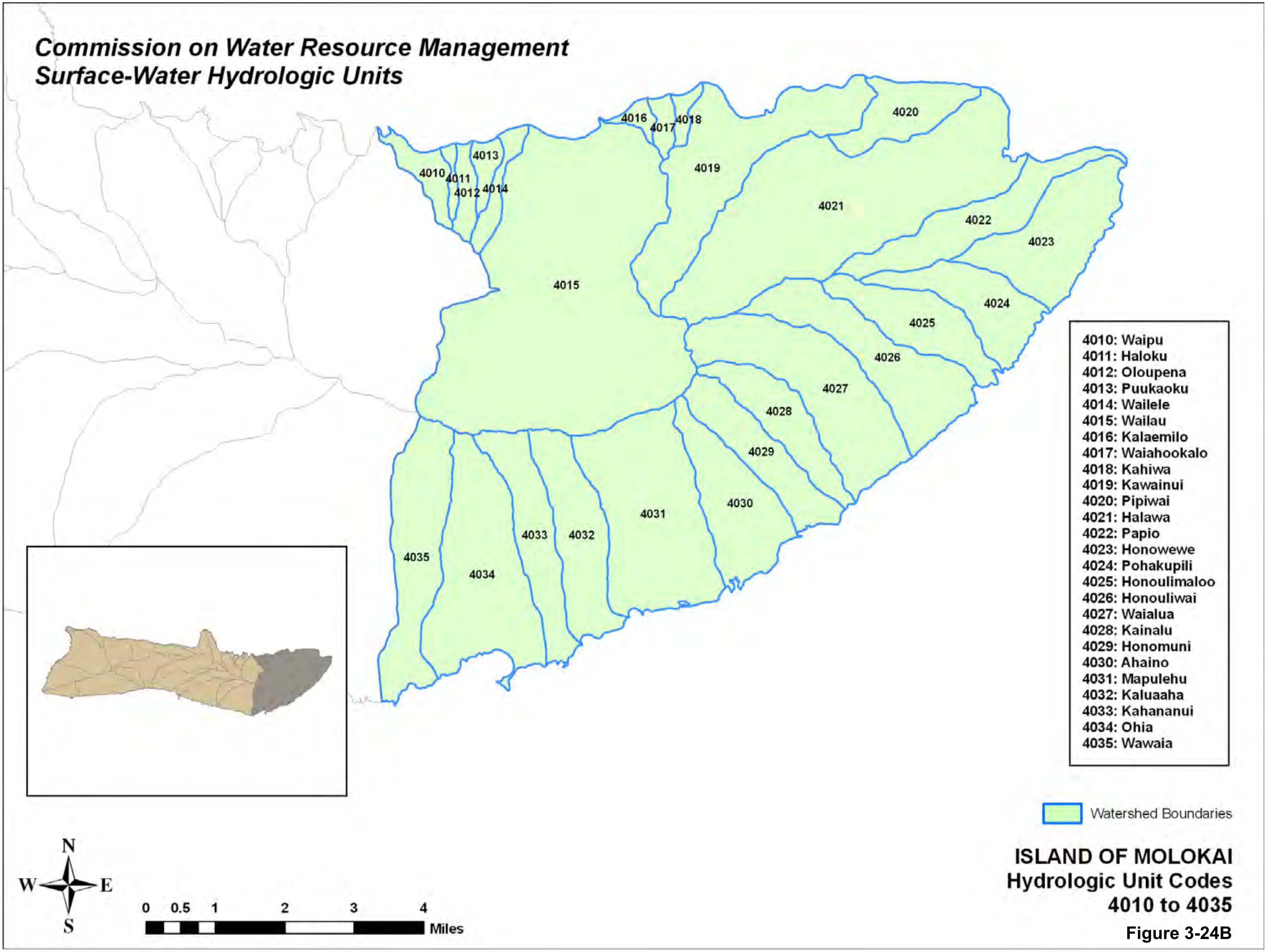
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF MOLOKAI
Hydrologic Unit Codes
4001 to 4009

Figure 3-24A

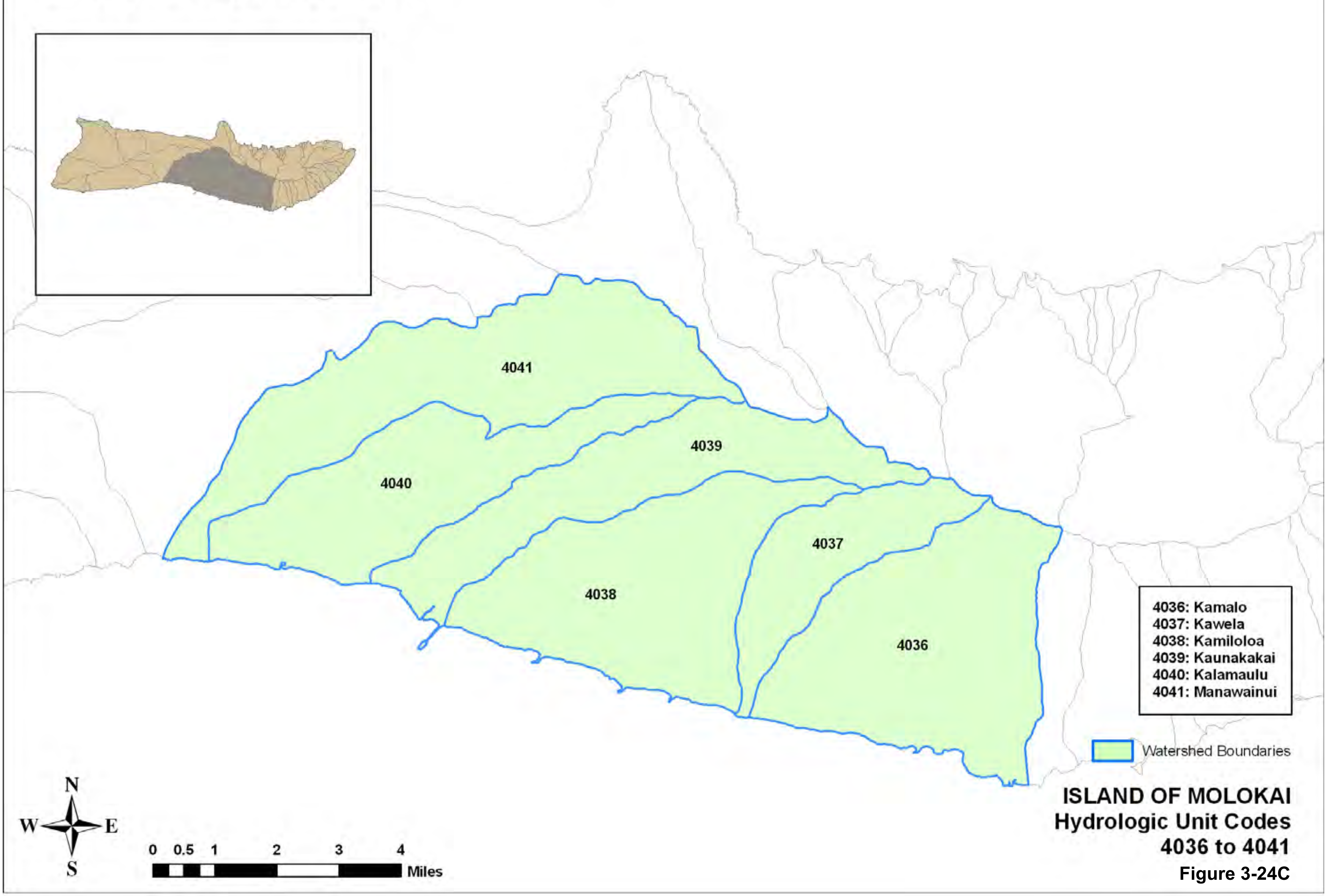
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF MOLOKAI
Hydrologic Unit Codes
4010 to 4035

Figure 3-24B

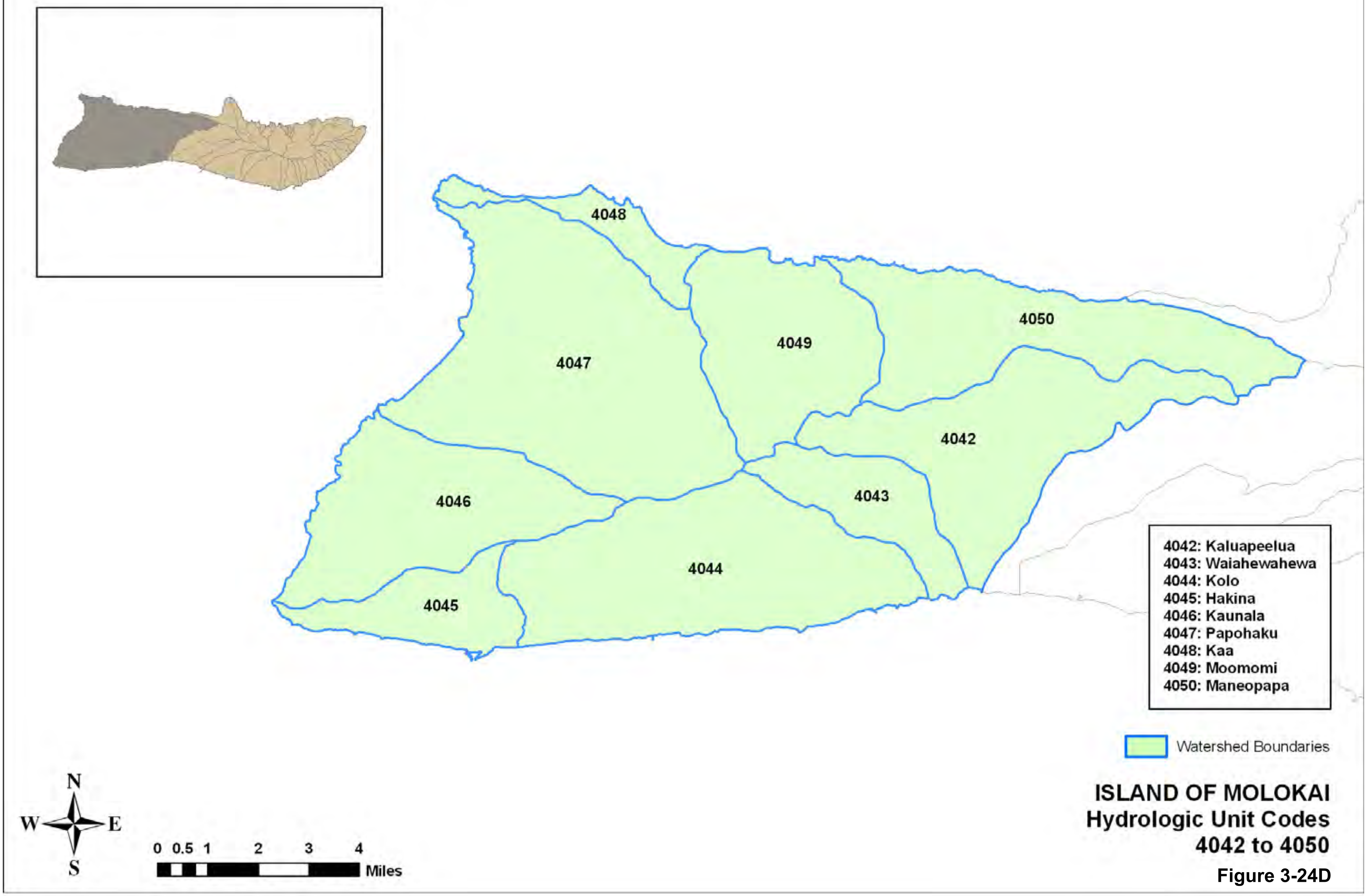
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF MOLOKAI
Hydrologic Unit Codes
4036 to 4041

Figure 3-24C

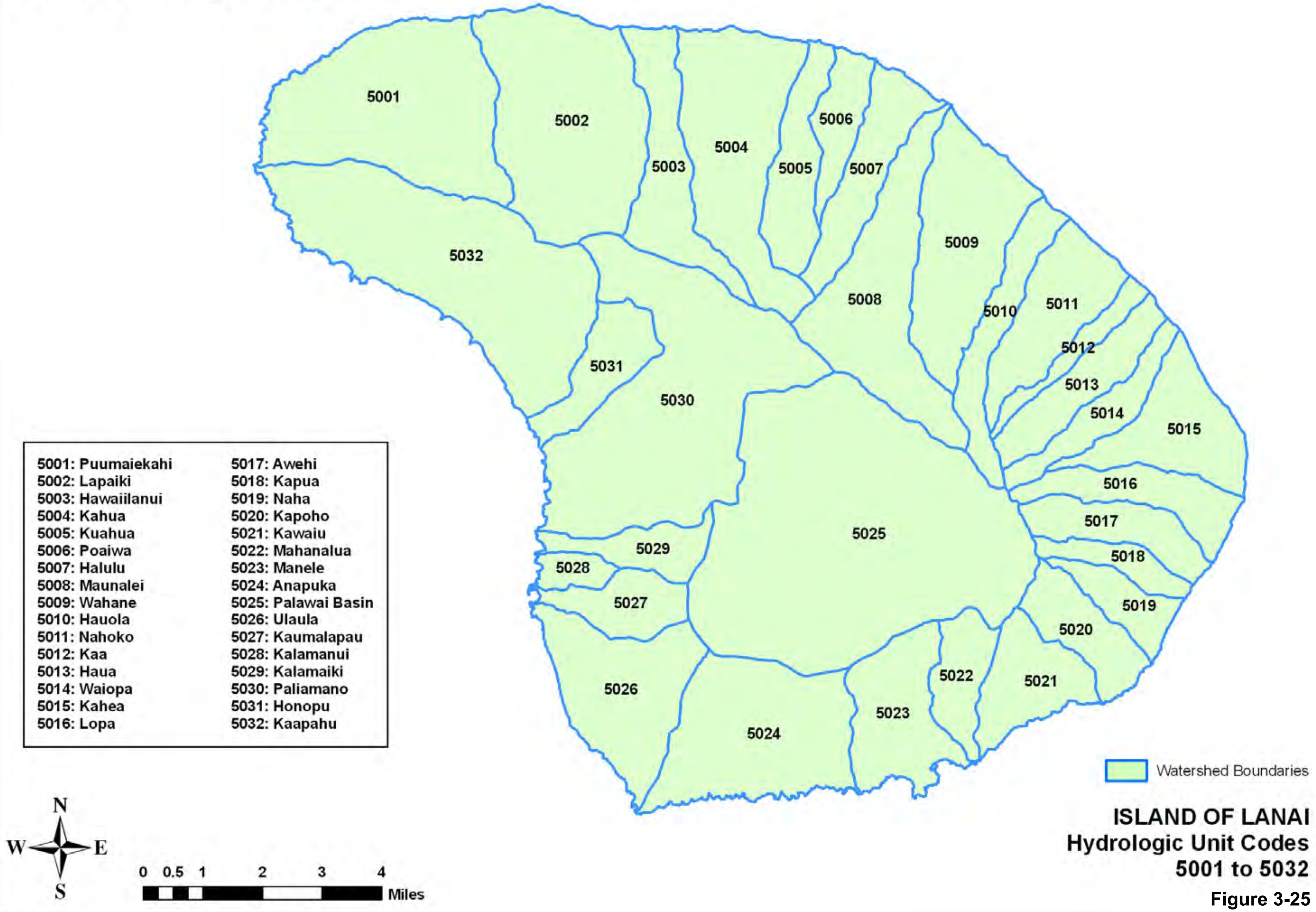
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF MOLOKAI
Hydrologic Unit Codes
4042 to 4050

Figure 3-24D

Commission on Water Resource Management
Surface-Water Hydrologic Units

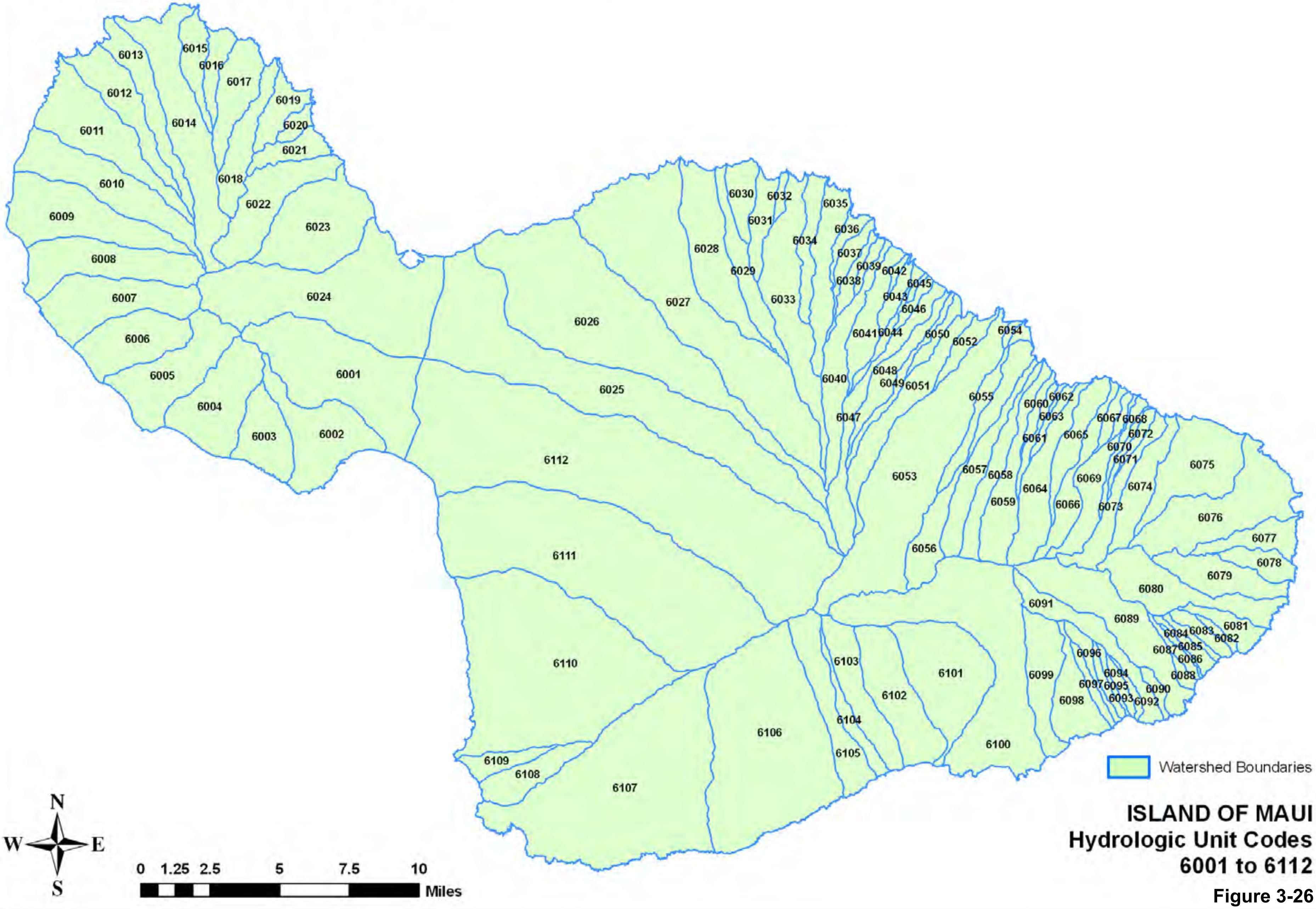


5001: Puumaiekahi
5002: Lapaiki
5003: Hawaiilanui
5004: Kahua
5005: Kuahua
5006: Poaiwa
5007: Halulu
5008: Maunalei
5009: Wahane
5010: Hauola
5011: Nahoko
5012: Kaa
5013: Haua
5014: Waiopa
5015: Kahea
5016: Lopa
5017: Awehi
5018: Kapua
5019: Naha
5020: Kapoho
5021: Kawaiu
5022: Mahanalua
5023: Manele
5024: Anapuka
5025: Palawai Basin
5026: Ulaula
5027: Kaumalapau
5028: Kalamanui
5029: Kalamaiki
5030: Paliamano
5031: Honopu
5032: Kaapahu

ISLAND OF LANAI
Hydrologic Unit Codes
5001 to 5032

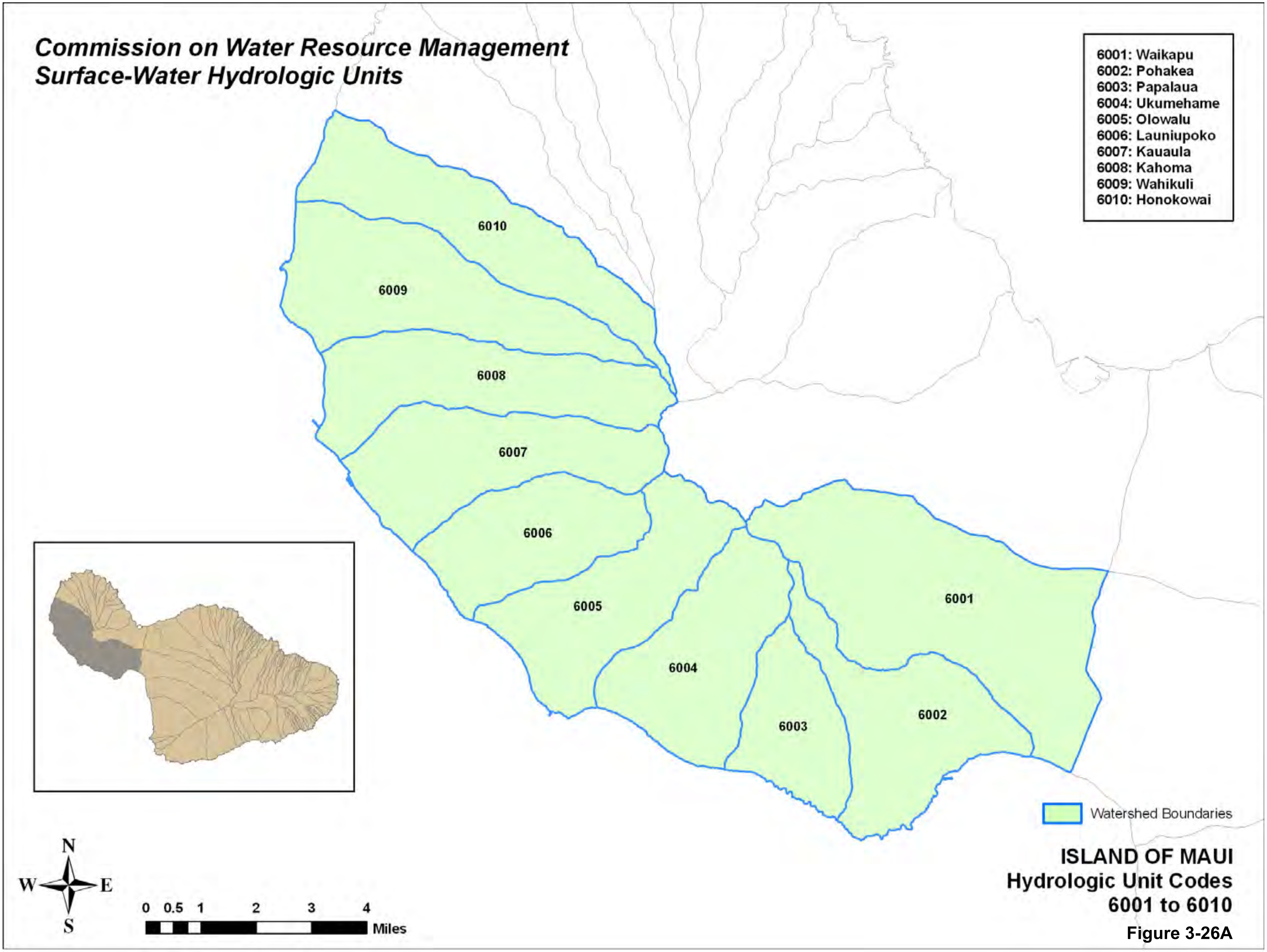
Figure 3-25

Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF MAUI
Hydrologic Unit Codes
6001 to 6112

Figure 3-26

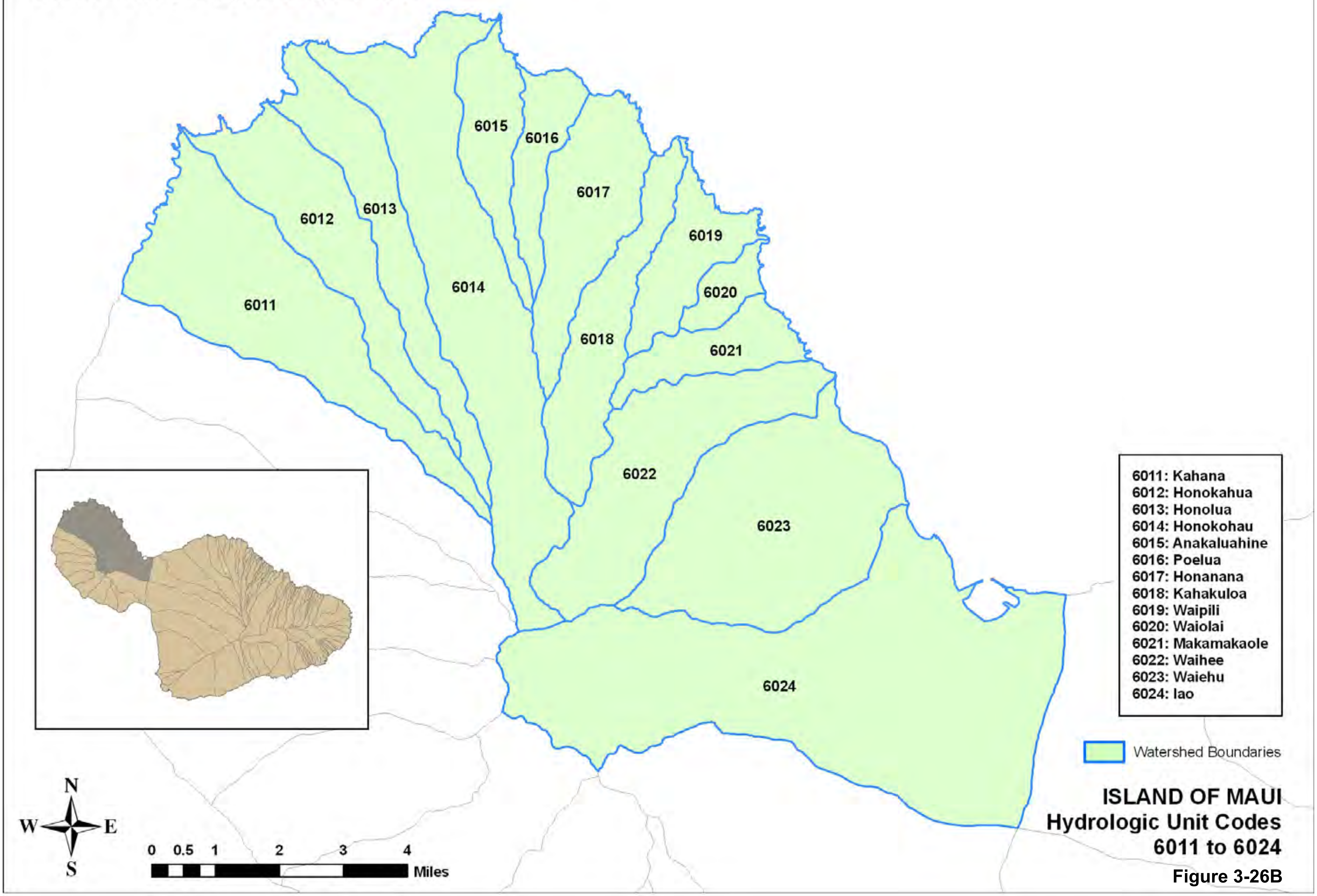


Commission on Water Resource Management
Surface-Water Hydrologic Units

ISLAND OF MAUI
Hydrologic Unit Codes
6001 to 6010

Figure 3-26A

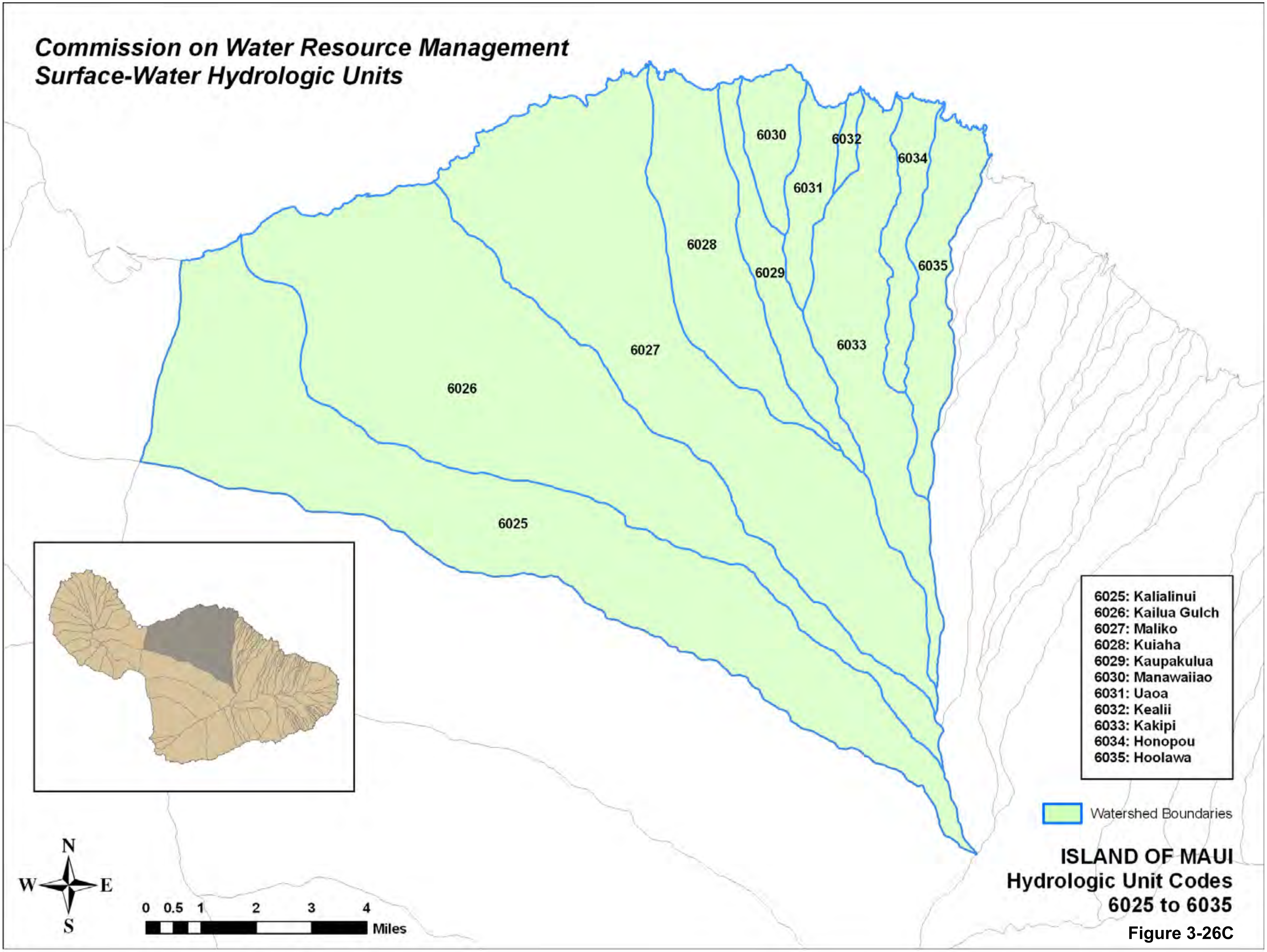
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF MAUI
Hydrologic Unit Codes
6011 to 6024

Figure 3-26B

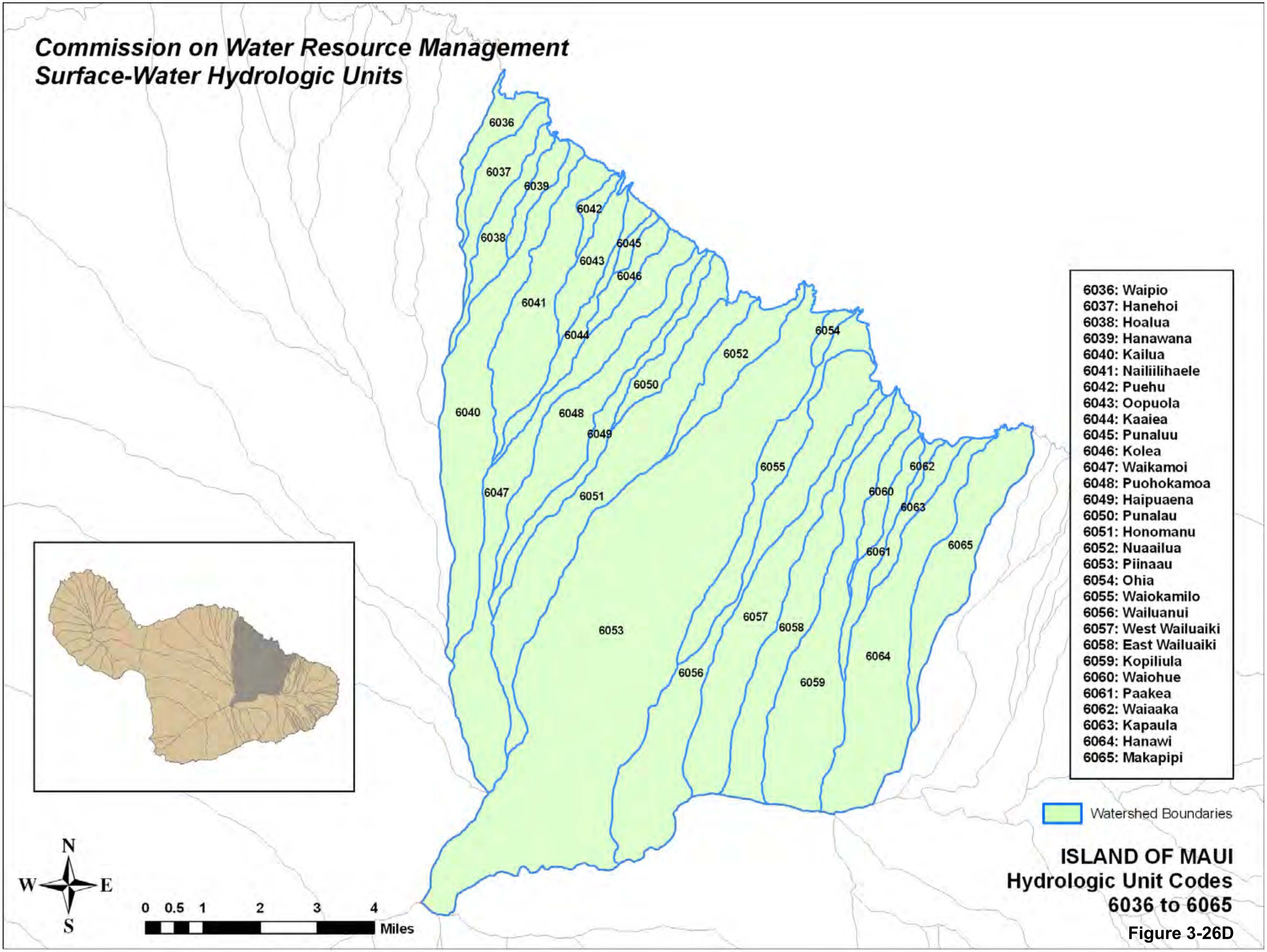
Commission on Water Resource Management
Surface-Water Hydrologic Units



6025: Kalialinui
6026: Kailua Gulch
6027: Maliko
6028: Kuiaha
6029: Kaupakulua
6030: Manawaiiao
6031: Uaoa
6032: Kealii
6033: Kakipi
6034: Honopou
6035: Hoolawa

ISLAND OF MAUI
Hydrologic Unit Codes
6025 to 6035

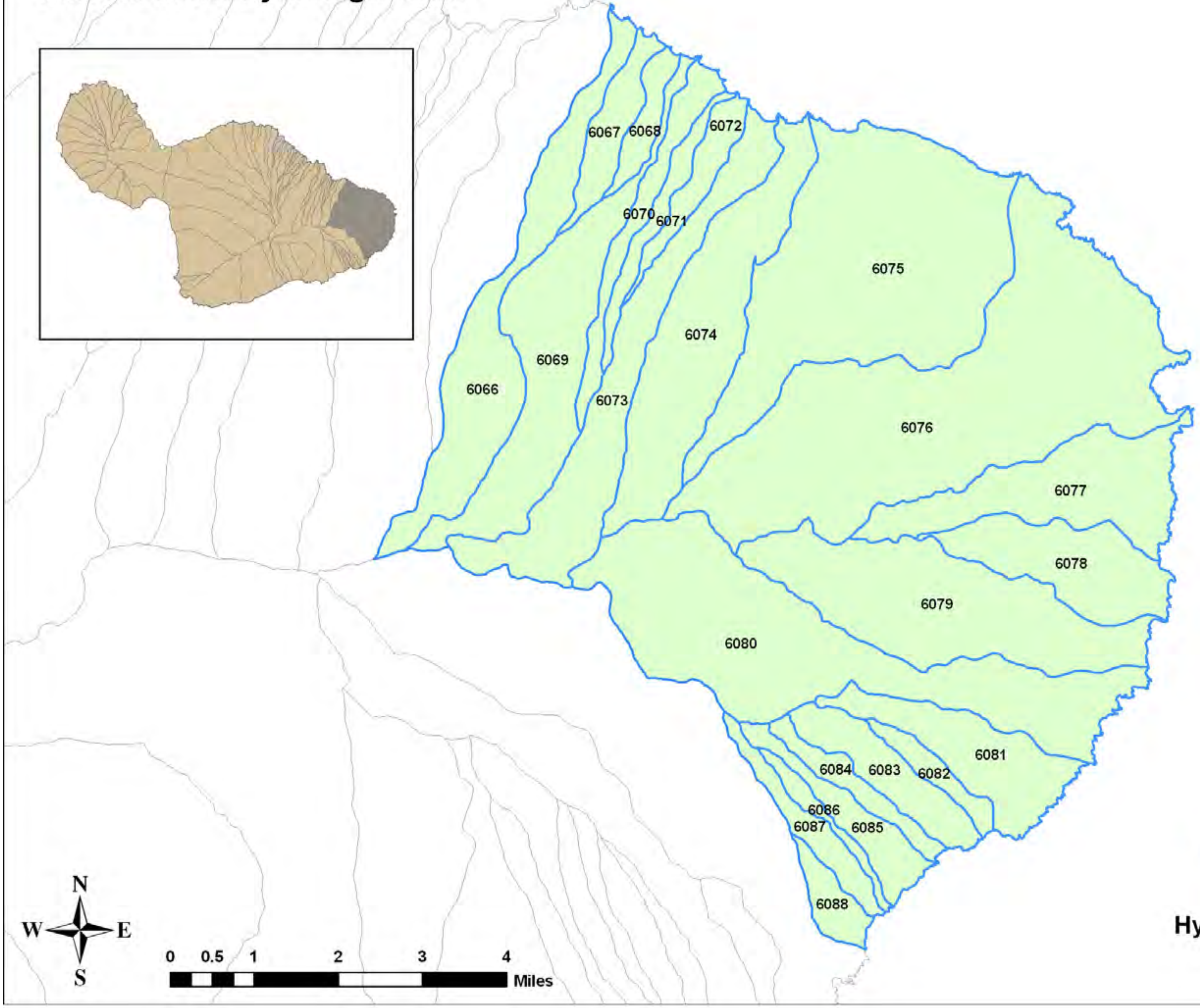
Figure 3-26C


Commission on Water Resource Management
Surface-Water Hydrologic Units

ISLAND OF MAUI
Hydrologic Unit Codes
6036 to 6065

Figure 3-26D

Commission on Water Resource Management
Surface-Water Hydrologic Units

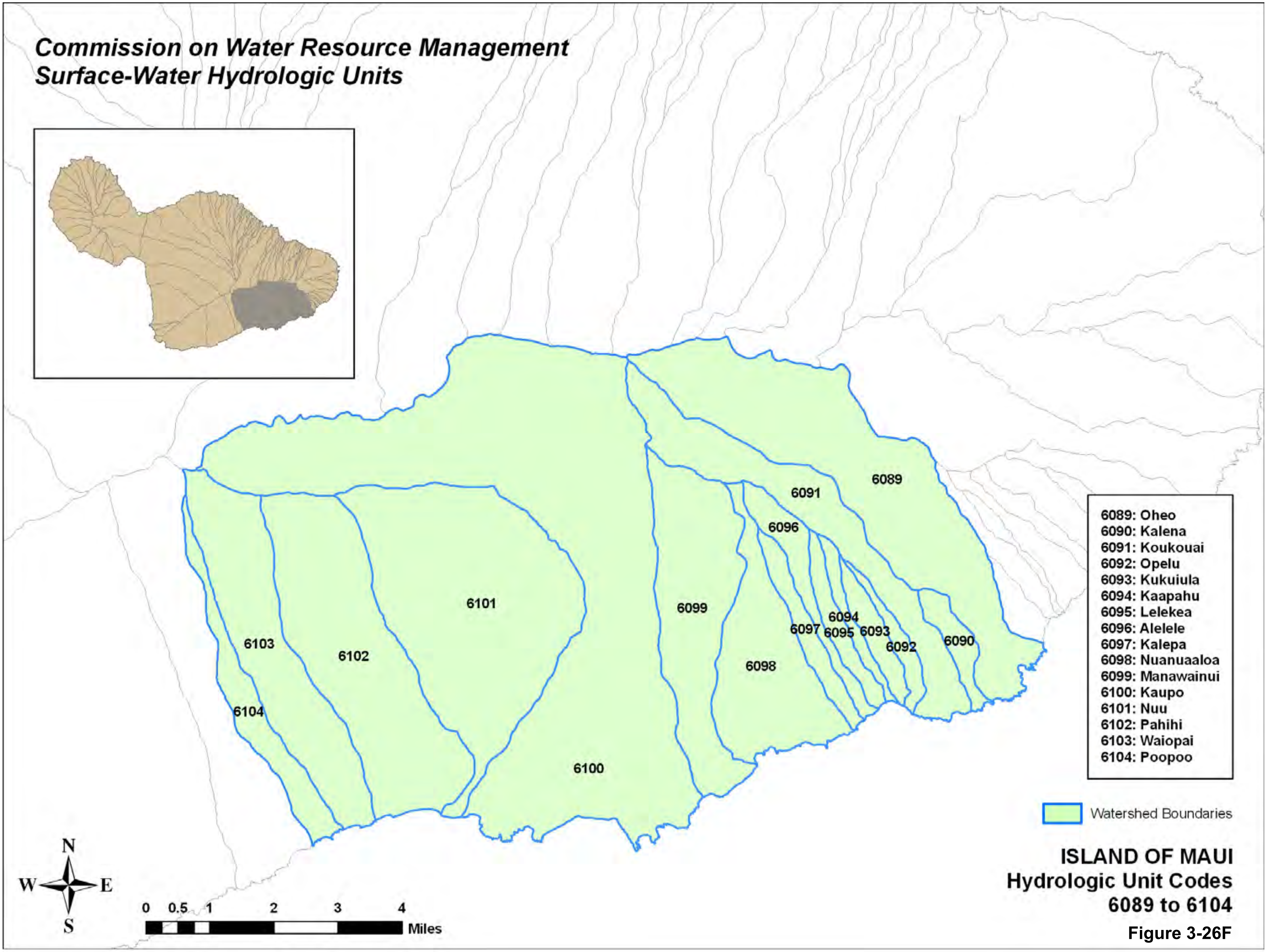


6066: Kuhiwa
6067: Waihole
6068: Manawaikeae
6069: Kahawaihapapa
6070: Keaaiki
6071: Waioni
6072: Kanikele
6073: Heleleikeoha
6074: Kawakoe
6075: Honomaele
6076: Kawaipapa
6077: Moomoonui
6078: Haneoo
6079: Kapia
6080: Waiohonu
6081: Papahawahawa
6082: Alaalaula
6083: Wailua
6084: Honolewa
6085: Waieli
6086: Kakiweka
6087: Hahalawe
6088: Puaaluu

🟩 Watershed Boundaries

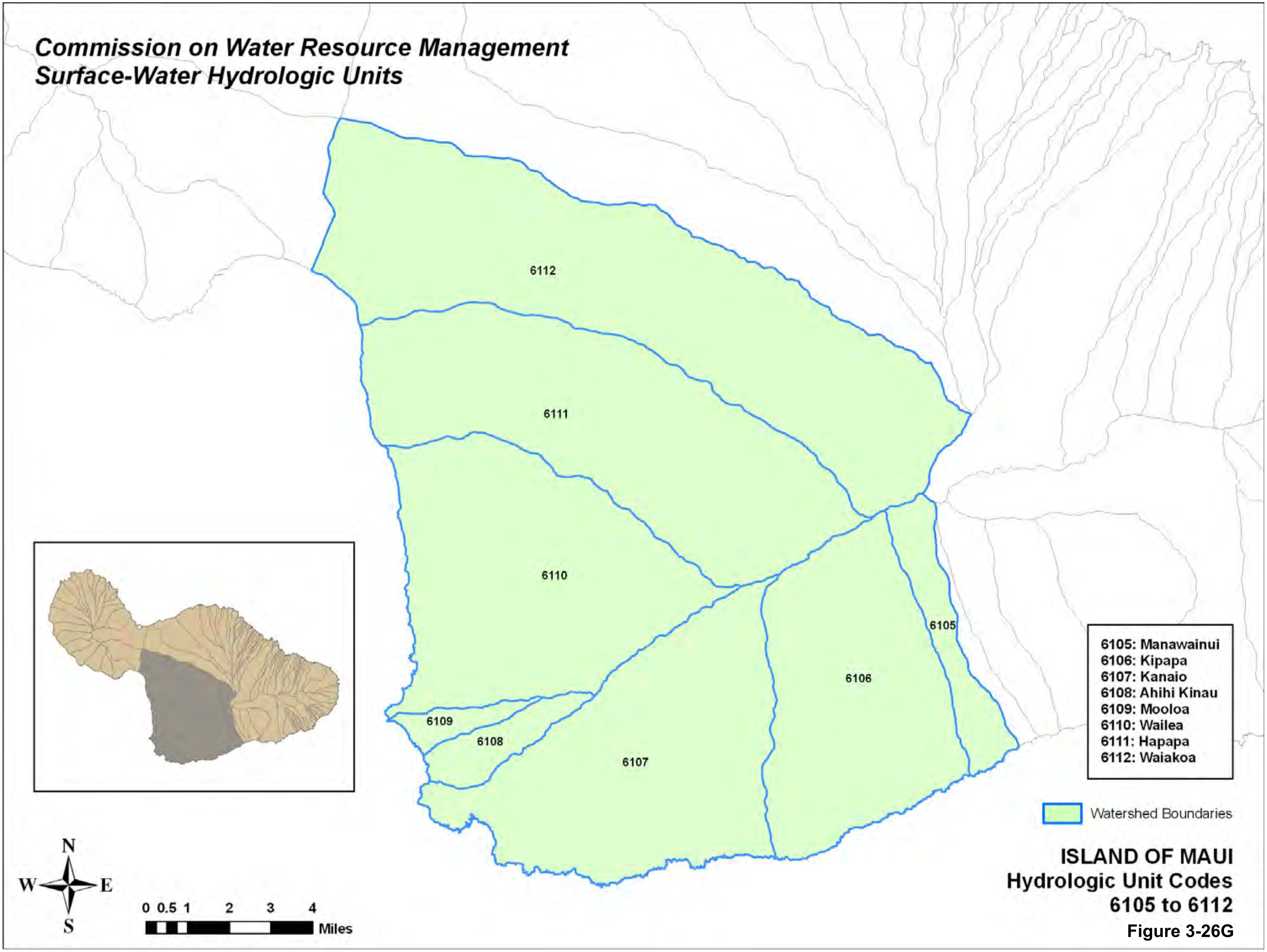
ISLAND OF MAUI
Hydrologic Unit Codes
6066 to 6088

Figure 3-26E



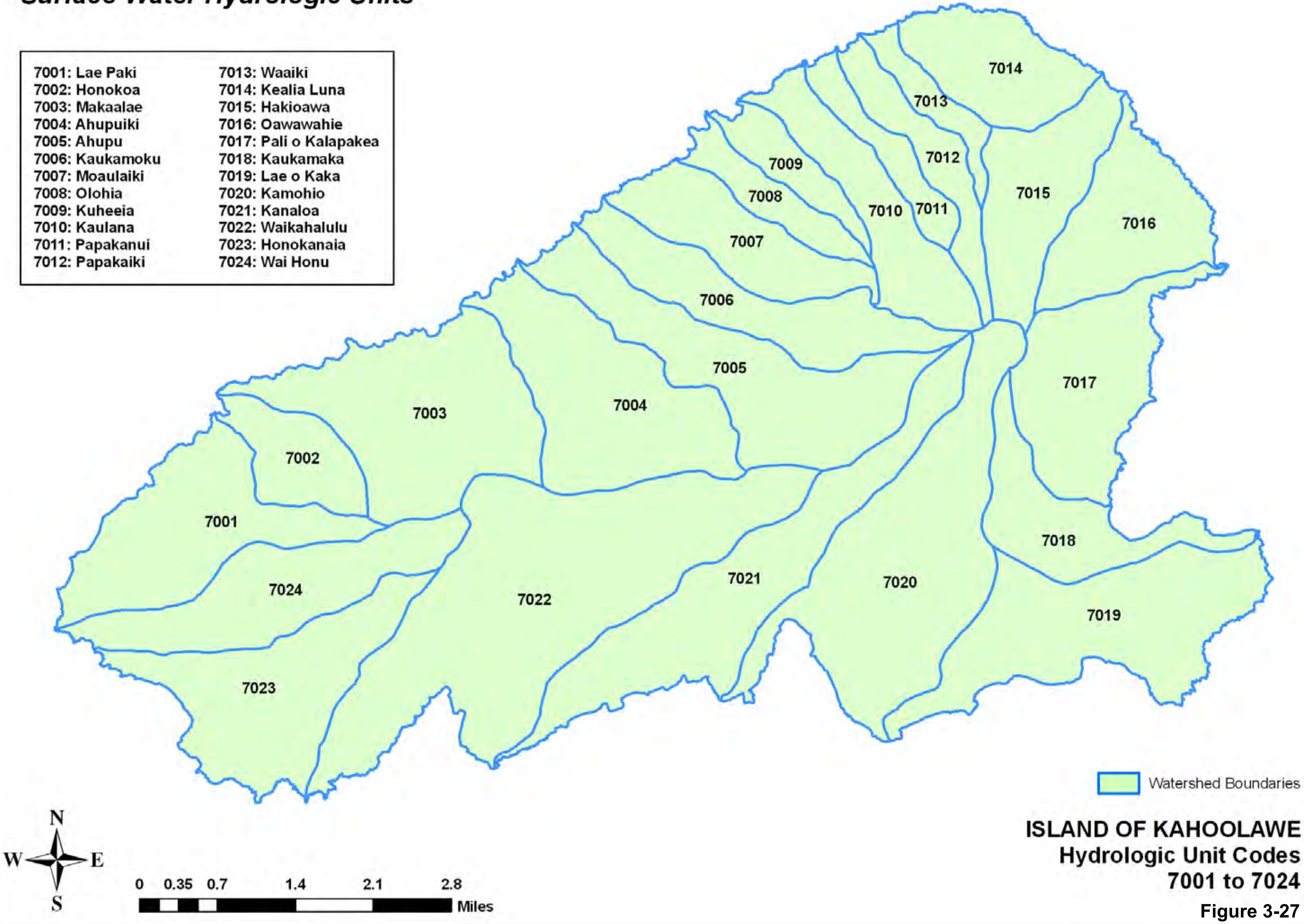
ISLAND OF MAUI
Hydrologic Unit Codes
6089 to 6104

Figure 3-26F



ISLAND OF MAUI
Hydrologic Unit Codes
6105 to 6112
Figure 3-26G

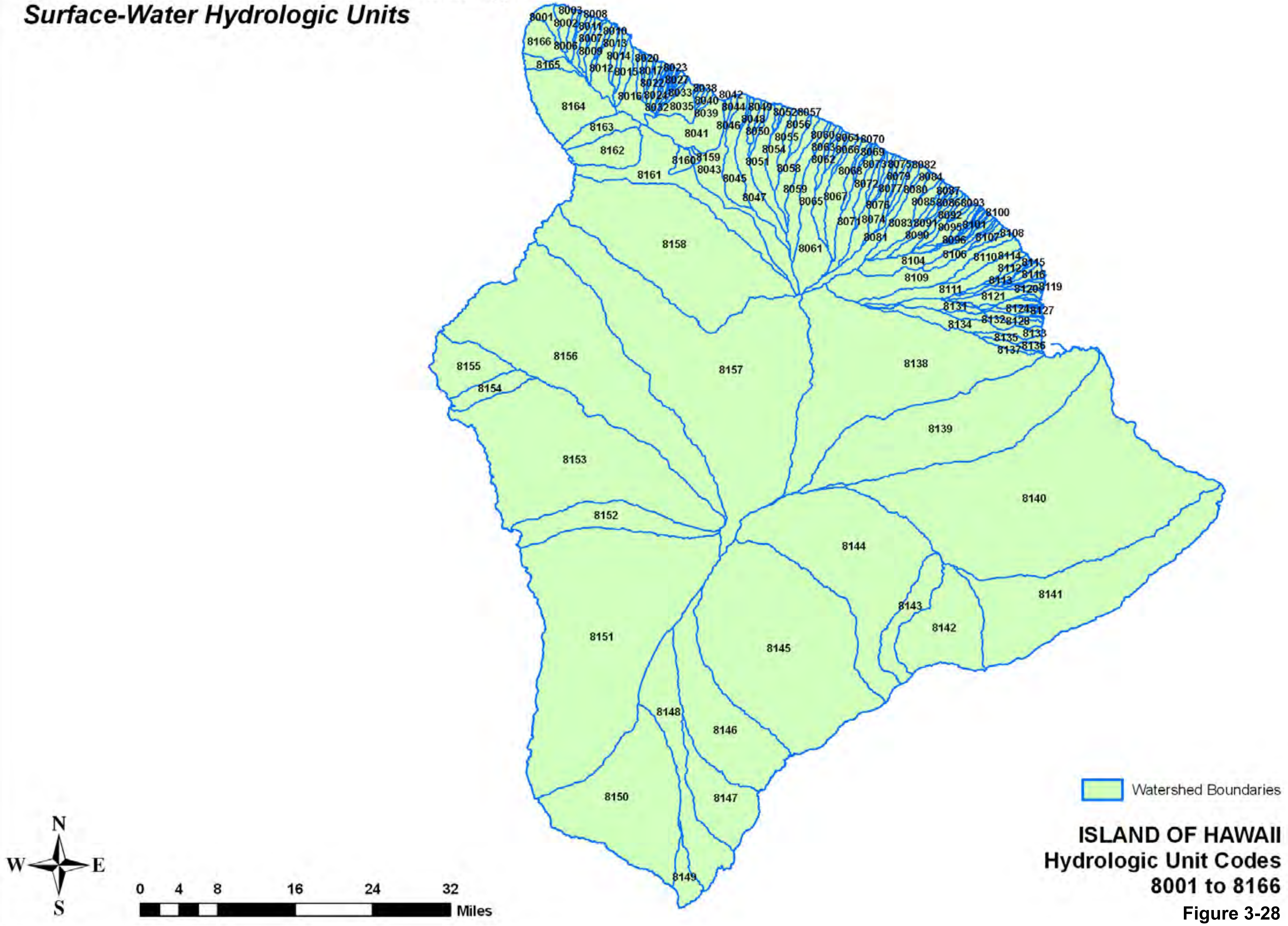
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF KAHOOLAWE
Hydrologic Unit Codes
7001 to 7024

Figure 3-27

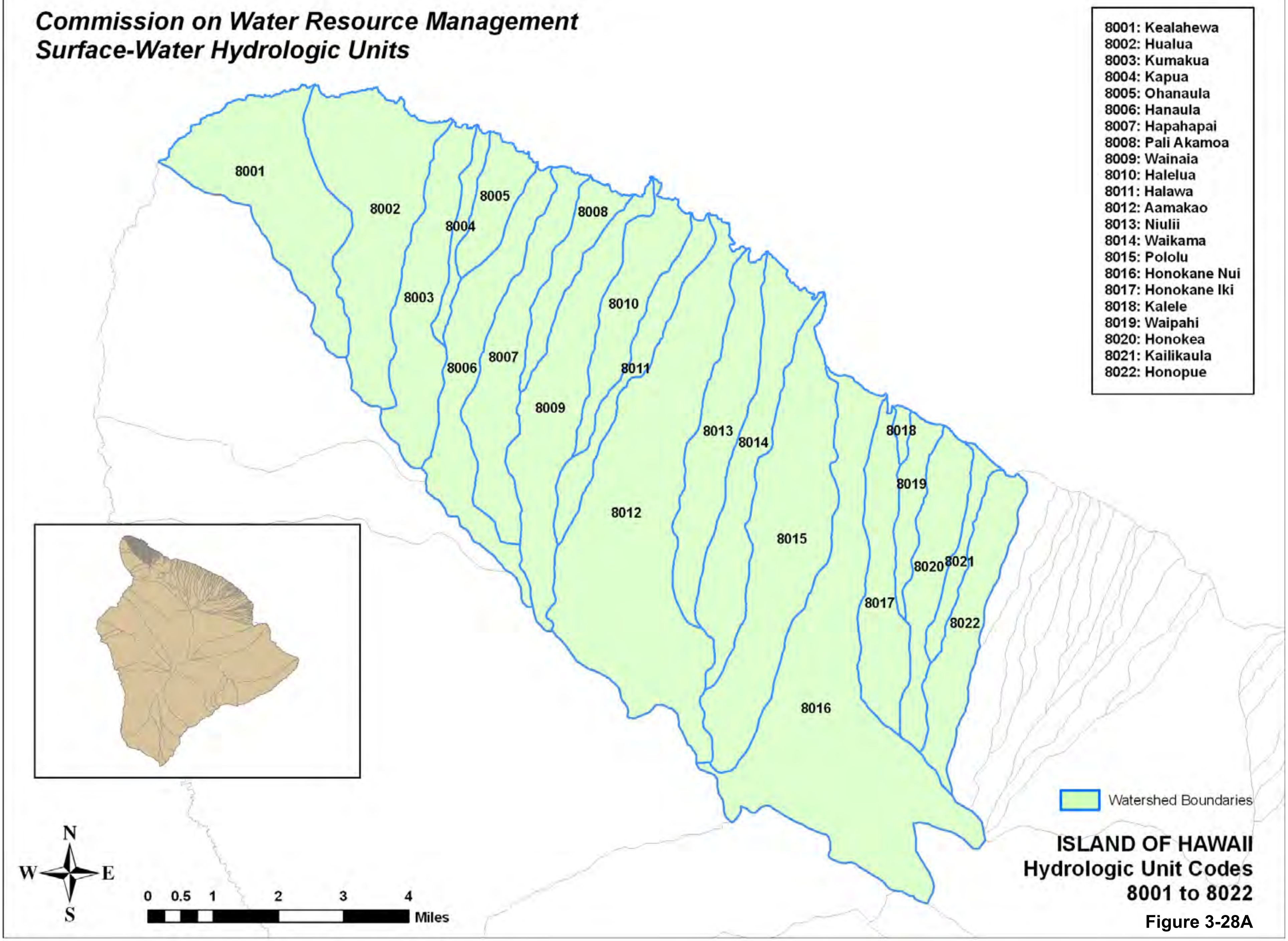
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF HAWAII
Hydrologic Unit Codes
8001 to 8166

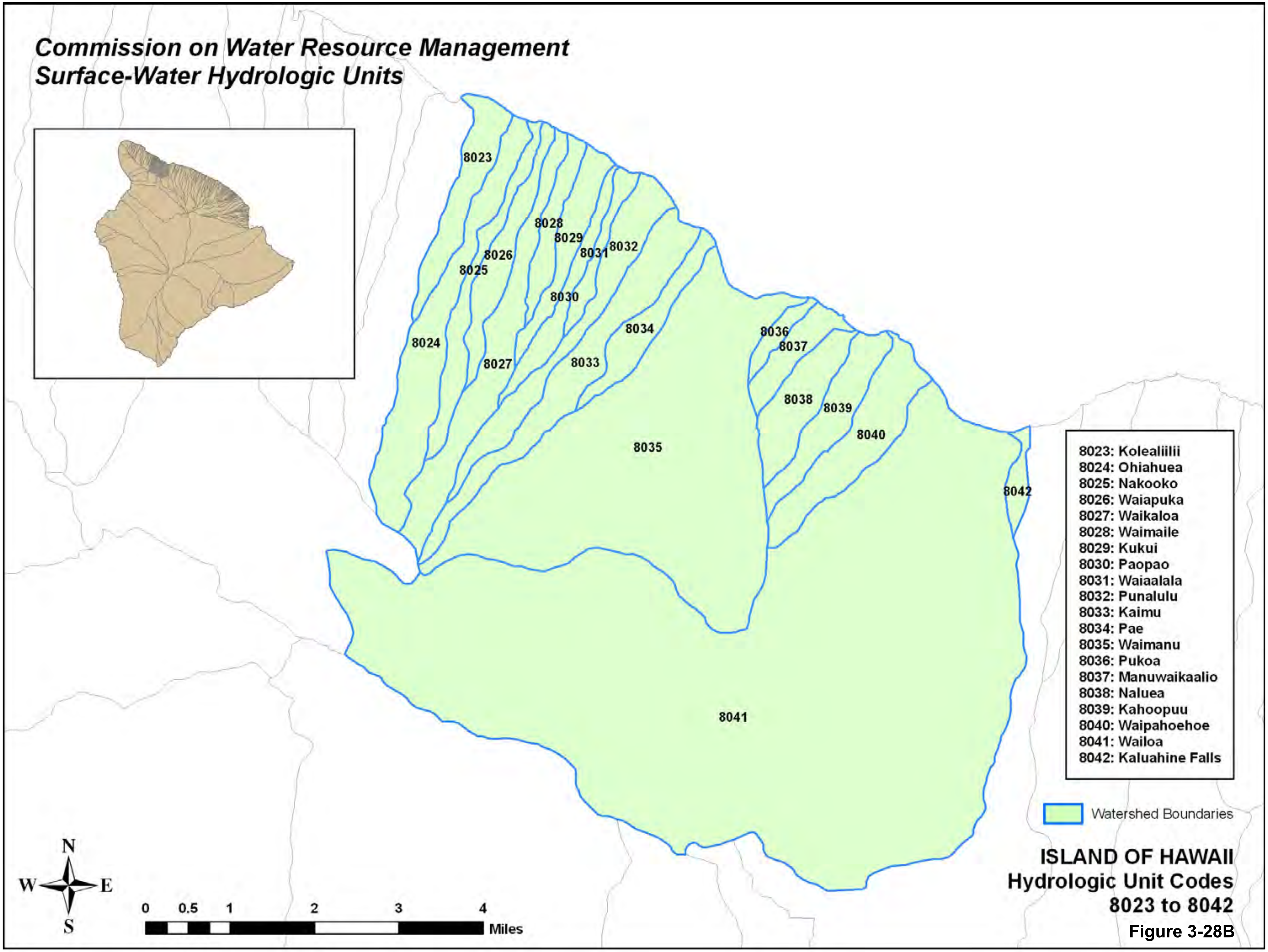
Figure 3-28

Commission on Water Resource Management
Surface-Water Hydrologic Units



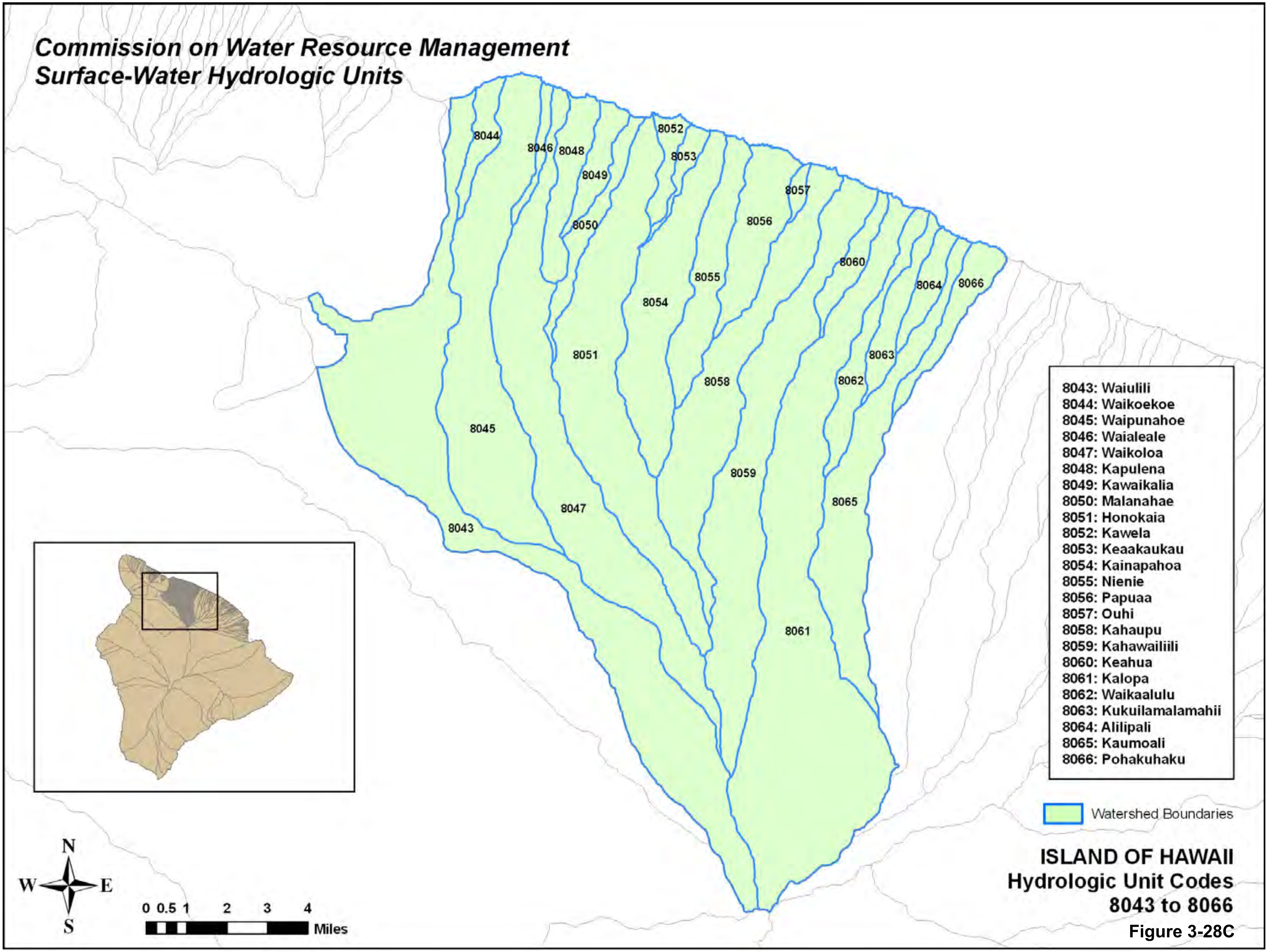
ISLAND OF HAWAII
Hydrologic Unit Codes
8001 to 8022

Figure 3-28A



ISLAND OF HAWAII
Hydrologic Unit Codes
8023 to 8042
Figure 3-28B

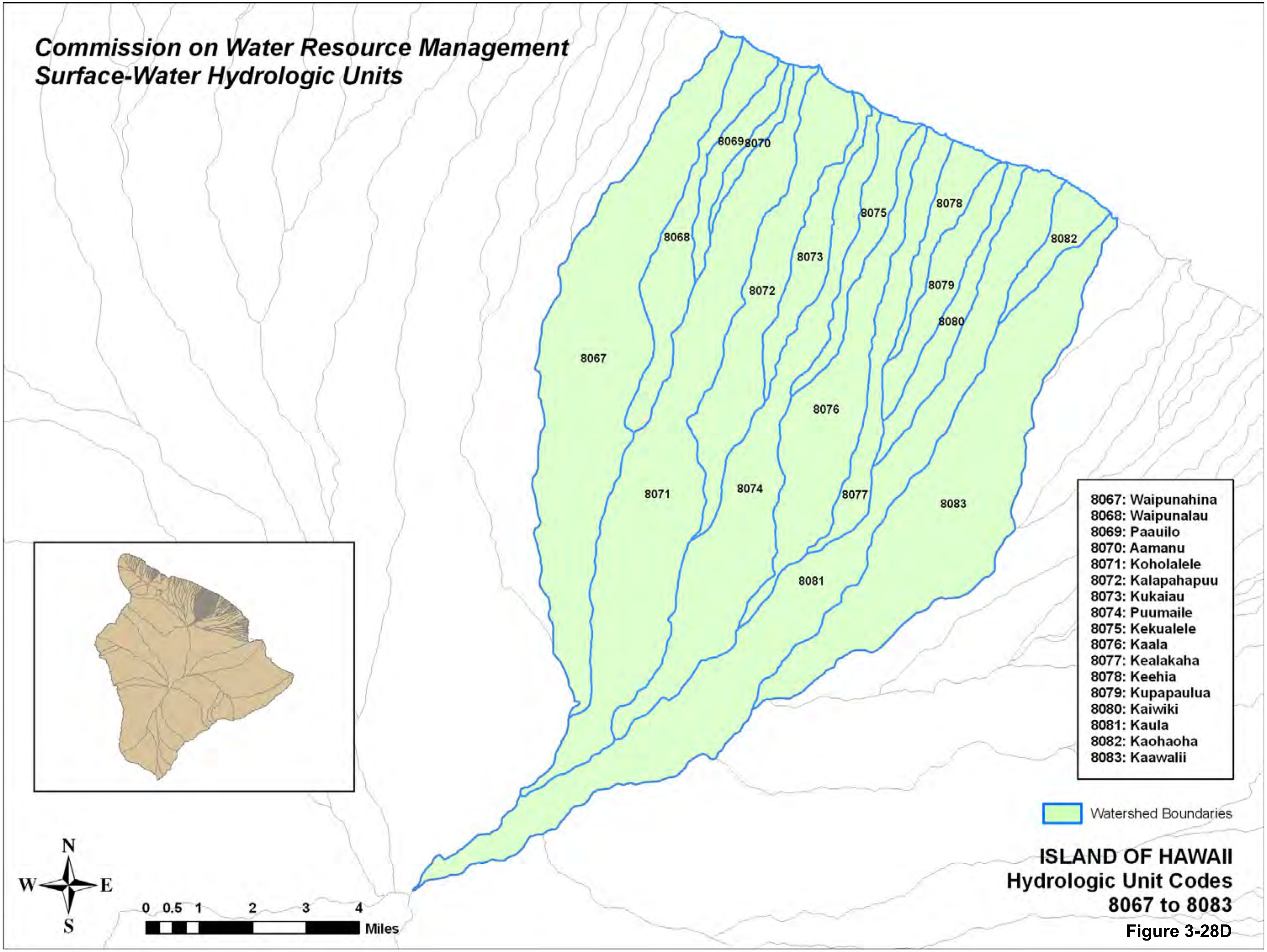
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF HAWAII
Hydrologic Unit Codes
8043 to 8066

Figure 3-28C

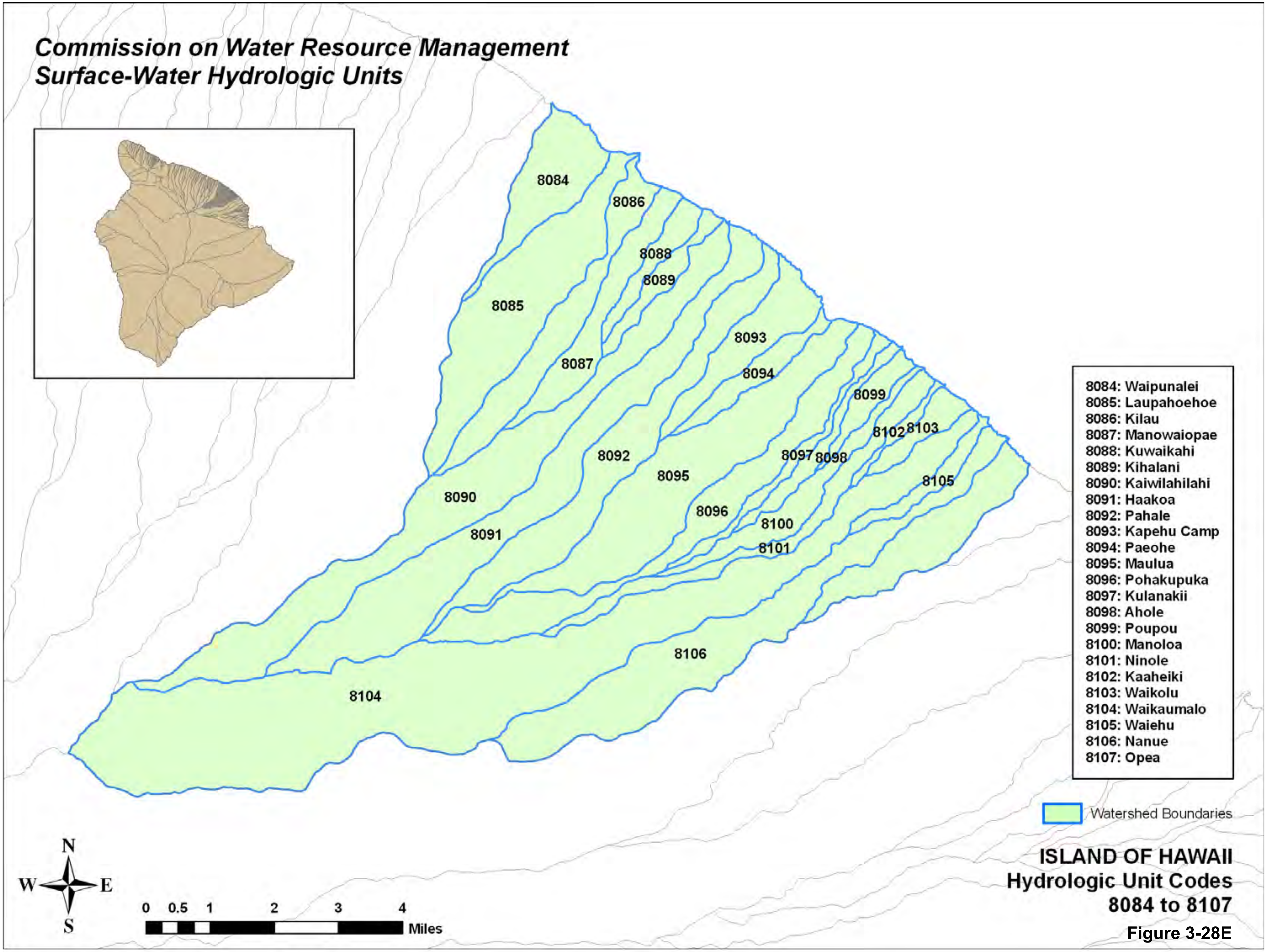
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF HAWAII
Hydrologic Unit Codes
8067 to 8083

Figure 3-28D

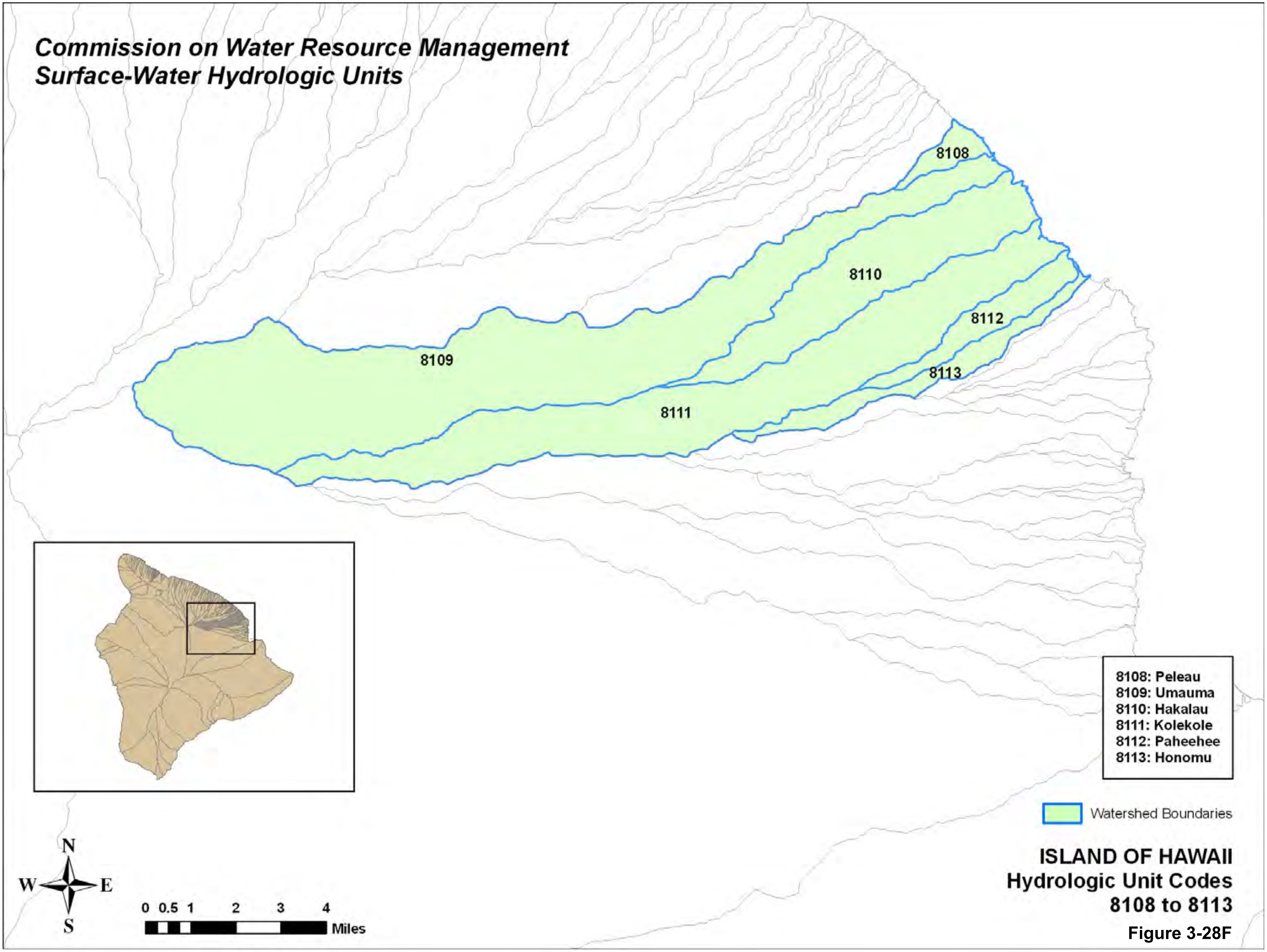
Commission on Water Resource Management
Surface-Water Hydrologic Units



8084: Waipunalei
8085: Laupahoehoe
8086: Kilau
8087: Manowaiopae
8088: Kuwaikahi
8089: Kihalani
8090: Kaiwilahilahi
8091: Haakoa
8092: Pahale
8093: Kapehu Camp
8094: Paeohe
8095: Maulua
8096: Pohakupuka
8097: Kulanakii
8098: Ahole
8099: Poupou
8100: Manoloa
8101: Ninole
8102: Kaaheiki
8103: Waikolu
8104: Waikaumalo
8105: Waiehu
8106: Nanue
8107: Opea

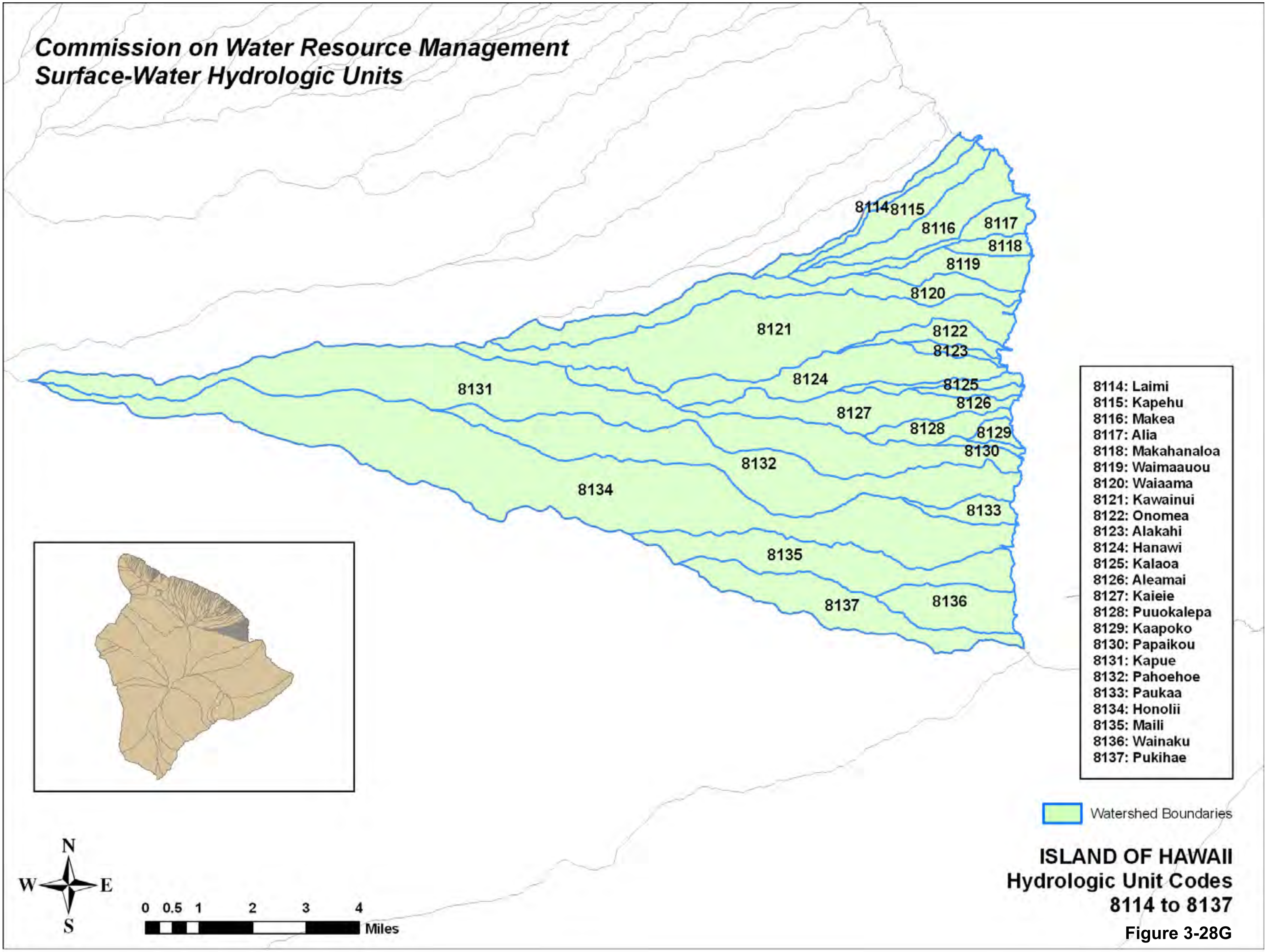
ISLAND OF HAWAII
Hydrologic Unit Codes
8084 to 8107

Figure 3-28E



ISLAND OF HAWAII
Hydrologic Unit Codes
8108 to 8113

Figure 3-28F



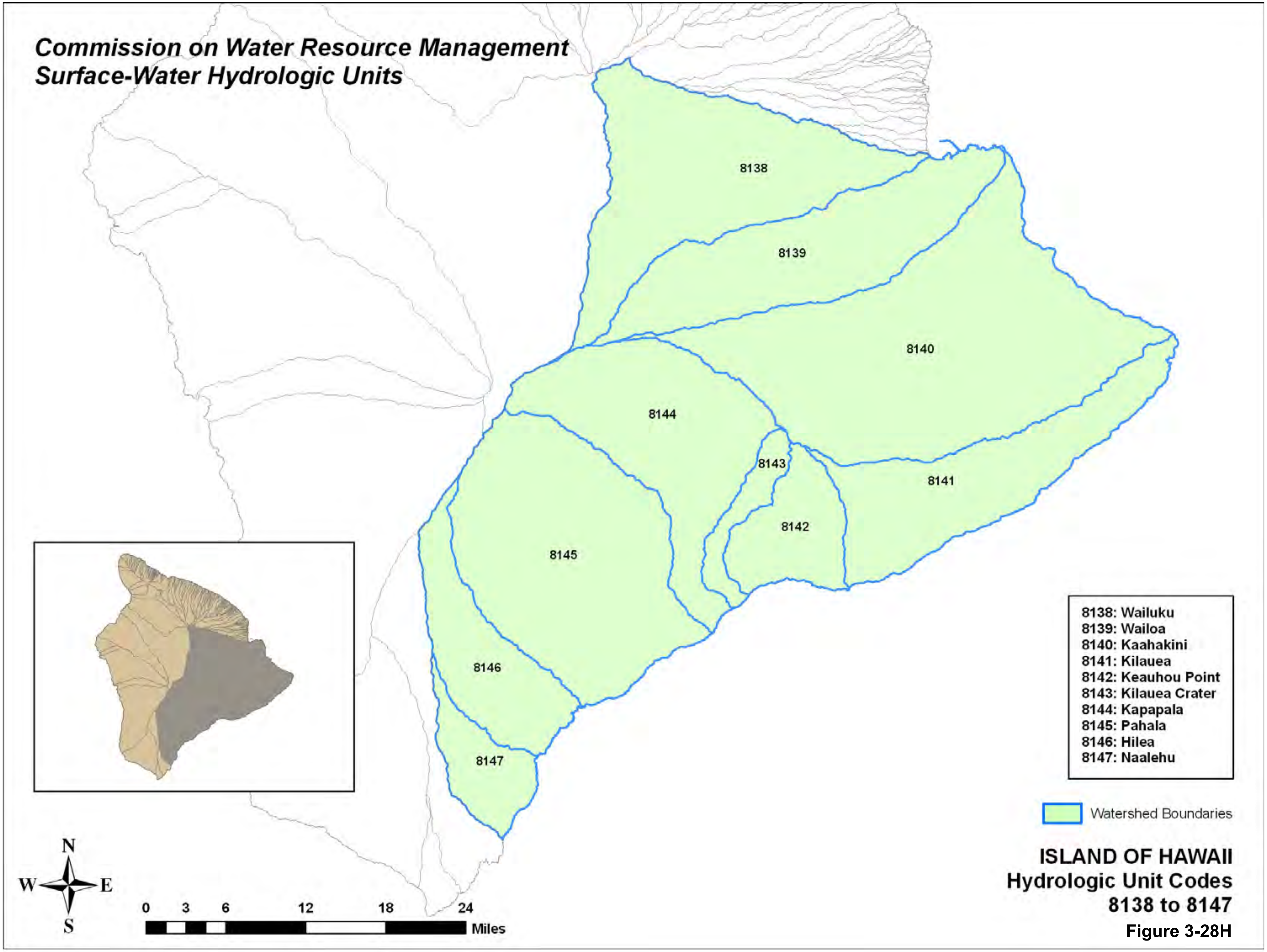
Commission on Water Resource Management
Surface-Water Hydrologic Units

8114: Laimi
8115: Kapehu
8116: Makea
8117: Alia
8118: Makahanaloa
8119: Waimaauou
8120: Waiaama
8121: Kawainui
8122: Onomea
8123: Alakahi
8124: Hanawi
8125: Kalaoa
8126: Aleamai
8127: Kaieie
8128: Puuokalepa
8129: Kaapoko
8130: Papaikou
8131: Kapue
8132: Pahoehoe
8133: Paukaa
8134: Honolii
8135: Maili
8136: Wainaku
8137: Pukihae

ISLAND OF HAWAII
Hydrologic Unit Codes
8114 to 8137

Figure 3-28G

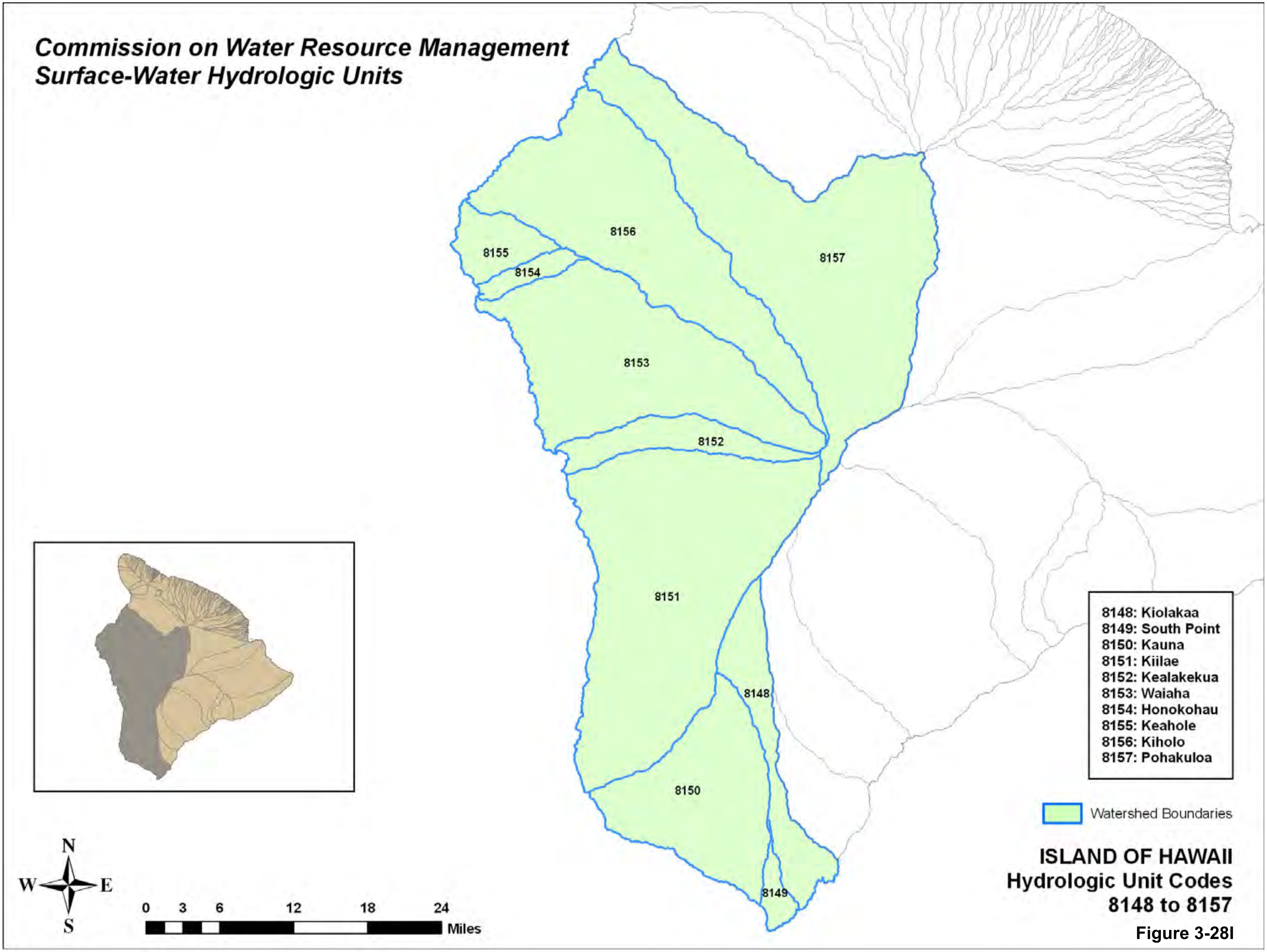
Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF HAWAII
Hydrologic Unit Codes
8138 to 8147

Figure 3-28H

Commission on Water Resource Management
Surface-Water Hydrologic Units

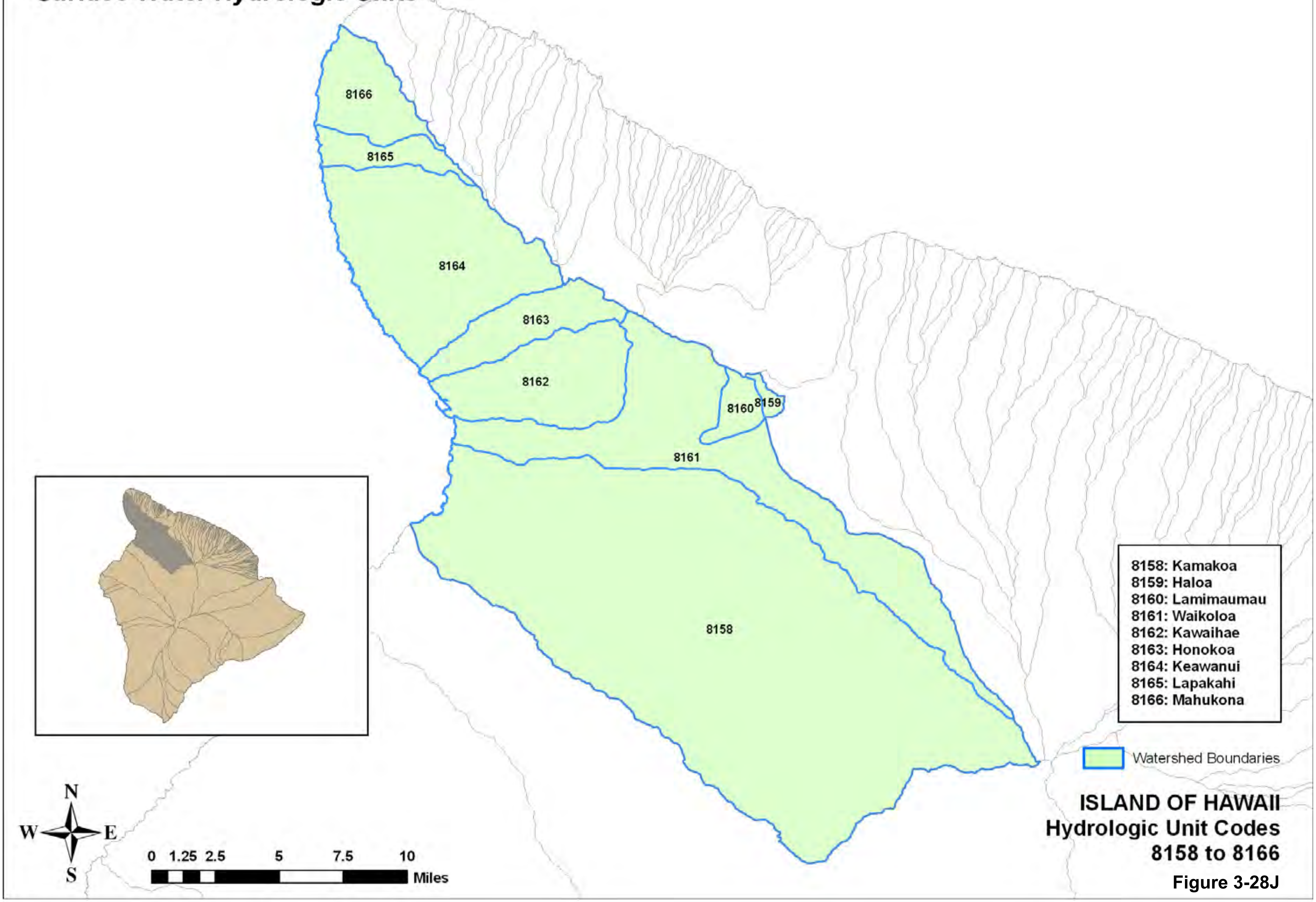


8148:	Kiolakaa
8149:	South Point
8150:	Kauna
8151:	Kiilae
8152:	Kealakekua
8153:	Waiaha
8154:	Honokohau
8155:	Keahole
8156:	Kiholo
8157:	Pohakuloa

ISLAND OF HAWAII
Hydrologic Unit Codes
8148 to 8157

Figure 3-28I

Commission on Water Resource Management
Surface-Water Hydrologic Units



ISLAND OF HAWAII
Hydrologic Unit Codes
8158 to 8166

Figure 3-28J

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3.4.3. Determining the Availability of Surface Water Resources: Assessing Instream Flow Standards

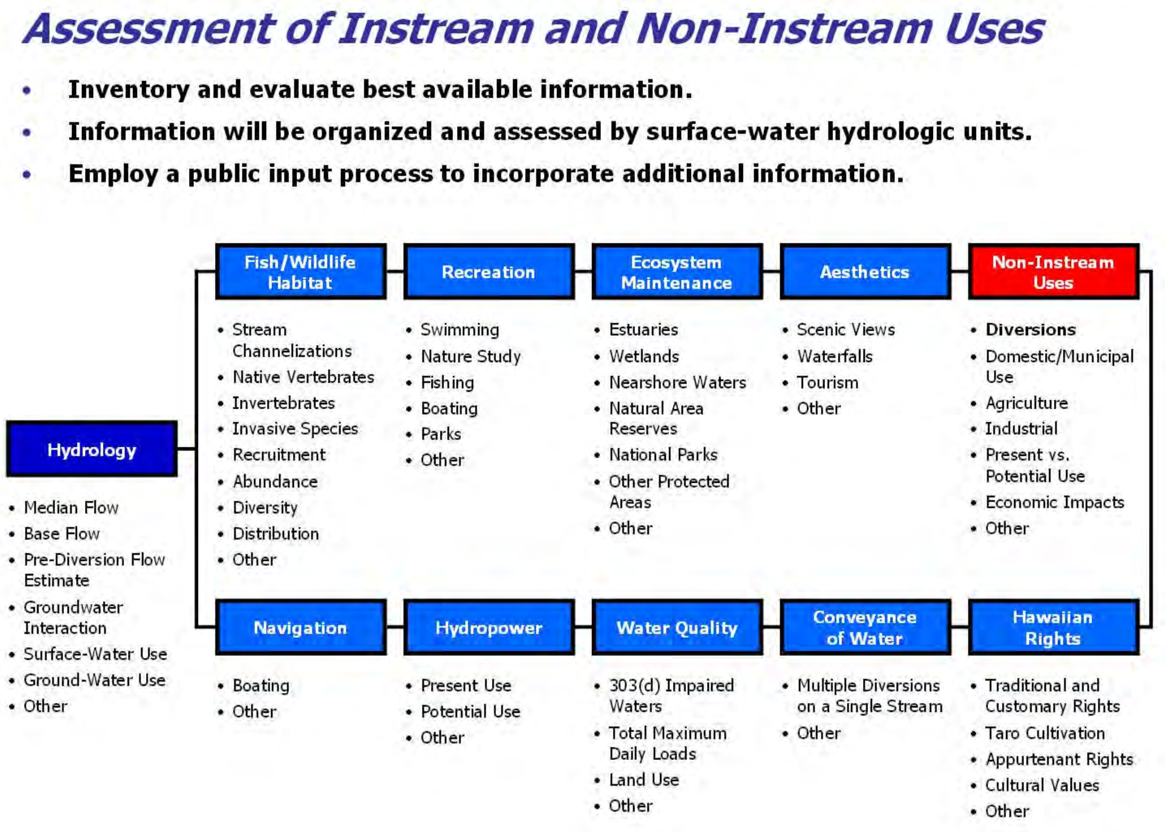
Unlike ground water resources that occur in subsurface aquifers, surface water resources are readily observed and measured. Scientists can rely on large amounts of field data and direct measurements, rather than assumptions based on interpolation and modeling tools. Field measurements can provide reliable information on streamflow and spring discharge, effectively indication how much water is present in surface water settings. However, it is a different exercise to determine the amount of surface water available for human use and consumption. Determining the availability of surface water resources requires the evaluation of environmental, social, cultural, and economic considerations as indicated by the State Water Code. The following sections provide an overview of the factors that must be addressed in the establishment of instream flow standards and the data available for review. For a discussion of the regulatory process for setting instream flow standards, see Section 5.

3.4.3.1. Assessing Instream Flow Standards

Instream flow standards are defined by the State Water Code as “a quantity or flow of water or depth of water which is required to be present at a specific location in a stream system at certain specified times of the year to protect fishery, wildlife, recreational, aesthetic, scenic, and other beneficial instream uses.” However, the State Water Code also prescribes that “in formulating the proposed standard, the commission shall weigh the importance of the present or potential uses of water from the stream for noninstream purposes, including the economic impact of restriction of such use.” CWRM is developing a methodology for establishing measurable instream flow standards based upon best available information, along with input from interested parties and agencies.

The sections below describe the types of information, based on the State Water Code’s definition of instream use, to be evaluated in establishing instream flow standards. In addition, instream flow standards must address water for public trust purposes (see Section 2 for a discussion of the Public Trust Doctrine and public trust purposes). Figure 3-29 provides a conceptual illustration of information categories that should inform instream flow standard assessments.

Maintenance of Fish and Wildlife Habitats: A stream’s ability to provide for fish and wildlife habitat is largely dependent upon the condition of the stream bed and/or stream banks. A stream in its natural, unaltered condition tends to have a higher potential for ensuring the survival of native stream animals. Streams that are highly altered, with features such as embankments, hardened channels, realignments, and culverts, have a tendency to inhibit the recruitment and viability of native species. Channelizations and, conversely, the integrity of stream channels are major factors in defining faunal habitat.



Assessment of Instream and Non-Instream Uses

- **Inventory and evaluate best available information.**
- **Information will be organized and assessed by surface-water hydrologic units.**
- **Employ a public input process to incorporate additional information.**

Hydrology
- Median Flow
- Base Flow
- Pre-Diversion Flow Estimate
- Groundwater Interaction
- Surface-Water Use
- Ground-Water Use
- Other

Fish/Wildlife Habitat
- Stream Channelizations
- Native Vertebrates
- Invertebrates
- Invasive Species
- Recruitment
- Abundance
- Diversity
- Distribution
- Other

Recreation
- Swimming
- Nature Study
- Fishing
- Boating
- Parks
- Other

Ecosystem Maintenance
- Estuaries
- Wetlands
- Nearshore Waters
- Natural Area Reserves
- National Parks
- Other Protected Areas
- Other

Aesthetics
- Scenic Views
- Waterfalls
- Tourism
- Other

Non-Instream Uses
- **Diversions**
- Domestic/Municipal Use
- Agriculture
- Industrial
- Present vs. Potential Use
- Economic Impacts
- Other

Navigation
- Boating
- Other

Hydropower
- Present Use
- Potential Use
- Other

Water Quality
- 303(d) Impaired Waters
- Total Maximum Daily Loads
- Land Use
- Other

Conveyance of Water
- Multiple Diversions on a Single Stream
- Other

Hawaiian Rights
- Traditional and Customary Rights
- Taro Cultivation
- Appurtenant Rights
- Cultural Values
- Other

Figure 3-29: Conceptual illustration of information that should be considered in assessments of instream flow standards and in the evaluation of instream and non-instream uses.

Stream channelization projects are generally implemented to reduce flood risk, drain low-lying areas, mitigate erosion, and provide road crossings or other construction. The effect is an increase in developable land area. Channellization can result in the loss of habitat for marine, aquatic and riparian species. Other negative impacts may include reduced recreational opportunities, loss of view planes and aesthetic resources, and reduced ground water recharge.

Hawaiian streams support a relatively small number of native aquatic fauna, including freshwater fish, mollusks, crustaceans, and insects. A number of these native stream animals have a life cycle involving both the stream and the ocean. This type of life history, in which an animal lives its entire adult life in freshwater and its early larval period in the ocean, is called amphidromy.

Although the habitat requirements of native stream animals are not fully understood, it is widely accepted that some native species utilize the entire stream in their life history. Stream connectivity with nearshore waters is important for recruitment of amphidromous organisms. Another consideration is the prevalence of non-native species that compete for food and habitat any may prey upon native species. Habitat requirements of native stream animals generally include clear, well-oxygenated stream water that flows over cobble and gravel. Some native fishes are clearly adapted to life in turbulent streams with modified (fused) ventral fins that function as suction disks. These organisms can climb waterfalls and colonize stream reaches inaccessible to other fishes.

In addition to native stream fauna, waterbirds such as stilts, coots, and the native duck Koloa, rely upon stream systems for breeding, nesting, and feeding. Aquatic stream fauna provide a food supply, while natural riparian areas present quality nesting and breeding habitats.

The HSA includes an assessment of biological and riparian resources for perennial streams statewide, including an inventory of channelizations statewide. Recent work by the DLNR Division of Aquatic Resources will provide an updated and improved database of information on biological resources statewide. Other sources of habitat information include the DLNR Division of Forestry and Wildlife, the U.S. Fish and Wildlife Service, and other studies conducted for specific streams. CWRM is also developing a comprehensive statewide database of stream channel activities (i.e., stream channel alteration permits, requests for determination, complaints, etc.). Information from the database may provide additional insight as to stream habitat availability.

Outdoor Recreational Activities: Water-related recreation is a part of everyday life in Hawaii, and though beaches clearly attract more users, many local residents grew up recreating in backyard streams. Certain recreational water activities, such as fishing, swimming, boating, and nature study, are relatively limited in Hawaii due to the short, narrow, and shallow nature of typical Hawaii streams in comparison to continental streams and rivers. Although not directly dependent upon streamflow, other land-based recreational activities, such as hiking, camping, and hunting, are enhanced by streams that provide added value to the experience.

A state Recreational Resources Committee was formed as part of the Hawaii Stream Assessment to design a recreation inventory and assessment that identified various opportunities related to specific streams. Regional committees were established on each island. Committees were tasked with compiling an inventory for their respective island. The regional committees ranked each stream using a modified U.S. Forest Service Recreation Opportunity Spectrum, based on factors such as diversity of experiences, quality of experiences, specific unique characteristics, and unique combinations of attributes. This assessment provides an excellent starting point for assessing streamflow requirements for outdoor recreational activities.

Maintenance of Estuarine, Wetland, and Stream Ecosystems: The maintenance of estuarine, wetland, and stream vegetation are directly dependent upon streamflow. These areas provide important riparian habitats for many species, often serving as nursery areas. Although relatively few studies have been conducted on the function of estuaries within the larger ecosystem, it is widely believed that estuaries play a vital role in the recruitment of native stream macrofauna and the development of fish species in the nearshore waters. For example, one study indicates that increases in salinity resulting from a reduction of freshwater to the estuary could affect the juvenile development of two native fish species.[39] In general, estuaries are regarded as some of the most ecologically productive areas in the world, primarily attributed to two general phenomena; 1) the continual movement of water, and 2) the trapping of nutrients. Tidal influences, salinity gradients, freshwater discharge, runoff, and winds, all contribute to water movement, while nutrients are washed into the estuary from the entire watershed and metabolic wastes are removed. The movement of nutrients throughout the entire estuarine system is critical to sustain both plants and animals.

There are various types of wetland classifications, not all of which are directly related to streamflow. However it is widely accepted that wetlands are valuable because they perform multiple ecosystem functions. Wetlands encourage ground water recharge, provide flood water storage, offer biological habitat, and promote the cycling, storage, and removal of nutrients. In Hawaii, many wetlands have been drained and converted to agricultural or urban land uses. It is increasingly important to protect remaining wetland areas.

The HSA briefly addresses wetlands, however, there are few studies of estuaries, wetlands, and stream vegetation in relation to instream uses. In recent years, awareness of the importance of estuaries and wetlands to the greater ecosystem has been emphasized. The DLNR Division of Aquatic Resources plans to expand its biological assessments into estuaries and study the recruitment patterns of native stream fishes, the function of estuaries as fishery nurseries, and energy flows within estuaries.

Aesthetic Values such as Waterfalls and Scenic Waterways: The relationship between streamflow and aesthetic value cannot be determined in quantitative or absolute terms. Aesthetic value depends on the perception of multi-sensory experiences that which vary between individuals. Despite the qualitative nature of aesthetics, the HSA attempts to address scenic views as part of its recreational resource assessment, considering view planes from roads, trails, and the ocean. Additional studies would need to be conducted and other resources should be examined to further assess the present and potential streamflow requirements to support aesthetic values.

Navigation: There are few navigable streams in Hawaii. Streams tend to be short, narrow, and shallow. Only a few areas have developed estuaries where recreational boating is possible. Even fewer streams are actually used for commercial boating operations. The HSA addresses boating as part of its recreational resource assessment, but does not differentiate between recreational and commercial use. Additional studies should be conducted and other resources should be examined to further assess the present and potential uses of streams for navigation and boating.

Instream Hydropower Generation: Hydroelectricity is typically generated by instream dams and power generators, but the nature of Hawaii streams requires a different hydropower plant design whereby surface water is usually diverted to an

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[39] Englund, R. 1998, Biological assessment and the effects of water withdrawls on Waikele Stream, Oahu, Aquatic biota, Report prepared for Belt-Collins Hawaii, 31 p.

offstream power plant. Generally, water is diverted through ditches, pipes and penstocks to the power plant, then returned to the stream. Hydropower plants may take advantage of changes in elevation to generate power; energy is recovered from the change in head and diverted water is subsequently applied to irrigate agricultural fields at lower elevations. When the HSA was conducted, 18 hydroelectric power plants were identified (seven on Kauai, four on Maui, and seven on Hawaii). At the time, hydroelectricity accounted for roughly 1.5% of the state's total electrical energy consumption.

In 1981, the State Department of Planning and Economic Development (now Department of Business, Economic Development and Tourism (DBEDT)), published *Hydrolectric Power in Hawaii: A Reconnaissance Survey*, in conjunction with the U.S. Department of Energy. The purpose of the survey was to assess potential sources of hydroelectric power, in consideration of various parameters such as storage, utilization of irrigation systems and reservoirs, upgrading of existing facilities, and construction of new power plants. Although the appeal of hydropower has since declined, renewed interest may be spurred by the desire to reduce Hawaii's dependence on oil, provided environmental considerations can be satisfied.

Maintenance of Water Quality: Water quality is an essential part of any evaluation of water requirements for health, safety and habitat protection. Information on surface water quality has been collected in Hawaii since the 1960's, however most agencies collect water quality data to meet specific short-term goals that are usually problem-oriented. The results of water quality monitoring are often used to assess mitigation actions and improve management practices. Though surface water monitoring at instream locations is ideal, testing of nearshore waters may also provide information about the quality of contributing surface water flows. Water quality parameters range widely, but can generally be grouped into the four categories listed below:

- **Physical characteristics** include temperature, specific conductance, turbidity, color, odor, pH, and suspended solids.

- **Biological characteristics** include bacteria (fecal coliform and fecal **streptococcus**), phytoplankton, zooplankton, periphyton, and macroinvertebrates.

- **Chemical characteristics** include total dissolved solids, major ions, hardness, silica, phosphorus species, nitrogen species, detergents, other minor elements, radiochemical species, organic species, pesticide species, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, and other dissolved gasses.

- **Sediment characteristics** include suspended sediment concentration, suspended sediment discharge, bed load, total concentration, and particle size and distribution.

The two primary sources of surface water quality information are the USGS and the DOH. The USGS has collected basic water quality information at stream gaging stations since 1967 as part of a nationwide program. More detailed water quality parameters are collected at certain sites for specific programs (e.g., National Stream Quality Accounting Network, National Water Quality Assessment) and projects. The DOH is responsible for monitoring the quality of water used for consumptive or recreational purposes and has varying standards for acceptable levels of contaminants, depending on the use. County water departments are another source of water quality information, as these agencies cooperate with DOH to monitor drinking water. Water quality data, both general and site-specific, may also be found in studies and reports that have been completed for particular projects.

The Conveyance of Irrigation and Domestic Water Supplies to Downstream Points of Diversion: To ensure the availability of steam water for irrigation and domestic use in downstream areas, upstream diversions must allow the bypass of sufficient water supplies and the stream channel must be protected to allow for unimpeded flow downstream. The State Water Code provides for the regulation stream diversions and alterations through a permitting system. In addition, CWRM has jurisdiction statewide to hear and render decisions on any dispute regarding water resource protection, water permits, constitutionally protected water interests, or insufficient water supply to meet competing needs.

CWRM is in the process of developing a comprehensive database to manage surface water resources statewide, which will include all registered and permitted surface water diversions, permitted stream channel alterations, complaints, and requests for determination of permitting requirements. A project to verify and characterize all registered surface water diversions is also being executed by CWRM to provide updated information on diversion structures, water uses, and basic stream conditions. Additional information related to stream channel conditions can be obtained through the various regulatory agencies that have jurisdiction related to stream channel alteration. Example of such agencies include the U.S. Army Corps of Engineers, the DOH's Environmental Management Division, DBEDT's Coastal Zone Management Program, and county planning and/or permitting departments.

The Protection of Traditional and Customary Hawaiian Rights: With regard to surface water resources, the State Water Code provides for the protection of traditional and customary rights including, but not limited to, the cultivation or propagation of taro and the gathering of hihiwai, opae, and oopu for subsistence, cultural, and religious purposes. This State Water Code also protects appurtenant water rights (see Section 2 for a discussion of water rights and uses in Hawaii).

The process for claiming and proving an appurtenant water right is the responsibility of the landowner and can be arduous, however, the State Water Code also assures that appurtenant rights shall not be diminished or extinguished by a failure to apply for, or claim such right. Very few claims for appurtenant rights have been made. Therefore, it is difficult to quantify the amount of water required to satisfy all appurtenant rights for a given area or hydrologic unit. Regardless, if an appurtenant right is established, it is CWRM's responsibility to assure that an appropriate volume of water is afforded to the claimant.

One method for assessing the protection of traditional and customary Hawaiian rights is to evaluate incidental sources of information, such as taro cultivation and various other cultural resources and studies. The HSA provides an initial assessment of cultural resources in relation to the stream valley, considering the extent of archaeological survey coverage, the ability to predict what historic sites might be in unsurveyed areas, the actual number of known historic sites, the overall significance of the valley, the density and significance of historic sites, and the overall sensitivity of the valley.

The HSA Cultural Resources Committee identified a number of factors important to current Hawaiian cultural practices: current taro cultivation, the potential for taro cultivation, appurtenant rights, subsistence gathering areas, and stream-related hydrology. Though the committee felt that these items should be included in the assessment, information was limited at the time such that only current taro cultivation could be assessed. Various other cultural studies and surveys are available for specific regions and may provide additional information with respect to present and potential surface water requirements.

3.4.3.2. Recommendations for Assessing Instream Flow Standards

Considerably more research and study should be completed to accumulate the data and perspective necessary to conduct a thorough and meaningful assessment of instream flow standards. While some of the information categories described above are partially addressed through existing federal, State, and county programs, other categories remain virtually unexplored. In many respects, CWRM’s ability to assess instream flow standards are dependant upon policy and program direction, funding availability, and staffing requirements. However, CWRM recognizes that the information in the HSA should be updated, expanded, and interpreted in light of developing case law. Notwithstanding the requirements of CWRM’s process for adopting interim instream flow standards (see Section 5 for discussion of the IFS and interim IFS adoption process), the following actions are recommended.

- Continue to execute work tasks described in the CWRM Stream Protection and Management Branch, Instream Use Protection Section Program Implementation Plan, as updated.
- Develop, fund, and conduct cultural resource studies or surveys in priority areas;
- Fund and complete an inventory of stream channel alterations; and
- Continue to coordinate with the USGS to fund and execute stream studies and share surface water information.

3.4.4. Inventory of Surface Water Resources and Interim IFS

Table 3-21 lists the surface water hydrologic units by island according to hydrologic unit code. Key characteristics of each hydrologic unit are listed, including the total area (in square miles), the number of registered and/or permitted stream diversions, and the number of historic and currently active USGS gages within the unit. The final column indicates the current interim IFS. In most cases, the current interim IFS were established pursuant to amendments to HAR §13-169, as noted here.

- Interim Instream Flow Standard for East Maui, HAR §13-169-44
  Date of Adoption: 6/15/1988
  Effective Date: 10/8/1988
- Interim Instream Flow Standard for Kauai, HAR §13-169-45
  Date of Adoption: 6/15/1988
  Effective Date: 10/8/1988
- Interim Instream Flow Standard for Hawaii, HAR §13-169-46
  Date of Adoption: 6/15/1988
  Effective Date: 10/8/1988
- Interim Instream Flow Standard for Molokai, HAR §13-169-47
  Date of Adoption: 6/15/1988
  Effective Date: 10/8/1988
- Interim Instream Flow Standard for West Maui, HAR §13-169-48
  Date of Adoption: 10/19/1988
  Effective Date: 12/10/1988
- Interim Instream Flow Standard for Leeward Oahu, HAR §13-169-49
  Date of Adoption: 10/19/1988
  Effective Date: 12/10/1988
- Interim Instream Flow Standard for Windward Oahu, HAR §13-169-49.1
  Date of Adoption: 4/19/1989
  Effective Date: 5/4/1992

Generally, the interim IFS for all streams in a given region were adopted by the Commission and defined as the “amount of water flowing in each stream on the effective date of this standard.” The interim IFS of individual streams have subsequently been amended as a direct result of petitions to amend the instream flow standards, contested case hearings, or other regulatory actions. References to specific actions amending the interim instream flow standard of specific streams are also provided in the last column of Table 3-21. For further clarification, refer to HAR §13-169. For a discussion of the regulatory process for setting IFS, see Section 5.

Table 3-21:
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
KAUAI						
2001	Awaawapuhi	1.29	0	0	0	HAR §13-169-45
2002	Honopu	1.74	0	0	0	HAR §13-169-45
2003	Nakeikionaiwi	0.49	0	0	0	HAR §13-169-45
2004	Kalalau	4.23	0	1	0	HAR §13-169-45
2005	Pohakuao	0.58	0	0	0	HAR §13-169-45
2006	Waiolaa	0.36	0	0	0	HAR §13-169-45
2007	Hanakoa	2.01	0	1	0	HAR §13-169-45
2008	Waiahuakua	0.66	0	0	0	HAR §13-169-45
2009	Hoolulu	0.38	0	0	0	HAR §13-169-45
2010	Hanakapiai	3.76	0	1	0	HAR §13-169-45
2011	Maunapuluo	0.45	0	0	0	HAR §13-169-45
2012	Limahuli	1.92	7	0	0	HAR §13-169-45. Amended to include SCAP KA-155 on Limahuli Stream for diversion of 0.115 mgd for landscape irrigation (7/19/1995).
2013	Manoa	1.04	1	0	0	HAR §13-169-45
2014	Wainiha	23.71	29	5	1	HAR §13-169-45
2015	Lumahai	14.44	0	1	0	HAR §13-169-45
2016	Waikoko	0.69	0	0	0	HAR §13-169-45
2017	Waipa	2.52	2	0	0	HAR §13-169-45
2018	Waioli	5.48	1	1	0	HAR §13-169-45
2019	Hanalei	23.96	10	5	1	HAR §13-169-45
2020	Waileia	0.82	0	0	0	HAR §13-169-45
2021	Anini	3.20	4	0	0	HAR §13-169-45
2022	Kalihikai West	0.30	0	0	0	HAR §13-169-45
2023	Kalihikai Center	0.24	0	0	0	HAR §13-169-45
2024	Kalihikai East	0.49	0	0	0	HAR §13-169-45
2025	Kalihiwai	11.36	6	4	0	HAR §13-169-45. Amended to include SCAP KA-060 on Pake Stream for diversion of 0.028 mgd for aquaculture (10/18/89).
2026	Puukumu	1.28	3	1	0	HAR §13-169-45
2027	Kauapea	1.05	0	0	0	HAR §13-169-45
2028	Kilauea	12.87	9	6	1	HAR §13-169-45
2029	Kulihaili	1.10	0	0	0	HAR §13-169-45
2030	Pilaa	2.58	4	1	0	HAR §13-169-45
2031	Waipake	2.46	1	0	0	HAR §13-169-45
2032	Moloaa	3.67	7	0	0	HAR §13-169-45
2033	Papaa	4.41	5	0	0	HAR §13-169-45
2034	Aliomanu	1.64	0	0	0	HAR §13-169-45
2035	Anahola	13.86	6	9	0	HAR §13-169-45
2036	Kumukumu	1.21	0	0	0	HAR §13-169-45
2037	Kapaa	16.74	13	9	0	HAR §13-169-45
2038	Moikeha	2.26	1	0	0	HAR §13-169-45

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
KAUAI (continued)						
2039	Waikaea	7.13	2	9	0	HAR §13-169-45. Amended to include SCAP KA-396 on Waikaea and Konohiki Streams for streams are impacted by a pumped well (7/12/2006).
2040	Wailua	53.34	30	17	3	HAR §13-169-45
2041	Kawailoa	3.94	0	0	0	HAR §13-169-45
2042	Hanamaulu	11.65	4	1	0	HAR §13-169-45
2043	Lihue Airport	1.83	0	0	0	HAR §13-169-45
2044	Nawiliwili	6.40	3	0	0	HAR §13-169-45
2045	Puali	2.05	6	0	0	HAR §13-169-45
2046	Huleia	28.32	26	9	0	HAR §13-169-45
2047	Kipu Kai	3.04	1	0	0	HAR §13-169-45
2048	Mahaulepu	13.43	6	1	0	HAR §13-169-45
2049	Waikomo	9.12	11	0	0	HAR §13-169-45
2050	Aepo	2.58	5	0	0	HAR §13-169-45
2051	Lawai	9.73	11	1	0	HAR §13-169-45
2052	Kalaheo	6.56	9	0	0	HAR §13-169-45
2053	Wahiawa	7.34	1	0	0	HAR §13-169-45
2054	Hanapepe	27.09	9	12	1	HAR §13-169-45
2055	Kukamahu	3.21	0	0	0	HAR §13-169-45
2056	Kaumakani	3.09	0	0	0	HAR §13-169-45
2057	Mahinauli	8.78	1	0	0	HAR §13-169-45
2058	Aakukui	5.27	3	0	0	HAR §13-169-45
2059	Waipao	9.26	1	1	0	HAR §13-169-45
2060	Waimea	86.50	46	28	3	HAR §13-169-45
2061	Kapilimao	6.44	1	0	0	HAR §13-169-45
2062	Paua	5.10	0	0	0	HAR §13-169-45
2063	Hoea	16.64	1	0	0	HAR §13-169-45
2064	Niu	2.82	0	0	0	HAR §13-169-45
2065	Kaawaloa	7.50	0	0	0	HAR §13-169-45
2066	Nahomalu	17.63	1	1	0	HAR §13-169-45
2067	Kaulaula	2.55	0	0	0	HAR §13-169-45
2068	Haeleele	2.45	0	0	0	HAR §13-169-45
2069	Hikimoe	2.20	0	0	0	HAR §13-169-45
2070	Kaaweiki	2.15	0	0	0	HAR §13-169-45
2071	Kauhao	3.98	1	1	0	HAR §13-169-45
2072	Makaha	2.80	0	0	0	HAR §13-169-45
2073	Milolii	4.34	1	0	0	HAR §13-169-45
2074	Nualolo	2.83	0	0	0	HAR §13-169-45

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
OAHU						
3001	Kalunawaikaala	2.30	1	0	0	HAR §13-169-49.1
3002	Pakulena	0.90	0	0	0	HAR §13-169-49.1
3003	Paumalu	7.79	1	2	0	HAR §13-169-49.1
3004	Kawela	2.07	1	0	0	HAR §13-169-49.1
3005	Oio	10.74	3	1	0	HAR §13-169-49.1
3006	Malaekahana	7.03	0	5	0	HAR §13-169-49.1
3007	Kahawainui	5.49	1	1	0	HAR §13-169-49.1
3008	Wailele	2.28	0	1	0	HAR §13-169-49.1
3009	Koloa	2.41	1	1	0	HAR §13-169-49.1
3010	Kaipapau	3.00	0	1	0	HAR §13-169-49.1
3011	Maakua	1.55	1	0	0	HAR §13-169-49.1
3012	Waipuhi	1.10	2	0	0	HAR §13-169-49.1
3013	Kaluanui	2.37	0	3	1	HAR §13-169-49.1
3014	Papaakoko	0.29	0	0	0	HAR §13-169-49.1
3015	Halehaa	0.25	0	0	0	HAR §13-169-49.1
3016	Punaluu	6.79	9	5	2	HAR §13-169-49.1
3017	Kahana	8.42	2	4	1	Pending. Amended to 13.3 mgd on Kahana Stream in accordance with the Commission's Decision and Order on Second Remand in the Waiahole Combined Contested Case Hearing (7/13/2006).
3018	Makaua	0.83	0	1	0	HAR §13-169-49.1
3019	Kaaawa	2.76	5	0	0	HAR §13-169-49.1
3020	Kualoa	0.87	0	0	0	HAR §13-169-49.1
3021	Hakipuu	2.09	7	1	1	HAR §13-169-49.1
3022	Waikane	2.69	3	3	1	Pending. Amended to 3.5 mgd on Waikane Stream in accordance with the Commission's Decision and Order on Second Remand in the Waiahole Combined Contested Case Hearing (7/13/2006).
3023	Waianu	1.07	0	0	0	HAR §13-169-49.1
3024	Waiahole	3.99	9	12	1	Pending. Amended to 8.7 mgd on Waiahole Stream and 3.5 mgd on Waianu Stream in accordance with the Commission's Decision and Order on Second Remand in the Waiahole Combined Contested Case Hearing (7/13/2006).
3025	Kaalaea	1.78	9	0	0	HAR §13-169-49.1
3026	Haiamoa	0.64	9	0	0	HAR §13-169-49.1

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
OAHU (continued)						
3027	Kahaluu	6.74	23	12	2	HAR §13-169-49.1
3028	Heeia	4.47	1	9	1	HAR §13-169-49.1
3029	Keaahala	1.17	1	2	0	HAR §13-169-49.1
3030	Kaneohe	5.73	2	21	0	HAR §13-169-49.1
3031	Kawa	2.11	1	1	0	HAR §13-169-49.1
3032	Puu Hawaiiloa	3.68	0	0	0	HAR §13-169-49.1
3033	Kawainui	15.05	15	17	1	HAR §13-169-49.1
3034	Kaelepulu	5.27	0	3	0	HAR §13-169-49.1
3035	Waimanalo	5.95	9	3	0	HAR §13-169-49.1
3036	Kahawai	4.68	0	1	0	HAR §13-169-49.1
3037	Makapuu	0.51	0	0	0	HAR §13-169-49.1
3038	Koko Crater	3.66	0	0	0	HAR §13-169-49
3039	Hanauma	0.39	0	0	0	HAR §13-169-49
3040	Portlock	0.74	0	0	0	HAR §13-169-49
3041	Kamiloiki	2.39	0	0	0	HAR §13-169-49
3042	Kamilonui	2.02	0	0	0	HAR §13-169-49
3043	Hahaione	2.18	0	0	0	HAR §13-169-49
3044	Kuliouou	1.82	0	1	0	HAR §13-169-49
3045	Niu	2.70	0	0	0	HAR §13-169-49
3046	Wailupe	5.12	0	1	0	HAR §13-169-49
3047	Waialaenui	6.03	0	1	0	HAR §13-169-49. Amended to include SCAP OA-309 on Kapakahi Stream for restoration of wetland habitat at Pouhala Marsh (6/21/2000).
3048	Diamond Head	0.39	0	0	0	HAR §13-169-49
3049	Ala Wai	19.02	16	11	3	HAR §13-169-49
3050	Nuuanu	9.54	9	12	0	HAR §13-169-49
3051	Kapalama	3.38	3	0	0	HAR §13-169-49
3052	Kalihi	6.27	1	3	1	HAR §13-169-49
3053	Moanalua	10.70	0	7	0	HAR §13-169-49
3054	Keehi	2.49	0	0	0	HAR §13-169-49
3055	Manuwai	6.65	0	0	0	HAR §13-169-49
3056	Salt Lake	0.62	0	0	0	HAR §13-169-49
3057	Halawa	14.21	1	5	3	HAR §13-169-49
3058	Aiea	2.06	0	0	0	HAR §13-169-49
3059	Kalauao	3.34	0	3	0	HAR §13-169-49
3060	Waimalu	12.30	1	8	0	HAR §13-169-49
3061	Waiawa	27.47	5	4	0	HAR §13-169-49. Amended to include SCAP OA-221 on Panakauahi Stream to address instream uses impacted by an arched culvert (10/22/1997).
3062	Waipio	2.81	0	0	0	HAR §13-169-49
3063	Kapakahi	3.45	3	0	0	HAR §13-169-49

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
OAHU (continued)						
3064	Waikele	48.92	13	7	4	HAR §13-169-49. Amended to include SCAP OA-046 on Waikele Stream for diversion of 2.95 mgd for irrigation of three golf courses (7/15/1992)
3065	Honouliuli	19.93	0	1	0	HAR §13-169-49
3066	Kaloi	26.53	0	1	0	HAR §13-169-49
3067	Makaiwa	12.03	0	2	0	HAR §13-169-49
3068	Nanakuli	5.45	0	1	0	HAR §13-169-49
3069	Ulehawa	4.62	0	1	0	HAR §13-169-49
3070	Mailiili	19.85	0	2	0	HAR §13-169-49
3071	Kaupuni	9.41	6	3	0	HAR §13-169-49
3072	Kamaileunu	1.97	0	0	0	HAR §13-169-49
3073	Makaha	7.37	0	2	1	HAR §13-169-49
3074	Keaau	4.24	0	0	0	HAR §13-169-49
3075	Makua	6.62	0	1	0	HAR §13-169-49
3076	Kaluakauila	2.14	0	0	0	HAR §13-169-49
3077	Manini	3.03	1	1	0	HAR §13-169-49
3078	Kawaihapai	7.01	0	0	0	HAR §13-169-49
3079	Pahole	2.45	0	0	0	HAR §13-169-49
3080	Makaleha	6.85	1	1	0	HAR §13-169-49
3081	Waialua	4.70	0	0	0	HAR §13-169-49
3082	Kiikii	59.03	4	14	2	HAR §13-169-49
3083	Paukauila	22.11	9	3	1	HAR §13-169-49
3084	Anahulu	16.48	4	3	0	HAR §13-169-49
3085	Loko Ea	2.17	4	0	0	HAR §13-169-49
3086	Keamanea	7.77	0	1	0	HAR §13-169-49
3087	Waimea	13.89	1	3	1	HAR §13-169-49
MOLOKAI						
4001	Waihanau	7.73	1	2	0	HAR §13-169-47
4002	Waialeia	4.36	0	0	0	HAR §13-169-47
4003	Waikolu	4.63	6	4	0	HAR §13-169-47. Amended to include SCAP MO-169 onWaikolu Stream for the installation of a fish ladder (3/14/1995).
4004	Wainene	0.54	0	0	0	HAR §13-169-47
4005	Anapuhi	0.44	0	0	0	HAR §13-169-47
4006	Waiohookalo	1.40	0	0	0	HAR §13-169-47
4007	Keawanui	0.21	1	0	0	HAR §13-169-47
4008	Kailiili	0.50	0	0	0	HAR §13-169-47
4009	Pelekunu	7.11	2	9	0	HAR §13-169-47
4010	Waipu	0.54	0	0	0	HAR §13-169-47
4011	Haloku	0.15	0	0	0	HAR §13-169-47
4012	Oloupena	0.37	0	0	0	HAR §13-169-47
4013	Puukaoku	0.31	0	0	0	HAR §13-169-47
4014	Wailele	0.42	1	0	0	HAR §13-169-47

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
MOLOKAI (continued)						
4015	Wailau	11.94	4	2	0	HAR §13-169-47
4016	Kalaemilo	0.19	0	0	0	HAR §13-169-47
4017	Waiahookalo	0.25	0	0	0	HAR §13-169-47
4018	Kahiwa	0.20	0	0	0	HAR §13-169-47
4019	Kawainui	3.74	0	1	0	HAR §13-169-47
4020	Pipiwai	1.21	0	0	0	HAR §13-169-47
4021	Halawa	7.64	3	1	1	HAR §13-169-47
4022	Papio	1.90	1	1	0	HAR §13-169-47
4023	Honowewe	2.45	0	0	0	HAR §13-169-47
4024	Pohakupili	1.61	0	1	0	HAR §13-169-47
4025	Honoulimaloo	1.62	2	0	0	HAR §13-169-47
4026	Honouliwai	2.65	8	0	0	HAR §13-169-47. Amended to include SCAP MO-139 on Honouliwai Stream for diversion of 1.008 mgd for taro and aquaculture (4/14/1994).
4027	Waialua	3.41	4	0	0	HAR §13-169-47
4028	Kainalu	1.41	0	0	0	HAR §13-169-47
4029	Honomuni	1.59	1	0	0	HAR §13-169-47
4030	Ahaino	2.14	1	0	0	HAR §13-169-47
4031	Mapulehu	4.22	1	1	0	HAR §13-169-47
4032	Kaluaaha	2.05	1	0	0	HAR §13-169-47
4033	Kahananui	1.78	0	0	0	HAR §13-169-47
4034	Ohia	3.77	2	0	0	HAR §13-169-47
4035	Wawaia	2.67	1	1	0	HAR §13-169-47
4036	Kamalo	13.74	1	0	0	HAR §13-169-47
4037	Kawela	5.44	5	1	1	HAR §13-169-47
4038	Kamiloloa	12.54	0	1	0	HAR §13-169-47
4039	Kaunakakai	9.23	0	2	1	HAR §13-169-47
4040	Kalamaula	9.65	0	0	0	HAR §13-169-47
4041	Manawainui	13.82	1	3	0	HAR §13-169-47
4042	Kaluapeelua	14.70	0	2	0	HAR §13-169-47
4043	Waiahewahewa	5.64	0	0	0	HAR §13-169-47
4044	Kolo	19.02	0	1	0	HAR §13-169-47
4045	Hakina	5.32	0	0	0	HAR §13-169-47
4046	Kaunala	13.27	0	1	0	HAR §13-169-47
4047	Papohaku	25.42	0	3	0	HAR §13-169-47
4048	Kaa	3.19	0	0	0	HAR §13-169-47
4049	Moomomi	11.45	0	0	0	HAR §13-169-47
4050	Maneopapa	13.79	0	1	0	HAR §13-169-47
MAUI						
6001	Waikapu	16.40	12	4	0	HAR §13-169-48
6002	Pohakea	8.31	0	1	0	HAR §13-169-48
6003	Papalaua	4.88	0	0	0	HAR §13-169-48
6004	Ukumehame	8.28	1	2	0	HAR §13-169-48
6005	Olowalu	8.40	2	3	0	HAR §13-169-48
6006	Launiupoko	6.60	1	1	0	HAR §13-169-48

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
MAUI (continued)						
6007	Kauaula	8.44	1	5	0	HAR §13-169-48
6008	Kahoma	8.50	7	8	0	HAR §13-169-48
6009	Wahikuli	9.79	0	0	0	HAR §13-169-48
6010	Honokowai	8.86	2	6	0	HAR §13-169-48. Amended to include SCAP MA-117 on Honokowai Stream for the installation of a flow-through desilting basin (8/17/1994).
6011	Kahana	9.07	1	1	0	HAR §13-169-48
6012	Honokahua	5.35	0	0	0	HAR §13-169-48
6013	Honolua	4.79	4	4	0	HAR §13-169-48
6014	Honokohau	11.58	8	2	1	HAR §13-169-48
6015	Anakaluahine	2.73	0	0	0	HAR §13-169-48
6016	Poelua	2.02	0	2	0	HAR §13-169-48
6017	Honanana	4.66	2	0	0	HAR §13-169-48
6018	Kahakuloa	4.24	10	3	1	HAR §13-169-48. Amended to include SCAP MA-133 on Kahakuloa Stream for reconstruction of an existing stream diversion (6/2/1994).
6019	Waipili	2.65	2	0	0	HAR §13-169-48
6020	Waiolai	0.97	1	0	0	HAR §13-169-48
6021	Makamakaole	2.28	4	2	0	HAR §13-169-48
6022	Waihee	7.11	5	4	1	HAR §13-169-48
6023	Waiehu	10.14	12	5	0	HAR §13-169-48
6024	Iao	22.55	9	6	1	HAR §13-169-48
6025	Kalialinui	30.28	0	3	0	HAR §13-169-44
6026	Kailua Gulch	29.76	0	0	0	HAR §13-169-44
6027	Maliko	27.38	10	2	0	HAR §13-169-44
6028	Kuiaha	8.38	30	0	0	HAR §13-169-44
6029	Kaupakulua	3.84	15	2	0	HAR §13-169-44
6030	Manawaiiao	2.37	3	0	0	HAR §13-169-44
6031	Uaoa	2.39	6	0	0	HAR §13-169-44
6032	Kealii	0.53	4	0	0	HAR §13-169-44
6033	Kakipi	9.53	21	8	0	HAR §13-169-44
6034	Honopou	2.73	23	9	1	HAR §13-169-44
6035	Hoolawa	4.86	37	2	0	HAR §13-169-44
6036	Waipio	1.03	15	0	0	HAR §13-169-44
6037	Hanehoi	1.43	12	0	0	HAR §13-169-44
6038	Hoalua	1.24	4	0	0	HAR §13-169-44
6039	Hanawana	0.65	5	0	0	HAR §13-169-44
6040	Kailua	5.25	6	13	0	HAR §13-169-44
6041	Nailiilihaele	3.57	12	8	0	HAR §13-169-44
6042	Puehu	0.36	1	0	0	HAR §13-169-44
6043	Oopuola	1.24	15	4	0	HAR §13-169-44
6044	Kaaiea	1.15	3	1	0	HAR §13-169-44
6045	Punaluu	0.22	1	0	0	HAR §13-169-44

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
MAUI (continued)						
6046	Kolea	0.71	8	3	0	HAR §13-169-44
6047	Waikamoi	5.30	11	10	0	HAR §13-169-44
6048	Puohokamoa	3.18	8	12	0	HAR §13-169-44
6049	Haipuaena	1.59	5	9	0	HAR §13-169-44
6050	Punalau	1.16	3	2	0	HAR §13-169-44
6051	Honomanu	5.60	8	5	0	HAR §13-169-44
6052	Nuaailua	1.56	2	0	0	HAR §13-169-44
6053	Piinaau	21.95	14	2	0	HAR §13-169-44
6054	Ohia	0.28	1	0	0	HAR §13-169-44
6055	Waiokamilo	2.47	18	0	0	HAR §13-169-44
6056	Wailuanui	6.05	8	3	1	HAR §13-169-44
6057	W. Wailuaiki	4.18	1	1	1	HAR §13-169-44
6058	E. Wailuaiki	3.52	1	1	0	HAR §13-169-44
6059	Kopiliula	5.20	2	1	0	HAR §13-169-44. Temporarily amended to include SCAP MA-352 on Kopiliula Stream for the implementation of a Land Restoration Plan (11/20/2002).
6060	Waiohue	0.82	3	1	0	HAR §13-169-44
6061	Paakea	1.05	2	1	0	HAR §13-169-44
6062	Waiaaka	0.19	1	2	0	HAR §13-169-44
6063	Kapaula	0.84	2	2	0	HAR §13-169-44
6064	Hanawi	5.60	6	2	1	HAR §13-169-44
6065	Makapipi	3.32	3	3	0	HAR §13-169-44
6066	Kuhiwa	3.41	0	0	0	HAR §13-169-44
6067	Waihole	0.88	2	0	0	HAR §13-169-44
6068	Manawaikeae	0.52	0	0	0	HAR §13-169-44
6069	Kahawaihapapa	3.73	0	0	0	HAR §13-169-44
6070	Keaaiki	1.03	2	0	0	HAR §13-169-44
6071	Waioni	0.63	2	0	0	HAR §13-169-44
6072	Lanikele	0.70	1	0	0	HAR §13-169-44
6073	Heleleikeoha	3.48	14	0	0	HAR §13-169-44
6074	Kawakoe	4.04	15	0	0	HAR §13-169-44
6075	Honomaele	7.94	4	1	0	HAR §13-169-44
6076	Kawaipapa	10.78	0	2	0	HAR §13-169-44
6077	Moomoonui	2.95	0	1	0	HAR §13-169-44
6078	Haneoo	2.13	0	0	0	HAR §13-169-44
6079	Kapia	4.71	3	0	0	HAR §13-169-44
6080	Waiohonu	7.15	0	1	0	HAR §13-169-44
6081	Papahawahawa	1.96	0	0	0	HAR §13-169-44
6082	Alaalaula	0.48	2	0	0	HAR §13-169-44
6083	Wailua	1.26	4	0	0	HAR §13-169-44
6084	Honolewa	0.63	1	0	0	HAR §13-169-44
6085	Waieli	0.96	0	0	0	HAR §13-169-44
6086	Kakiweka	0.34	1	0	0	HAR §13-169-44
6087	Hahalawe	0.74	1	1	0	HAR §13-169-44

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
MAUI (continued)						
6088	Puaaluu	0.53	4	0	0	HAR §13-169-44
6089	Oheo	9.70	0	2	1	HAR §13-169-44
6090	Kalena	0.71	1	0	0	HAR §13-169-44
6091	Koukouai	4.56	2	0	0	HAR §13-169-44
6092	Opelu	0.53	2	0	0	HAR §13-169-44
6093	Kukuiula	0.74	1	1	0	HAR §13-169-44
6094	Kaapahu	0.50	0	0	0	HAR §13-169-44
6095	Lelekea	0.78	0	0	0	HAR §13-169-44
6096	Alelele	1.20	0	0	0	HAR §13-169-44
6097	Kalepa	0.97	2	0	0	HAR §13-169-44
6098	Nuanuaaloa	4.24	3	0	0	HAR §13-169-44
6099	Manawainui	5.17	3	0	0	HAR §13-169-44
6100	Kaupo	22.50	1	0	0	HAR §13-169-44
6101	Nuu	10.48	0	1	0	HAR §13-169-44
6102	Pahihi	7.85	0	0	0	HAR §13-169-44
6103	Waiopai	5.38	0	0	0	HAR §13-169-44
6104	Poopoo	1.92	0	0	0	HAR §13-169-44
6105	Manawainui Gulch	6.07	0	0	0	HAR §13-169-44
6106	Kipapa	28.42	0	1	0	HAR §13-169-44
6107	Kanaio	34.11	0	0	0	HAR §13-169-44
6108	Ahihi Kinau	3.68	0	0	0	HAR §13-169-44
6109	Mooloa	1.90	0	0	0	HAR §13-169-44
6110	Wailea	35.76	4	2	0	HAR §13-169-44
6111	Hapapa	40.89	0	1	0	HAR §13-169-44
6112	Waiakoa	55.76	0	2	0	HAR §13-169-44
HAWAII						
8001	Kealahewa	5.08	0	0	0	HAR §13-169-46
8002	Hualua	5.53	0	0	0	HAR §13-169-46
8003	Kumakua	3.48	0	0	0	HAR §13-169-46
8004	Kapua	0.65	0	0	0	HAR §13-169-46
8005	Ohanaula	1.26	0	0	0	HAR §13-169-46
8006	Hanaula	3.55	0	0	0	HAR §13-169-46
8007	Hapahapai	3.33	1	1	0	HAR §13-169-46
8008	Pali Akamoa	1.36	0	0	0	HAR §13-169-46
8009	Wainaia	4.30	5	0	0	HAR §13-169-46
8010	Halelua	2.28	0	0	0	HAR §13-169-46
8011	Halawa	1.75	2	0	0	HAR §13-169-46
8012	Aamakao	10.56	7	0	0	HAR §13-169-46
8013	Niulii	3.27	9	1	0	HAR §13-169-46
8014	Waikama	3.39	7	0	0	HAR §13-169-46
8015	Pololu	6.31	6	1	0	HAR §13-169-46
8016	Honokane Nui	10.51	6	10	0	HAR §13-169-46
8017	Honokane Iki	2.62	0	2	0	HAR §13-169-46
8018	Kalele	0.17	0	0	0	HAR §13-169-46
8019	Waipahi	1.00	0	0	0	HAR §13-169-46
8020	Honokea	2.38	0	0	0	HAR §13-169-46

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
HAWAII (continued)						
8021	Kailikaula	0.79	0	0	0	HAR §13-169-46
8022	Honopue	2.65	0	0	0	HAR §13-169-46
8023	Kolealiilii	0.86	0	0	0	HAR §13-169-46
8024	Ohiahuea	1.96	0	0	0	HAR §13-169-46
8025	Nakooko	0.76	0	0	0	HAR §13-169-46
8026	Waiapuka	0.73	0	0	0	HAR §13-169-46
8027	Waikaloa	1.62	0	0	0	HAR §13-169-46
8028	Waimaile	0.48	0	0	0	HAR §13-169-46
8029	Kukui	0.67	0	1	0	HAR §13-169-46
8030	Paopao	0.54	0	1	0	HAR §13-169-46
8031	Waiaalala	0.34	0	1	0	HAR §13-169-46
8032	Punalulu	1.25	0	1	0	HAR §13-169-46
8033	Kaimu	1.70	0	1	0	HAR §13-169-46
8034	Pae	0.65	0	0	0	HAR §13-169-46
8035	Waimanu	8.79	0	2	0	HAR §13-169-46
8036	Pukoa	0.21	0	0	0	HAR §13-169-46
8037	Manuwaikaalio	0.50	0	0	0	HAR §13-169-46
8038	Naluea	0.88	0	0	0	HAR §13-169-46
8039	Kahoopuu	0.86	0	0	0	HAR §13-169-46
8040	Waipahoehoe	1.34	0	0	0	HAR §13-169-46
8041	Wailoa/Waipio	25.84	37	24	2	HAR §13-169-46
8042	Kaluahine Falls	0.22	0	0	0	HAR §13-169-46
8043	Waiulili	28.93	1	4	0	HAR §13-169-46
8044	Waikoekoe	1.61	0	0	0	HAR §13-169-46
8045	Waipunahoe	16.51	0	0	0	HAR §13-169-46
8046	Waialeale	0.79	0	0	0	HAR §13-169-46
8047	Waikoloa	16.95	0	0	0	HAR §13-169-46
8048	Kapulena	3.08	0	0	0	HAR §13-169-46
8049	Kawaikalia	1.84	0	0	0	HAR §13-169-46
8050	Malanahae	2.24	0	0	0	HAR §13-169-46
8051	Honokaia	16.09	0	1	0	HAR §13-169-46
8052	Kawela	1.31	0	0	0	HAR §13-169-46
8053	Keaakaukau	0.87	0	0	0	HAR §13-169-46
8054	Kainapahoa	9.08	1	1	0	HAR §13-169-46
8055	Nienie	4.95	2	0	0	HAR §13-169-46
8056	Papuaa	4.73	0	2	0	HAR §13-169-46
8057	Ouhi	0.45	0	0	0	HAR §13-169-46
8058	Kahaupu	11.27	0	0	0	HAR §13-169-46
8059	Kahawailiili	15.56	0	0	0	HAR §13-169-46
8060	Keahua	1.70	0	0	0	HAR §13-169-46
8061	Kalopa	30.94	0	0	0	HAR §13-169-46
8062	Waikaalulu	3.06	0	0	0	HAR §13-169-46
8063	Kukuilamalamahii	2.28	0	0	0	HAR §13-169-46
8064	Alilipali	1.60	0	0	0	HAR §13-169-46
8065	Kaumoali	9.39	0	0	0	HAR §13-169-46
8066	Pohakuhaku	2.45	0	0	0	HAR §13-169-46
8067	Waipunahina	15.86	0	0	0	HAR §13-169-46

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
HAWAII (continued)						
8068	Waipunalau	3.84	0	0	0	HAR §13-169-46
8069	Paauilo	1.57	1	0	0	HAR §13-169-46
8070	Aamanu	0.64	0	0	0	HAR §13-169-46
8071	Koholalele	14.40	0	0	0	HAR §13-169-46
8072	Kalapahapuu	6.43	0	0	0	HAR §13-169-46
8073	Kukaiau	2.40	0	0	0	HAR §13-169-46
8074	Puumaile	9.13	0	0	0	HAR §13-169-46
8075	Kekualele	2.18	0	0	0	HAR §13-169-46
8076	Kaala	6.62	0	0	0	HAR §13-169-46
8077	Kealakaha	3.49	0	0	0	HAR §13-169-46
8078	Keehia	1.72	0	1	0	HAR §13-169-46
8079	Kupapaulua	2.54	0	0	0	HAR §13-169-46
8080	Kaiwiki	2.24	0	0	0	HAR §13-169-46
8081	Kaula	14.35	0	0	0	HAR §13-169-46
8082	Kaohaoha	1.49	0	0	0	HAR §13-169-46
8083	Kaawalii	13.93	0	0	0	HAR §13-169-46
8084	Waipunalei	2.07	0	0	0	HAR §13-169-46
8085	Laupahoehoe	4.71	0	0	0	HAR §13-169-46
8086	Kilau	2.43	1	0	0	HAR §13-169-46
8087	Manowaiopae	1.74	2	1	0	HAR §13-169-46. Amended to include SCAP HA-195 on Manowaiopae Stream for a permitted diversion (5/3/1996).
8088	Kuwaikahi	0.72	1	0	0	HAR §13-169-46
8089	Kihalani	0.70	1	0	0	HAR §13-169-46
8090	Kaiwilahilahi	6.69	1	0	0	HAR §13-169-46
8091	Haakoa	6.26	0	0	0	HAR §13-169-46
8092	Pahale	3.92	0	0	0	HAR §13-169-46
8093	Kapehu Camp	1.74	2	0	0	HAR §13-169-46
8094	Paeohe	0.85	0	0	0	HAR §13-169-46
8095	Maulua	5.30	0	0	0	HAR §13-169-46
8096	Pohakupuka	3.63	1	1	0	HAR §13-169-46
8097	Kulanakii	0.71	0	0	0	HAR §13-169-46
8098	Ahole	0.67	0	0	0	HAR §13-169-46
8099	Poupou	0.62	0	0	0	HAR §13-169-46
8100	Manoloa	1.32	0	0	0	HAR §13-169-46
8101	Ninole	1.67	2	0	0	HAR §13-169-46
8102	Kaaheiki	0.27	1	0	0	HAR §13-169-46
8103	Waikolu	0.63	4	0	0	HAR §13-169-46
8104	Waikaumalo	16.10	0	0	0	HAR §13-169-46
8105	Waiehu	0.61	1	0	0	HAR §13-169-46
8106	Nanue	5.53	1	0	0	HAR §13-169-46
8107	Opea	2.31	0	0	0	HAR §13-169-46

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
HAWAII (continued)						
8108	Peleau	1.12	3	0	0	HAR §13-169-46. Amended to include SCAP HA-314 on Peleau Stream for diversion of 8.0 mgd for agricultural use (8/23/2000).
8109	Umauma	33.83	1	0	0	HAR §13-169-46
8110	Hakalau	10.26	0	0	0	HAR §13-169-46
8111	Kolekole	20.82	8	0	0	HAR §13-169-46
8112	Paheehee	2.87	0	0	0	HAR §13-169-46
8113	Honomu	3.12	2	0	0	HAR §13-169-46. Amended to include SCAP HA-317 on Malamalamaiki Stream for 2.0-in. pipe diversion for washing farm equipment (2/28/2001).
8114	Laimi	0.89	1	0	0	HAR §13-169-46
8115	Kapehu	1.60	2	1	0	HAR §13-169-46
8116	Makea	2.08	4	0	0	HAR §13-169-46
8117	Alia	1.31	2	1	0	HAR §13-169-46. Amended to include SCAP HA-387 on Alia Stream for diversion of 0.058 mgd for agricultural use (5/24/2006).
8118	Makahanaloa	0.48	0	0	0	HAR §13-169-46
8119	Waimaauou	1.33	1	0	0	HAR §13-169-46
8120	Waiaama	3.53	2	0	0	HAR §13-169-46
8121	Kawainui	8.52	1	1	0	HAR §13-169-46
8122	Onomea	0.85	5	0	0	HAR §13-169-46. Amended to include SCAP HA-214 on Onomea Stream for relocation of a pipe diversion to mitigate concerns over an existing diversion dam (3/19/1997).
8123	Alakahi	0.30	1	0	0	HAR §13-169-46
8124	Hanawi	3.96	0	0	0	HAR §13-169-46
8125	Kalaoa	0.51	3	0	0	HAR §13-169-46
8126	Aleamai	0.32	0	1	0	HAR §13-169-46
8127	Kaieie	2.75	0	0	0	HAR §13-169-46
8128	Puuokalepa	0.93	2	0	0	HAR §13-169-46
8129	Kaapoko	0.32	0	0	0	HAR §13-169-46
8130	Papaikou	0.19	0	0	0	HAR §13-169-46
8131	Kapue	11.86	0	0	0	HAR §13-169-46
8132	Pahoehoe	6.96	1	0	0	HAR §13-169-46
8133	Paukaa	0.65	0	0	0	HAR §13-169-46
8134	Honolii	16.59	0	2	1	HAR §13-169-46
8135	Maili	4.09	1	0	0	HAR §13-169-46
8136	Wainaku	1.86	0	0	0	HAR §13-169-46
8137	Pukihae	3.23	0	0	0	HAR §13-169-46

Table 3-21: (continued)
Inventory of Surface Water Resources

Unit Code	Unit Name	Area (mi^2)	No. of Diversions	No. of Gages	Active Gages	Interim IFS
HAWAII (continued)						
8138	Wailuku	225.56	11	14	1	HAR §13-169-46. Amended to include SCAP HA-219 on Waiau Stream for a diversion dam constructed to generate electricity for a farm operation (10/22/1997). Amended to include SCAP HA-047 on Hookelekele Stream for three diversions structures constructed as part of a hydroelectric project (10/18/89).
8139	Wailoa	180.18	1	5	0	HAR §13-169-46
8140	Kaahakini	388.99	3	0	0	HAR §13-169-46
8141	Kilauea	152.29	0	0	0	HAR §13-169-46
8142	Keauhou Point	66.58	0	0	0	HAR §13-169-46
8143	Kilauea Crater	27.10	0	0	0	HAR §13-169-46
8144	Kapapala	183.57	0	0	0	HAR §13-169-46
8145	Pahala	271.38	1	3	1	HAR §13-169-46
8146	Hilea	94.44	6	3	0	HAR §13-169-46
8147	Naalehu	46.45	1	4	0	HAR §13-169-46
8148	Kiolakaa	66.21	0	0	0	HAR §13-169-46
8149	South Point	11.75	1	0	0	HAR §13-169-46
8150	Kauna	140.63	0	0	0	HAR §13-169-46
8151	Kiilae	340.31	4	1	0	HAR §13-169-46
8152	Kealakekua	45.29	0	0	0	HAR §13-169-46
8153	Waiaha	224.39	8	4	0	HAR §13-169-46
8154	Honokohau	14.20	0	0	0	HAR §13-169-46
8155	Keahole	32.73	0	0	0	HAR §13-169-46
8156	Kiholo	236.29	0	0	0	HAR §13-169-46
8157	Pohakuloa	348.76	4	0	0	HAR §13-169-46
8158	Kamakoa	192.20	0	2	0	HAR §13-169-46
8159	Haloa	1.07	0	1	0	HAR §13-169-46
8160	Lamimaumau	3.88	0	1	0	HAR §13-169-46
8161	Waikoloa	51.96	11	4	2	HAR §13-169-46
8162	Kawaihae	22.03	0	1	0	HAR §13-169-46
8163	Honokoa	12.61	10	0	0	HAR §13-169-46
8164	Keawanui	43.90	2	0	0	HAR §13-169-46
8165	Lapakahi	6.27	0	0	0	HAR §13-169-46
8166	Mahukona	12.61	0	0	0	HAR §13-169-46

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