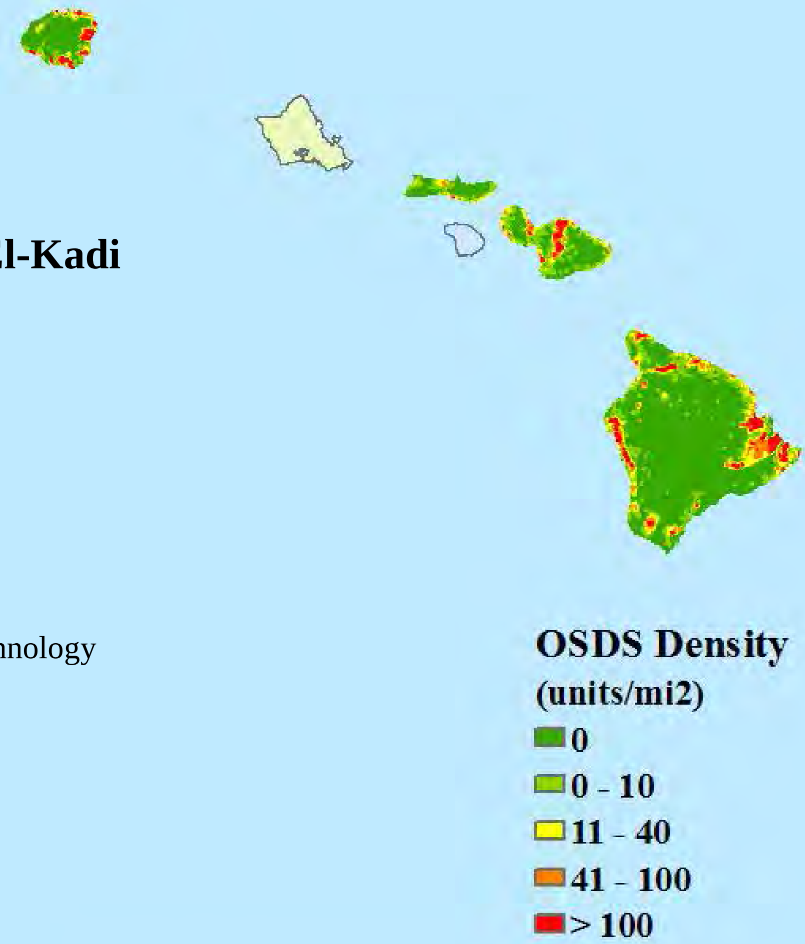
HUMAN HEALTH AND ENVIRONMENTAL RISK RANKING OF ON-SITE SEWAGE DISPOSAL SYSTEMS FOR THE HAWAIIAN ISLANDS OF KAUAI, MOLOKAI, MAUI, AND HAWAII

FINAL



Robert B. Whittier and Aly I. El-Kadi

September 2014

PREPARED FOR

State of Hawai‘i Department of Health
Safe Drinking Water Branch

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Executive Summary

Outside of the urban centers and major towns, residences and small businesses dispose of wastewater at the location where it is generated. This on-site disposal of wastewater gives rise to risks to human health and the environment. This study assessed the potential risk posed by on-site sewage disposal systems (OSDS) to human health and critical ecosystems on the islands of Hawaii, Kauai, Maui, and Molokai. To assess this risk, the number and locations of OSDS were estimated based on a search of wastewater and tax databases. The risk posed to critical ecosystems and human health was evaluated based on the volume and water quality characteristics of the effluent discharged and the proximity of OSDS to receiving ecosystems and potential points of human contact. Finally, a cumulative risk severity score was calculated to rank the relative risk posed by each OSDS.

Project Goals and Methods

The objectives of this study were to:

1. Estimate the quantity, location, and types of OSDS on the islands of Hawaii, Kauai, Maui, and Molokai;
2. Estimate the effluent load added to the environment by these systems;
3. Identify and map the factors influencing the risk posed by OSDS to the environment and to human health;
4. Evaluate the potential risk to the receptors of concern (ROC) that may be impacted by OSDS;
5. Develop a scoring system to map the severity and distribution of OSDS risk factors for each class of ROCs; and
6. Based on the ROC scoring results, compute an overall risk score to rank the severity of the risk posed by individual OSDS.

The objectives are met by:

- Completing an inventory to estimate the quantity, characteristics, and location of the OSDS (Section 3);
- Modeling the impact to the groundwater from the effluent discharged from these OSDS (Section 4);
- Using Geographical Information Systems to map the spatial distribution of the hydrologic parameters that affect the vulnerability of the human and environmental receptors to OSDS effluent contamination (Sections 4, 5, 6, and 7); and
- Linking the OSDS locations to the OSDS risk factors to compute a relative risk-ranking score for each OSDS parcel.

Data developed by this study can be used by planning and regulatory agencies to set policy regarding OSDS, identify areas most suitable for locating OSDS, and delineate those areas where the negative impact from OSDS effluent is most likely to occur. The information can also be used to develop a schedule for OSDS inspections by prioritizing systems based on relative risks.

OSDS Inventory Results

This study and the pilot study done for Oahu (Whittier and El-Kadi, 2009) represent the most comprehensive census of OSDS performed to date for the State of Hawaii. The two studies estimate that the number of the OSDS in the State of Hawaii exceeds 110,000. Table ES-1 gives a breakdown of the OSDS inventory by type and by island. Figures ES-1 through ES-4 show the OSDS distribution for the islands evaluated by this study (Hawaii Island, Kauai, Maui, and Molokai) with density expressed as OSDS per mile squared (mi^2). The majority of these OSDS (80 percent) are cesspools where the effluent receives no treatment prior to being released to the environment. It is estimated that statewide OSDS discharge nearly 70 million gallons per day (mgd) of minimally treated effluent to groundwater. This produces an estimated nutrient load to the environment of over 12,500 and 3,500 kilograms per day (kg/d) of nitrogen and phosphorus, respectively. Nearly half of the OSDS in the state are located on Hawaii Island. However, the highest OSDS density is on Kauai where there are approximately 32 units per square mile (mi^2). Molokai, which is the least developed of these islands, has the lowest total population (7,345) and OSDS density (approximately 7.5 units/mi^2).

Table ES-1. The OSDS inventory results and effluent discharge totals

Island	Total OSDS	CLASS I	CLASS II	CLASS III	CLASS IV	Effluent Discharge (mgd)	N FLUX (kg/d)	P FLUX (kg/d)
Hawaii	58,982	8,951	694	68	49,344	34.6	6,607	1,848
Kauai	18,011	3,107	910	304	13,688	12.5	2,115	607
Maui	16,883	4,015	559	75	12,242	11.6	1,869	554
Molokai	1,956	477	33	4	1,442	1.2	206	59
Oahu*	14,606	2,620	534	199	11,253	9.7	1,732	500
Total	110,438	19,170	2,730	650	87,969	69.6	12,529	3,568

*Oahu OSDS data taken from Whittier and El-Kadi (2009)

Class I – OSDS utilizing soil treatment

Class II – Septic systems discharging to a seepage pit

Class III – Aerobic treatment units discharging to a seepage pit

Class IV – Cesspools

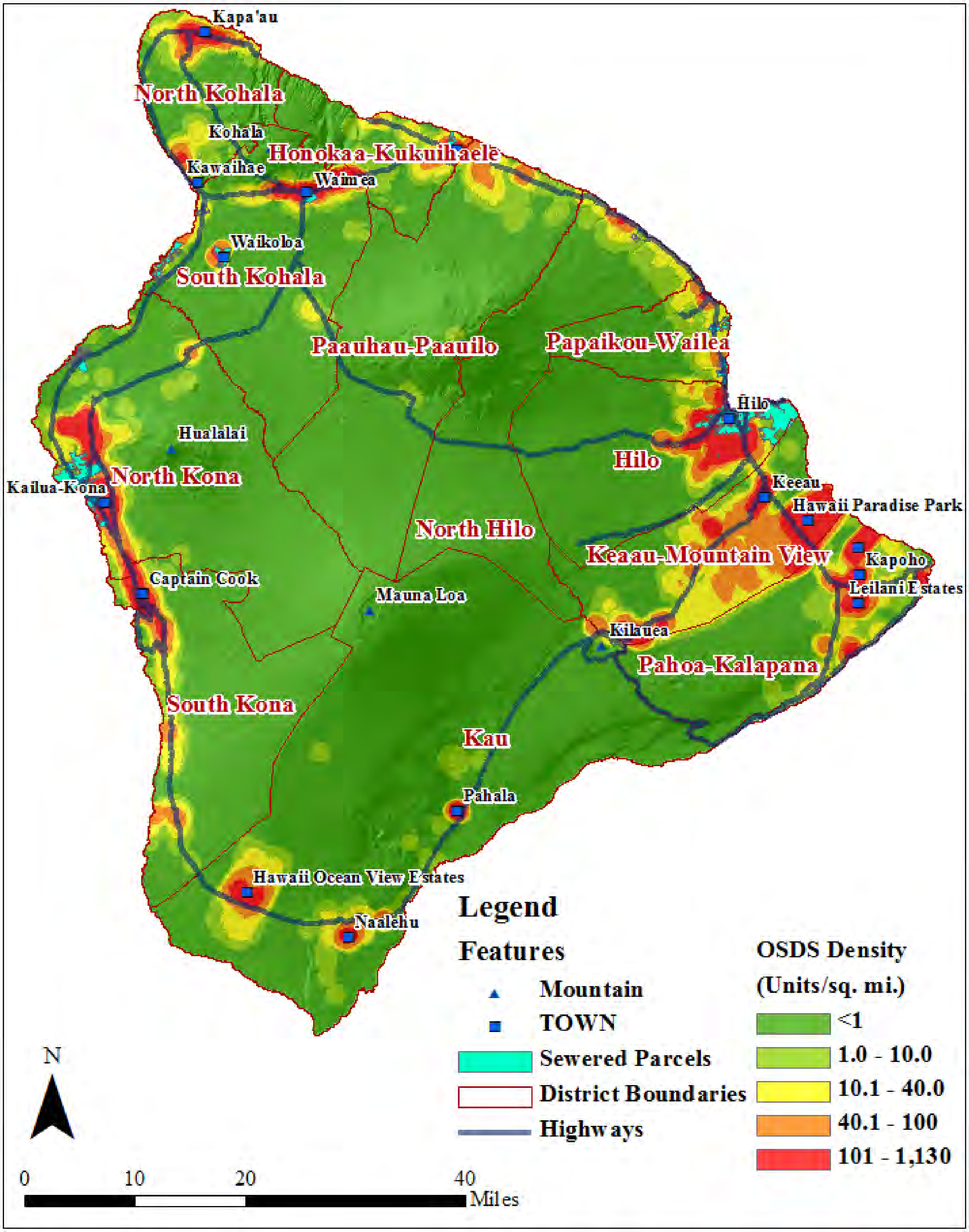

Figure ES-1. The distribution of OSDS density on Hawaii Island shown with district boundaries and sewered areas

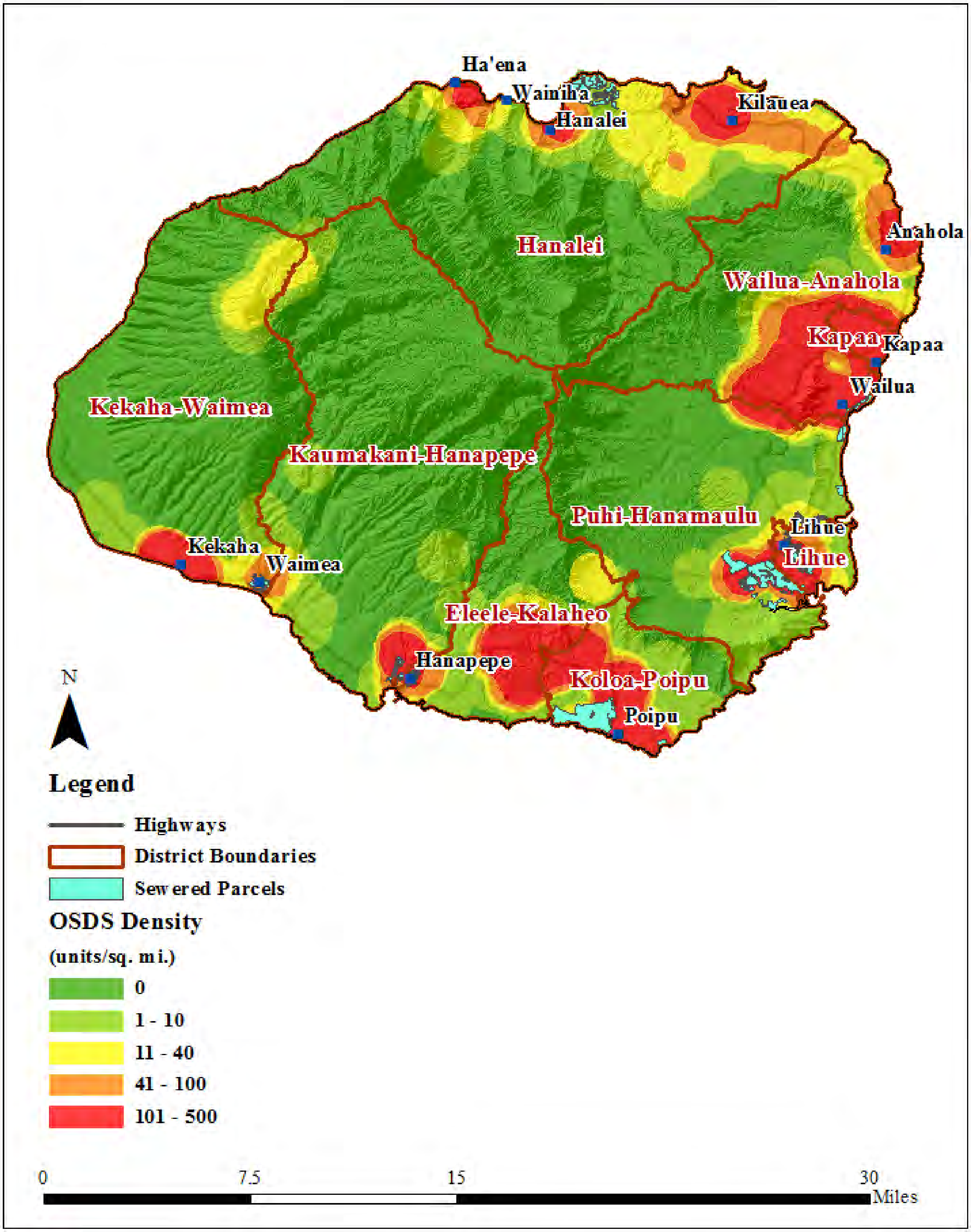

Figure ES-2. The distribution of OSDS density on Kauai shown with district boundaries and sewered areas

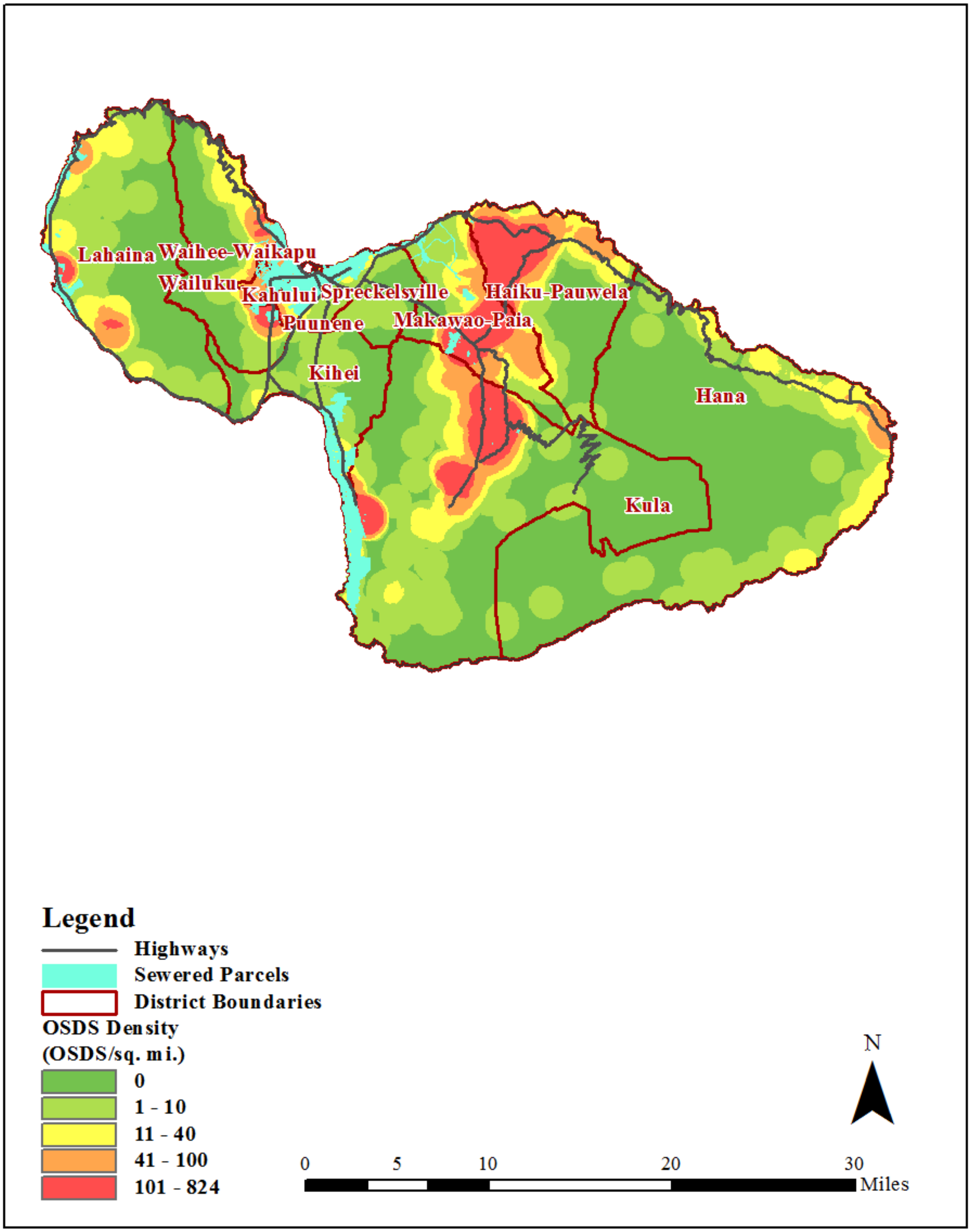

Figure ES-3. The distribution of OSDS density on Maui shown with district boundaries and sewered areas

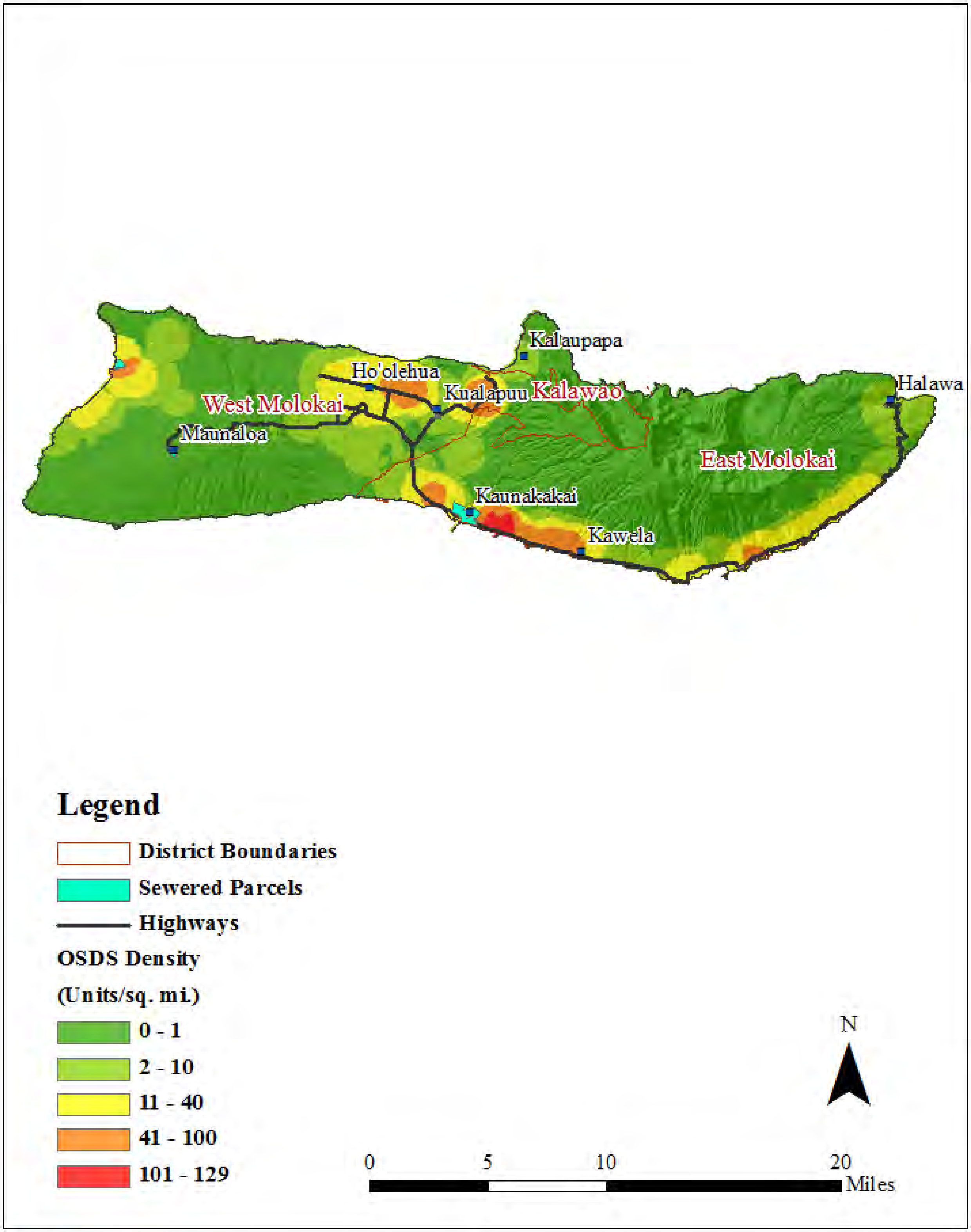

Figure ES-4. The OSDS density distribution on Molokai shown with district boundaries and sewered areas

Summary of OSDS Risk

The risk that an OSDS poses to sensitive ecosystems and human health is dependent upon on the likelihood that the effluent can reach a receptor where harm may occur. The points of potential human contact and sensitive ecosystems will be referred to as receptors of concern (ROC) by this study. Many factors govern the transport of OSDS effluent from its point of discharge to where harm may occur. The factors include the proximity of the OSDS to the ROC, the ability of the soil to transmit and remediate the OSDS effluent, the amount of dilution the effluent is subjected to in the saturated zone, and the hydrologic factors allowing the effluent contaminated groundwater to return to the surface and impact the ROC. The distribution of these factors was mapped and a weighting coefficient was assigned as a semi-quantitative method for estimating the distribution of risk to ROCs. The following sections describe the ROC and the method of estimating an OSDS's relative risk.

Characteristics of OSDS That Determine Risk

The inherent risk posed by an OSDS varies by the quantity of effluent, the system type, and the method of effluent treatment. This study classified OSDS by the type of treatment the wastewater effluent receives. Table ES-1 below lists the OSDS classes.

Table ES-2. OSDS Classes and Corresponding Treatment and Disposal Type

OSDS Class	Treatment and Disposal Type
Class I	Any system receiving soil treatment. This includes disposal types listed as bed, trench, and infiltration/chambers.
Class II	Septic systems discharging to a seepage pit. The effluent receives primary treatment only.
Class III	Aerobic units discharging to a seepage pit. The effluent receives primary and secondary treatment.
Class IV	All cesspools where the effluent receives no treatment.

Note: A seepage pit is a dry well that disperses effluent from septic tanks. The effluent receives no treatment other than settling of solids that occurs in the septic tank

EFFLUENT QUANTITY

The risk that OSDS pose to human health and the environment is strongly influenced by the rate of effluent discharge. Therefore, it is critical in any risk evaluation to quantify the amount of effluent being released to the environment. The OSDS effluent discharge rate was estimated using residential dwelling characteristics or by the type of activity occurring at non-residential parcels. For residential units, guidance was provided by Hawaii Administrative Rules Title 11, Chapter 62 that estimates an effluent rate of 200 gallons per day (gpd) for each bedroom served by OSDS. OSDS effluent discharge rates for systems serving non-residential structures needed an alternative method estimation method. These non-residential activities included businesses, churches, schools, parks, and condominiums. The OSDS discharge rate for non-residential systems was based on estimates given in Metcalf and Eddy (1991).

EFFLUENT QUALITY

The mass of nutrients reaching surface or coastal waters determines the degree of impact on the receiving bodies. The risk to human health is driven by the concentration and types of contaminants in drinking water impacted by OSDS. It is beyond the scope of this study to evaluate all of the contaminants in the OSDS effluent. The contaminants of greatest concern are the nutrients that cause excessive bio-productivity in surface waters and, in the case of nitrate, toxic substances. The nutrients evaluated, nitrogen and phosphorous, were considered with nitrogen used as the primary species to evaluate risk. This approach was taken because nitrogen can be a limiting nutrient in aquatic and marine waters, making it a contaminant of concern. The transport of nitrogen in the form of nitrate can be more reliably modeled due its conservative nature in oxic waters. The contaminant flux to the environment was based on concentration estimates given by the Water Resources Research Center (WRRC) and Engineering Solutions, Inc. (2008). The concentration was then multiplied by the estimated effluent rate to compute the total nutrient load. Table 2-3 lists the effluent characteristics by OSDS type.

Table ES-3. Effluent Characteristics of OSDS Classes

(WRRC and Engineering Solutions, 2008)

OSDS Class	**Typical Nitrogen Concentration** (mg/L as nitrogen)	**Typical Phosphate Concentration** (mg/L as phosphorus)	**Typical Fecal Coliform Concentration** (colony forming units [CFU]/100 mL)	**Table or Page Number** (WRRC and Engineering Solutions, 2008)
Class I, Soil Treatment	1	<2	13	Table 4-1, page 4-6
Class II, Septic tank to seepage pit	39-82	11-22	1-100E+06	Table 4-1, page 4-6
Class III, Aerobic treatment to seepage pit	7-60	2-18	1.00E+06	Page 5-19
Class IV, Cesspools	15-90	5-20	1-100E+06	Table 4-1, page 4-6

colony forming units (CFU); milligrams per liter (mg/L); milliliter (mL)

Table ES-2 shows that the quality of effluent released to the environment from an OSDS varies with the amount of treatment it receives. The effluent from cesspools, the Class IV OSDS, receives no treatment and thus no reduction in nutrients and pathogens prior to release to the environment. Systems utilizing soil treatment (Class I OSDS) and can attain nitrogen removal rates of greater than 90 percent (refer to Table ES-2).

Summary of risk to groundwater and drinking water

Constituents in wastewater that may a pose risk to health include pathogens, regulated contaminants such as nitrate, and a wide spectrum of unregulated and emerging contaminants. Knowledge of the OSDS that are located within a drinking water source's zone of contribution is critical when evaluating the risk that OSDS pose to drinking water. The current analysis benefited from the drinking water source zones of contributions delineated by the Source Water Assessment Program (SWAP) (Whittier et al., 2004). The SWAP delineated two zones of contribution referred to as capture zone delineations (CZD) for all public drinking water sources in the State of Hawaii based on time-of-travel (TOT) criteria. The first CZD was a 10-year TOT delineation designated as the Zone B CZD. The second delineation, Zone C CZD, included a zone of contribution to the drinking water well where the TOT was greater than 2 years but less than or equal to 10 years. We estimate that nearly 2,800 OSDS are located within the Zone B. OSDS located within this zone have the potential to introduce pathogens into the intake of these wells. In excess of 3,000 OSDS are estimated to be located within Zone C. The introduction of pathogens into the well intakes from these OSDS within Zone C is unlikely, but the undesirable chemical constituents of wastewater can degrade the quality of the water captured by the affected wells. Maui has the highest number of OSDS within the specified zones of contributions to the drinking water wells. There are estimated to be over 1,000 OSDS in Zone B and over 1,100 OSDS in Zone C. This is equivalent to over 12 percent of the OSDS on Maui that are located within a 2 or 10 year CZD of drinking water wells. Molokai has the lowest number with only 52 OSDS within each zone.

It is expected that an isolated OSDS that is not located in the immediate vicinity of a drinking water well poses a very small risk potential. OSDS in clusters, such as would occur within a housing development, will have a cumulative and adverse impact on the groundwater. The cumulative effects of OSDS on water quality were investigated through modeling, with nitrogen, primarily as nitrate, as a representative chemical of those existing in the effluent. The OSDS effluent discharge with its entrained nitrogen was combined with natural and agricultural recharge. The recharge values used by Whittier et al. (2004) were updated to include the contribution of the OSDS effluent based on the total effluent discharge per TMK in the OSDS inventory. The groundwater flow models based on MODFLOW were then rerun with the updated recharge coverage to generate a groundwater flow field. The contaminant transport model MT3D-MS used the groundwater flow model results to simulate the increase in groundwater nitrogen concentration that could be attributed to OSDS effluent discharge. The nitrogen transport simulations were run for 50 years to approximate the long-term impact of OSDS on groundwater. The nitrogen transport simulations did not account for the travel time from the point of discharge to the water table or any natural attenuation processes that might reduce the nitrogen content in the leachate.

This approach identified the groundwater zones most impacted by OSDS and the drinking water wells most at risk from these systems. On Hawaii Island, the transport modeling indicated that the zones of contribution for most of the drinking water wells serving communities from near the Keahole Airport to south of Captain Cook may be impacted by elevated levels of OSDS derived groundwater nitrogen (ODGWN). Additionally, a few wells near the communities of Pahala, Waimea, and along the northeast coast may likewise be impacted. On Kauai, nearly all of the wells near the coastal communities may have elevated levels of ODGWN with their zones of contribution. This is a particularly serious problem in the Wailua/Kapaa area where modeling indicated highly elevated ODGWN concentrations. On Maui, modeling indicated increased ODGWN concentrations are restricted to the western slope of Haleakala, primarily upcountry Maui. There were also elevated ODGWN concentrations in the CZDS of drinking water sources in the Iao and Waihee Aquifer Sectors. Molokai has only two areas with elevated ODGWN concentrations within the drinking water well CZDs. These are CZDs for the wells in the Kualapuu area and for the Ualapue Shaft. Of the islands assessed, Kauai has the highest probability of drinking water impact from OSDS.

Summary of risk to streams

OSDS effluent has the potential to degrade stream water quality by the introduction of pathogens and nutrients. The risk posed to streams and watersheds was evaluated by inventorying the OSDS that were located within the watersheds of perennial streams. This study only considered perennial streams because these hydrologic systems commonly have a baseflow component that is supplied by groundwater, the primary transport medium of OSDS effluent contaminants. The risk weight assigned to each OSDS reflects the probability that it is located in an area where groundwater discharges to surface water. The locations where groundwater discharges to surface include:

- high level aquifers within a perennial watershed;
- areas of perched water within a perennial watershed;
- a corridor within 200 feet (ft) from stream channels; and
- areas where the depth to the water was less than 25 ft.

The last weighting factor was based on the modeled ODGWN concentration in the groundwater. Elevated ODGWN concentrations identified the reaches of streams that are most likely to be impacted by currently installed OSDS.

Another indicator of potential OSDS impact was the nutrient load to the watershed. This was calculated by dividing nitrogen and phosphorus flux estimated based on field data from OSDS within the zone that potentially contributes groundwater to streamflow by the area of that zone. This was calculated in units of $kg/d/m^2$ of watershed area.

The study results showed that Kauai streams are most at risk to degradation due to contributions from OSDS. The prevalence of perennial streams and high-level aquifers increases the area where groundwater likely discharges to surface water. Kauai also has the highest modeled ODGWN concentration of the islands assessed. The highest ODGWN concentrations occurred within perennial watersheds on the east side of this island, suggesting that these streams are at elevated risk from OSDS effluent contamination.

The risk to streams on the islands of Hawaii and Maui from OSDS effluent is much less than on Kauai due to the smaller fraction of the perennial watershed area with elevated ODGWN concentrations. However, future development on both of these islands could result in adverse OSDS impact on streams due to the dominance of high-level aquifers on the east side of both islands. On the island of Maui, the current population of OSDS poses a moderate risk to streams in the Waihee and Waiehu regions based on the modeled ODGWN. However, as residential development in current agricultural areas increases so will the risk to stream water on the north and east slopes of Haleakala.

There were very few OSDS in the perennial watersheds of Molokai. This resulted in very low-modeled ODGWN concentrations within these watersheds. The risk of OSDS contamination to Molokai streams is currently low.

Summary of risk to coastal waters

All groundwater not extracted by pumping, discharged to streams, or lost to evapotranspiration eventually discharges to the ocean along with any nutrients and pathogens it contains. As with the stream risk assessments, we identified the areas of the shoreline most likely to be adversely impacted by OSDS effluent by modeling the ODGWN concentrations. This approach did not account for factors in the marine environment that may mitigate the impact of OSDS, such as strong long shore currents that may dilute the nutrients in the OSDS laden groundwater discharge.

The second approach used to assess the risk to the coastal waters from OSDS effluent discharge was the proximity of the OSDS to the shoreline. The OSDS located closest to the shoreline have the greatest probability of adversely affecting coastal waters. Two setback zones were delineated. The first was a 200 ft setback from the shoreline and the second was an area within which groundwater travel to shoreline would take two years or less, which is termed the time of travel time or TOT. The TOT setback was modeled using the particle-tracking model MODPATH on the flow field generated by the Source Water Assessment Program (SWAP) models for each island. Factors considered for risk scoring were areas within 200 ft of the shoreline, areas within a two year time of travel for groundwater to the coast; and areas where the simulated ODGWN concentration adjacent to and upgradient of the coastal two year time of travel setback was greater than 5.0 mg/L. Considering that the risk weights were additive, the highest risk score would be assigned to those OSDS located within 200 ft of the shoreline and in an area of elevated ODGWN. Outside of the 200 ft setback, the maximum score was assigned to areas within the 2-year TOT but farther than 200 ft from the shoreline and where the ODGWN is estimated to be greater than 5.0 mg/l.

The islands of Hawaii and Kauai have the highest percentage of coastal zones at elevated risk to OSDS impact. On Kauai, the south shore area from Poipu to Hanapepe, Nawiliwili, and the Wailua/Kapaa areas have the highest scores due to the high concentration of OSDS. On the island of Hawaii, nearly all of the northeast coast and much of the west coast from the westernmost point of Hualalai to south of Captain Cook has a high coastal risk severity score. On the island of Maui, the areas of Kaanapali, Kihei to Makena, Waihee/Waiehu, and the coastal area fronting the northwest slopes of Haleakala have elevated risk scores. On Molokai, the coast fronting the unsewered areas near the community of Kaunakakai has an elevated coastal risk score.

Summary of soil suitability for OSDS siting

Soil is the primary treatment medium for OSDS effluent. Although the effluent from cesspools is assumed to not undergo any treatment, the leachate from cesspools undergoes natural remediation if a sufficient thickness of soil exists between the bottom of the cesspool and the water table. The suitability of soil for siting a septic system is one of the many soil properties evaluated by the

NRCS in their soil surveys. This suitability is based on the degree of limitation of eight factors that control the treatment and infiltration of septic system leachate or the ease of leach field installation. These factors are as follows:

- The depth to bedrock or cemented pan;
- The degree to which the soil is subject to flooding or ponding;
- The filtering characteristics of the soil;
- The rate of water infiltration through the soil;
- The rate of seepage out of the bottom layer of the soil;
- The topographic slope;
- The amount of subsidence the soil is likely to undergo after the leach field installation; and
- The fraction of rock fragments in the soil.

This study mapped the distribution and limitation severity of the first four factors individually based on the NRCS soils database. The last four factors were lumped together and evaluated as a single factor that deals primarily with degree of difficulty encountered when installing a septic system. Each factor was assigned a score that varied from 0 to 100 based on the severity of the limitation. The scores of the five categories were averaged so that the maximum score possible would be 100.

The weighted sum of the soil limitation scores was used to map the suitability of the soils to properly treat OSDS effluent. The summed soil limitation scores varied from 22 to 27. This is much less than the maximum possible score of 100 because there was no area where the limitation for each of the soil parameters was the most severe possible. Kauai soils are most limiting for OSDS installation while the soils on Maui are the most suitable. On Kauai, the most severe limitation is low permeability. This may be a function of the age of the soils because Kauai is oldest of the islands evaluated. On Hawaii Island, the youngest island evaluated, the most limiting factor is the depth to rock. This also is an artifact of the island's age because Hawaii has had less time to develop the deep soils that are present on the other islands. However, generalizations are not helpful when evaluating a specific site on each island due to large variations in OSDS suitability scores. To more specifically identify areas where the soil's ability to properly treat OSDS effluent is marginal, this study produced maps of the severity of the soil limitations for wastewater treatment and disposal.

Summary of overall risk distribution

The cumulative risk that an OSDS poses to human health and the environment includes the vulnerability of ROC to degradation due to OSDS effluent, the type of OSDS, and the ability of the soil to remediate the effluent. An OSDS risk severity score was assigned to each Tax Map Key (TMK) parcel that hosts an OSDS with an increasing score reflecting the greater overall risk that these systems pose to human health and environment. The results of the ROC risk severity scores were summed to compute an overall ROC risk severity score for each OSDS or group of OSDS if multiple units were located on a single TMK parcel. To this score was added a type risk score of three for Class IV OSDS. Finally, the septic siting suitability score was scaled from a range of 0 to 100 down to a range of 0 to 5 to be consistent with the other risk factors. The septic siting suitability score was then added to the previous sum for an OSDS risk ranking score. The sum of the individual risk factors resulted in a maximum possible risk ranking score of 31.

The inventory estimated a total of 96,896 OSDS are located on 81,844 TMK parcels. Table ES-2 summarizes the risk scoring for the islands while Figures ES-5 through ES-8 show the distribution of the risk scores. The OSDS risk severity scores vary from 1 to 26. Kauai has the highest average risk score of 14, while Maui has the lowest risk average score at 9.2. Kauai also has the highest number of OSDS risk severity scores greater than 25. The OSDS with the highest risk are those located in clusters where high ODGWN concentrations occur near ROCs. Of particular note are the areas of Wailua/Kapaa where a dense clustering OSDS are located in perennial watersheds and in close proximity (less than a two-year time of travel) to the shoreline. Also notable is the west coast area of Hawaii Island where most residences are located within a two-year time of travel of the coast and utilize OSDS for wastewater treatment and disposal.

Table ES-2. The OSDS risk ranking scores for the islands of Hawaii, Kauai, Maui, and Molokai

				Risk Score			
Island	Total OSDS	OSDS Parcels	OSDS Density (per mi^2)	Minimum	Average	Maximum	Standard Deviation
Hawaii	58,982	53,530	14.6	3	11.2	24	2.6
Kauai	19,075	13,883	32.5	3	14.0	26	2.6
Maui	16,883	12,780	23.2	1	9.2	19	2.9
Molokai	1,956	1,651	7.5	3	10.1	16	2.5
Total	**96,896**	**81,844**	**-----**	**-----**	**-----**	**-----**	**-----**

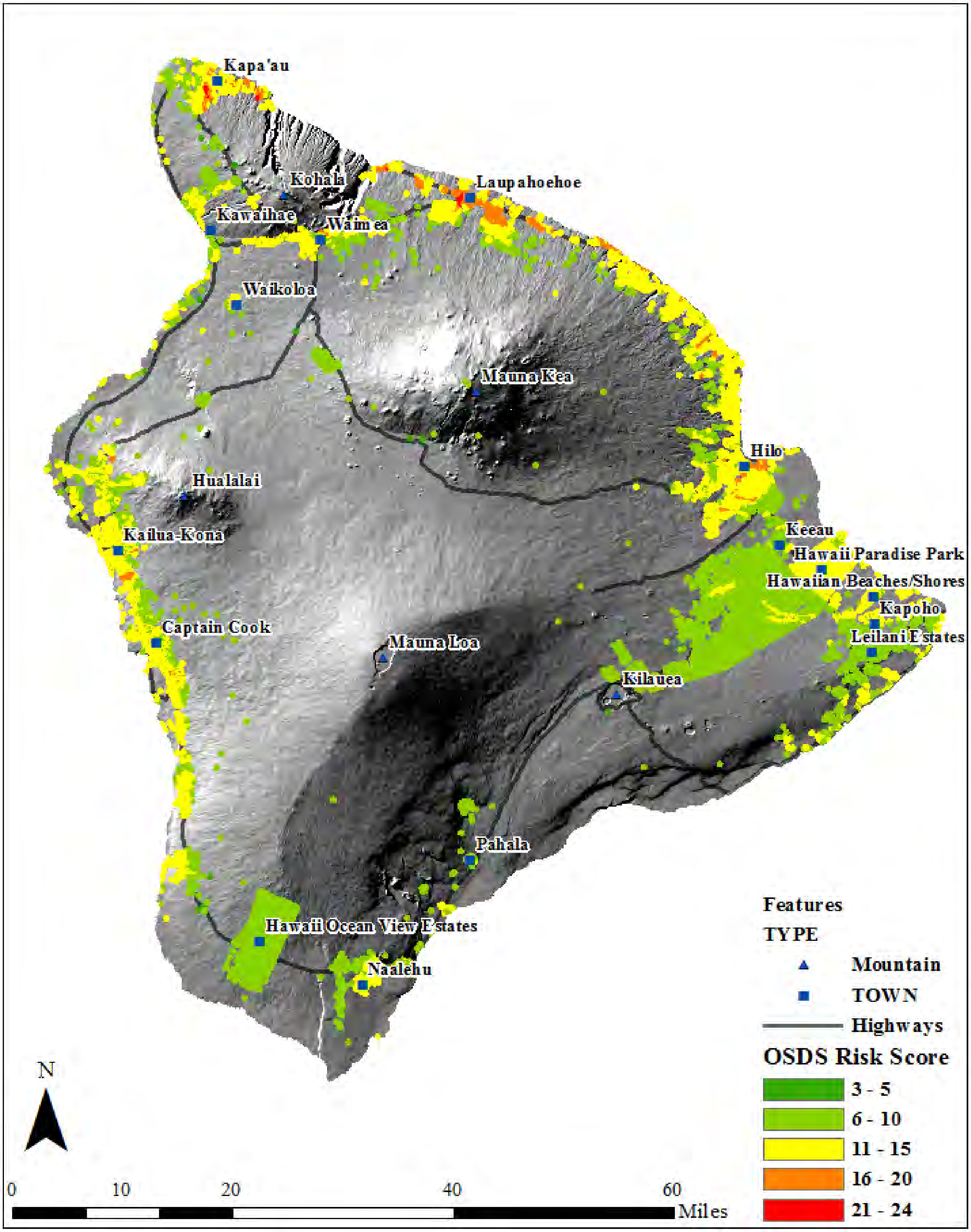

Figure ES-5. The distribution of the OSDS risk ranking scores for Hawaii Island

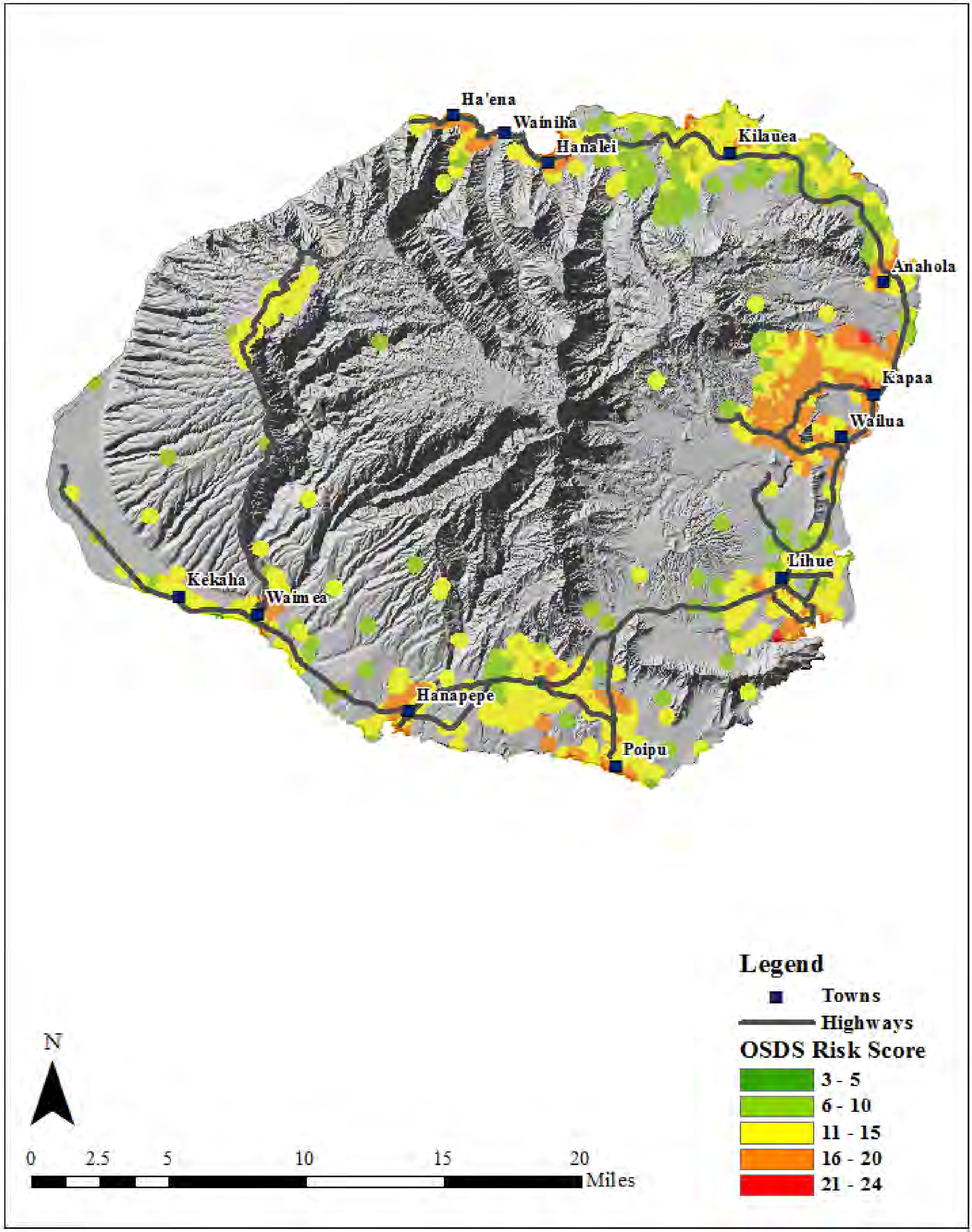

Figure ES-6. The distribution of the risk ranking scores for Kauai

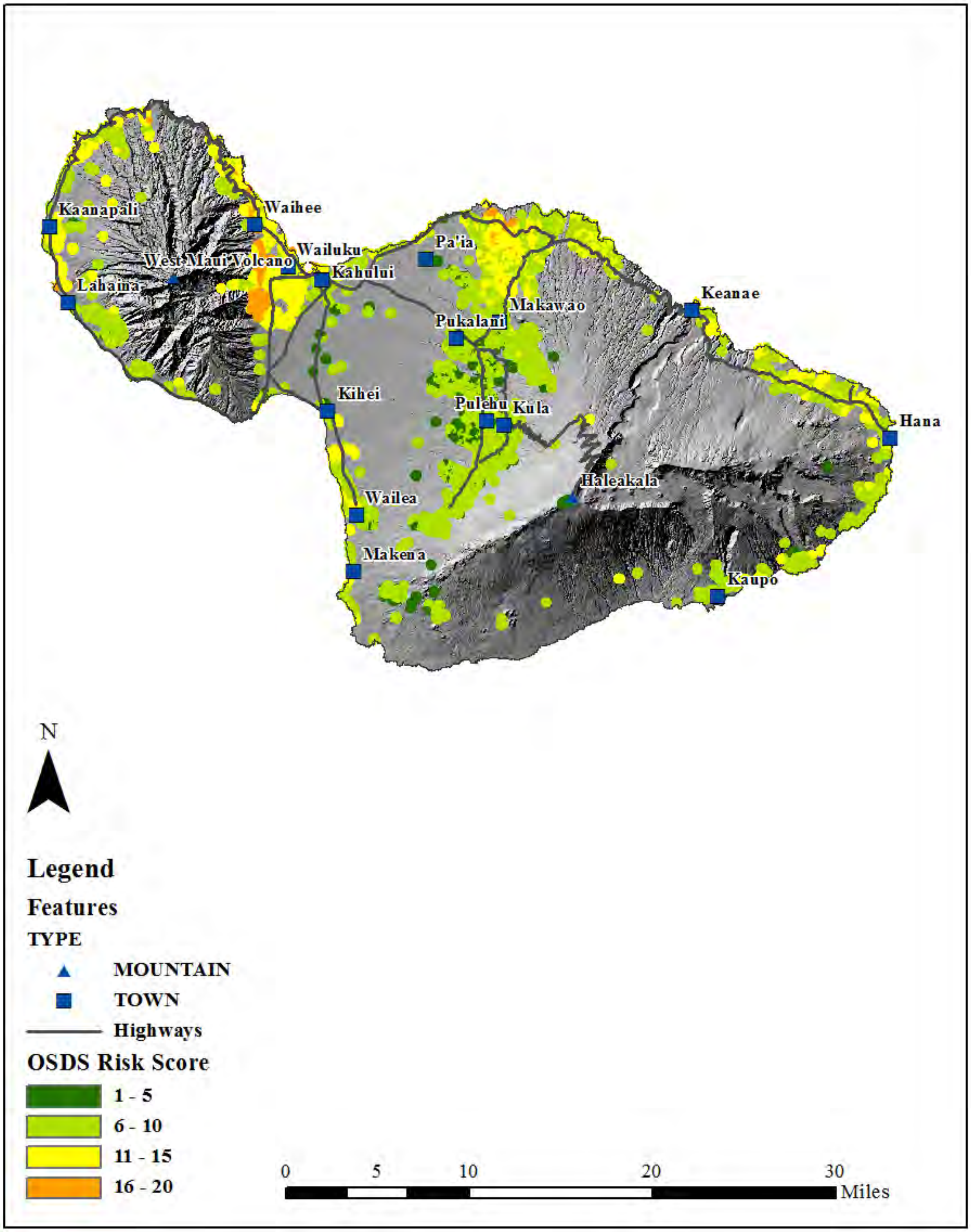

Figure ES-7. The distribution of the risk ranking scores for Maui

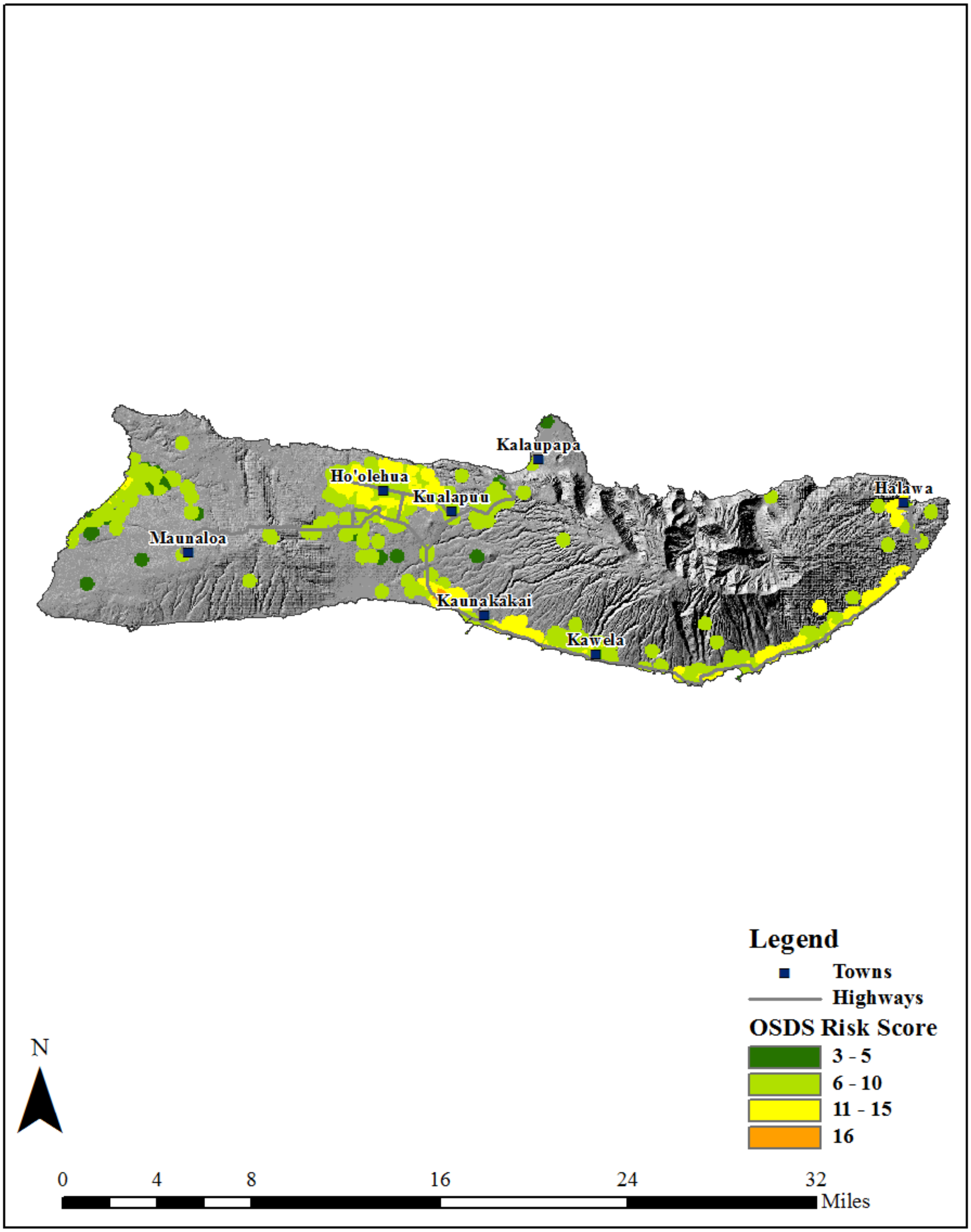

Figure ES-8. The distribution of risk ranking scores for Molokai

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ACROYNMS

CWA	Clean Water Act
CFU	Colony Forming Units
CZD	capture zone delineation
d	day
DBEDT	Department of Business, Economic Development, and Tourism
DRASTIC	USEPA index overly groundwater susceptibility to contamination model
DSDB	Dwellings and Structures Database
ft	feet
ft/d	feet per day
ft msl	feet above mean sea level
gpd	gallons per day
GIS	Geographical Information Systems
GMS	Groundwater Modeling System
HAR	Hawaii Administrative Rules
HDOH	Hawaii Department of Health
HFB	horizontal flow barrier
IWS	Individual Wastewater System
in/yr	Inches per year
KAR	Kentucky Administration Rule
kg	kilogram
kg/d	kilograms per day
mi	mile
mi^2	square mile
mgd	Millions gallons per day
mg/L	milligrams per liter
mL	milliliter
MODFLOW	Modular three-dimensional finite-difference ground-water flow model
MODPATH	A particle-tracking postprocessor model for MODFLOW
MT3D-MS	Modular Three Dimensional Transport Model - Multispecies

NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
ODGWN	OSDS derived groundwater nitrogen
OSDS	on-site sewage disposal system
OWTS	on-site wastewater treatment system
ROC	receptor of concern
SBD	Soils Database
SWAP	Source Water Assessment Program
TMDL	Total maximum daily load
TMK	tax map key
TOT	time of travel
TSSSLS	Total Septic Siting Soil Limitation Score
UIC	Underground Injection Control
USEPA	U. S. Environmental Protection Agency
USGS	U.S. Geological Survey
WRRC	Water Resources Research Center
WWTP	wastewater treatment plant
yr	year

SECTION 1. INTRODUCTION

1.1 STUDY OVERVIEW

This study estimates the number and location of on-site sewage disposal systems (OSDS) on the islands of Hawaii, Kauai, Maui, and Molokai. This study then evaluates the risks posed by OSDS to human health and the environment. The risk that OSDS pose to human health and the environment are well documented (see, e.g., Anderson et al., 1991; Calderon et al., 1991; Knobeloch et al., 2000; Morgan et al., 2007; Novello, 2000; Yates, 1985). To result in harm, the OSDS effluent must migrate from the subsurface point of discharge to a well intake or a point of discharge to surface water. To reach a point of potential human health or environmental harm, the OSDS effluent must migrate vertically to the groundwater then travel laterally to a drinking water well, stream, or coastal discharge point. The soil between the point of OSDS' discharge and the water table is the primary medium for removal of the potentially harmful constituents in the OSDS effluent (Dawes and Goonetilleke, 2003; Higgins et al., 2000; Tanimoto et al., 1968; Tasoto and Dugan, 1980). This study used soils, property tax, and hydrologic databases to compile the data needed to estimate the number and locations of OSDS, and evaluated the potential for these systems to adversely affect human health and the environment. Geographic information system (GIS) analysis and groundwater models were then used to estimate the severity and spatial distribution of the potential OSDS risk. The results of this study include the following:

- The number and distribution of OSDS;
- Distribution and relative severity of the risk that OSDS pose to critical receptors;
- The distribution the soil's relative ability to mitigate the harmful effects of OSDS effluent;
- A ranking of risk posed by OSDS to specific classes of receptors; and
- A ranking of the overall risk that each parcel with an OSDS poses to the human health and the environment.

This study will aid in prioritizing candidates for an OSDS inspection program and identifying those areas where OSDS may have the most negative impact on human health and the environment. Flexibility of the developed approach allows implementing future updates as more information becomes available.

1.1.1 On-Site Sewage Disposal Systems

Various titles are given to systems that dispose of wastewater effluent at the location where it is generated. These include individual wastewater systems (IWS) and on-site wastewater treatment systems. The title chosen by this study was on-site sewage disposal system (OSDS). As denoted in the Kentucky Administrative Rules (KAR), an OSDS is defined as (State of Kentucky, 2012)

> "On-site sewage disposal system" means a complete system installed on a parcel of land, under the control or ownership of any person, which accepts sewage for treatment and ultimate disposal under the surface of the ground. The common terms "on-site sewage system" or "on-site system" also have the same meaning. This definition includes, but is not limited to, the following:
>
> > (a) A conventional system consisting of a sewage pretreatment unit(s), distribution box(es), and lateral piping within rock-filled trenches or beds;

> (b) A modified system consisting of a conventional system enhanced by shallower trench or bed placement, artificial drainage systems, dosing, alternating lateral fields, fill soil over the lateral field, or other necessary modifications to the site, system or wasteload to overcome site limitations;
>
> (c) An alternative system consisting of a sewage pretreatment unit(s), necessary site modifications, wasteload modifications, and a subsurface soil absorption system using other methods and technologies than a conventional or modified system to overcome site limitations;
>
> (d) Cluster systems which accept effluent from more than one (1) structure's or facility's sewage pretreatment unit(s) and transport the collected effluent through a sewer system to one (1) or more common subsurface soil absorption system(s) of conventional, modified or alternative design; and
>
> (e) A holding tank which provides limited pretreatment and storage for off-site disposal where site limitations preclude immediate installation of a subsurface soil absorption system, or connection to a municipal sewer.

The State of Hawaii statutes include most OSDS in the category of IWS (Hawaii Administrative Rules [HAR] Title 11, Chapter 62, Wastewater Systems).

> "'Individual wastewater system' means a facility which is used and designed to receive and dispose of no more than one thousand gallons per day of domestic wastewater. Each individual wastewater system includes all connected plumbing, treatment (if any), and disposal components that could, if not connected, serve as separate wastewater systems."

However, this definition excludes systems that receive greater than one thousand gallons per day of effluent but dispose of the wastewater on site. Examples of these systems would be small wastewater treatment plants serving apartment buildings and hotels that dispose of the wastewater at the location it is generated.

The U.S. Environmental Protection Agency (USEPA) uses the title "Onsite Wastewater Treatment Systems" (OWTS) to refer to systems that receive, treat, and dispose of wastewater effluent at the point of generation. Specifically the definition of OWTS is as follows (USEPA, 2002):

> "A system relying on natural processes and/or mechanical components that is used to collect, treat, and disperse/discharge wastewater from single dwellings or buildings."

The above definition and that used by Kentucky do not include cesspools because in that type of system the effluent receives no treatment prior to release to the environment. Including cesspools in a study of OSDS in Hawaii is essential because that is primary method of on-site sewage disposal in this state.

This study defines an OSDS as a complete wastewater system installed on a parcel of land, under the control or ownership of any person, which accepts ultimate sewage disposal under the surface of the ground of the parcel where the wastewater is generated. In a general sense this applies primarily to cesspools and septic systems but can include small aerobic treatment systems that collect, treat, and dispose of the wastewater beneath the same parcel where the wastewater is generated.

1.2 STUDY AREA DESCRIPTION

1.2.1 Study Area Setting

This study estimated the number and distribution of OSDS and the potential risk posed on the islands of Hawaii, Maui, Molokai, and Kauai. Oahu, Lanai, and Niihau were not included for the following reasons. An OSDS inventory and risk assessment was already done for Oahu (Whittier and El-Kadi, 2009). There are very few OSDS on Lanai (J. Stubbard, 2011, personal communication). Lanai City, the population center of this island, and the two resorts areas are all served by a centralized sewer system. There are a limited number of isolated residences on Lanai's north shore that use OSDS, but most are not permanently occupied making the wastewater release to the environment negligible. Niihau has a population of 170 persons (County of Kauai, 2012) and only 27 occupied structures. Access to this island is very tightly controlled by the owners. Due to its small population and the lack of access to the island, Niihau was excluded from the study.

The four islands investigated in this study are part of the Hawaiian-Emperor Volcanic Chain in the Pacific Ocean that is approximately 3,700 miles (mi) long. The main Hawaiian Islands of Hawaii, Maui, Lanai, Molokai, Oahu, and Kauai occupy the first 400 miles of this chain (Clague and Dalrymple, 1987). Hawaii Island, Kauai, Maui, and Molokai, the four islands evaluated by this study, have a combined area of 5,582 per square mile (mi^2), accounting for 88.2 percent of the land area of the six main islands (Kauai, Oahu, Molokai, Lanai, and Hawaii) of the State of Hawaii. Although these islands account for a majority of the land area of the main Hawaiian Islands, they are much more rural compared the more developed island of Oahu. These islands have a combined population of 403,789, only 29.6 percent of the state population of 1,360,301 (Department of Economic Development and Tourism [DBEDT], 2011). These islands are more dependent on OSDS to serve their wastewater than is Oahu, the island investigated in the previous study (Whittier and El-Kadi, 2009). Figure 1-1 shows the land cover of these four islands. As the figure shows, much of these island areas are undeveloped as forest/rangeland, wetlands or barren. OSDS will primarily be present in agricultural areas and the communities on the fringe of the urban cores outside of the service zones for sewage collection systems.

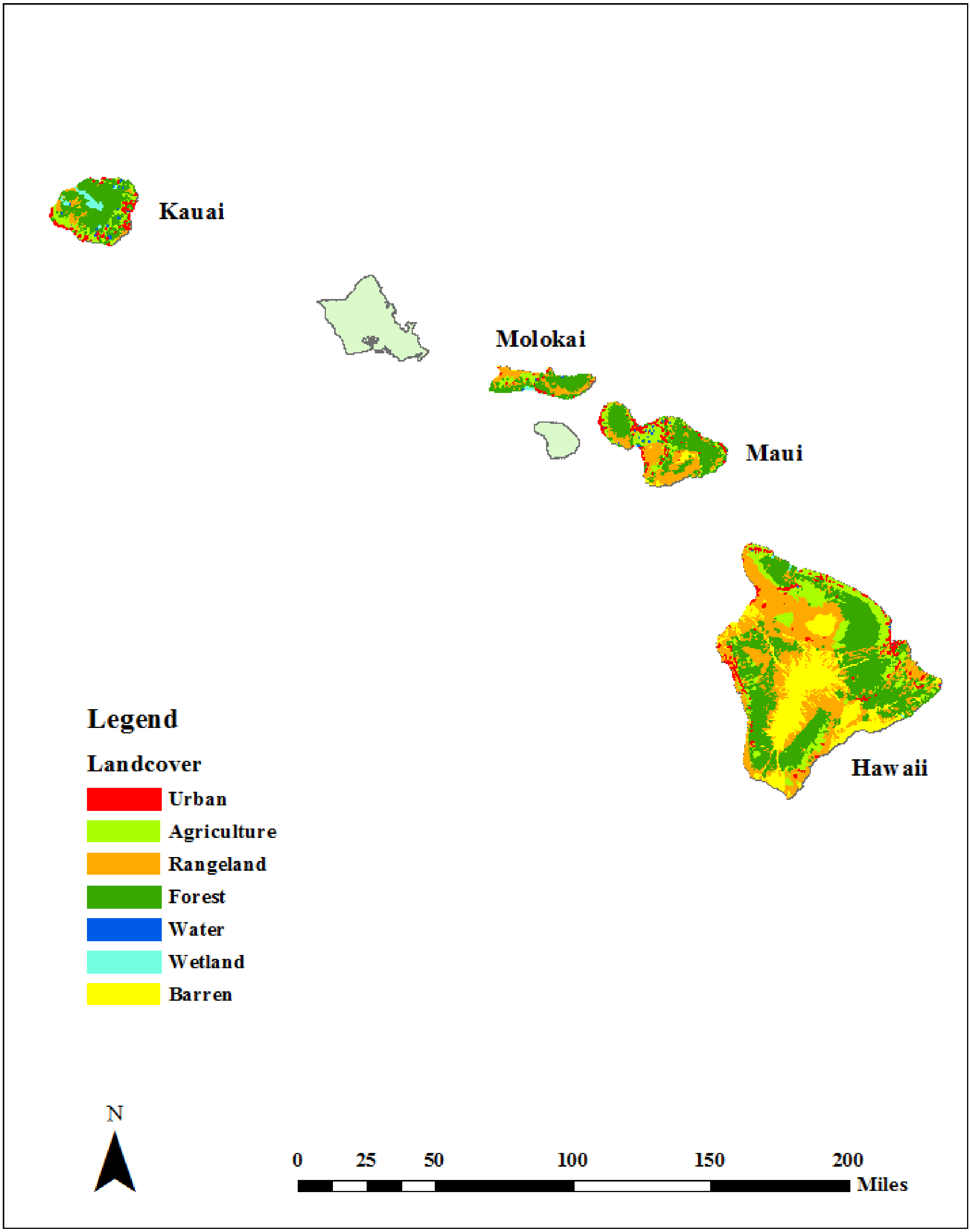

Figure 1-1. Land cover map of the islands of Kauai, Molokai, Maui, and Hawaii

1.2.1.1 Physical Setting

The State of Hawaii is part of an island arc that formed as the Pacific Tectonic Plate moved over a mid-ocean hotspot. A hotspot is a relatively stationary area of volcanic activity the exact origin of which has not been precisely defined (Stearns, 1985). As the Pacific Tectonic Plate moves over this hotspot a series of subaerial volcanoes are formed that extend from the island of Hawaii to more than 1,500 miles to the northwest (Figure 1-2). The major islands of this chain start at the Island of Hawaii. This is the southernmost (latitude of 18° 54.7') and easternmost island (longitude of 154° 48.3') in the chain. The island of Kauai is the northernmost (latitude of 22° 14') and westernmost (longitude of 159° 47.4') of the islands included in this study. However, the island chain actually extends westward well beyond Kauai to an island chain referred to as the Northwest Hawaiian Islands. The subaerial islands extend to the west northwest to the Kure Atoll, which is located at a latitude of 28° 25' N and 178° 20' W. Past Kure Atoll, cessation of volcanic activity, erosion, and subsidence beneath the ocean surface have reduced the volcanoes to seamounts (Moore, 1987). These seamounts extend to the northwest and disappear just east of the Kamchatka Peninsula of Russia where the Pacific Plate is subducted beneath the Asian Plate (Clague and Dalrymple, 1987).

The evolution from an island to a seamount results from the intensity of the volcanic activity relative to the island’s position over the hotspot. The volcanic activity is greatest in that portion of the Hawaiian Island Chain that is located over the hotspot. Voluminous amounts of lava are extruded that are sufficient to bring the ocean floor from depths exceeding 10,000 feet (ft) to above the sea surface (Clague and Dalrymple, 1987). The volcanic activity persists after the first emergence of the new island above the ocean surface, giving rise to volcanic mountains that can exceed 10,000 ft above mean sea level (ft msl). The cumulative bulk of the erupted lava depresses the Earth’s crust into plastic mantle and asthenosphere. Once an island moves past the hotspot the volcanic activity subsides and eventually ceases. However, the subsidence of the island continues. This results in a general trend of deceasing island area and decreasing summit elevations going from the southeast to the northwest of the island arc (Clague and Dalrymple, 1987; Stearns, 1985). Eventually, due to subsidence and erosion the summit of the islands sink below the sea surface. Coral growth retards the submergence of the island but that rate of growth is less than the rate of subsidence. Eventually the subsidence dominates over the coral growth and the former island becomes a deep seamount.

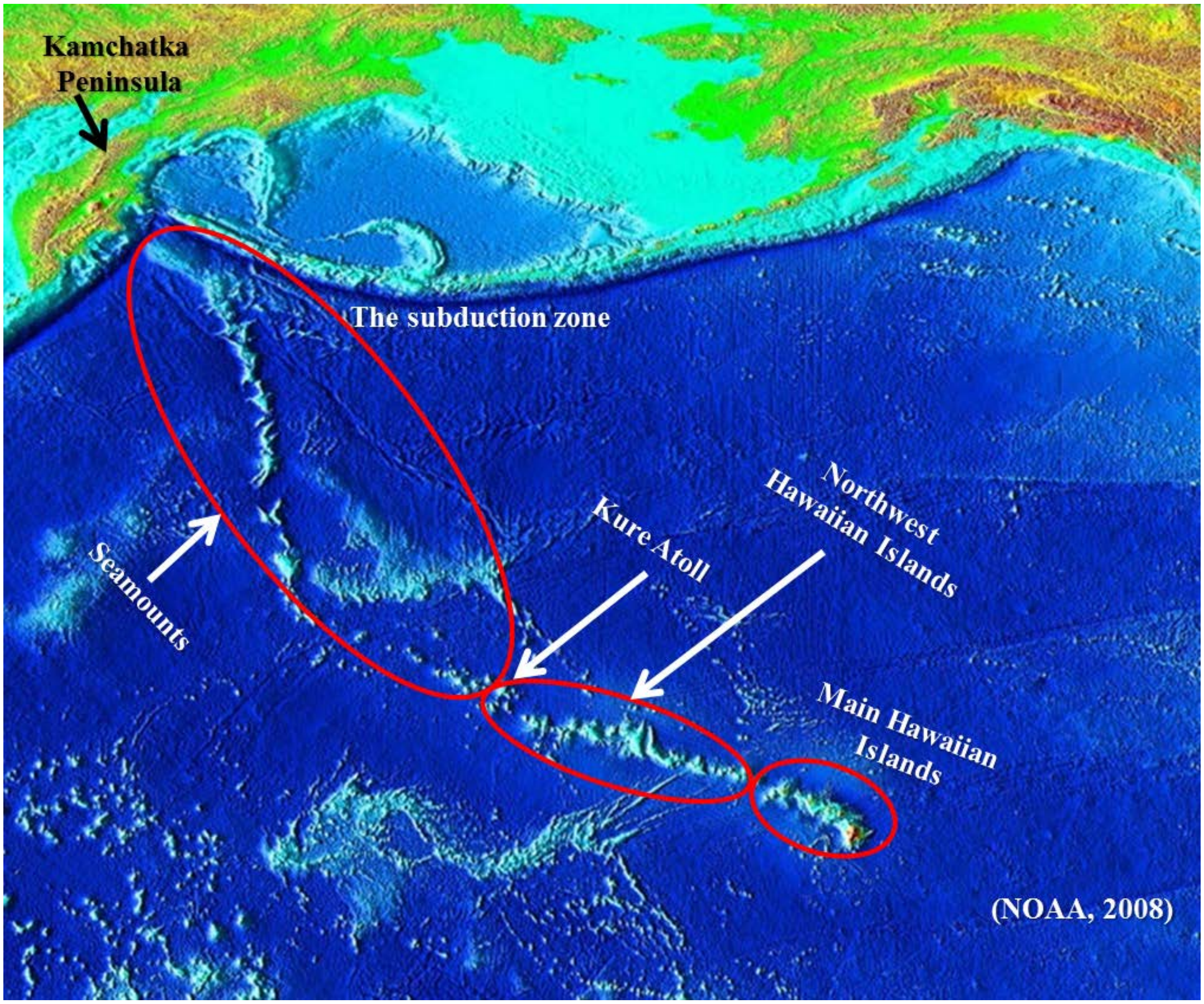

Figure 1-2. The Hawaiian-Emperor Volcanic Chain extends from the Main Hawaiian Islands to the subduction zone near the Kamchatka Peninsula

1.2.1.2 Hydrologic Setting

1.2.1.2.1 Rainfall

The State of Hawaii falls in the upper reaches the northern tropical zone, which is defined as being south of the Tropic of Cancer but north of the Equator. In this zone, an upper atmospheric circulation known as the Hadley Cell moves air from the equatorial region upward, where it cools and descends as cool, dry air at about 30° North Latitude. At ground elevations, the air currents move in an oblique direction from northeast to southwest back toward the equator. This results in a dominant northeast wind direction known locally as the northeast tradewinds (Schroeder, 1993). These air currents move across the ocean surface picking up moisture. Upon encountering windward facing slopes of the Hawaiian Islands, the moisture laden air is lofted upward and begins to cool. This adiabatic cooling decreases the moisture holding capacity of the air, resulting in a zone of cloud formation that usually begins at an elevation of 2,000 ft msl and ends at elevations ranging from 8,000 to 10,000 ft msl. The lofting of moist air is interrupted by the cool and dry descending air of the Hadley Cell. This forms a temperature inversion where a temperature increase occurs at an elevation from about 8,000 to 10,000 ft msl capping the zone of cloud formation at these elevations. This capping, called the tradewind inversion, generally limits the tradewind-derived precipitation to elevations below 8,200 ft msl (Giambelluca and Nullet, 1991). Another wind condition known locally as “Kona Winds” occurs when upper atmospheric disturbances north of Hawaii propagate southward and into the lower atmosphere producing large storms in Hawaii (Otkin and Martin, 2004; Schroeder, 1993). This results in more intense storms that form at a higher elevation. The leeward regions of the Hawaiian Islands get most of their precipitation from these storms (Otkin and Martin, 2004; Schroeder, 1993).

The combination of prevailing tradewind flow from the northeast and the high topographic relief of the islands produces a dramatic variation in the rainfall amounts for a given island. Figure 1-3 shows the annual rainfall distribution for the islands assessed by this study. The northeast facing slopes of all islands intercept the moisture laden air and form zones of high precipitation that extend from the elevation of cloud formation at about 2000 ft msl to the elevation of the tradewind temperature inversion.

The dominant wind direction, high topographic relief, and temperature inversion layer result in dramatic variations in rainfall over relatively short distances. Figure 1-3 clearly shows the rain shadow effect on the leeward slopes of all of the islands. The windward (northeast facing) slopes of all the islands in this study have significantly more rainfall than the leeward (southwest facing) slopes. The rainfall contrast between the windward and leeward slopes is very evident on Hawaii Island. Figure 1-4 shows the rainfall distribution for Hawaii Island and the 2,000 and 8,000 ft elevation contours that delineate the approximate zone of cloud formation on the windward slopes of this island. The annual rainfall for the most of the northeast facing slopes is 150 inches per year (in/yr) or more compared to 50 in/yr year or less for the entire western half of island. The zone of cloud formation can be seen in the rainfall distribution on the island of Hawaii where the slopes of Mauna Kea and Mauna Loa extend well above the 8,000 ft msl temperature inversion elevation. The rainfall above this zone of cloud formation is less than 50 in/yr. The upper elevation rainfall value is 96 percent lower than the maximum annual rainfall rate on the northeast facing exposure of this island within the zone of cloud formation. On windward facing slopes between 8,000 and 2,000 ft msl, the annual rainfall varies from 50 to nearly 400 in/yr. On the islands with summits less than 8,000 ft, the rainfall maximums occur near the maximum elevations. The summits of the islands of Kauai and Molokai as well as the West Maui Mountain are below the temperature inversion. On these islands a positive correlation exists between rainfall and elevation.

1.2.1.2.2 Hydrogeology

More pertinent to this study are the hydrologic processes that occur at and beneath the earth surface. The disposal of OSDS effluent is a subsurface process. It is the subsurface movement of water that transports the effluent and its undesirable constituents from the point of origin to areas where it can negatively impact human health or the environment. This process starts with rainfall. When rainfall encounters the ground surface it partitions between evaporation, where water is returned to atmosphere as vapor; transpiration where water extracted by plants is returned to the atmosphere as vapor; direct runoff to surface streams; storage in the soil; and the water that infiltrates to the water table as groundwater recharge. The recharge resulting from the infiltrating rainwater is supplemented by anthropogenic sources (irrigation, OSDS discharge, and infiltration ponds for example) and by recharge from other natural sources (fog condensation and streambed infiltration for example).

The infiltration that exceeds the soil moisture storage capacity reaches the water table as groundwater recharge. Generally the recharge patterns follow the rainfall patterns in that areas with higher rainfall have higher recharge due to the greater abundance of rainfall and low intensity of sunlight due to rain producing clouds. For example at the high rainfall elevations on the northeast facing slopes of the island of Hawaii recharge is about 300 in/yr, while in the very low rainfall areas of the west coast of this island recharge is less than 5 inches per year (Engott, 2011). Section 4 provides the recharge distribution for islands assessed in this study and also shows the potential influence that OSDS have on the quality of this recharge.

Fresh groundwater in Hawaii exists in three primary occurrences: high-level groundwater (normally occurring in dike intruded zones); groundwater perched on ash or soil layers; and basal groundwater floating on denser saltwater. Figure 1-5 (from Gingerich and Oki, 2000) shows a hydrogeological cross-section of Oahu. This cross-section is representative of the hydrogeology of many of the Hawaiian Islands. The high-level groundwater is impounded to high elevations by the poorly permeable dikes that are pervasive in the volcanic rift zones of the Hawaiian Islands. Dikes are sheet-like structures of lava that solidified during the vertical migration from the deep magma chamber to the ground surface. Due to the low permeability of dikes, the groundwater in dike intruded areas must be at a high elevation relative the basal groundwater to induce a sufficiently high hydraulic gradient to force the water to flow out of dike zone in the flank lava areas.

Another occurrence of high-level groundwater is that groundwater perched (Figure 1-5 detail F) above the main aquifer. In the high recharge areas perched water exists where near horizontal structures of low permeability such as soil or ash layers retard the downward infiltration of groundwater. The groundwater on top of these formations must develop a sufficient saturated thickness for that the downward rate of percolation to equal to rate of infiltration. The thickness and the persistence of perched water can provide exploitable groundwater sources. In the Kohala area of Hawaii Island groundwater perched on the pervasive Pahala Ash formation provides water in the form of springs or water development tunnels that have been used for agriculture and municipal water supplies (Stearns and MacDonald, 1946). Perched water can also act as a barrier between the groundwater surface and the main aquifer. Infiltrating can be captured by perched and diverted back to the surface at spring discharge points rather reaching the main aquifer

Once the groundwater flows out of the high-level water body, it becomes a lens of freshwater floating the underlying saltwater with a water table elevation of less than a few tens of feet above sea level. The Ghyben-Herzberg principal states that the thickness of the freshwater lens is much greater than the elevation of the water table above sea level due to the density difference between saltwater and fresh water (Freeze and Cherry, 1979). This is only an estimate because the actual thickness of the freshwater lens can deviate from this value due to factors such as non-horizontal flow and heterogeneous geology (Izuka and Gingerich, 1998). Figure 1-5 shows the freshwater lens separated from the saltwater by a mixing zone of freshwater with the underlying seawater as the groundwater flows to coastal discharge points. This mixing is referred to as the freshwater/salter transition or just the transition zone. The mid-point of the freshwater/saltwater transition zone is estimated by the Ghyben-Herzberg Principle to be at or near a depth that is 40 times the elevation of the water table. The freshwater lens thins as the distance to the coast decreases. Near the shoreline, the groundwater may encounter sedimentary deposits and formations that retard its flow. These formations, referred to collectively as caprock, have an effective hydraulic conductivity that is significantly lower than that of thin-bedded lavas. This results in a thicker freshwater lens due to the higher water table that is required to push the groundwater through the caprock to submarine discharge points. The caprock also acts as a barrier that retards saltwater intrusion into the aquifer. Whether the groundwater flow is retarded by caprock or has a free flow path to the ocean, groundwater not discharged to surface water or extracted by wells is eventually discharged into the ocean.

The water transport characteristics of the various aquifer materials vary greatly along the flow path. The hydraulic conductivity of the dike-intruded lavas in Hawaii is estimated to range from 1 to 500 feet per day (ft/d) (Hunt, 1996). The low end of this estimate would be more representative of the permeability of the volcanic rift zones due to the high density of dikes. In his groundwater model of West Hawaii, (Oki, 1999) used hydraulic conductivities that ranged from 0.1 ft/d to 10 ft/d for the dike-intruded lavas of Hualalai. There also is a large contrast in the hydraulic conductivity of the flank lavas outside of the rift zones. In a groundwater model of West Maui, Gingerich (2008) assigned a horizontal hydraulic conductivity of 2,097 ft/d and a vertical hydraulic conductivity of 10.5 ft/d to the thin-bedded Wailuku Basalts in the Lahaina area. More massive lavas such as the Honolula Volcanics in West Maui are poorly permeable. Gingerich (2008) used a hydraulic conductivity of 0.08 ft/d for this formation. However, most of the flank lavas in the Hawaiian Islands are very permeable and have hydraulic conductivities in hundreds or thousands of ft/d. The very permeable nature of the lavas that make up these islands favor faster groundwater flow velocities increasing the distance OSDS impacted groundwater can travel before pathogens die-off or contaminants can degrade to the point where they become benign.

1.2.1.2.3 Surface Water Hydrology

Stream flow is driven by the direct runoff component of rainfall and discharge of groundwater to springs that feed the streams. Hawaii streams typically have small catchment areas with steep slopes. This makes streams “flashy” during stormy periods where stream flow can increase from a trickle to flood stage in a short period (Oki, 2003). During floods the streams may overtop their banks flooding the adjacent fluvial plain. OSDS located in the flood zone can become inundated, forcing the effluent to ground surface.

In Hawaii streams are commonly perennial in the upper elevations. This is due to the abundant rainfall and, in many instances, the discharge of groundwater to the surface. In the volcanic rift zones, the dike impoundment of the groundwater is breached in areas where erosion has cut deep valleys and subterranean water discharges to the surface providing sustained stream flow. In other areas the groundwater is perched on poorly permeably layers such as volcanic ash or massive lavas. Where this occurs, such as the north slope of Haleakala, the groundwater again discharges to the surface (Gingerich, 1999a and 1999b). The discharge of groundwater to surface water sustains the stream's base flow. From a resource and environmental perspective this is importance because base flow maintains stream flow during periods of little or no rain. In the lower reaches, the streams are often ephemeral and lose water to streambed infiltration, evaporation, and diversions. Near the coast, streams can again become perennial due to the streambed elevation being lower than the water table. The Pololu Stream on Hawaii Island is such case with the stream gaining reaches in the upper elevations, followed by ephemeral reaches until just before the coast where groundwater discharge reestablishes the stream flow (Presley, 1999). Other pathways for subsurface water to enter streams are from bank storage and subsurface storm flow. Water from the stream infiltrates into the stream banks and flows out into the fluvial aquifer beneath the fluvial plain. This water is known as bank storage. During times of falling stream stage, water from the stream banks and adjacent areas will flow back into the stream channel. Subsurface storm flow is rain water that infiltrates into the shallow subsurface during storms and flows laterally to streams in the more permeable upper horizons of the soil. Any OSDS effluent in the bank storage water or entrained in the subsurface storm flow can deliver pathogens or nutrients to the stream. This increases the risk to human health and may result in undesirable aquatic plant growth due to the increased nutrient load.

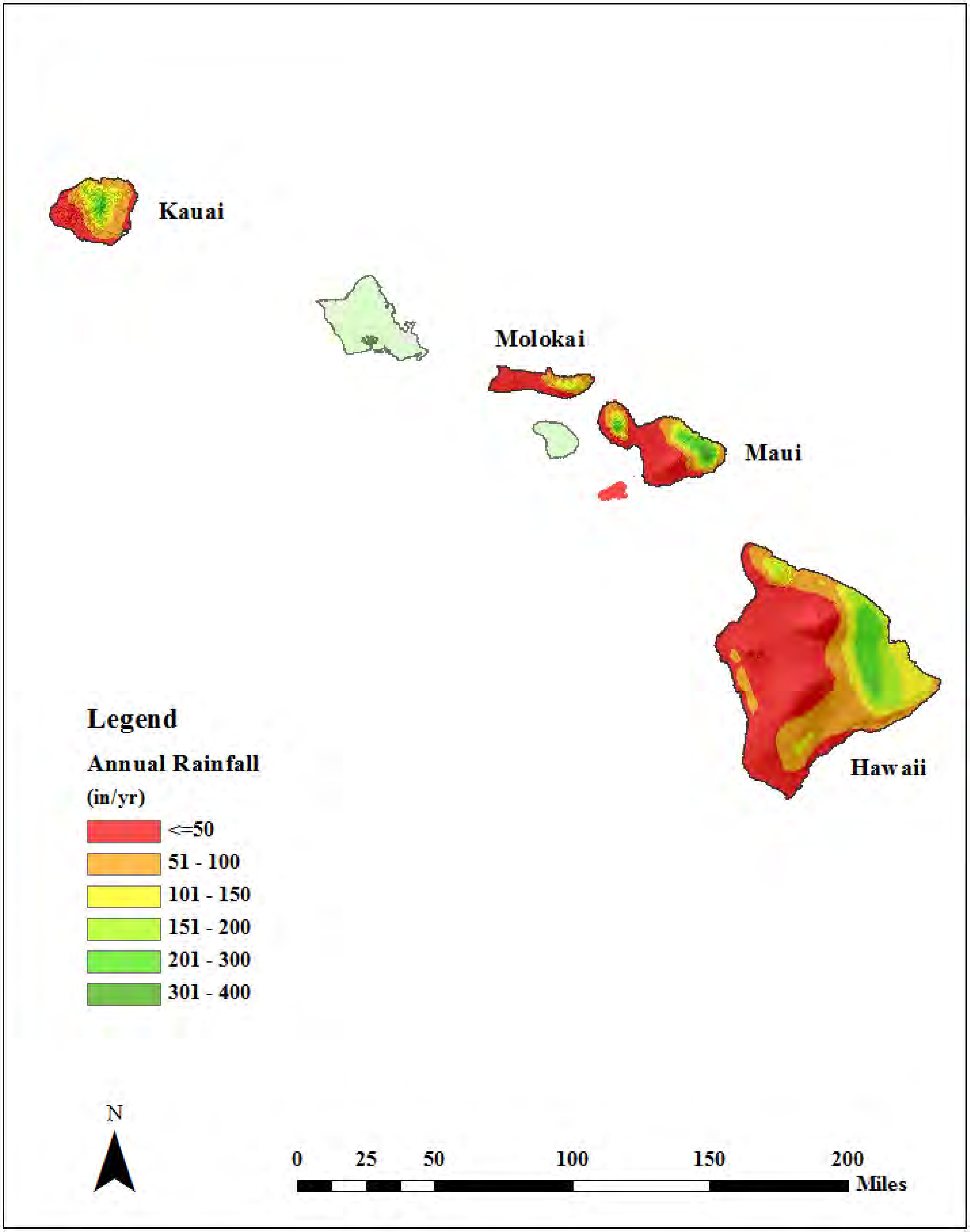

Figure 1-3. Rainfall distribution for the islands of Kauai, Molokai, Maui, and Hawaii (from Giambelluca et al., 2011)

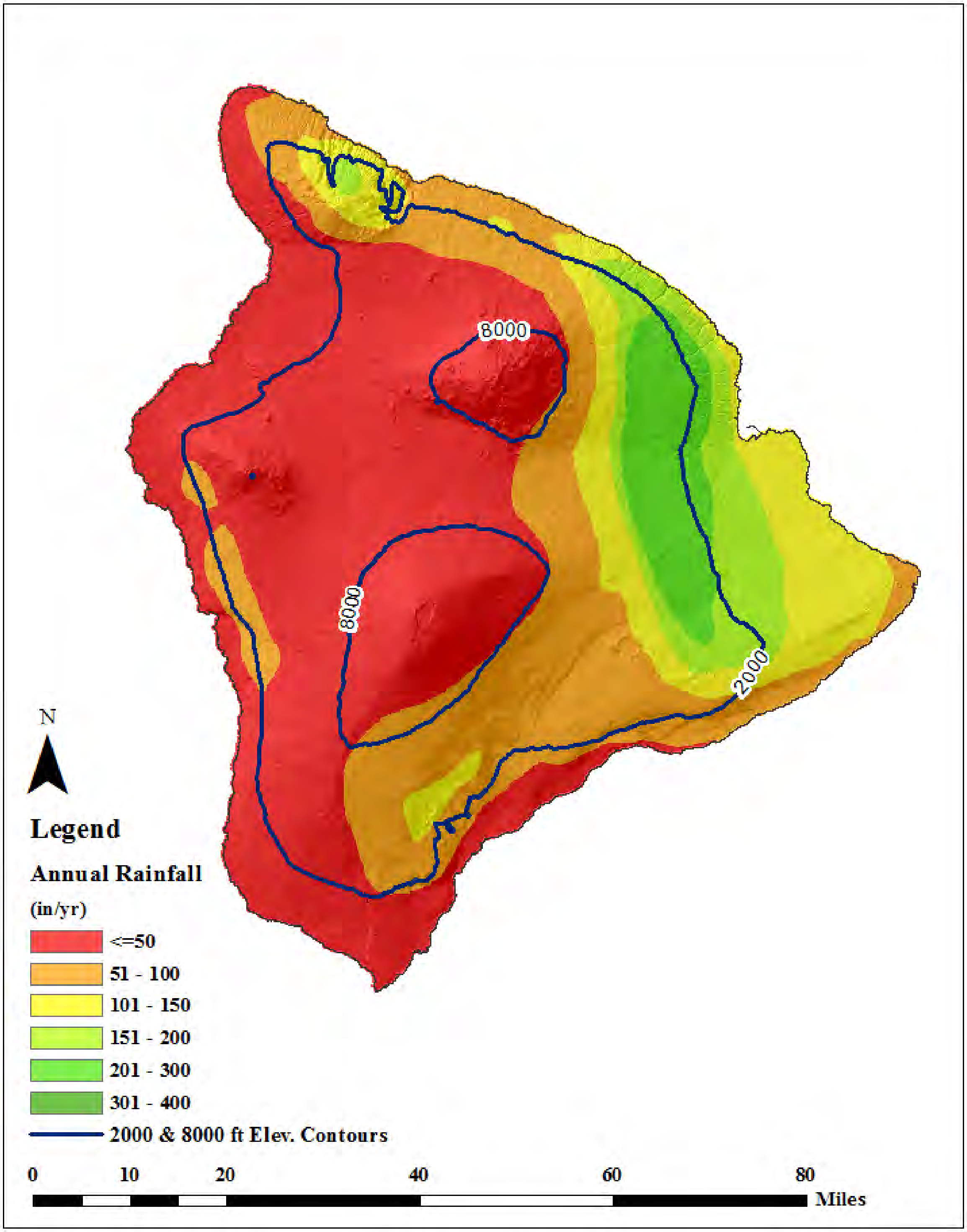

Figure 1-4. A rainfall map of the Island of Hawaii showing the 2,000 and 8.000 ft elevation contours that approximate the zone of cloud formation

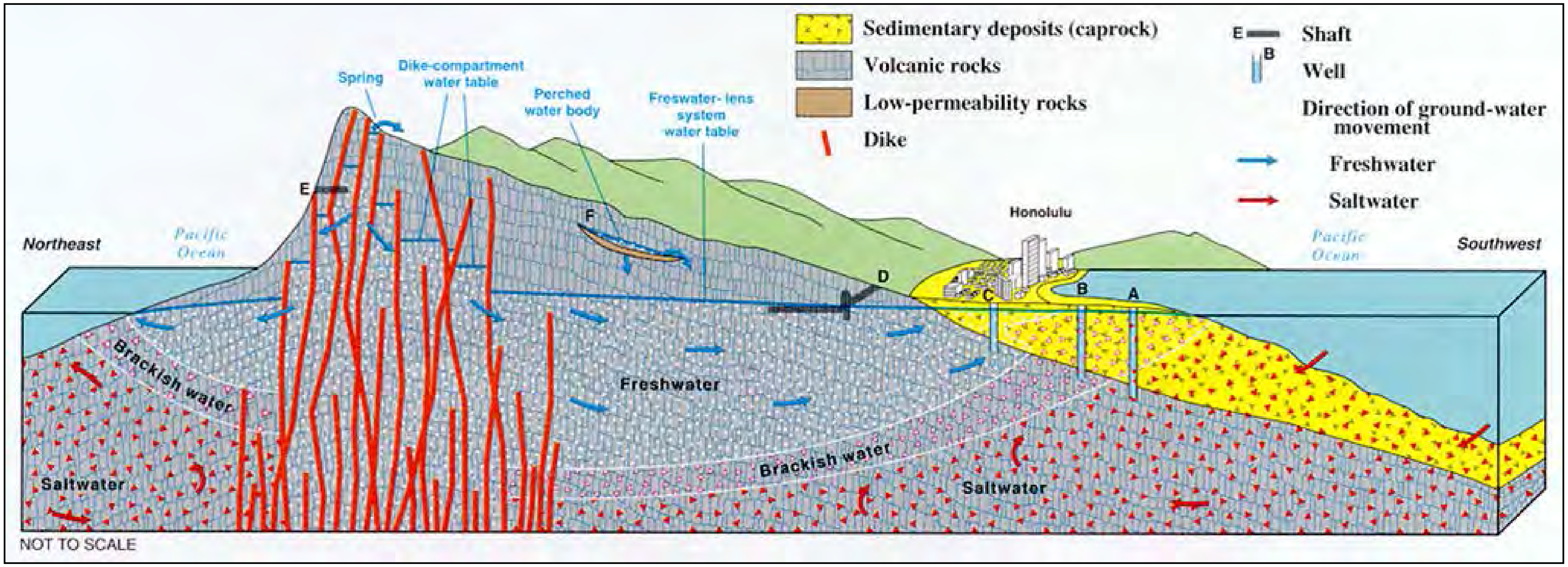

Figure 1-5. A hydrogeologic cross-section of Oahu showing dike impounded, perched, and basal groundwater (Gingerich and Oki, 2000)

1.3 STUDY OBJECTIVES

The objectives of this study were as follows:

1. Estimate the quantity, location, and types of OSDS on the islands of Hawaii, Kauai, Maui, and Molokai;
2. Estimate the effluent load added to the environment by these systems;
3. Identify and map the factors influencing the risk posed by OSDS to the environment and to human health;
4. Evaluate the potential risk to the receptors of concern (ROC) that may be impacted by OSDS;
5. Develop a scoring system to map the severity and distribution of OSDS risk factors for each class of ROCs; and
6. Based on the ROC scoring results, compute an overall risk score to rank the severity of the risk posed by individual OSDS.

The objectives are met by:

- Completing an inventory to estimate the quantity, characteristics, and location of the OSDS (Section 3);
- Modeling the impact to the groundwater OSDS effluent discharge OSDS (Section 4);
- Using GIS to map the spatial distribution of the hydrologic factors that affect the vulnerability of the human and environmental receptors to OSDS contamination (Sections 4, 5, 6, and 7); and
- Linking the OSDS locations to the OSDS risk factors to compute a relative risk-ranking score for each OSDS parcel.

This study's outcome can be used by planning and regulatory agencies to set policy regarding OSDS, delineate those areas most suitable for locating OSDS, and identify the most likely areas where OSDS effluent is creating negative impacts.

SECTION 2. OSDS AND THEIR RISK

This section describes the types, effluent chemistry, and discharge rates of OSDS. The potential risk posed by these systems to the environment and human health are also discussed. Prior to this study, there was no central database that detailed the number, types, and locations of OSDS. This study linked existing OSDS databases, sewer infrastructure data, and dwelling structure databases to create a detailed OSDS location listing for the islands of Kauai, Maui, Molokai, and Hawaii. The volume and chemistry of the OSDS effluent was estimated based on structure characteristics or use, and the type of treatment the effluent is subjected to. The primary purpose in developing this OSDS database is to evaluate the potential environmental and health impacts that result from onsite disposal of wastewater.

2.1 OSDS IN HAWAII

The Water Resource Research Center (WRRC) of the University of Hawaii noted that a 1999 survey by the Hawaii State Department of Health estimated that there were over 176,000 OSDS in Hawaii. Of those, only about 4,500 were septic systems with the remainder being cesspools (WRRC and Engineering Solutions, 2008). This study updates this previous work and does a more comprehensive assessment of OSDS type, location, and potential impact to human health and the environment.

2.2 OSDS TYPES

Residences and other structures that have a bathroom must deal with the wastewater produced. If there is no connection to a sewage collection system, then the wastewater must be disposed of on-site. WRRC and Engineering Solutions (2008) list the types of OSDS by the effluent treatment and disposal characteristics. For this study the OSDS types were placed in four classes based on effluent quality as determined by the level of treatment provided and disposal method used.

Table 2-1. OSDS Classes and Corresponding IWS and Disposal Type

OSDS Class	IWS and Disposal Type
Class I	Any system receiving soil treatment. This includes disposal types listed as bed, trench, and infiltration/chambers.
Class II	Septic systems discharging to a seepage pit. The effluent receives primary treatment only.
Class III	Aerobic units discharging to a seepage pit. The effluent receives primary and secondary treatment.
Class IV	All cesspools where the effluent receives no treatment.

Note: A seepage pit is a dry well that disperses effluent from septic tanks. The effluent receives no treatment other than settling of solids that occurs in the septic tank

Note: A seep pit is a dry well that disperses effluent from septic tanks. The effluent receives no treatment other than settling of solids that occurs in the septic tank

2.3 EFFLUENT QUALITY AND DISCHARGE RATE ESTIMATION

2.3.1 OSDS Discharge Estimation Method

The risk that OSDS poses to the human health and the environment is strongly influenced by the rate of effluent discharge. Therefore, it is critical in any risk evaluation to quantify the amount of effluent being released to the environment. The OSDS effluent discharge rate was estimated using the residential dwelling characteristics or by the type of activity occurring at non-residential parcels. For residential units, guidance was provided by HAR Title 11, Chapter 62, which estimates an effluent rate of 200 gallons per day (gpd) for each bedroom served by the OSDS. The daily effluent rate was calculated by multiplying the number of bedrooms per structure, from the IWS and Dwellings and Structures Databases (DSDB), by 200 to get a daily effluent rate. OSDS effluent discharge rates for systems serving non-residential structures needed an alternative method estimation method. These non-residential activities included businesses, churches, schools, parks, and condominiums. The effluent rate for schools was taken from Metcalf and Eddy (1991), who estimated a typical daily rate of 25 gpd per student for schools with a cafeteria and gym, and 15 gpd per student for schools with a cafeteria only. The number of students in the schools was taken from official enrollment counts (Hawaii Dept. of Education, 2012). Obtaining effluent rate estimates for the remaining large capacity units was very difficult, but representative values were assigned based on best estimates of the number of people using the facilities. For example, a large church was estimated to produce 540 gpd of effluent. This assumes that the church will only be occupied for one-half day twice a week. The rate per person given in Metcalf and Eddy (1991) for an assembly hall is 3 gpd per person. Table 2-2 lists the respective activities and estimated effluent discharge rates for each.

Table 2-2. Estimated Effluent Discharge Rate of Large OSDS by Activity

Activities With Large Disposal Units	Estimated Effluent Rate Range (gpd)	Rate Used (gpd)		
		Small	Med.	Large
Baseyards	195 -390	228	293	357
Businesses	130 – 4,590	873	2,360	3847
Cemeteries	1,200 – 2,400	1,400	1,800	2,200
Churches	540 – 2,600	883	1,570	2,257
Golf courses	540 – 1,080	630	810	990
Government Organizations	240 – 2,200	667	1220	1873
Non-profit Organizations	240 – 2,200	667	1220	1873
Non-profit Organizations With Showers	1,825 – 2,500	1,938	2,163	2,388
Parks	200 – 800	300	500	700
Schools Without Gyms	600 – 5,640	1,440	3,120	4,800
Schools With Gyms	12,625 – 42,425	17,592	27,525	37,458

From Eddy and Metcalf (1991)

2.3.2 OSDS Effluent Chemistry

The mass of nutrients reaching surface or coastal waters determines the degree of impact on the receiving bodies. The risk to human health is driven by the concentration and types of contaminants in OSDS impacted drinking water. It is beyond the scope of this study to evaluate all of the contaminants in the OSDS effluent. Nitrogen and phosphorous were selected as OSDS constituents of concern based on the risk to the environment, common occurrence in effluent, toxicity, and inclusion in analyses of water samples. Of the two primary nutrients considered, nitrogen is used as the primary species to evaluate risk. This approach was taken because nitrogen can be a limiting nutrient in aquatic and marine waters and due to the conservative nature of nitrate in oxic waters it is an ideal tracer of OSDS impact. The nitrogen and phosphorus concentrations were estimated using data from WRRC and Engineering Solutions, Inc. (2008). The concentrations were then multiplied by the estimated effluent rate to compute the flux of these two constituents. Table 2-3 lists the effluent characteristics by OSDS type.

Table 2-3. Effluent Characteristics of OSDS Classes

(WRRC and Engineering Solutions, 2009)

OSDS Class	**Typical Nitrogen Concentration** (mg/L as nitrogen)	**Typical Phosphate Concentration** (mg/L as phosphorus)	**Typical Fecal Coliform Concentration** (colony forming units [CFU]/100 mL)	**Table or Page Number** (WRRC and Engineering Solutions, 2009)
Class I, Soil Treatment	1	<2	13	Table 4-1, page 4-6
Class II, Septic tank to Seepage Pit	39-82	11-22	1-100E+06	Table 4-1, page 4-6
Class III, Aerobic treatment to Seepage Pit	7-60	2-18	1.00E+06	Page 5-19
Class IV, Cesspools	15-90	5-20	1-100E+06	Table 4-1, page 4-6

CFU – colony forming units

mg/L – milligrams per liter

mL – milliliter

2.4 OSDS REGULATIONS

The goal of government regulation and oversight is to ensure the protection of human health and the environment from any negative impacts resulting from the subsurface disposal of wastewater. OSDS fall under both state and federal regulations. In many cases the enforcement of regulations is left to the states with oversight provided by federal government.

2.4.1 State of Hawaii Regulations

In the State of Hawaii IWS are regulated by HAR, Chapter 62, Title 11. Subchapter 3 specifically addresses IWS and this regulation establishes that: the minimum lot size served by an IWS is 10,000 ft^2; the effluent discharge should not exceed a rate of 1,000 gpd; and the residential development should not exceed fifty single family residential lots or dwelling units. Also included in this statute are engineering standards such as percolation test rates and the minimum depth of the soil profile. A permit from the State of Hawaii Department of Health is not required to construct an IWS, but the unit must be registered. Also the design must be approved by a licensed professional engineer (PE) prior to construction, and inspected and approved by a PE after construction. The actual permit for an IWS is part of the respective county building permit process, but a signature from Hawaii Department of Health (HDOH) must be obtained for the building permit. Units that are larger than an IWS but dispose of the effluent on site must get an Underground Injection Control (UIC) permit and thus are also regulated by the USEPA and the State of Hawaii. Large capacity cesspools are no longer allowed so wastewater disposal systems larger than an IWS require treatment of the effluent before it is discharged to the environment.

The Safe Drinking Water Branch of HDOH regulates the underground injection of wastewater under HAR Title 11, Chapter 23 – Underground Injection Control. This rule regulates OSDS that utilize a seepage pit or similar disposal method serving more than one residence and having a daily load greater than 1,000 gpd. The majority of OSDS are exempted because they are for a single residence. Sewage injection wells are classified as Class V, Subclass A if they inject into an underground source of drinking water or Subclass AB if they inject into an exempted aquifer. An exempted aquifer is not considered an underground source of drinking water. The exempted aquifers are commonly coastal zones where the chloride or total dissolved content in the groundwater is too high for use as drinking water. The portion of the aquifer that is exempted is seaward of a UIC line delineated by HDOH. Since July 6, 1984 no new Subclass A injections wells are allowed. Also, such an injection well is not permitted within one-quarter mile of a drinking water source. Thus to be permitted, a sewage injection well will only be allowed seaward of the UIC line restricting this disposal method to coastal areas.

OSDS are not allowed to discharge directly to surface waters. Regulations promulgated under the Clean Water Act, such as the National Pollutant Discharge Elimination System have discharge requirements more stringent than OSDS can meet. More specifically, the engineering requirements in HAR Chapter 62, Title 11-Wastewater Systems only allows subsurface discharge of OSDS effluent. However, the Clean Water Act (CWA), Section 303 directs states to establish water quality standards and implementation plans to meet those standards for streams and coastal water bodies that exceed those standards. To meet this requirement total maximum daily load (TMDL) standards are set for water bodies not in attainment. When effluent contaminated groundwater discharges to surface water, this process will add to the TMDL of the surface water body. OSDS operational changes and/or removal may be required to reach attainment of TMDL levels. There are 88 stream segments and 225 marine segments listed under the State of Hawaii CWA, Section 303 as not meeting water quality standards (HDOH, 2013). Excessive nutrient levels were a factor in the majority of the stream segment listings. OSDS impacted groundwater discharging to these surface water bodies will increase the TMDL and need to be considered in any management plan.

2.4.2 Federal Regulations

2.4.2.1 Coastal Zone Management Act

The Coastal Zone Management Act of 1972 encouraged states to develop and implement coastal zone management plans. Section 6217(b) of the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 requires that state coastal nonpoint pollution control programs provide for the implementation, at a minimum, of management measures in conformity with guidance published by the National Oceanic and Atmospheric Administration (NOAA) and the EPA. Hawaii's 6217 management area includes all lands of the State and the area extending seaward to the limit of the State’s power and management authority, including the U.S. territorial sea. The program must be sufficient to control the land and water uses that have or are reasonably expected to have a significant impact on the coastal waters of Hawaii. Each participating state must develop coastal zone management plans that include provisions for new OSDS siting, design, and installation in order to protect surface waters. This requires that OSDS be sited, designed, and installed so the impact to water bodies will be reduced to the extent practicable. This includes not siting conventional OSDS in areas where the soil adsorption is inadequate to remove nitrogen, phosphorus, pathogens, and non-conventional pollutants.

2.4.2.2 Underground Injection Control

Federal regulations control decentralized systems serving 20 or more people. These systems, if disposing of effluent underground, are regulated by the UIC Program, 40 CFR 146, 147, and 148. The UIC program, as part of the Safe Drinking Water Act of 1974, prevents contamination of underground sources of drinking water by establishing specific requirements for underground injection of wastes. All large capacity systems are required to treat the effluent prior to disposal. On April 5, 2000 the USEPA banned new large capacity cesspools and effective April 5, 2005 a ban on existing large capacity cesspools went into effect. The USEPA Region 9 (USEPA, 2010) defines a large capacity cesspool as a sanitary wastewater disposal system with human wastes that:

- has an open bottom and/or perforated sides;
- serves multiple domestic dwellings (this includes a duplex, single family dwellings with an ohana unit, apartments and condominiums); or
- serves a non-residential location with the capacity to serve 20 or more persons per day.

2.5 RISKS POSED BY OSDS

The effluent discharged by OSDS poses significant threats to human health and ecosystems. Pathogens in the OSDS wastewater can spread disease by contaminating drinking water sources (Novello, 2000) or by bodily contact with contaminated water (Calderon et al., 1991). Chemical contaminants in effluent can also be fatal to infants (Knobeloch et al., 2000) and many of the trace organic contaminants are found to have detrimental impact on aquatic organisms (University of Florida, no date; Milnes et al., 2006; Blazer et al. 2007; Vajda et al. 2008). Nutrients in wastewater can induce excessive algal growth in coastal and aquatic waters thereby severely degrading these environments (Hazen and Sawyer, 2009; Gilbin and Gaines, 1990; Lapointe et al., 1990).

2.5.1 Human Health Risks From OSDS

Studies assessing human health risks from OSDS include Hrudey and Hrudey (2007), who reviewed 75 cases of waterborne disease outbreaks in developed countries. Wastewater contamination was identified as the major cause in 40 of those cases. Typical of these cases was an outbreak that occurred at the Washington County Fair in 1999 (Novello, 2000), which resulted in two deaths. The suspected source of the pathogens was contaminated leachate from a septic tank seepage pit located 38 ft away from a well used to make beverages and ice at the fair. A total of 781 infections of either an enteropathogenic coli bacteria (a disease causing bacteria that resides in the gut) or *Camplyobacter jejuni* (*C. jejuni*) were confirmed. A follow-up survey indicated that at least 2,800 people were infected but the specific pathogen was not identified. Other developed countries also have experienced similar disease events. Said et al. (2003) identified sewage effluent as a source of waterborne disease outbreaks associated with private drinking water supplies in England and Wales.

As described in the USEPA Wastewater Treatment Systems Manual (USEPA, 2002), common pathogens in wastewater include bacteria, protozoa, and viruses. Bacteria are the group of pathogens most associated with raw wastewater and include *Escherichia coli* (*E. coli*), which causes gastroenteritis, and others that cause serious illnesses such as leptospirosis, salmonellosis, and cholera. Bacteria are effectively removed by soil treatment units so very few are found beyond 3 ft from a properly operating system. Soil filtration and sorption are the primary mechanisms to retard bacteria migration. Unsaturated soil is generally considered an environment hostile to the growth of sewage generated bacteria, resulting in die-off or deactivation. Soil conditions that hasten these processes include higher soil temperatures. The die-off rate is doubled for each 10°C increase in the range from 5 to 30°C. Other hostile conditions are acidic pH, lack of organic nutrients, high ionic strength, and presence of oxygen (Canter and Knox, 1985). Complicating OSDS impact studies is the pervasiveness of sewage indicator bacteria in Hawaii. Byappanahalli and Fujioka (1998) have shown that strains of *E. coli* can inhabit and multiply in Hawaii's tropical soils. This appears to be more of a monitoring issue rather than health risk problem because these strains have not been shown to be pathogenic. Research by Calderon et al. (1991), as described by Fujioka (2001), could not correlate disease incidence in swimmers with commonly used fecal bacteria indicators when the source of the indicators was not from sewage.

Pathogenic viruses contained in raw wastewater include: enteroviruses (viruses that reside in the gut) and Norwalk-like viruses that cause gastroenteritis; Hepatitis A causes infectious hepatitis; and adenoviruses cause conjunctivitis, a type of eye infection. Viruses are not a normal constituent of human waste, but are excreted by infected persons. Due to the small diameter of these pathogens, sorption is the primary mechanism in soil retarding their transport. These organisms are retained by the soil matrix but are more persistent than bacteria, which results in their accumulation and later mobilization under saturated conditions. However, soil is still an effective retardation and inactivation matrix, resulting in three orders of magnitude or a 10^3 removal in the first 2 to 3 ft of sandy media (USEPA, 2002).

Other wastewater pathogens include protozoa such as *Giardia lambia* and *Cryptosporidium* that result in gastrointestinal infections and Helminthes, which are parasitic worms that infect and are passed through the digestive tracts of mammals. Due to their large size, filtration is the primary retardation mechanism. However, these organisms can be very persistent because they can form cysts when the surrounding environment is not conducive to their growth. The cysts can exist in a viable state for many months (USEPA, 2002).

Time needed for the die-off of pathogens can be used to estimate the appropriate minimum TOT. Such a die off can be approximated by a log-linear relationship (Easton et al., 2005) that can be expressed in the form

$$\ln C_t = k*t + \ln C_o$$

where

C_t = the microorganism concentration at time t days [colony forming units (cfu)/100 ml]

k = the die-off rate (d^{-1})

t = time (d)

C_o = the microorganism concentration at time zero (CFU/100 ml).

The experimentally derived die-rate for *E. coli* based on this study was 0.244 d^{-1}. This die-off rate would result in a pathogen survival half-life of 2.8 days. This rate of reduction varies by pathogen and half-life is not an adequate benchmark to assess the risk to human health. Table 2-4 shows the time required for a 90 percent (10^1) reduction in emerging pathogens of concern. A computed die-off rate and the time required for a 5-log (100,000 times) reduction in pathogen population is also included in this table. A 10^5 removal rate was used by Crockett (2007) as the value in treated water that would reduce the annual risk of infection to 1 in 10,000 in a population exposed to water that had been subject to this magnitude of pathogen reduction. Table 2-4 shows the die-off rates for some common wastewater pathogens.

Table 2-4. Pathogen Kinetics and Time Required for a 10^5 Reduction in Population

Pathogen	Time For a 10^1 Population Reduction		Die-Off Rate			Time for 10^5 reduction
	Minimum	Maximum	Minimum	Maximum	Geometric Mean	
	(d)	(d)	(d^{-1})	(d^{-1})	(d^{-1})	(d)
Camplylobacter jejuni	0.5	6	4.61	0.38	1.33	24
Coliforms	0.5	3	4.61	0.77	1.88	12
Coxsackievirus	1	10.5	2.30	0.22	0.71	42
*Entamoeba histoly*tica	2	20	1.15	0.12	0.36	80
Fecal *Streptoccoci*	1	23	2.30	0.10	0.48	92
Salmonella	1	23	2.30	0.10	0.48	92
Viruses	2.5	15.5	0.92	0.15	0.37	62
Poliovirus	1	10.5	2.30	0.22	0.71	42
Rotavirus	3	4.5	0.77	0.51	0.63	18
Shigella	1.5	7	1.54	0.33	0.71	28

From Crockett (2007)

Chemical constituents of raw wastewater that affect human health include nitrogen (usually nitrate), toxic organics and heavy metals disposed of as household waste, and endocrine disruptors. This last group of contaminants mimics human hormones, potentially resulting in negative impacts on growth and reproduction (USEPA, 2002). Of the contaminants listed, nitrate is the major contaminant in OSDS effluent due to its high concentration, mobility, and demonstrated impact on human health. In high concentrations, nitrates can interfere with the transport of oxygen in the bloodstream of young children. This condition, known as methemoglobinemia (or blue baby syndrome), results in blue color to the skin. Water used to make baby formula with as little as 12 mg/L of nitrate can significantly impair the oxygen carrying capacity of an infant's blood stream (Knobeloch et al., 2000). For this reason, the USEPA has established a maximum contaminant limit of 10 mg/L for nitrate (as nitrogen) in groundwater. Nitrate in groundwater may be reduced by denitrification (the biological conversion of nitrate to gaseous nitrogen), but this only occurs under anoxic conditions. Most Hawaii drinking water aquifers are well oxygenated and denitrification is not expected to occur.

The key to any study assessing risk is to identify the entities at risk (see Section 2.5.3), identify the factors that enhance or mitigate that risk, and develop a method to estimate the severity of the risk. The primary event that has to occur for there to be a negative health impact is exposure of the human body to waters contaminated by OSDS effluent. This can occur at any of the ROCs but drinking water is of primary concern due to ingestion of water. The next significant factor is the magnitude of the pathogen or chemical contamination. For pathogens, die off or other inactivation starts occurring at the point of release. Thus the time it takes the effluent to get from the point of release to an ROC is a major consideration in assessing OSDS risk. As described previously, pathogens can also be filtered out by or become attached to soil (see Section 7). Additionally, contaminants can either decay or become attached (sorption) to the porous media through which the groundwater travels. Thus the characteristics of the soil into which the effluent discharges are an important risk mitigation factor. Lastly, both pathogens and contaminants can be diluted to benign levels by un-impacted groundwater upgradient of the OSDS leachate plume.

2.5.2 OSDS Environmental Risks

OSDS effluent can increase the biologic productivity in receiving waters. Nitrate and phosphate, both enriched in OSDS effluent, are the most common limiting nutrients in receiving waters. Excessive concentrations of either or both of these ions can result in over production of plant matter crowding out native plants, producing hypoxic conditions in the lower water column, and causing incidence of toxic algal blooms (Rabalais, 2002). Sewage effluent has been linked to excessive algal growth. Kaneohe Bay experienced a significant decrease in excessive growths of macroalgae on the outer reef flats when the discharge of primary treated municipal sewage was ended in the 1970s (Rabalais, 2002; and Smith, 1981). Hunt (2006) has shown through isotope chemistry and modeling that sewage injectate near Kihei, Maui nearly doubled the nitrogen nutrient load in the groundwater discharge along an 8 mile span of shoreline. University of Hawaii researchers concluded that sewage related submarine groundwater discharge contributes a significant fraction of the nitrogen in the near shore waters off of Kihei and Lahaina, Maui (Dailer et al., 2010). Although the Kihei, Lahaina, and Kaneohe Bay examples involve municipal wastewater, the sheer numbers of OSDS in some communities produce a cumulative effluent volume that is comparable to that of municipal wastewater treatment plants. This condition is made more serious by the lack of treatment most OSDS effluent receives before discharge.

Factors determining the magnitude of the OSDS effluent's negative environmental impacts are mitigation by the soil, dilution by un-impacted groundwater, and the characteristics of the receiving ecosystem (usually water). Many of these factors are the same as for human health except the primary threat is nutrient loading and pharmaceutical contaminants rather than disease causing microbes. Often nitrogen is considered the limiting nutrient in marine waters. The nitrate form of nitrogen tends to be conservative during groundwater transport (Howarth and Marino, 2006). Phosphorous is the other primary nutrient in OSDS effluent, but tends to get strongly sorbed during transport (Reay, 2004; Cogger et al., 1988; Robertson, 1995). Pharmaceuticals enter the wastewater stream by normal bodily functions and the disposal of unused medicines into the sink or toilet. Once in the wastewater stream these constituents can migrate to aquatic and coastal ecosystems. The results can result in adverse behavior modification of the resident species or changes in their sexual biology (Chau, 2010; Raloff, 2008). The attenuation of these constituents is the same as for other chemicals in that they can be sorbed, transformed, diluted by un-impacted water, or decay (Snyder et al., 2004; Heberer et al., 2004; Carrara et al., 2008). In spite of natural attenuation and dilution of these compounds, they are still pervasive in natural waters. Koplin et al. (2002) found that 80 percent of the 139 streams surveyed in the continental U.S. had organic wastewater contaminants. The group of compounds surveyed included pharmaceuticals and hormones.

2.5.3 Receptors of Concern (ROC)

OSDS effluent creates problems only when that effluent comes in contact with humans or sensitive ecosystems causing undesirable consequences. This study borrows the term ROC from environmental risk assessments. The State of West Virginia (2002) defines ROCs as:

> "specific ecological communities, populations, or individual organisms protected by federal, state, or local laws and regulations or those local populations which provide important natural or economic resources, functions, and values"

For this study the definition of ROC has been expanded to include the human population and refers to those points where sensitive ecosystems or the human population can potentially be adversely affected by OSDS effluent. This study considers three ROCs: (1) drinking water sources; (2) streams and watersheds; and (3) coastal waters.

2.5.3.1 Drinking Water Sources

Drinking water sources were selected as an ROC because they are the primary pathway for water to enter the human body. If the water supplying these sources is contaminated with OSDS effluent then ingestion of OSDS pathogens or contaminants becomes possible. As described above and in more detail in Section 4, groundwater is the primary means of OSDS contaminant transport. Groundwater is also a major source of drinking water because nearly 90 percent of Hawaii's public drinking systems are groundwater wells (Whittier and El-Kadi, 2010). Surface water sources of drinking water are also at risk because flooding can cause overland flow of effluent to streams or OSDS contaminated groundwater can reach the ground surface and discharge into streams

2.5.3.2 Streams and Watersheds

Streams and watersheds were selected as an ROC because nutrients from OSDS can degrade their water quality resulting in unwanted algae growth. Streams are also used recreationally, potentially infecting humans that enter the streams.

In the 2006 State of Hawaii Water Quality Monitoring and Assessment Report, 93 perennial streams were listed as impaired. Of these listings 75 were for nitrate/nitrite exceedance, 67 for total nitrogen exceedance, and 41 for total phosphorous exceedance (Hawaii Dept. of Health, 2006). Although this report does not link the contamination to sources, OSDS effluent contains these constituents and is a contributor to the degradation of stream water quality (Hossain et al. 2010; Oakley et al. 2010).

2.5.3.3 Coastal Waters

Coastal waters were selected as a ROC for the same reasons that streams and watersheds were. That is that OSDS contaminated groundwater may discharge pathogens and nutrients to coastal waters. The nutrients in OSDS effluent are a well-documented source of the coastal nutrient load (see Reay, 2004; Lapointe et al., 1990). Where they occur, OSDS have the potential to degrade the coastal environment due to nutrient loading that can result in excessive algae growth that can smother the coral reefs. In the report referenced above, 209 marine areas were listed as impaired. Turbidity was the most common reason for the impairment listing. However, 56 marine areas were listed as impaired due to the presence of the sewage indicator bacteria *Enterococcus*. However, this bacterium is not a definitive sewage indicator because it has been shown to occur naturally (Hawaii Dept. of Health 2006, Fujioka, 2001).

2.6 RISK ANALYSIS

2.6.1 Risk Analysis Models

The USEPA describes risk as

> "…the chance of harmful effects to human health or the ecological systems result from exposure to an environmental stressor. A stressor is any physical, chemical, or biological entity that can induce an adverse response. Stressors may adversely affect specific natural resources of entire ecosystems, including plants and animals, as well as the environment with which they interact." (USEPA, no date)

Risk analysis models attempt to characterize the risk associated with a particular activity and either quantify or rank that risk to a particular receptor. The receptor can be an ecosystem of the health of the human population. The study uses simplified risk modeling to characterize the risk associated with OSDS to human health, and aquatic and marine ecosystems. Described below are some approaches used in risk modeling.

2.6.2 Overlay Models

Overlay models "stack" risk factors geographically on top of each other. The area where the risk is being evaluated is divided into subunits based on similar characteristics. The risk at each subunit is a combination of multiple factors that contribute to the total risk at that location. Each factor is assigned a parameter weighting based on the relative importance of that factor to the groundwater contamination potential. The weighting is multiplied by a scalar that is proportional to the factor's risk severity relative to its maximum potential risk. The total risk at any point is the sum of the weighted risk factors for each layer. For example, two risk factors A and B are being considered and the risk of A is three times compared to that of B. Factor A would be assigned a weighting percentage of 75 while B would be assigned a weight percentage of 25 percent. The totals risk would be the sum of A and B risk factor scores. An example of an overlay model is the USEPA DRASTIC Model.

DRASTIC was developed for the USEPA to evaluate the potential risk to groundwater pollution anywhere in the United States based on the hydrogeologic setting. The description of this model and a summary of information are contained in Aller et al. (1985). The acronym DRASTIC is made up of the primary risk factors for groundwater contamination.

D – depth to water

R – (net) recharge

A – aquifer media

S – soil media

T – topography (slope)

I – impact of the vadose zone

C – (hydraulic) conductivity of the aquifer

Each of the above parameters is assigned a weighting factor based on the relative contribution to risk. These weights are as follows:

- Depth to water, 5 for both non-agricultural and agricultural areas;
- Net Recharge, 4 for both non-agricultural and agricultural areas;
- Aquifer media, 3 for both non-agricultural and agricultural areas;
- Soil media, 2 for non-agricultural areas, 5 for agricultural areas;
- Topography, 1 for non-agricultural areas, 3 for agricultural areas;
- Impact of the vadose zone, 5 for non-agricultural areas, 4 for agricultural areas, and
- Hydraulic conductivity of the aquifer, 3 for non-agricultural areas, and 2 for agricultural areas.

The weight is then multiplied by a rating value based on the magnitude of that parameter. The pollution potential is the sum of the products of each parameter's weight times the parameter rating value using the equation:

$$\text{Pollution Potential} = D_R*D_W + R_R*R_W + A_R*A_W + S_R*S_W + T_R*T_W + I_R*I_W + C_R*C_W$$

Where the subscript:

R = the parameter rating,

W = the parameter weight.

It should be noted that DRASTIC evaluates the hydrologic/hydrogeologic factors that affect groundwater pollution but does not evaluate the risk to surface water bodies. It also does not evaluate OSDS specific parameters such as the unit density and disposal type. Hence it was concluded that such an approach was not appropriate for the current study without significant modifications.

This study took the same basic approach as the DRASTIC model, but tailors it to use GIS and numerical modeling. As will be discussed in detail in the following sub-sections, this study used a weight and rating method to assign scores for individual risk factors. Again, as with DRASTIC the scores were summed to get a composite risk score. Incorporating GIS allowed the calculations to be distributed spatially, producing an OSDS risk map of the islands assessed by this study. Numerical modeling was used to simulate the impact of existing OSDS on the groundwater and group many of the many of the hydrogeologic factors, such as recharge and dilution by unimpacted groundwater, into a single risk parameter for scoring. Thus our approach was more deterministic than that of the DRASTIC risk model.

2.6.2.1.1 Geographical Information System (GIS) and Analytical Models

A geographical information system (GIS) attaches data values to a graphical representation of the spatial environment. Spatial data and numerical data can be manipulated in the same application allowing analytical calculations to be performed on spatially sensitive data. GIS is well suited for use in the overlay model analysis described above because the risk layers are spatially stacked on another. However, the weighting and risk scoring in overlay models has an element of subjectivity. To more concisely evaluate risk, the weighting and scoring can be replaced with direct calculations using an analytical model. Evans and Meyers (1990) incorporated the DRASTIC risk factors into GIS rasters to facilitate the development of pollution potential risk maps for large areas. This DRASTIC approach allows the standardization and regional mapping of risk. Maps can be made available to the general public with easy access due to the availability of free GIS viewing software and GIS internet servers.

Another example of such an application is the Pesticide Leaching Tool. This model, developed by the University of Hawaii and Hawaii Department of Agriculture, is a GIS based screening tool that evaluates a pesticide's leaching potential to groundwater (Stenemo et al., 2007). This model uses the spatial distribution of soil, pesticide characteristics, and hydrogeologic factors to classify the risk to groundwater from pesticide leaching as "likely", "uncertain", or "unlikely". This study by Stenemo et al. (2007) also did a comprehensive uncertainty analysis. Such an analysis is necessary considering that, as is the case with any models, many risk factors are difficult to quantify and the results must be interpreted conservatively.

As is the case with DRASTIC, this model does not address issues specific to OSDS risk assessment. For example, leaching risk is based on the retardation and degradation processes and the time required to reach the groundwater. For nitrate, the major contaminant associated with OSDS, the risk is less governed by sorption and degradation than by the characteristics of treatment, disposal, and OSDS density.

2.6.2.1.2 GIS and Numerical Models

Analytical model use in hydrologically complex applications are limited because analytical solutions are not available for conditions with significant hydrologic or geologic heterogeneity. Numerical models, particularly in the case of groundwater flow and transport, can handle more complex geometry and process modeling.

Nobre et al. (2008) used an approach similar to DRASTIC, but incorporated numerical modeling and a fuzzy logic tool into the evaluation process in addition to mapping risk parameters in GIS. The fuzzy logic uses a sliding scale that equates to a "degree of truth" rather than discrete values such as yes or no represented by 0 and 1. This logic tool was used to assign weights and ratings for features and attributes associated with a potential contamination source. The numerical models MODFLOW and MODPATH were then used to create well capture zones and receptor indexes.

The Source Water Assessment Program (SWAP) (Whittier et al., 2004) assessed the susceptibility of drinking water sources to contamination using numerical groundwater flow and transport modeling, and GIS analysis. This program delineated 2 and 10-year times of travel to drinking water wells using the groundwater flow model MODFLOW and the particle tracking model MODPATH. The Watershed Modeling System was used to delineate watershed areas topographically up gradient of points of diversion for surface supplies drinking water systems. Field surveys and GIS analysis were used to inventory potentially contaminating activities inside of the delineated drinking source zones. A susceptibility to contamination score was estimated for each source based on the quantity and risk associated with activities inside of the delineated source zones.

2.6.2.1.3 Statistical Models

Statistical models can be as simple as providing simple descriptive statistics such as means, medians, standard deviation, and percentiles or as complex as predictive models using techniques such logistical regression (Focazio et al., 2002). With logistical regression, an outcome is predicted using a limited number of categorical dependent variables. Mair and El-Kadi (2012) used statistical regression evaluate the current SWAP susceptibility analysis. This study also identified the factors that are most closely associated with detected contamination at a well. They showed that a groundwater nitrate concentration was a key parameter in predicting the risk of wells to other sources of contamination.

2.6.2.2 Risk Analysis – Selected Approach

The selected approach is an index method that assigns a risk score based on the type of OSDS, the cumulative impact to groundwater, and the hydrologic factors that affect the probability that an ROC will be impacted by OSDS contaminated water. This was done by using property tax and structures databases, sewer GIS coverages, and existing OSDS databases to identify those locations that likely use an OSDS. These data sources were also used to estimate the probable discharge volume and the effluent chemistry. Next the fate and transport of this effluent including the TOT to selected ROCs was simulated using numerical models. The numerical model results mapped the area of groundwater impacted by OSDS contamination and the location of that impacted area to ROCs. The likelihood that an ROC would intercept OSDS contaminated water was evaluated using existing hydrologic and drinking water GIS coverages. The OSDS risk severity to the ROCs was assessed using the hydrologic/hydrogeologic characteristics of the ROC and the magnitude of OSDS' impact on the groundwater potentially discharging to the ROC. The ability of the environment to mitigate the negative consequences of OSDS effluent was also considered. Soil plays a major role in reducing or eliminating the negative impact of OSDS effluent. The ability of the soil to perform this mitigation was assessed using the National Resources Conservation Services (NRCS) soil database and GIS coverage. Finally, the individual ROC risk assessments at the points where OSDS are located were considered to compute a relative risk severity score for each OSDS or group of OSDS located on a TMK parcel.

2.6.2.2.1 Inventorying the OSDS

The first step in the OSDS risk assessment was to estimate the quantity, type, location, and effluent discharge characteristics of these systems. This process is covered in greater detail in Section 3 of this report. Tax, dwelling and structure, sewer billing, and wastewater treatment plant databases were used to identify those parcels that have a high likelihood of utilizing an OSDS. The attributes contained within the databases were used to estimate the effluent discharge rate. The effluent nutrient chemistry was then estimated based on the OSDS type and on the method of effluent treatment.

2.6.2.2.2 Modeling the Groundwater Impact

Groundwater modeling provides an effective method to estimate the extent and magnitude of OSDS impact on the groundwater. Groundwater modeling can also identify those ROCs most likely to be to be affected by OSDS effluent. Groundwater flow is the primary mechanism that moves the effluent from the OSDS to a ROC. Except in cases of overflow, the effluent percolates downward to the groundwater table. Once it reaches the water table it is transported downgradient by the flow of groundwater. At some point this groundwater will be captured by a well or discharged to an above ground ecosystem such as to a stream or to coastal waters. The flow of groundwater was simulated using the U.S. Geological Survey (USGS) modeling code MODFLOW (Harbaugh et al., 2000). The transport of the OSDS effluent was simulated using the U.S. Army Corps of Engineers transport modeling code MT3D-MS (Zheng and Wang, 1999) using the flow field generated by the MODFLOW model. The effluent constituent that was modeled was the OSDS derived groundwater nitrogen (ODGWN). This is a major constituent contaminant of concern associated with OSDS discharge, and if modeled as a conservative species provides the worst-case scenario for OSDS groundwater contamination.

2.6.2.2.3 Assessing the Relative ROC Susceptibility to OSDS Contamination

The susceptibility of a ROC to OSDS contamination is strongly influenced by the hydrologic factors at and in proximity to the ROC. For example, for OSDS contaminated groundwater to degrade a stream, the streambed elevation must be below the water table. Each factor, such as the elevation of the streambeds relative to the groundwater table, was spatially overlaid to compute susceptibility to contamination scores. This process produces maps with numerical scores representing the increasing risk of contamination.

2.6.2.2.4 Assess the OSDS Soil Risk Factors

Soil is not only the designed method of treatment for effluent Class I OSDS, but it also mitigates the impact from all OSDS to varying degrees. For example Field et al. (2007) found that total nitrogen decreased rapidly with distance from the sidewalls of a seepage pit. The current study mapped the soil characteristics that influenced the severity of the impact that OSDS pose to groundwater and to the environment. Examples of these characteristics include the soil's ability to properly filter out pathogens, permeability of the soil, thickness of the soil (i.e., the depth to bedrock), and whether or not the soil is susceptible to flooding or ponding.

The influence that the soil has on mitigating the potential OSDS effluent impact should be considered as a composite of the soil characteristics. The soil factors or attributes affecting the treatment and transmission of OSDS effluent are listed in the NRCS Soils Spatial Database. This database assigns a score that varies from 0 to 1 to individual soil characteristics. A higher score reflects the decreasing ability of the soil characteristic to mitigate the OSDS effluent impact. For this study, the NRCS soil factors scores were then summed to map the relative ability of the soil mitigate the impact of OSDS effluent.

2.6.2.2.5 Ranking the Risk Posed by OSDS

The aforementioned factors evaluate the potential risk to a ROC. The other component of the risk assessment includes those characteristics attributable to the OSDS such as the type, treatment method, and spatial density. These characteristics were combined with the hydrological risk characteristics and the modeled ODGWN to calculate the relative risk ranking posed by the individual OSDS. Because the spatial resolution of the OSDS inventory was done at the tax map key (TMK) parcel level, the risk ranking was also done at this level. The scores for the OSDS type, ROC risk severity, and soil OSDS siting unsuitability were summed to get a risk score for each TMK parcel utilizing OSDS. The product is a relative risk ranking of individual parcel utilizing OSDS.

SECTION 3. OSDS INVENTORY, DISCHARGE RATES, AND EFFLUENT QUALITY

To assess the human health and environmental risks posed by OSDS, knowledge of the quantity, location, and effluent discharge rates of these systems is critical. Physically locating and inventorying each unit, however, is not feasible. There are sufficient data in state and county records to estimate the OSDS inventory by type and location. Available engineering data can then be used to estimate the volume and quality of effluent being released into the environment by each unit. This section describes the methods used and the results of OSDS inventory.

3.1 OSDS INVENTORY

On-site sewage disposals systems have been in use long before electronic databases became available. Records were first kept on index or punch type cards. The sheer numbers of cards and obsolete records make it impractical to accurately estimate the number of and identify the types of systems using this data set. With the widespread use of desktop computers, the OSDS records were entered into electronic databases. More recently, records that had been entered on index and punch type cards were scanned and entered into a database. But the IWS and cesspool databases have not been consolidated into a single comprehensive database. This study links the various databases to the TMK GIS coverage and data table to produce a map of OSDS locations, types, and effluent discharge quantity and chemistry.

3.1.1 Data Sources

Below is summary of the data sources that were queried to develop the OSDS database. A brief description is given of each as well how that source was used to estimate number and location of OSDS on the islands of Hawaii, Kauai, Maui, and Molokai.

3.1.1.1 Tax Map Key (TMK) GIS Coverage

Tax map key shape file and associated data table provide the key data set to which all other data was referenced. This data assigns a unique TMK number to each parcel in a polygon shapefile. This shapefile provides the spatial data needed for linkage to other data. Data included in this source are the spatial location of the parcel, value of any buildings on the property, whether or not the property owner is the homeowner, and a tax base classification based on use, such as hotel/resort development, apartment complex, or agricultural.

3.1.1.2 Hawaii Department of Health Records

The Hawaii Department of Health records provided the most detailed OSDS data. This information is included in two separate databases. The first database, referred to as the IWS database, is a record of OSDS plan submissions and approvals and includes a description of the system. The second database, referred to as the cesspool database, includes scans of the index and punch card records that are linked to a TMK number. The following sections provide more detail about these data sources and how that data were used by this study.

3.1.1.2.1 Individual Wastewater System Database

This database is an electronic record of the IWS plan submittals. A record is entered into this database when an application is submitted to construct or modify an OSDS. This includes information critical to this study such as OSDS type, effluent disposal method, inspection date, final approval date, number of bedrooms served by the system, and TMK where OSDS is to be constructed or upgraded. The IWS data were screened to identify those systems that had an entry in the field labeled 'final inspection date' or 'final approval date'. An entry in this data field infers that the system has actually been constructed and approved by HDOH. Records with no entry in one of these fields were not included in the preliminary OSDS database. The number of bedrooms field was used to estimate the daily effluent discharge rate from each system.

The OSDS type and disposal method were used to estimate the concentration of the primary nutrients in the effluent. Where an IWS or disposal type was uncertain, a worst-case assumption was made. For example, if the disposal type was listed as unknown, a seepage pit was assumed. Effluent nutrient chemistry for each OSDS type and disposal method was estimated using criteria from WRRC (WRRC and Engineering Solutions, 2008) as described in Section 2.3.2, Table 2-3.

3.1.1.2.2 Cesspool Database

The cesspool database includes records that were kept on index or punch cards before the development of electronic databases. These cards have recently been digitized and entered into a database. Important data in this source are the TMK number of the parcel where the cesspool is located and a scanned image of the actual card. A limited number of the records also have address information. Lacking in this database is the information necessary to estimate the effluent discharge rate. The effluent discharge rate for the cesspool database records were estimated using information in the dwellings and structures database (DSDB) described below.

3.1.1.3 Dwellings and Structures Database (DSDB)

The IWS and cesspool databases are an incomplete listing of OSDS due to such factors as lost records, final IWS inspections not being documented, or systems installed without obtaining a permit. As part of the property tax database, each county maintains a record of structures located within the respective counties (County of Hawaii, 2012; County of Kauai, 2012; County of Maui, 2012). The DSDB contains specific structure information, monetary value, and a TMK number. The critical structure information in this database is the number of bedrooms and bathrooms. The number of bedrooms is used to estimate the effluent discharge rate as described in Section 2.3.1. Parcels with structures that utilize a bathroom or are valued at more than $25,000 were assumed to need some sort of sewage disposal system. The TMK number was used to link this data source to the other databases.

3.1.1.4 Centralized Wastewater Collection System Data

A key approach used when estimating the number and location of OSDS was to identify those areas served by an off-site wastewater treatment and collection system (OWTCS). The parcels that fell within the OWTCS service areas were then excluded from the list of TMKs that potentially utilize an OSDS. As with OSDS data, there was no single source listing all areas served by an OWTCS. Available sewer service area data included:

- GIS coverages of the sewer service area;
- Sewer and water billing data;

- Maps of sewer service areas;
- Lists of parcels served by sewer system; and
- An HDOH list of permitted wastewater treatment plants (WWTP).

These data were collected from the HDOH Wastewater Branch, municipal wastewater systems, private wastewater systems, and the USEPA.

3.2 OSDS INVENTORY METHODOLOGY

Using the data sources above, we estimated the quantity and location of OSDS for Hawaii, Kauai, Maui, and Molokai. This involved many screening steps to ensure the integrity of the results. The descriptions below list the processes that were used to develop the final OSDS database.

3.2.1 IWS and Cesspool Database Screening and Consolidation

The first step in the IWS Database screening was to remove those records where there was no indication that the system had been constructed. If there was no entry in the "Plan Approved", "Use Approved", or "Final Approval Date" fields it was assumed that the OSDS had not been constructed and the record was removed. Once the records with no indication of plan approval were removed, TMKs with multiple records were consolidated into a single record unique to that TMK. The total number of OSDS, number of OSDS of each type, number of bedrooms, effluent flux, and nitrogen and phosphorous flux were totaled for each unique TMK record.

In many cases a TMK was listed in both the IWS and cesspool database. If the IWS database listed the OSDS type as a cesspool, it was assumed that the cesspool database listing was duplicated in the IWS database and only the IWS database record was entered into the interim OSDS database. The final IWS and cesspool databases were then merged with the TMK database into a single TMK/IWS/cesspool database.

3.2.2 Dwellings and Structures Database (DSDB) Screening and Consolidation

The DSDB was reviewed and those records with no indication of a bedroom or bathroom were identified. These records were then removed if they were not listed in the IWS/cesspool database. In many cases there were multiple dwellings listings for a single TMK parcel. The duplicated TMK records were consolidated by TMK and the number of structures, bedrooms, and bathrooms were summed. This database was then merged with the TMK/IWS/cesspool database. In cases where the TMK number of the dwelling or structure was also present in the TMK/IWS/cesspool listing, the dwellings' information was merged with the existing TMK/IWS/cesspool record.

3.2.3 Sewer and Wastewater Treatment Plant (WWTP) Data

The sewer and WWTP data were used for two purposes: (1) to exclude those parcels served by an OWTCS; and (2) to correctly quantify the number of OSDS in a parcel with multiple dwellings that are served by a single wastewater disposal system on the same TMK parcel (i.e., an apartment building, condominium, or hotel). The County of Hawaii and the County of Maui provided sewer main GIS coverages. Using these shapefiles, a 75 ft buffer was created around the sewer main to represent the probable extent of the sewer system laterals that branch from the main to points of collection. TMK parcels that were intersected by the sewer service buffer zone were annotated as being served by OWTCS.

As described in Section 3.1.1.4, the WWTP permit database was reviewed to identify those plants with a sewage collection system that extended beyond the boundaries of the TMK parcel upon which the plant is located. To assess whether or not the WWTP utilized an off-site sewage collection system, the WWTP type, owner, UIC permit status, and plant class were considered. If the WWTP type was listed as “reuse” then it was removed from consideration because the effluent disposal occurs offsite. Those plants that used a sewer system to collect effluent from other TMK parcels were further evaluated to identify to the probable extent of the OWTCS service area. The service area was delineated using GIS coverages, maps and data tables provided by the WWTP owner, or a best estimate was made based on the resort or other development boundaries. Once the parcels served by an OWTCS were identified the corresponding records were removed from the OSDS database. Those plants that were identified as serving a single TMK parcel were retained in the list of parcels potentially utilizing an OSDS. Criteria that indicated the WWTP served only one parcel included the structure use and plant classification. If the owner was a condominium, apartment, or organization such as a produce processer it was assumed that the effluent was disposed of on-site and these records were retained in the OSDS database. Other criteria such as being a Class 1 or 2 WWTP indicated that the plant was likely to be small and not have an off-site sewer collection system. The WWTP permit records that were assumed to dispose of the effluent on-site were considered to be an OSDS with a level of treatment equivalent to a Class III OSDS. The appropriate records in the TMK/IWS/Cesspool database were appended to include the pertinent WWTP fields that included:

- WWTP Permit Number;
- UIC Permit Number;
- Type of plant (WWTP or Reuse);
- Owner information (private of public, name, operator, and point of contact); and
- Class of plant (1 through 4).

This new database with the parcels removed that are served by OWTCS was designated the OSDS Working Database.

3.2.4 The OSDS Working Database

This database contained the final data set for the linkage to the TMK shapefile. Prior to the linkage the data were reviewed to remove duplicated fields (for example, the TMK number was used in all source databases and was thus duplicated many times in this database) and compute the final sums for the total number of OSDS, bedrooms, and bathrooms for a parcel. The data were also screened for the OSDS that served non-dwelling parcels and appropriate effluent discharge rates were assigned based on the non-residential activity occurring on the parcel (refer to Table 2-2).

The final OSDS Working Database was imported into GIS as a table and linked to the TMK shapefile using the TMK number as the key field. The TMK shapefile was then queried to select those records with an OSDS quantity greater than zero and exported to a new OSDS polygon shapefile. Finally the OSDS polygon shape file was converted to a point shapefile, which assumed that the OSDS were located at the centroid of the polygon. For large polygons (greater than 100 acres), the estimated location of the OSDS was moved if an overlay of this shapefile on a georeferenced aerial photograph indicated no buildings at the assumed location. These final shapefiles were used as the basis for the risk assessments described in the remainder of this report.

3.2.5 OSDS Density

A single OSDS is expected to pose only a small risk to the environment. However, a dense cluster of OSDS will have a cumulative effect because little dilution of the effluent contaminants will occur. Pang et al. (2006) demonstrated with field data and modeling that the groundwater nitrate concentration increased as the number of OSDS along a groundwater flow path increased. Pang et al. further found that nitrate concentrations did not return to background concentrations until the groundwater had traveled about 1.8 miles past the last OSDS. However, due to filtration in the soil and die-off kinetics, there was no cumulative effect associated with fecal coliform bacteria.

The USEPA has designated areas with an OSDS density of greater than 40 units per mi^2 as regions of potential groundwater contamination. A 1977 study done by the USEPA identified three density ranges (Yates, 1985):

- Less than 10 units per mi^2 as low density;
- 10 to 40 units per mi^2 as medium density; and
- Greater than 40 units per mi^2 as high density.

Yate's review of the studies that investigated OSDS' impact on groundwater showed that developments using septic systems on lot sizes of about 0.5 acres resulted in nitrate concentrations of greater than 45 mg/L, the regulatory limit for drinking water at that time. Yates recommended that septic system use be restricted to lot sizes of 2 to 10 acres.

To calculate the OSDS density, the GIS ArcTool point density function was used. A search radius of 0.93 mi was used to calculate the OSDS per square mile. This value was mapped to a grid made up of 328 ft x 328 ft cells. The resulting raster was then broken down into five classes. These classes were as follows:

- 0 OSDS/mi^2;
- 1 – 10 OSDS/mi^2;
- 11 – 40 OSDS/mi^2;
- 41 – 100 OSDS/mi^2; and
- Areas with greater than 100 OSDS/mi^2.

The resulting raster was used for two purposes: (1) to map the areas where OSDS have the greatest risk potential due to high density; and (2) to refine resolution of the groundwater recharge polygons in the areas of greatest OSDS impact. Section 4.2.3.1 describes how the OSDS density results were used to model the OSDS derived nitrogen in the groundwater recharge.

3.2.6 Inventory Assumptions

Numerous data sources were used by this study and many of these sources are incomplete or do not directly specify the presence and type wastewater water disposal. Thus, many assumptions were required when estimating the number and locations of OSDS. These assumptions include:

- Any parcel within the service area of an OWTCS has no OSDS;
- The volume of effluent that is discharged from a residential dwellings is 200 gpd multiplied by the number of bedrooms in that dwelling;
- Condominiums or apartment buildings that have a WWTP permit to dispose of the effluent do so using a Class III OSDS;

- TMK parcels listed in the DSDB as having a bathroom, but with no corresponding listing in the IWS, cesspool, or WWTP databases dispose of their wastewater in a Class IV OSDS (i.e., a cesspool);
- A TMK listed in the cesspool database and IWS Database as a cesspool is a duplicate listing; and
- The OSDS is located at the centroid of the TMK parcel.

3.2.7 Possible Sources of Error

As described above the data used to estimate the number and location of OSDS was taken from databases that in many cases may be incomplete, contain duplicate records, or do not directly list the presence or absence of OSDS. These conditions, of course, could lead to errors. These errors include:

- Multiple OSDS listings for a TMK parcel in the IWS database that actually reflect an upgrade of an existing system rather than a new system;
- Structures in a OWTCS coverage area that never connected to the sewer and thus continue to utilize an OSDS for wastewater disposal;
- Structures assumed to be outside of an OWTCS coverage area that are actually connected to a centralized wastewater collection system;
- The incorrect default assumption that a structure/dwelling discharges its wastewater to a cesspool;
- Cesspools that have been removed or upgraded are not reflected in the current data;
- No OSDS on a parcel that is assumed to have a unit;
- Discharge rates and chemistry that vary from that assumed; and
- Spatial error introduced by assuming an OSDS is the centroid of a large TMK parcel.

This list of potential errors is substantial and thus the data provided by this study needs to be viewed as a qualitative assessment of where negative impacts from OSDS are most likely to occur and what ROCs are most likely to be negatively impacted.

3.3 OSDS INVENTORY RESULTS

This study estimated the number and locations of OSDS on the islands of Hawaii, Kauai, Maui, and Molokai using the methods described above. In this section we will describe the results of the surveys, the data that were available for the individual islands, and any necessary modifications that were made due to the differences in available data.

This compilation of information from OSDS related databases done by this study and the previous study (Whittier and El-Kadi, 2009) estimate that the total number of OSDS on the islands of Hawaii, Kauai, Maui, Molokai, and Oahu exceeds 110,000. Table 3-1 lists the results of the OSDS surveys by island and by OSDS class. The majority (58,982) are located on the island of Hawaii. About 88,000, or nearly 80 percent, of the total OSDS are Class IV systems (cesspools) where the effluent receives no treatment. These OSDS discharge approximately 68.8 million gallons per day (mgd) of effluent with an estimated primary nutrient load 12,278 kilograms per day (kg/d) of nitrogen and 3,503 kg/d of phosphorus.

Table 3-1. OSDS Inventory and fluxes for the Islands of Hawaii, Kauai, Maui, Molokai, and Oahu

Island	Total OSDS	CLASS I	CLASS II	CLASS III	CLASS IV	EFFLUENT (mgd)	N FLUX (kg/d)	P FLUX (kg/d)
Hawaii	58,982	8,951	694	68	49,344	34.6	6,607	1,848
Kauai	18,011	3,107	910	304	13,688	12.5	2,115	607
Maui	16,883	4,015	559	75	12,242	11.6	1,869	554
Molokai	1,956	477	33	4	1,442	1.2	206	59
Oahu	14,606	2,620	534	199	11,253	9.7	1,732	500
Total	110,438	19,170	2,730	650	87,969	69.6	12,529	3,568

Oahu OSDS data taken from Whittier and El-Kadi (2009)

3.3.1 Hawaii

Individual wastewater system, cesspool, dwelling, TMK databases were available for the Island of Hawaii to identify those parcels that likely require a system to dispose of wastewater. This data was augmented by identifying those parcels that are unlikely to need an OSDS because they are served by a sewage collection system. Off-site wastewater treatment and collection system data were gathered from a variety of sources. These sources included a sewer main GIS coverage and sewer billing data from the County of Hawaii as well as maps of the sewer service areas from private WWTP operators.

3.3.1.1 Hawaii County Sewer Service Area

The County of Hawaii provided sewer billing data and GIS coverage of the county sewer mains. Hawaii County (as does Honolulu and Maui Counties) includes sewer charges with their water billing, listing the sewer billing status by TMK number. This data was supplemented by sewer coverage maps provided by the Hawaii County Wastewater Division. Likewise, maps of coverage areas were provided by Parker Ranch and Hawaii Water Services for their respective service areas. These maps were georeferenced in ArcGIS. The coverage area was then traced out manually and exported as a shapefile. Finally, this shapefile was intersected with the TMK shapefile to extract those TMKs that were served by the OWTCS. Tables with TMK listings of serviced parcels were provided by Kukio Resorts, Mauna Kea Development Corporation, Seascape Condominium, Keauhou Community Services, and Hualalai Resorts. The information from these tables, as well as the TMK data exported from the OWTCS shapefiles, were combined into a single file that was merged with the preliminary OSDS database. Those parcels identified as being served by an OWTCS were then removed from the OSDS Database.

The major population centers in Hawaii County are served by an OWTCS. Figure 3-1 shows the extent of sewered parcels and the density of OSDS on this island. The core of the Hilo, Kailua-Kona, Waimea, Waikoloa, Honokaʻa, as well as the resort areas of West Hawaii are served by

OWTCS. However, areas surrounding the sewered urban centers rely on OSDS to dispose of wastewater.

3.3.1.2 Hawaii County OSDS

Hawaii County has approximately 59,000 OSDS discharging about 35 mgd of effluent to the environment. Class IV systems (cesspools) account for nearly 50,000 of that total and Class I systems account for about 8,950 of the systems. About 6,600 kilograms (kg) and 1,850 kg of nitrogen and phosphorus respectively are discharged from these systems. Figure 3-1 shows the distribution of OSDS on the island and the census districts for the island of Hawaii. Table 3-2 lists the OSDS population and the effluent, nitrogen, and phosphorus fluxes for each district. The districts with highest number of OSDS are Hilo and Keeau/Mountain View. Together these two districts have 45 percent of the OSDS on the Island of Hawaii. These two districts also have average OSDS densities above the 40 units/mi^2 threshold that the USEPA considers to pose a significant risk to groundwater (Yates, 1985). Other areas that exceed the 40 units/mi^2 threshold include the communities of East Hawaii (Pahoa, Keeau, Hawaii Paradise Park), coastal communities of the Kona district, and Waimea. Small rural communities are also potential problem areas. These include Kapa‘au, which is on the northernmost tip of the island, and Hawaiian Ocean View Estates, Naalehu, and Pahala to the south.

Table 3-2. Summary of OSDS on Hawaii Island by Census District

District	Class I	Class II	Class III	Class IV	Total	Effluent (mgd)	N Flux (kg/d)	P Flux (kg/d)	OSDS Density (OSDS/mi^2)
Hilo	1,469	172	7	10,635	12,272	7.8	1,554	432	41.0
Honokaa-Kukuihaele	19	10	0	1,339	1,368	0.8	183	50	11.8
Kau	834	75	6	2,561	3,473	1.8	309	88	3.7
Keaau-Mountain View	2,329	69	7	11,741	14,136	7.6	1,432	400	60.7
North Hilo	16	17	0	879	912	0.6	120	34	2.9
North Kohala	297	62	1	2,193	2,546	1.5	299	83	18.0
North Kona	1,561	95	18	7,529	9,190	5.8	1,074	302	18.9
Paauhau-Paauilo	18	20	0	980	1,012	0.6	130	36	2.2
Pahoa-Kalapana	1,203	29	11	4,213	5,450	2.9	507	143	20.3
Papaikou-Wailea	24	11	4	973	1,012	0.6	135	37	10.4
South Kohala	745	78	7	3,096	3,916	2.4	439	124	11.4
South Kona	425	56	6	3,198	3,676	2.1	424	119	11.1
Total	**8,951**	**694**	**68**	**49,344**	**58,982**	**34.6**	**6,607**	**1,848**	**14.6**

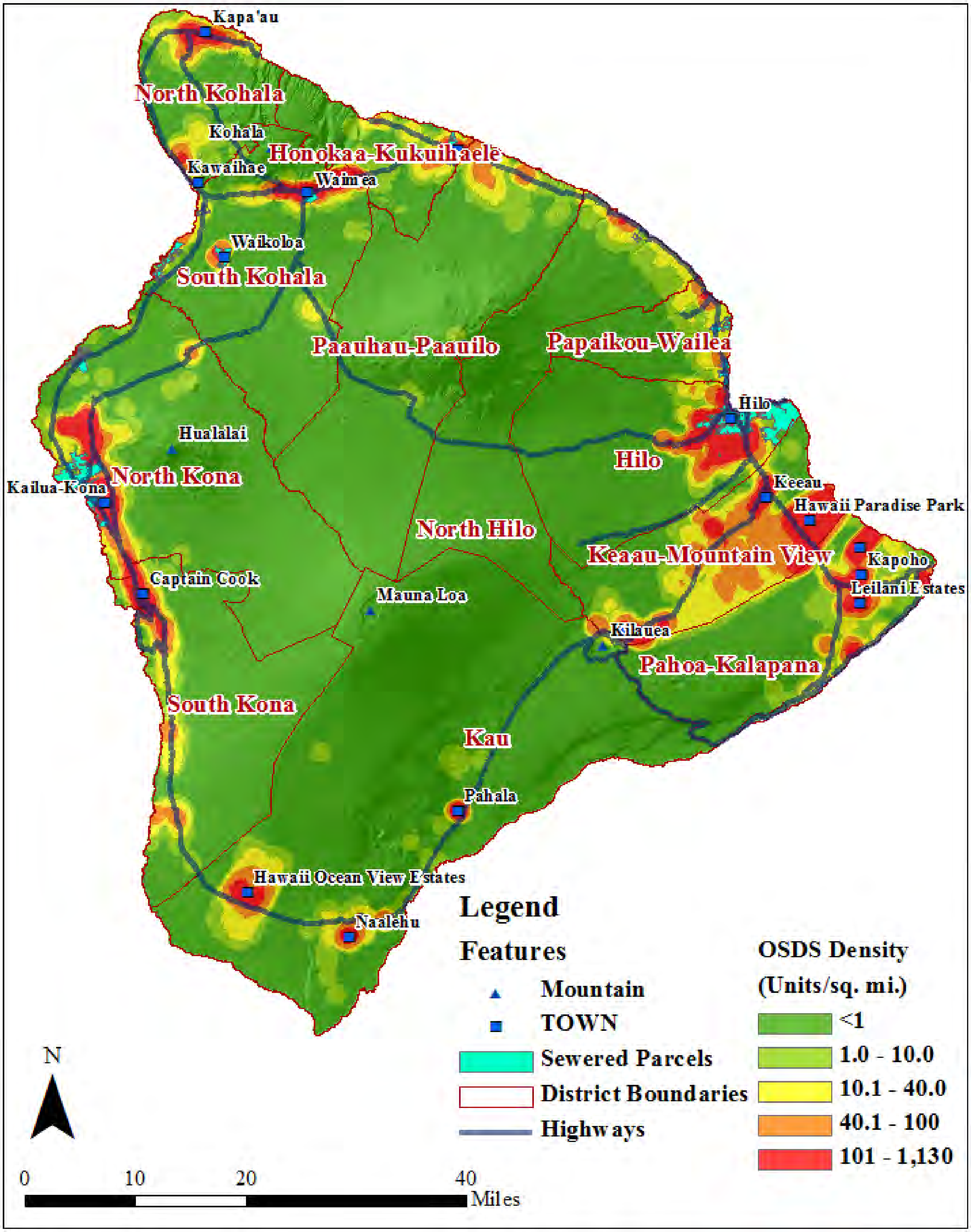

Figure 3-1. The OSDS density and sewer coverage on Hawaii Island

3.3.2 Kauai

Kauai has the highest overall OSDS density of the islands assessed by this study. Available data that was used to make this assessment include IWS, cesspool, dwelling, and TMK databases for identifying those parcels that likely to require an OSDS to dispose of wastewater. Sewer service coverage tables and maps were provided by municipal and private wastewater system operators to assist in identifying those parcels where wastewater was collected by a sewer system.

3.3.2.1 Kauai Sewer Service Area

The OWTCS data for Kauai came from maps and tables of service areas. Unfortunately there was no GIS data available for sewered areas on this island. Maps of sewer service areas were provided by Kauai County, Princeville Utilities, and Grove Farms. These maps were geo-referenced and the outline of the service was traced in GIS and converted to a shapefile. The TMK numbers of the parcels falling within the service area delineations were added to the OWTCS database. Data tables of sewer service areas collected for the USEPA by the HDOH Wastewater Branch were also used. These tables were provided to HDOH by Kukuiʻula South Shore Community, Puhi Sewer and Water Company, and the Hyatt Resort.

As with Hawaii County, the major population centers are served by an OWTCS. Figure 3-2 shows the distribution of the sewer service coverage areas overlaid on a map of OSDS density. These include the communities of Lihue, Waimea, Hanapee, Wailua, Waialua, and Kapaa and the resort developments at Princeville and Poipu. Similar to the Island of Hawaii, the sewage collection service area in the population centers on Kauai are surrounded by peripheral areas that utilize OSDS for wastewater disposal.

3.3.2.2 Kauai OSDS

This study estimated that there are approximately 18,011 OSDS on Kauai. Table 3-3 tabulates the OSDS inventory by census district and includes totals of each type of OSDS. This table also lists the estimated effluent, nitrogen, and phosphorus fluxes. Figure 3-2 shows the spatial distribution of the density of OSDS and the census district boundaries for this island. Considering the entire island, Kauai had the highest OSDS density at about 32 units for each mi^2. The district of Kapaa, with over 750 units/mi^2, has the highest OSDS density of all of the census districts evaluated in this study. The districts of Wailua-Anahola, Kapaa, Koloa-Poipu, Lihue, and Eleele-Kalaheo Districts all had OSDS densities greater than 40 units/mi^2. Localized areas of high OSDS densities can be found in Haʻena, Wainiha, Hanalei, Kilauea, Hanapepe, and Kekaha even though the average OSDS density for their respective districts was low. By type, the Class IV OSDS (cesspools) dominate the OSDS inventory accounting for 76 percent of the systems. The combined effluent discharge from OSDS on Kauai is estimated to be 12.5 mgd, resulting in a daily release of 2,115 kg of nitrogen and 607 kg of phosphorus to the environment.

Table 3-3. Summary of OSDS on Kauai by Census District

District	Class I	Class II	Class III	Class IV	Total	Effluent (mgd)	N Flux (kg/d)	P Flux (kg/d)	OSDS Density (OSDS/mi^2)
Eleele-Kalaheo	230	257	29	2,130	2,646	1.9	353	101	73
Hanalei	993	110	0	1,455	2,558	1.8	223	67	21
Kapaa	241	179	1	2,325	2,746	1.9	357	101	759
Kaumakani-Hanapepe	17	0	0	468	485	0.3	62	17	4
Kekaha-Waimea	254	9	16	1,193	1,472	1.0	168	48	16
Koloa-Poipu	296	111	239	1592	2,238	1.6	259	75	89
Lihue	56	37	1	645	739	0.5	96	27	119
Puhi-Hanamaulu	61	19	11	410	501	0.3	64	18	6
Wailua-Anahola	959	188	7	3,470	4,624	3.2	533	153	67
Total	**3,107**	**910**	**304**	**13,688**	**18,011**	**12.5**	**2,115**	**607**	**32.5**

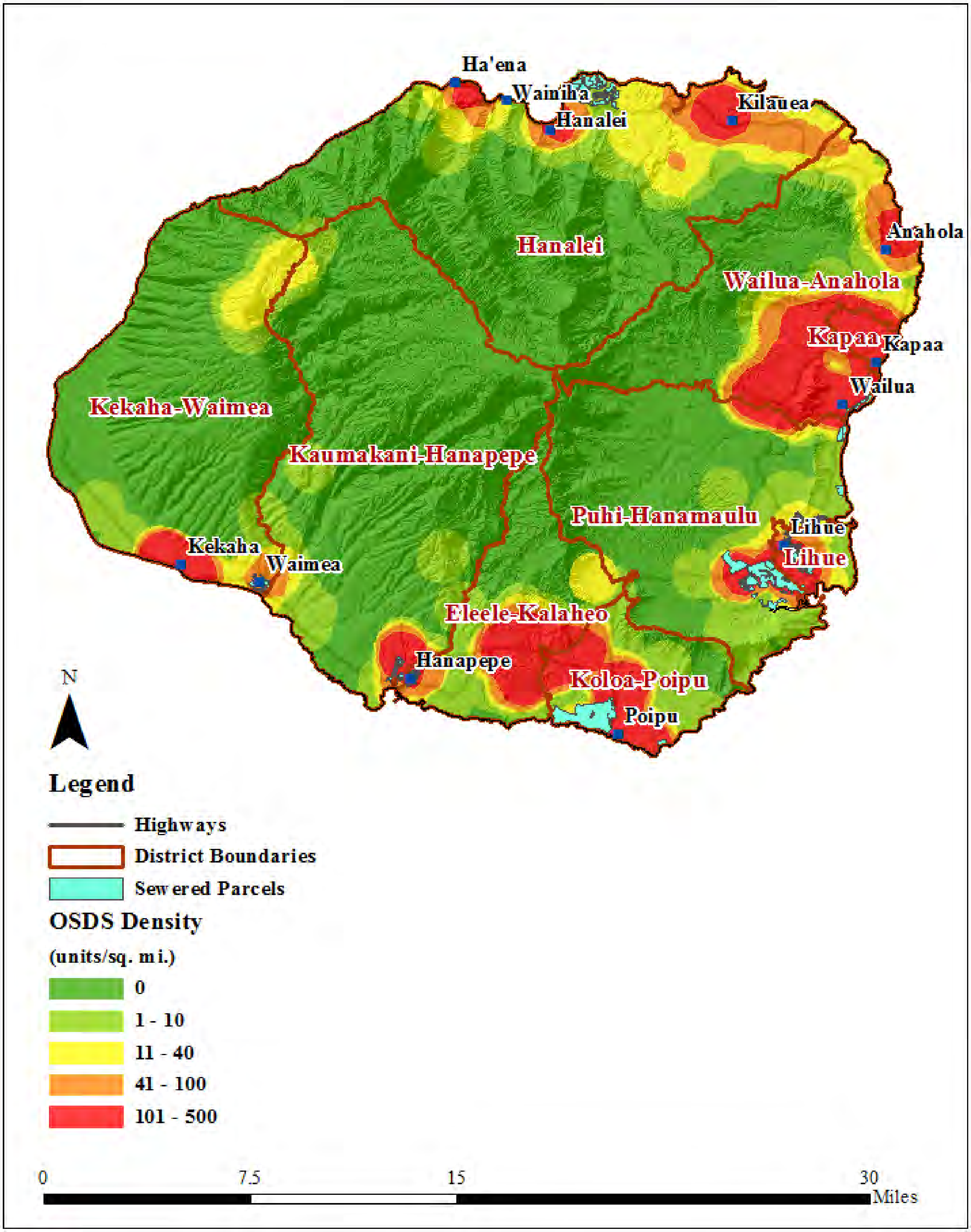

Figure 3-2. The OSDS density and sewer coverage on Kauai

3.3.3 Maui

Maui has the second highest OSDS density for the islands included in this study. However, this island also has the best sewer coverage. Data available to identify parcels on Maui that utilize OSDS were the IWS, cesspool, dwelling, TMK databases, and water/wastewater billing data. The OWTCS data sources used to identify those parcels generating wastewater but not utilizing an OSDS included sewer main GIS coverage and descriptions provided by municipal and private wastewater operators.

3.3.3.1 Maui Sewer Coverage

The best quality sewer coverage of the islands assessed by this study was available for Maui. A GIS coverage of the sewer mains and wastewater billing data were provided by Maui County. As with the GIS coverage provided by Hawaii County, a 75 ft buffer was delineated around the sewer mains to approximate the extent of the sewer laterals. This shapefile was then intersected with the TMK shapefile to identify the parcels likely served by the county OWTCS. A description of their sewer service area was provided by Hawaii Water Services for the Pukalani and the Makena Wastewater Treatment Plants. This data were supplemented by tables of sewer services areas collected for the USEPA by the HDOH Wastewater Branch. The tables included listings of parcels served by many resort and small private wastewater utilities. These tables usually included a TMK reference that was linked to the TMK shapefile to provide the spatial data needed for this study. When a TMK was not provided, the sewer coverage was assumed to extend to the boundaries of the resort development.

Figure 3-3 shows the sewer service area coverage overlaid on an OSDS density map for Maui. Areas of significant residential development, particularly Upcountry Maui (this includes the communities of Pulehu, Kula, Makawao, and much of Pukalani), lack access to an OWTCS. However, outside of Upcountry Maui the major population centers are served by an OWTCS. This includes Wailuku/Kahului, coastal West Maui including Lahaina and Kaanapali, and the south-central communities from Kihei to Makena. But as with the other islands there are many small communities and areas peripheral to urban centers that rely on OSDS for wastewater disposal. For example, there is no sewer service available for the developments in West Maui south of Lahaina, in much of Waiehu, or in the community of Hana.

3.3.3.2 Maui OSDS

This study estimated that there are 16,883 OSDS on Maui. Of these, 12,242 or 73 percent are Class IV (cesspools). The area of greatest concern is Upcountry Maui where OSDS densities exceed 800 units/mi^2. Figure 3-3 is a map of OSDS density and the census district boundaries. Table 3-4 summarizes the results of the OSDS inventory listing island and census district totals for each OSDS type, effluent discharge rate, and nitrogen and phosphorus fluxes. The Makawao-Paia district has the highest OSDS density at about 111 units per mi^2. Other districts that exceed the 40 units/mi^2 include Haiku-Pauwela and Wailuku. The OSDS on this island discharge an estimated 11.6 mgd of effluent, containing 1,869 kg of nitrogen and 554 kg of phosphorus. Based on the prevalence of Class IV OSDS, the majority of this effluent receives no treatment.

Table 3-4. Summary of OSDS on Maui by Census District

District	Class I	Class II	Class III	Class IV	Total	Effluent (mgd)	N Flux (kg/d)	P Flux (kg/d)	OSDS Density (OSDS/mi^2)
Haiku-Pauwela	1,226	110	4	2,062	3,402	2.1	278	87	56.7
Hana	216	25	2	642	885	0.6	97	32	4.1
Kahului	14	0	10	139	163	0.1	23	6	28.2
Kihei	40	11	9	343	403	0.4	71	20	10.5
Lahaina	434	27	0	831	1,284	1.3	218	65	13.5
Makawao-Paia	821	203	3	3,817	4,844	3.2	552	158	111.4
Puunene	2	3	0	8	13	0.0	4	2	3.2
Spreckelsville	16	2	0	71	89	0.1	10	3	4.5
Waihee-Waikapu	156	35	2	640	833	0.6	101	30	15.2
Wailuku	39	14	0	484	537	0.3	71	20	96.4
Kula	1,049	128	44	3,204	4,425	2.8	444	131	23.7
Total	**4,015**	**559**	**75**	**12,242**	**16,883**	**11.6**	**1,869**	**554**	**23.2**

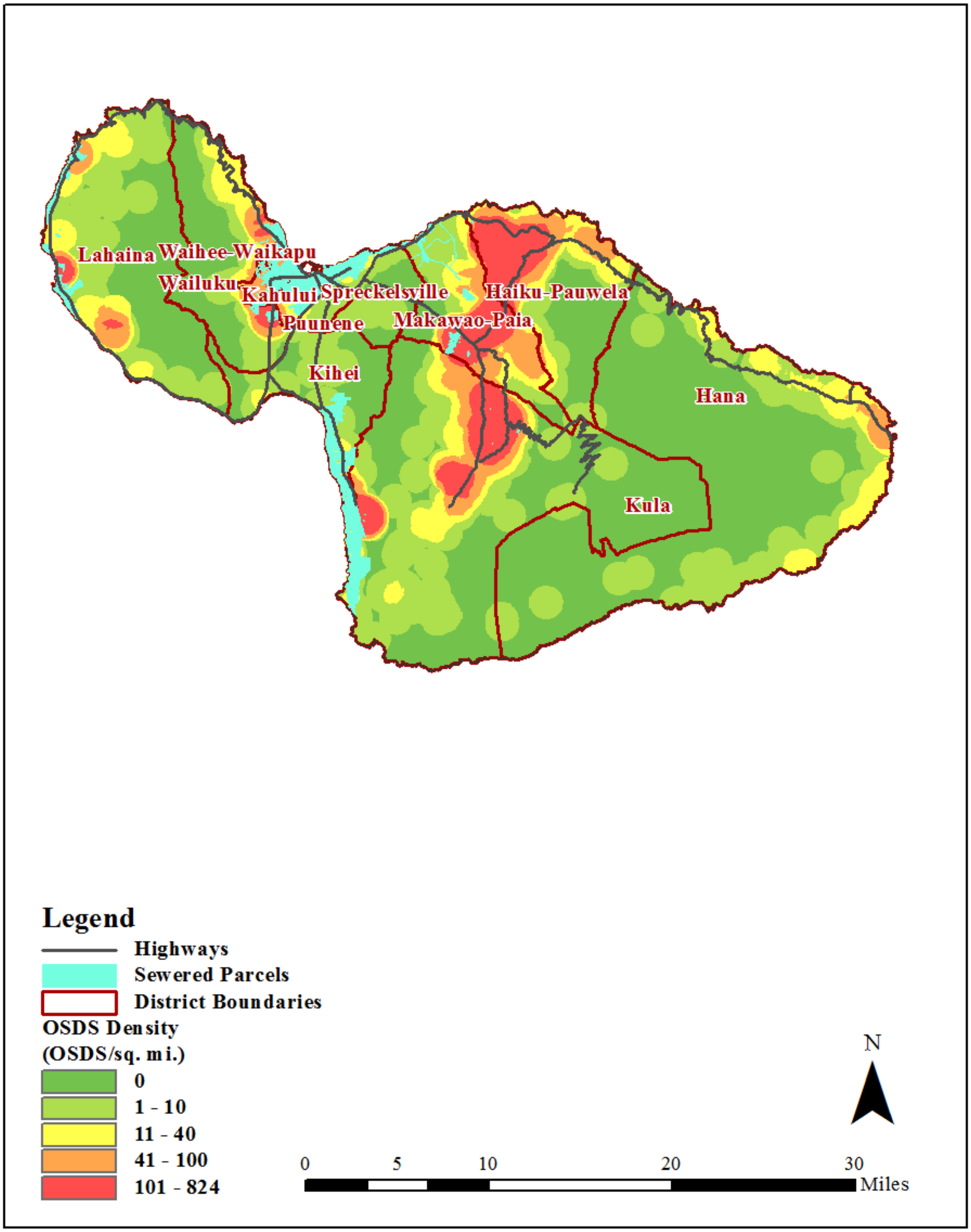

Figure 3-3. The OSDS density and sewer coverage on Maui

3.3.4 Molokai

Molokai with its low population density was evaluated as having the lowest human health and environmental risks from OSDS. Data to identify parcels that generate wastewater on Molokai were collected from IWS, cesspool, dwelling, and TMK databases. The OWTCS data were gathered from interviews and site visits.

3.3.4.1 Molokai Sewer Coverage

The data source for sewer coverage on the island of Molokai was a visit to and interviews with the utility owners/operators. Maui County owns and operates the wastewater reclamation facility that serves the island's major community of Kaunakakai. The extent of the sewer collection system for this plant was provided during an interview with the plant supervisor and later surveyed with a Global Positioning System instrument. Molokai Ranch owns the wastewater treatment facilities for Kaluakoi Resort and the communities of Maunaloa and Kaulapuu. As with the Kaunakakai OWTCS, the extent of the system was similarly surveyed following an interview with owner. This data was then imported into GIS. Figure 3-4 overlays the OWTCS coverage areas on a map of the OSDS density on Molokai. The TMKs served by the OWTCS were removed from the OSDS database.

3.3.4.2 Molokai OSDS

This study estimated that there were 1,956 OSDS on Molokai. Table 3-5 tabulates Molokai's OSDS by type and census district. Of the islands included in this study, Molokai has the lowest population. This is reflected in it also having the lowest OSDS density at 7.5 units/mi^2. The OSDS density in all three census districts is well below the critical threshold of 40 units/mi^2. Figure 3-4 shows the spatial distribution of the OSDS density. Areas where the OSDS densities exceed the critical threshold of 40 units/mi^2 occur on the southern coast between Kaunakakai and Kawela, to the west of Kaunakakai, areas outside of the Kaulapuu OWTCS coverage area, Ho'olehua, and a small portion of West Molokai. The estimated total effluent discharge is also very low at 1.2 mgd. The low population density of Molokai and the OWTCS coverage has resulted in a low OSDS density and effluent output for this island.

Table 3-5. Summary of OSDS on Molokai by District

District	Class I	Class II	Class III	Class IV	Total	Effluent (mgd)	N Flux (kg/d)	P Flux (kg/d)	OSDS Density (OSDS/mi^2)
Kalawao	10	4	0	0	14	0.01	0.3	0.1	1.2
East Molokai	323	27	4	805	1,158	0.76	119	34	9.4
West Molokai	143	2	0	632	777	0.47	86	24	6.2
Total	**477**	**33**	**4**	**1,442**	**1,956**	**1.23**	**206**	**59**	**7.5**

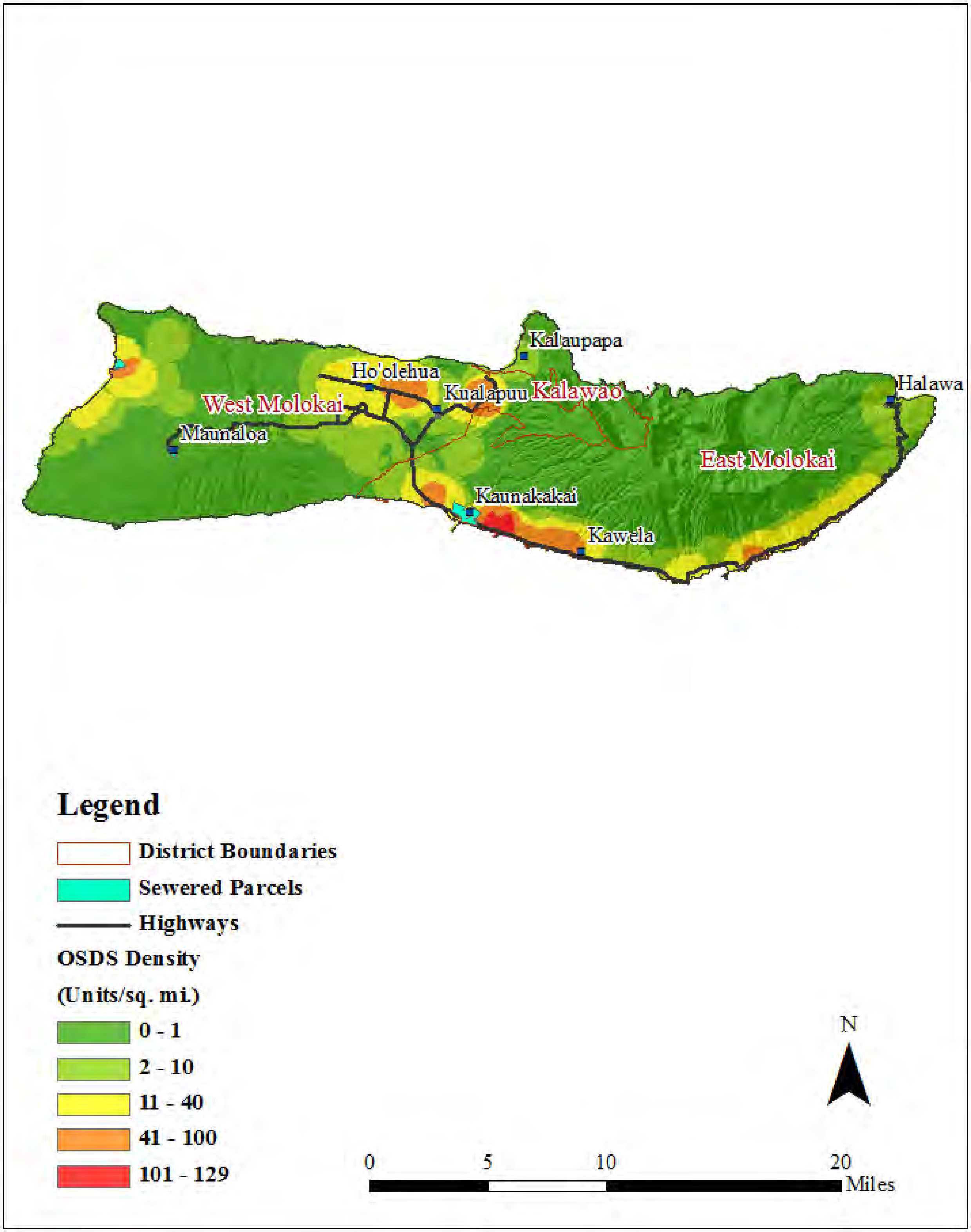

Figure 3-4. The OSDS density and sewer coverage on Molokai

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SECTION 4. GROUNDWATER AND DRINKING WATER IMPACT

Various characteristics of an aquifer determine its susceptibility to contamination. This section evaluates those characteristics for the aquifers of Hawaii Island, Kauai, Maui, and Molokai. This section then assigns a spatially distributed risk score to rank the potential risk of each aquifer to OSDS leachate contamination. In a second phase of the OSDS groundwater risk assessment, groundwater flow and transport models were used to evaluate the extent and relative severity of the current OSDS impact on groundwater. The output of the groundwater flow and transport models were also used in risk evaluation for surface water and the nearshore waters.

4.1 EVALUATION OF THE SUSCEPTIBILITY OF GROUNDWATER TO OSDS CONTAMINATION

Groundwater in the State of Hawaii provides the majority of the water for agricultural and municipal use (Wilson Okamoto Corporation, 2008). Groundwater also discharges to streams and to the coastal environment, which can be degraded if the groundwater is contaminated by OSDS leachate. The goal of the aquifer evaluations was to produce a map that shows the relative risk to the groundwater from OSDS contamination. This assessment provides a qualitative risk scoring of an aquifer's susceptibility to OSDS leachate contamination based on its characteristics and use.

4.1.1 Aquifer Characteristics

The hydrogeologic setting of groundwater has a significant influence on probability that a contaminant source will impact that groundwater. The factors affecting susceptibility to contamination include: depth to groundwater; presence of perched groundwater between the ground surface and the main aquifer; and existence of a confining layer or aquifer is "cap". The current or potential use of an aquifer determines what ROCs may be impacted by contaminated groundwater. These aquifer attributes, with the exception of depth to groundwater, have been evaluated and mapped by Mink and Lau (1990, 1992a, 1992b, and 1993) and are available as GIS shapefiles (http://hawaii.gov/dbedt/gis/dohaq.htm), which are referred to in this study as the HDOH Aquifer Shapefiles.

4.1.1.1 Depth to Groundwater

The first consideration was those areas where the depth to groundwater is less than 25 ft. This shallow depth to groundwater inhibits the natural remediation of OSDS effluent, increasing the risk to groundwater. An insufficient vertical distance between the point of discharge and the water table creates the potential for groundwater contamination and may decrease the natural nutrient removal efficiency by the soil.

The depth to groundwater was estimated as the difference between the ground surface elevation and the water table elevation. Digital elevation models downloaded from the University of Hawaii at Manoa, Coastal Geology Group data website (http://www.soest.hawaii.edu/coasts/data/hawaii/dem.html) provided the ground surface elevation data needed to compute the depth to groundwater. The elevation of the groundwater table was simulated by the groundwater flow models used by this study to estimate the extent and severity of groundwater contamination from OSDS leachate (Section 4.2.3).

In this study, the minimum depth to groundwater that allows for sufficient pathogen removal was based on the OSDS design regulations for cesspools. HAR Title 11, Chapter 62 establishes the regulations for wastewater systems and requires that:

- the top of a cesspool inlet pipe must be 1.5 ft below grade;
- there is a minimum of 10 ft between the inlet pipe and the bottom of the tank; and
- a minimum of 3 ft from the bottom of the tank and the highest known level of groundwater.

Based on these values, a minimum depth to the water table should be approximately 15 ft. However, the analysis can be uncertain due to the fact that the elevation of the water table is not static; it varies on seasonal and longer time scales influenced by such factors as recharge and groundwater withdrawals. Using the methodology described in Whittier and El-Kadi (2009) a depth to water of 25 ft or more is sufficient to meet the requirements of HAR Title 11, Chapter 62 when the uncertainty of the water table elevation is considered. Zones where the estimated depth to groundwater was less than 25 ft were assigned a risk score of 1.

4.1.1.2 Zones of Perched Water

Water perched on low permeability formations above the main aquifer will intercept OSDS leachate as it percolates downward reducing the vulnerability of main aquifer to contamination. This does not provide perfect protection as some percolation occurs through perching layers. In many cases however, the perched water that is returned to the surface and does not reach the main aquifer. Such conditions exist in northeast Maui (Gingerich, 1999a and 1999b) and the Hawi region of Hawaii Island (Oki, 2002). Where perched groundwater is not present, the main aquifer is more susceptible to contamination. The aquifer zones where perched groundwater was absent were assigned a risk score of 1.

4.1.1.3 Confined Aquifers

In confined aquifers, a low permeability structure or aquitard overlies a zone of higher permeability, which is referred to as an aquifer. The interface between the two is below the water table elevation that the main aquifer is capable of supporting. When a borehole is drilled through an aquitard there will be a rise in the water level in the hole to a level consistent with the confined pressure (Freeze and Cherry, 1979). The positive pressure in the aquifer will prevent contamination from a shallow subsurface source such as a septic system leach field from contaminating the aquifer. Areas where there are no confining layers are more susceptible to contamination. The unconfined aquifer zones were assigned a risk score of 1.

4.1.1.4 Aquifer Utility and Current Water Quality

The potential use of an aquifer is also an important consideration. The HDOH Aquifer Shapefiles designate the utility of the aquifer as: (1) drinking (i.e., suitable in yield and quality for drinking water); (2) ecologically important if, for example, the groundwater supplies a wetland; (3) or neither. If either "drinking" or "ecologically important" were applicable to an aquifer polygon it was assigned a risk score of 1.

4.1.1.5 Drinking Water Sources

The final consideration was given to those portions of the aquifers that contribute water to public drinking water sources. The SWAP study (Whittier et al., 2004) delineated three zones around public drinking water sources to assess the source's susceptibility to contamination. The zone immediately adjacent to the source was designated Zone A and delineated to consider contaminant sources that could get directly introduced into the well or surface water intake. The second zone was designated Zone B and considered contaminant sources that could indirectly contribute both biological and chemical contamination into the drinking water source. The third delineation, Zone C, considered chemical sources that indirectly contribute chemical contamination into the drinking water source.

For groundwater sources these zones were based on the TOT for a particle of water to reach the intake of a well. The travel time considered was only that occurring in the aquifer and did not consider the vertical travel time from the ground surface to the aquifer. The vadose zone, which is the zone from the ground surface to the aquifer, transport is complex and difficult to model with confidence on the scale needed for this study. For the SWAP, the TOT delineations were modeled by using MODPATH based on the flow field created by MODFLOW. For these simulations, the MODPATH particles were inserted in the cell representing the well. The backwards tracking option was used to delineate the TOT represented by a polygon that enveloped all the termination points for particles originating from the well. Fixed setback and contributing watershed delineations were used for surface water sources.

4.1.1.5.1 Zone B

The purpose of the Zone B TOT buffer is to prevent waterborne disease outbreaks due to consumption of drinking water. For groundwater sources a two year TOT was delineated. Such a buffer can be considered as a conservative estimate in protecting groundwater-drinking water sources when compared to the travel times listed in Table 2-4, which shows a maximum pathogen survivability of 92 days. Using a conservative TOT is necessary because Powell et al. (2003) showed that the velocity of pathogens can be much greater than that of the bulk flow of groundwater. Their research on groundwater contamination caused by leaking sewers showed detectable and viable populations of pathogens at distances much greater than could be accounted for using average groundwater flow velocities. More specific to Hawaii, the Lahaina Groundwater Tracer Study (Glenn et al., 2013) showed maximum tracer velocity as indicated by the first arrival time, which was over five times faster than the average tracer dye velocity. Thus, any TOT buffer should be much greater than the expected viable lifespan of pathogens. The state of scientific knowledge regarding the fate and subsurface transport of sewage related pathogens and the range of heterogeneities in the Hawaiian subsurface preclude identifying a definitive TOT value that protects wells. The two-year TOT used for this study is longer than the time required for a 10^5 reduction in pathogen populations (refer to Table 2-4) if only the average groundwater velocity is considered. However, as shown by Craig et al. (2013), the velocity in fast transport paths can be as much as five times faster than the average groundwater flow velocity and needs to be accounted for in any protective setback. The use of the two-year TOT also maintains consistency between this study and the Zone B capture zone delineation (CZD) that was approved by the USEPA for use with the SWAP (HDOH, 1999).

The Zone B delineations for surface water sources included a 200 ft setback from channels of streams or from drinking water transmission canals and a 400 ft setback from an open reservoir.

For both groundwater and surface water sources of drinking water, Zone B identifies those OSDS that can potentially introduce pathogens into a public drinking water supply. Zone B CZDs were an assigned a risk score of 2.

4.1.1.5.2 Zone C

Contaminants from OSDS, particularly nitrate, can also pose health risk to consumers of contaminated water. Because nitrate tends to act conservatively in groundwater, the contaminant will not degrade with time as is the case with pathogens. Therefore a 2-year TOT is not adequate when considering the risk from this contaminant. The delineation of a 10-year TOT was used to assess the number of OSDS that pose a contaminant risk to a drinking water well. The 10-year TOT is the same as the Zone C CZD used for the SWAP. For surface water sources the Zone C delineation included the entire contributing watershed upgradient of the point where the water enters a protected conduit. Zone C CZDs were assigned a risk score of 1.

4.1.2 Results

Maps were produced showing the relative susceptibility of groundwater resources to OSDS contamination on the four islands evaluated by this study. Summing of the risk score assignments produces a maximum possible of 8; the actual scores varied from 1 to 7. The following sections summarize the results for each island evaluated.

4.1.2.1 Hawaii

The intrinsic groundwater risk score for the island of Hawaii varied from 2 to 6 (Fig. 4-1). There are no confining layers on Hawaii to protect the groundwater from contamination and all groundwater is classified as a potential source of drinking water. Groundwater contamination of the basal aquifers is mitigated by perched water on the slopes of Mauna Kea, summit area of the Kohala Volcano, and southeast flank of Mauna Loa affording these areas the lowest score of 2.

Active use of the aquifers for drinking water accounted for the highest risk scores. The maximum score of 6 occurred in West Hawaii where the Zone B area of contribution of one drinking water well overlapped the Zone C CZD of a second well. Because the aquifers are not confined, are a potential source of drinking water, and have no intervening perched water the sum of these conditions was 6.

4.1.2.2 Kauai

The groundwater OSDS susceptibility risk score varied 2 to 7. Many of the conditions that would normally protect the primary drinking water aquifer, such as a deep depth to groundwater or a confining layer, are not pervasive on Kauai. In many cases, such as the Lihue area, the upper aquifer is the primary drinking water aquifer. This is in contrast to southern Oahu where the upper groundwater body is a sedimentary aquifer and protective of the lower aquifer that is the source of drinking water. If the upper aquifer was a source of drinking water, it was scored as an unconfined aquifer with no intervening perched water. Figure 4-2 shows the spatial distribution of the OSDS susceptibility risk score. The lowest score of 2 was assigned to interior regions of eastern and southern Kauai where perched water mitigates the contamination potential of the lower aquifer that is the primary drinking water aquifer. However, water development tunnels in the perched water do draw drinking water from these zones giving the minimum score for this island of 2 rather than of 1. The high score of 7 is assigned to the Zone B delineation area near the coast where the depth to water is shallow (less than 25 ft), the upper aquifer has ecological importance, and the lower aquifer is a potential source of drinking water. Most other areas within the Zone B delineation area were assigned a moderate risk score of 5 or 6.

4.1.2.3 Maui

The susceptibility of groundwater to OSDS contamination on Maui is low throughout most of Maui relative to the other islands evaluated. Figure 4-3 shows the distribution of risk to groundwater and drinking water sources. Based on designations by Mink and Lau (1990) perched water aquifers exist throughout much of east Maui. Perched water zones in east Maui resulted in a risk severity score of 2 for the areas not within a capture zone for a public drinking water source. The zones of contribution to drinking water systems that are supplied by surface water were also included in this assessment because groundwater provides the baseflow for these streams. Including drinking water sources supplied by surface water resulted in a risk score of 4 for the north slopes of Haleakala. The large area on the northeast flank of Haleakala is the zone of contribution to the ditch system for the East Maui Irrigation Company that supplies drinking water to east and central Maui. Much of this water is supplied by the discharge of groundwater to the streams. Similar conditions exist in the interior of West Maui where the Iao, Honolua, Honokohau, and Kanaha watersheds provide drinking for West Maui. The zones with the highest OSDS groundwater risk score were in the interior of the West Maui Mountain. The highly elevated water table resulted in a depth to groundwater of less than 25 ft within the Iao and Honokohau watersheds. Confining layers in west and central Maui afford protection to the underlying aquifers as indicated by the low risk severity score of 1.

4.1.2.4 Molokai

The maximum groundwater OSDS risk severity score for the island of Molokai is lower than that for other islands assessed. Figure 4-4 shows the distribution of risk to Molokai's groundwater and drinking water sources. The high score for this island was 5 compared to 6 or 7 for other islands. This high score occurred in coastal areas where the depth to groundwater was less than 25 ft, and the groundwater was both a potential source of drinking water and ecologically important. In these areas there is no confining layer or perched groundwater to mitigate the impact of OSDS effluent. The other areas where a score of 5 was assigned were zones that fell within a Zone B CZD. The low score of 2 occurred in West Molokai where the groundwater is too salty to be a source of drinking water and Central Molokai where perched water mitigates the impact of OSDS effluent.

4.1.2.5 Inventory of OSDS in Drinking Water SWAP Zones

As part of the evaluation of OSDS risk to drinking water sources the number of OSDS in the SWAP zones was inventoried (Table 4-1). There are an estimated 6,000 OSDS within the drinking water zones of contribution, about 2,800 in Zone B and about 3,000 in Zone C. About 4,300 of these are Class IV OSDS where the wastewater receives no treatment during the disposal process. An estimated 3.8 mgd of effluent is discharged into the zones of contribution, with 1.8 mgd being discharged into the Zone B, creating a potential for pathogen contamination of the drinking water sources. At about 2,100 units, Maui had the greatest number of OSDS within the drinking water zones of contribution. Most of the OSDS that lie within a CZD are in the Waihee/Waiehu area or in upcountry Maui. As expected, due to the lower number of drinking water sources and population, Molokai had the fewest OSDS in the SWAP Zones.

Table 4-1. Inventory of OSDS in Drinking Water SWAP Zones

	Total OSDS	Class I	Class II	Class III	Class IV	Effluent Flux (mgd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)
Hawaii								
Zone B	992	198	8	2	787	0.61	106.7	30.2
Zone C	606	81	2	0	523	0.34	67.6	18.8
Kauai								
Zone B	730	147	46	20	517	0.50	82	24
Zone C	1,277	268	68	0	941	0.90	147	42
Maui								
Zone B	1,004	330	26	10	638	0.68	96	28
Zone C	1,128	262	29	0	845	0.70	115	34
Molokai								
Zone B	52	27	13	0	12	0.030	2.66	0.91
Zone C	52	9	4	0	39	0.032	5.84	1.65
Total								
Zone B	2,778	702	93	32	1,954	1.82	287	83
Zone C	3,063	620	103	0	2,348	1.97	336	97

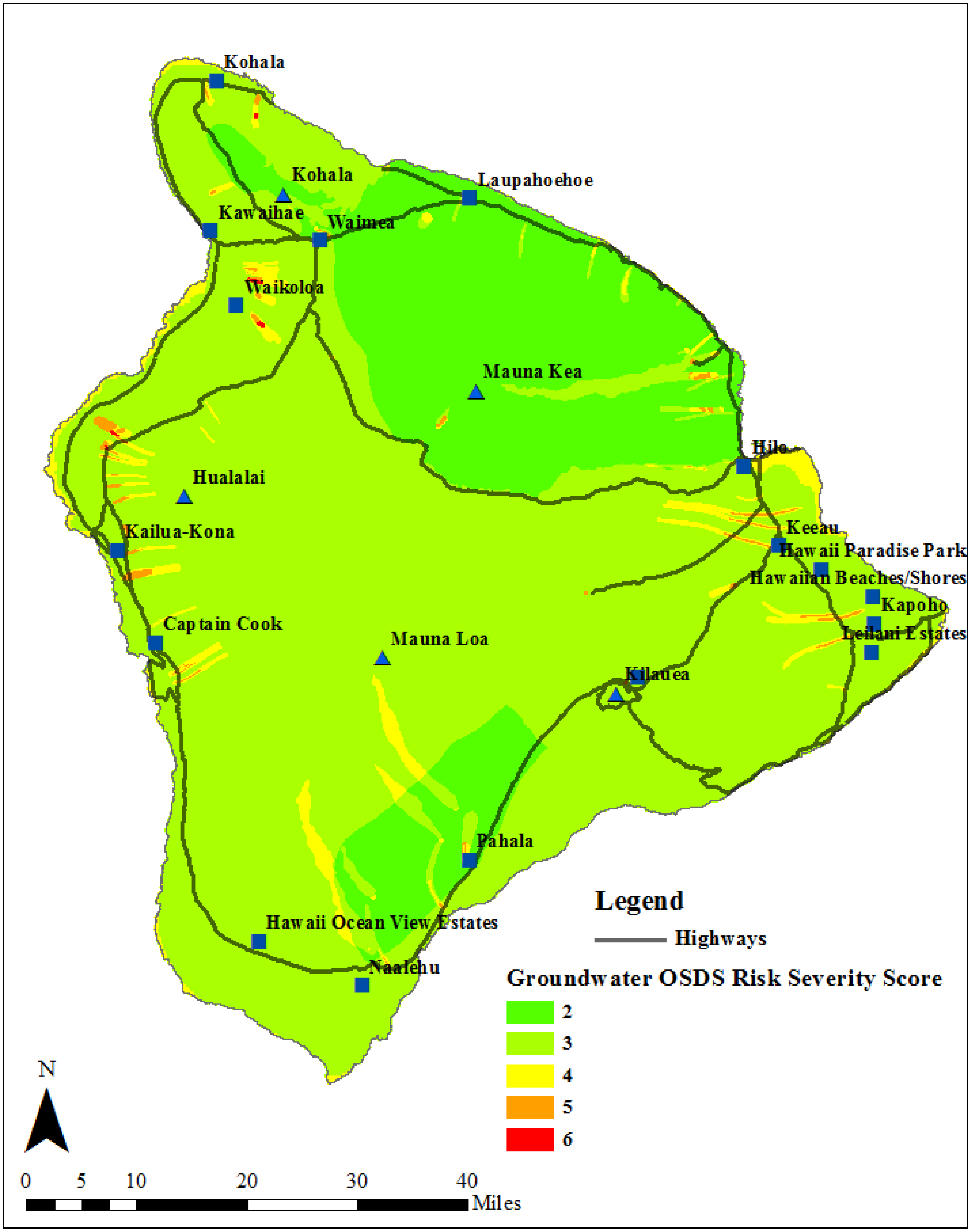

Figure 4-1. A map of the susceptibility of groundwater and drinking water to OSDS contamination on Hawaii Island

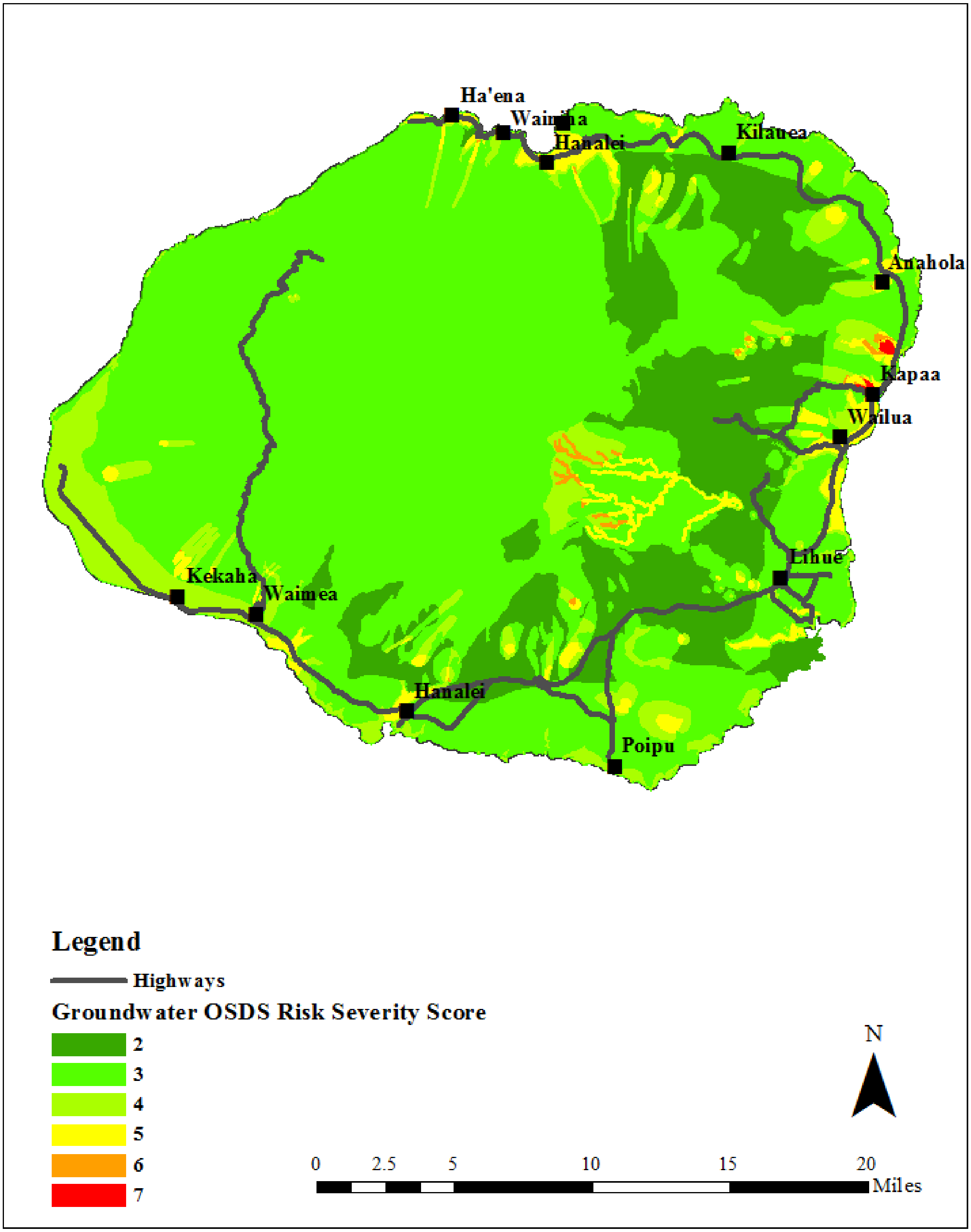

Figure 4-2. A map of the susceptibility of groundwater and drinking water to OSDS contamination on Kauai

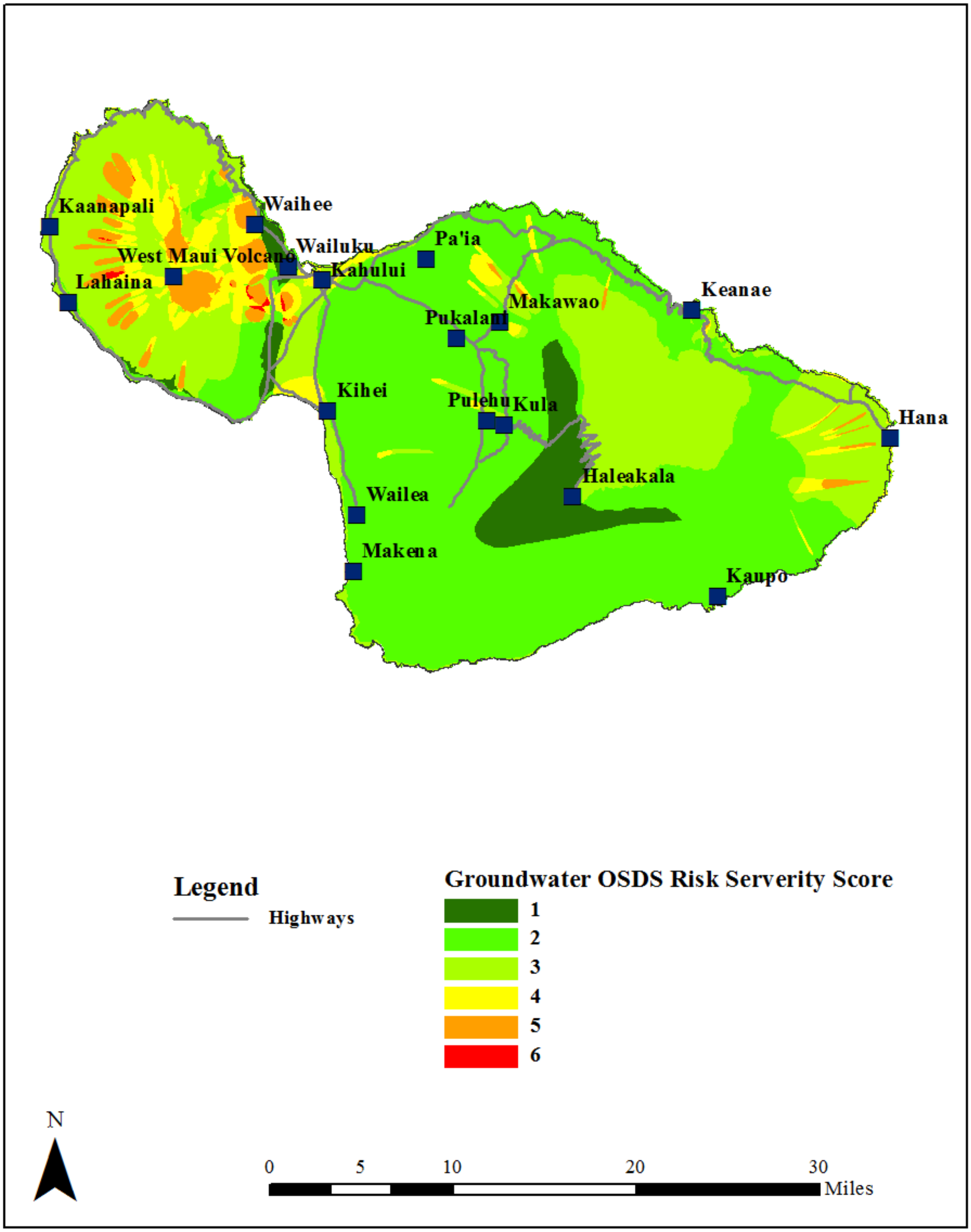

Figure 4-3. A map of the susceptibility of groundwater and drinking water to OSDS contamination on Maui

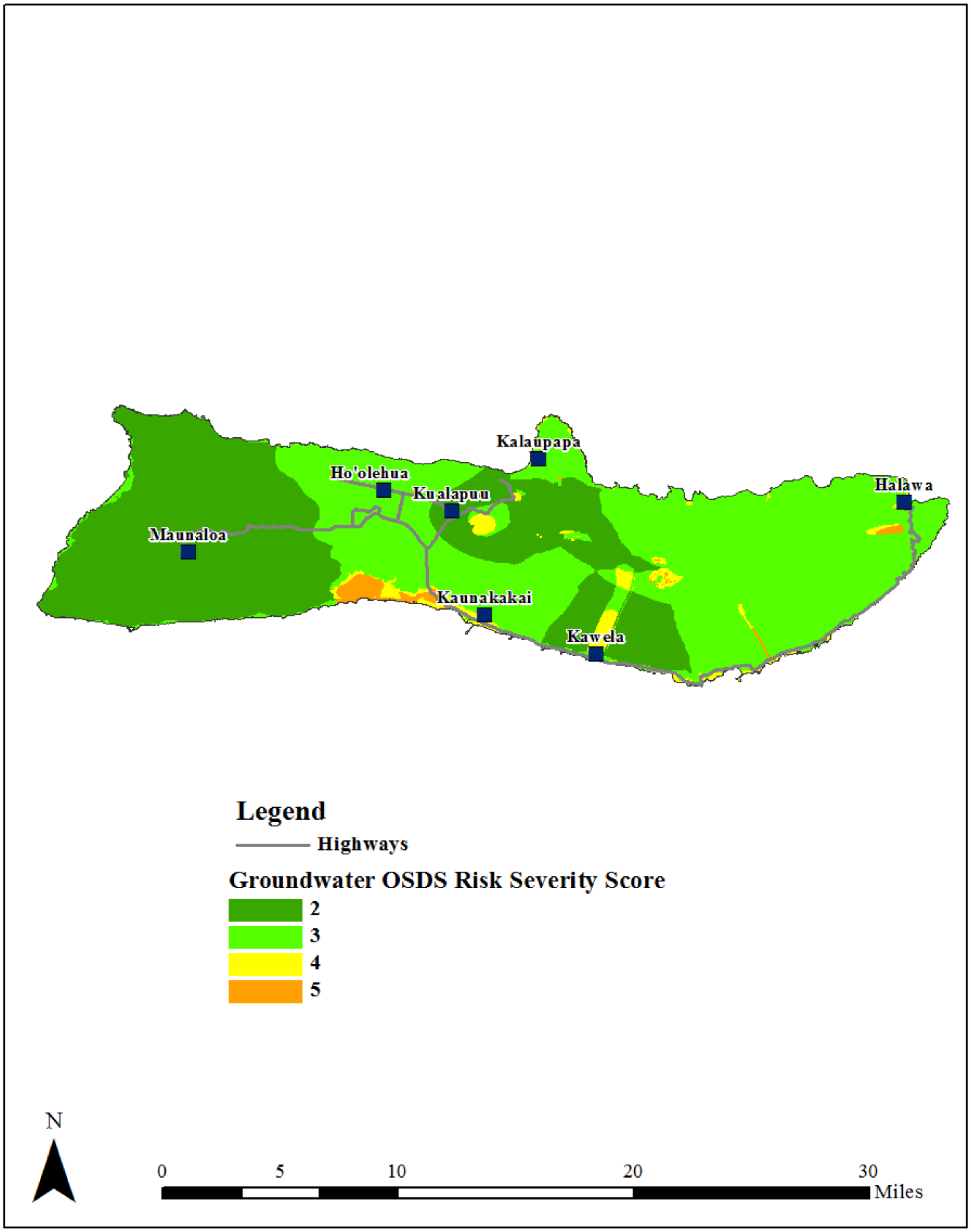

Figure 4-4. A map of the susceptibility groundwater and drinking water to OSDS contamination on Molokai

4.2 EVALUATION OF THE EXISTING OSDS THREAT TO GROUNDWATER

4.2.1 Nitrogen as an Indicator of OSDS Impact

As described in Section 2.3.2 and listed in Table 2-3, nitrogen is one of the primary constituents in wastewater. Dissolved nitrogen is predominantly present in groundwater as the nitrate ion (Hunt, 2004; Canter and Knox, 1985, WRRC and Engineering Solutions, 2009). However, nitrogen can exist in groundwater in other forms such as nitrite or the ammonium ion. In this discussion, the dissolved forms of inorganic nitrogen will be referred to as a nitrogen. Under oxic conditions nitrates (and thus nitrogen) tend to be transported as a conservative species (Canter and Knox, 1985; Gold et al., 1990; Hunt, 2004; Wilhelm et al., 1994). The presence of nitrogen in OSDS effluent and its conservative transport properties make nitrogen an ideal tracer to model the OSDS impact on groundwater. In areas of heavy OSDS utilization the groundwater nitrogen concentration can be elevated far above background concentrations and in many cases result in an exceedance of the 10 mg/L maximum contaminant limit (Canter and Knox, 1985; Pang et al., 2006; USEPA, 2002). Because the background concentrations of nitrogen in Hawaii aquifers are typically less that 1 mg/L in non-agricultural areas (Hunt, 2004), this constituent can also be used to validate the OSDS effluent transport model results.

4.2.2 Groundwater Flow and Transport Models

Numerical modeling is ideally suited for evaluating the impact of OSDS effluent on groundwater. It can incorporate hydrogeological heterogeneities, spatial variability in groundwater recharge and OSDS effluent discharge, and the mixing of the OSDS leachate with non-impacted groundwater. Numerical models and the associated graphical user interface facilitate the export of the model results to GIS for incorporation into the study's risk analysis. This study modified the groundwater flow models used for the SWAP (Whittier et al., 2004) by incorporating the OSDS effluent leachate into the recharge.

The SWAP used the Modular Finite Difference Groundwater Flow Model (MODFLOW) (Harbaugh et al., 2000) to generate the groundwater flow field for delineating the Zone B and C capture zones. This model, developed by the U.S. Geological Survey, is the most widely used software for simulating groundwater systems. In general, the applicability of MODFLOW for Hawaii is limited due to its inability to simulate density-dependent flow. However, the majority of the flow of OSDS transport occurs in the freshwater zone, justifying the use of such an approach. To accomplish this, the bottom boundary of the model was defined as the centerline of the freshwater/seawater-mixing zone.

The groundwater flow solution computed by MODFLOW is used by transport models to simulate the movement of dissolved constituents in groundwater. The first such model used by this study was the USGS particle tracking model (MODPATH) (Pollock, 1994). The MODPATH was used to generate the time of travel setbacks from the drinking water wells and from the coast. The model uses the groundwater flow solution from MODFLOW to track the virtual particle movement due to flow of groundwater. This model does not consider the spreading of a plume due to hydrodynamic dispersion or molecular diffusion. The output is a visual track representing the path the virtual particles take from a point of origin to a point of termination. The point of termination can either be defined by an elapsed time designated by the modeler, or as a boundary or sink in the modeled area.

The results of the MODFLOW run were also used as an input to the solute transport code Multi-Species Transport Model in Three Dimensions (MT3DMS) (Zheng and Wang, 1999; Zheng, 2006) to simulate the transport of the ODGWN. The MT3DMS is a contaminant transport model that simulates the dissolved transport of multiple species. The model simulates the effects of advection, hydrodynamic dispersion, retardation (slowing of the plume transport due to the dissolved species sorbing onto the aquifer matrix), and the role that hydraulic conductivity anisotropy play in the transport of the dissolved constituents.

To simplify the model setup, the Groundwater Modeling System (GMS) (www.aquaveo.com/GMS) graphical user interface was used. The GMS is used to create a conceptual model directly or to extract data from Geographic Information System (GIS) maps that are read into GMS. Once the model simulation has been completed, the results can be converted to shapefiles or to a GIS raster for use in ArcGIS.

4.2.2.1 Modeling OSDS Derived Nitrogen in the Groundwater Recharge

The SWAP groundwater flow models were used to evaluate the extent and severity of OSDS effluent contamination of the groundwater. The SWAP groundwater models were modified by merging the OSDS density polygon shapefile with the groundwater recharge shapefile to estimate the concentration and distribution of ODGWN in the groundwater recharge. The merging of the two shapefiles provided the spatial resolution needed to adequately model the effect of an increase in groundwater nitrogen concentration from OSDS effluent. The nitrogen loading for each polygon was calculated by multiplying the OSDS effluent rate by the nitrogen concentration in the effluent based on the OSDS category and disposal type using data from WRRC and Engineering Solutions, Inc. (2009) (Table 2-3). The resulting shapefile included natural and irrigation recharge, additional recharge due to the effluent flux of the OSDS, and the OSDS derived nitrogen concentration in the recharge water.

4.2.2.2 Modeling the Transport of the OSDS Derived Nitrogen in Groundwater

Nitrogen was treated as a conservative species with no degradation/transformation simulated. This is consistent with the stability of nitrate in an oxidizing environment below the biologically active zone, and is considered a worst-case scenario. A reduction in the nitrogen concentration will occur by the mixing nitrogen due to groundwater movement, hydrodynamic dispersion, and the addition of nitrogen free recharge. These processes were modeled using the groundwater flow model developed for SWAP and the contaminant transport model MT3D. A dispersivity of 112 ft was used based on stochastic analysis of the lithology of four different boreholes in central Oahu using methodology described in Domenico and Schwartz (1990) (TEC, Inc., 2001 and 2004). The nitrogen transport simulation was run for 50 years to ensure that the simulated nitrate concentrations would reach a steady state distribution. The results of the nitrogen transport model were then mapped to a shapefile with polygons delineated using the nitrogen concentration contours. The goal of the nitrogen transport modeling was to map the distribution and magnitude of additional nitrogen added to the groundwater by the leaching of OSDS effluent. Simplifying assumptions were used that make the results of the model a qualitative rather than quantitative indicator of OSDS impact. These assumptions include:

- effluent discharge rates described in Section 2.3.1 and nitrogen concentrations listed in Table 2-3 accurately reflect what is released to the environment;
- all of the nitrogen remains dissolved in the leachate and in the groundwater (i.e., not subject to transformation processes such as denitrification or uptake by plants); and
- nitrogen does not sorb into the media during travel.

The most significant result of any of these assumptions not being true is that the simulated nitrogen concentrations will be greater than the actual concentrations. Also, the modeling did not account for the travel time in the unsaturated zone. The usable product of these models is the relative distribution and magnitude of OSDS effluent in the groundwater. This is produced in a map that shows the location and severity of OSDS effluent contamination.

4.2.3 Island Model Descriptions and Results

The following is a brief description of the models used to simulate the transport of ODGWN. The results of these nitrogen transport simulations provided critical data to assess the impact of current OSDS impact on the ROCs evaluated by this study.

4.2.3.1 Hawaii

4.2.3.1.1 Hawaii Conceptual Model

The MODFLOW for the Island of Hawaii was adapted from the SWAP Hawaii groundwater model (Whittier et al., 2004). The three separate models used previously for the SWAP were combined into a single three-layer model that covered the entire island. Figure 4-5 shows the boundary conditions and major features incorporated into the Hawaii Island conceptual model. The coastline of the model was a specified head boundary with an assigned hydraulic head equal to that measured in wells nearest the coast. The upper boundary was an assigned flux boundary that simulated the groundwater recharge. The lower boundary of the model was a no-flow boundary at the estimated mid-point of the freshwater/saltwater transition zone.

Major hydrogeologic features that control the direction of groundwater flow are the margins of the volcanic rift zones, major faults, and streams that intersect the water table. The margins of the major volcanic rift zones were delineated using horizontal flow barriers (HFB). A HFB is a line type feature used to represent physical obstructions to groundwater flow, with a specified hydraulic characteristic expressed as the product of the hydraulic conductivity of the barrier divided by its width. This feature represented the dikes at the boundary between the high-level groundwater and the basal groundwater. HFBs were also used to simulate the groundwater divide of the major volcanic rift zone and major faults. Streams that intersected the water table were modeled as drains. A drain is a point or arc feature that removes water from the model. In this model the arc feature was used to represent streams with modeled outflow to the arc controlled by drain conductance, an option that seems to be an appropriate representation. The conductance (a composite parameter describing the hydraulic conductivity and thickness of the media surrounding the streambed) and bottom elevation of the drains representing the streams were adjusted so that the uptake of the drain approximated the baseflow of the stream. The final feature that extracts water from the model are wells, the locations of which are shown of Fig. 4-5.

In qualitative terms the hydraulic conductivity of an aquifer describes the ease with which water moves through the rocks. The values of hydraulic conductivity can range from 1 ft/d for heavily dike-intruded lavas to over 5,000 ft/d for thin-bedded flank lavas (Hunt, 1996). The distribution of hydraulic conductivity zones followed the aquifer boundaries of Mink and Lau (1993). Where available, the aquifer hydrogeologic properties were based on values used by Oki (1999 and 2002). The hydraulic conductivity of the high-level water bodies was based on representative values from the literature (Hunt, 1996) and interpretations of specific capacity well tests (Rotzoll and El-Kadi, 2008). Figure 4-6 shows the distribution and values of the hydraulic conductivities used in this model. The hydraulic conductivity values assigned varied from 0.3 ft/d in the heavily dike intruded rift zones to 7,500 ft/d in lowland flank lavas along the west coast and in the east-central area of the island. The north flank of the Mauna Kea Volcano and the flanks of the Kohala Volcano had intermediate hydraulic conductivities that varied from 200 to 500 ft/d.

Recharge provides the input of water into the groundwater flow model. Recharge also includes the simulated flux of OSDS leachate into the transport model. As described above, the recharge into the model was developed by merging OSDS effluent discharge with the SWAP model recharge coverage. Figure 4-7 shows the recharge distribution for the island of Hawaii. The values for recharge were taken from Oki (1999 and 2002) and from Whittier et al. (2004). The recharge used for this model varied from about 2 inches per year along the coast in central-west Hawaii to greater than 200 inches per year in central-east Hawaii. Bands of significantly elevated recharge (greater than 50 inches per year) occur in cloud formation zones on the southeast facing slope of Mauna Loa and the northeast facing slope of the Kohala Volcano. Recharge added 5,980 mgd of water to grid. Losses of groundwater included 3,860 mgd discharged at the coastal boundary, 130 mgd in well extraction, and 1,990 mgd of groundwater discharge to streams.

4.2.3.1.2 Hawaii Numerical Model

The hydraulic parameters of the conceptual model were mapped to a MODFLOW finite difference numerical grid. This grid consisted of 184,275 cells arranged in 273 rows and 225 columns. Figure 4-8 shows the model grid in plan view and in cross-section. Only 111,172 cells were actively used for groundwater flow computations because the remainder of the cells fell outside of model boundaries and were inactivated.

The bottom of the model was the bottom boundary described above. The top of the model grid was the topographic surface. However, only that part of the top layer at the simulated water table and below was actively used in the groundwater flow computations. The layers were used for better vertical resolution of the model to facilitate the quasi-three dimensional flow calculations and did not reflect the bedding plane of the lava flows. The bottom of the top layer was set to -15 m (49 ft) or one-third of the distance between the water table and the bottom boundary, whichever was the shallowest. The bottom of the model grid was set to an elevation that was -40 times the water elevation in basal water zones based on the Ghyben-Hertzberg Principle (Freeze and Cherry, 1979). In the zone of transition from basal to high-level groundwater the depth of the bottom boundary was proportionally decreased to a maximum depth of -2000 m (-6,560 ft).

4.2.3.1.3 Hawaii Transport Model

The MT3D transport model used the groundwater flow solution calculated by the MODFLOW to simulate the transport of ODGWN. This required two additional inputs: the nitrogen concentration in the groundwater recharge; and the porosity of the aquifers. The nitrogen concentration in the groundwater recharge (Fig. 4-9) was calculated using the methodology described in Section 4.2.2. There were only few areas with a significantly elevated nitrogen concentration (greater than 2.5

mg/L) in the recharge. Throughout most of the island the nitrogen contribution attributable to OSDS is negligible due to dilution by recharge. However, in west Hawaii the localized nitrogen concentration in the recharge was calculated to be greater than 30 mg/L. This is significant because the irrigation and natural recharge in this area is low. In rural east Hawaii where there are significant numbers of OSDS (Hawaii Paradise Park and Volcano Village for example) high recharge rates dilute the contribution of OSDS nitrogen, reducing the concentration to values less than 2.5 mg/L. However, caution must be exercised when considering these results. This analysis was done on the regional scale of the Island of Hawaii. Because many of the residences are relatively closely spaced and use domestic wells for household water the local affects may be more significant. The close proximity of residences and domestic wells to OSDS may constitute a significant health risk.

4.2.3.1.4 Current Relative Impact to Hawaii Groundwater

The model results show only a small fraction of the groundwater on Hawaii Island is significantly affected by OSDS leachate. However, as indicated by the modeled groundwater nitrogen concentrations (Fig. 4-10), the ODGWN concentration beneath and down gradient from some communities has the potential to exceed drinking water standards. For the purposes of this study any groundwater nitrogen concentration greater than the approximate background concentration of 1 mg/L is considered significant (Hunt, 2004). Any area with a modeled groundwater nitrogen concentration greater than or equal to 9 mg/L is considered serious because when added to the approximate background concentration of 1 mg/L that nitrogen concentration would result in a value that exceeds the drinking water maximum contaminant limit for nitrate. This occurs in the aquifers at North Kona, Kohala, and Waimea. However, it must be emphasized that this is a worst-case scenario because the model did not account for degradation, sorption, or transformation of dissolved nitrogen to nitrogen gas. Also, the model did not account for the transport time from the point of OSDS recharge to the water table. Kelley (2012) estimated that the water in West Hawaii well samples was recharged from 21 to 50 years prior to the date of collection. The prolonged time between recharge and arrival of the water at the intake implies the full impact of the OSDS leachate may not be evident in the samples collected to date. With rapid development in previously non-developed agricultural areas within the last decade the concentration of ODGWN will very likely increase.

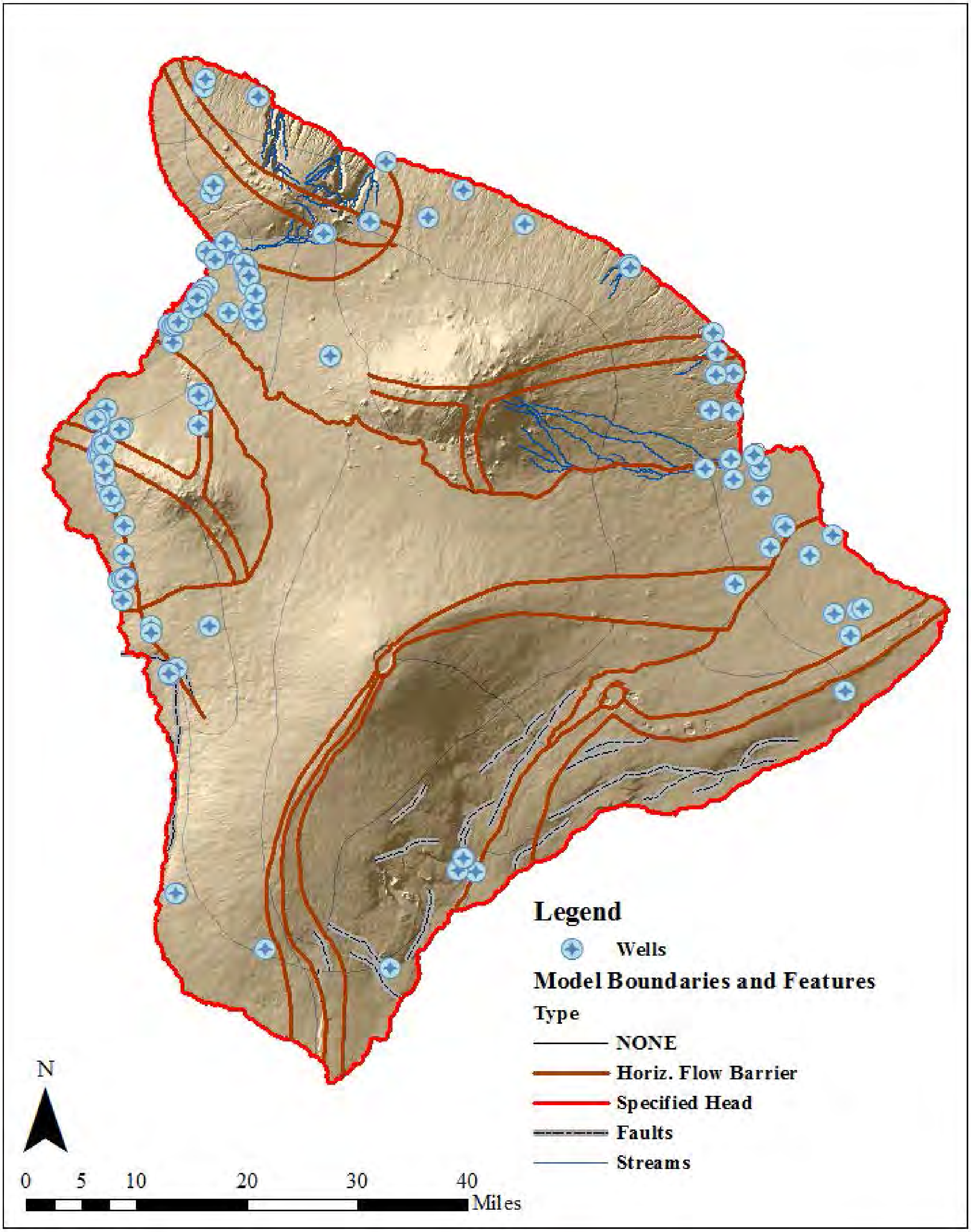

Figure 4-5. The boundary conditions and major features of the Hawaii Island groundwater and nitrogen transport model

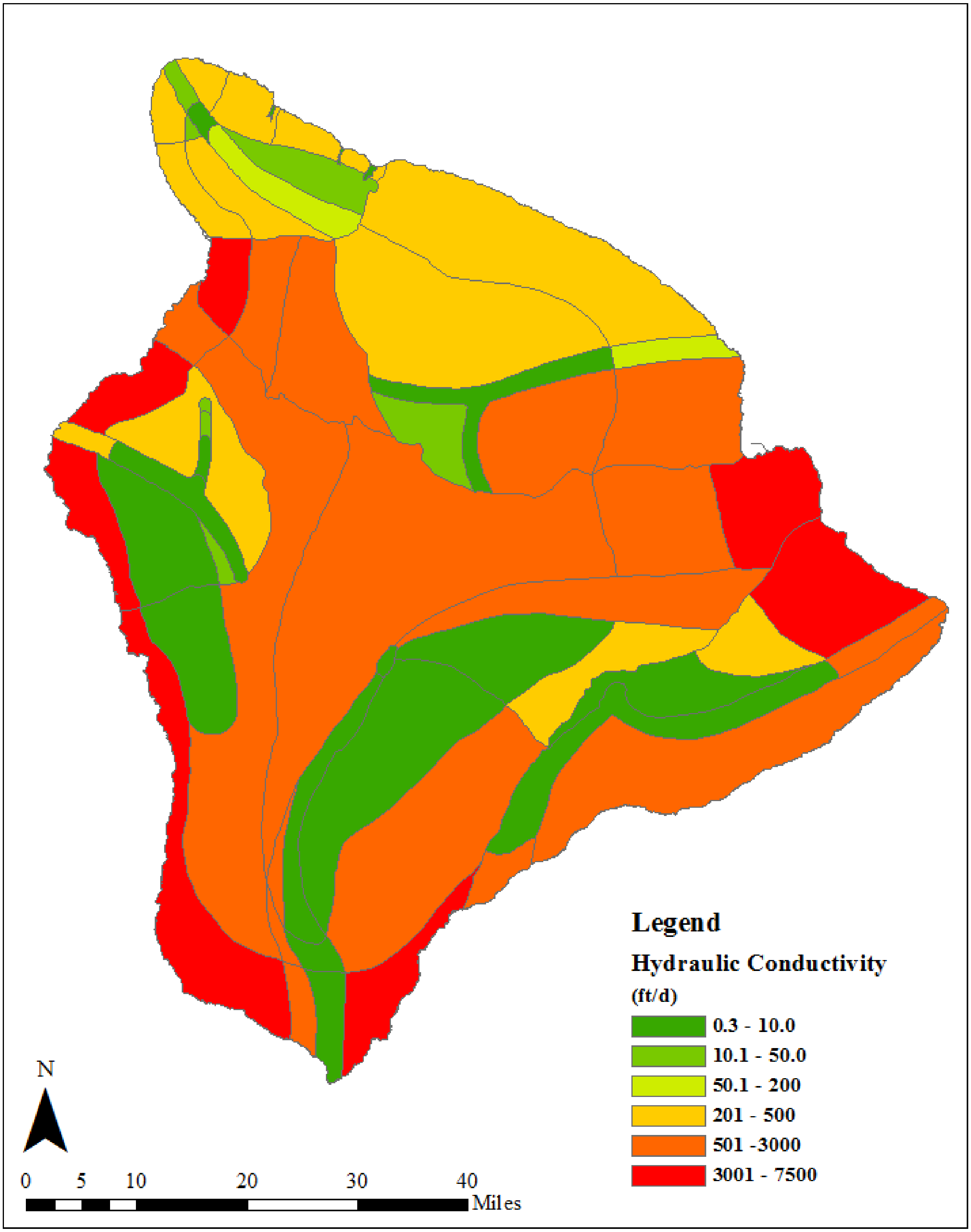

Figure 4-6. The hydraulic conductivities used in the Hawaii Island groundwater flow model

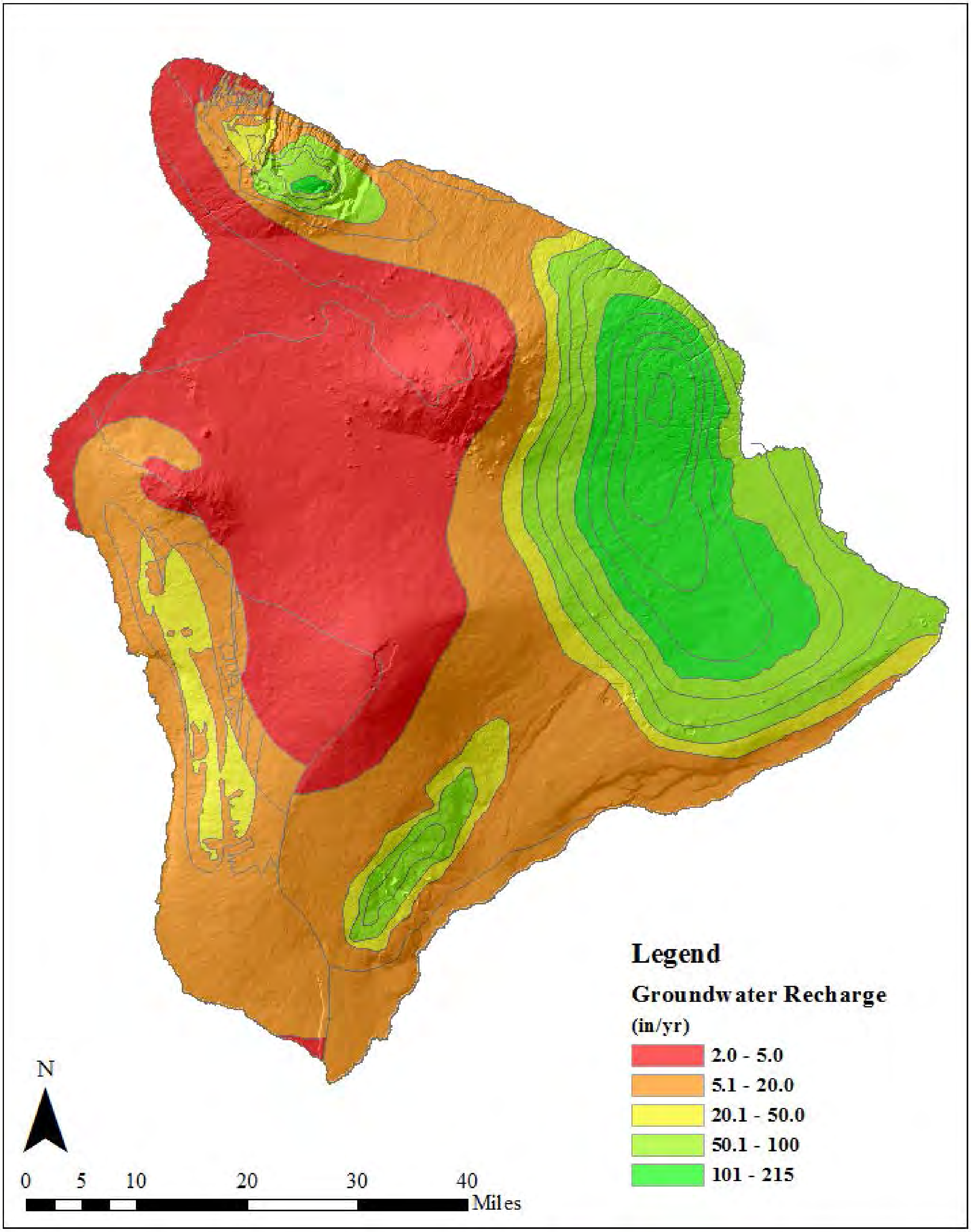

Figure 4-7. The groundwater recharge for the Hawaii Island model

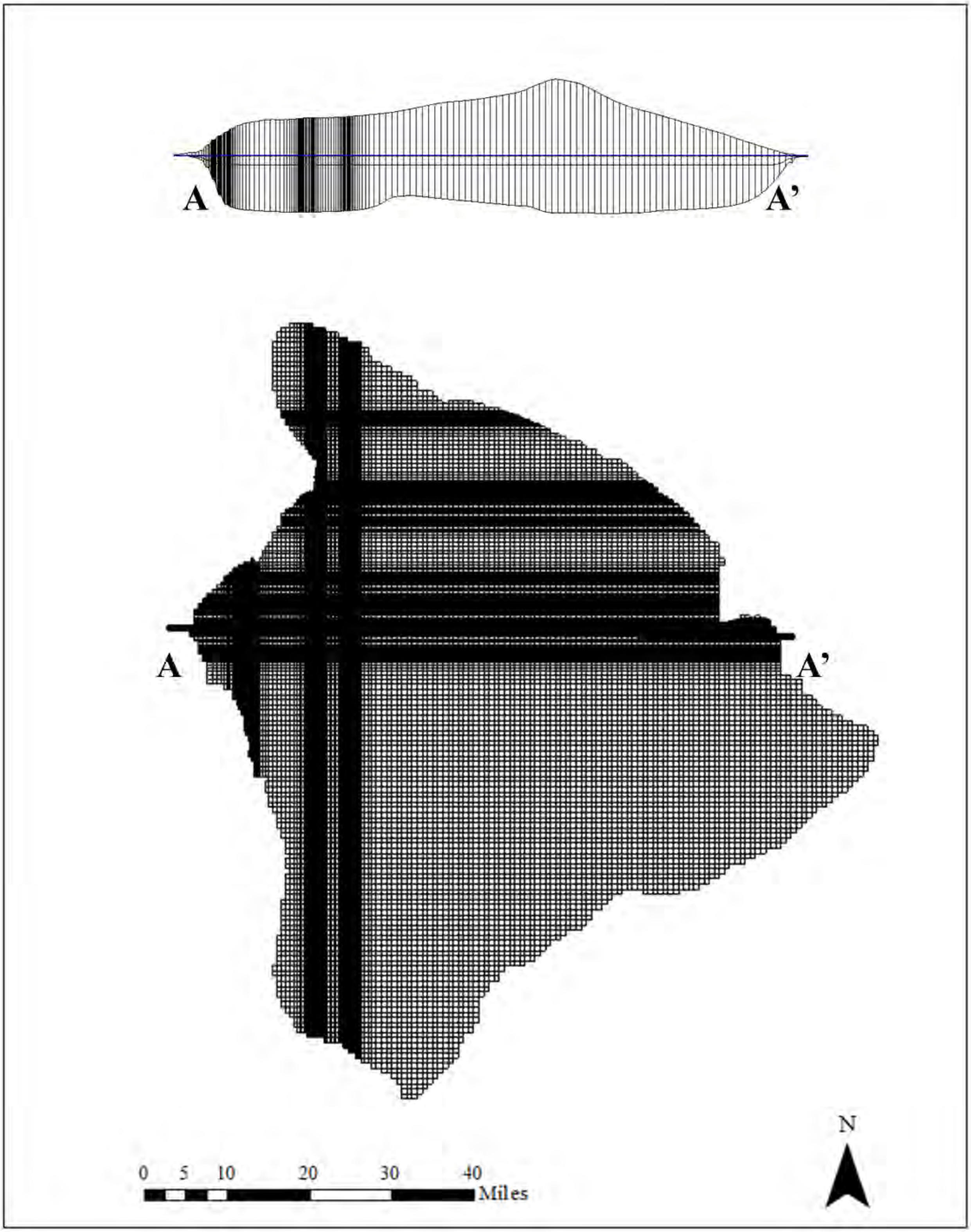

Figure 4-8. The numerical model grid for the Hawaii Island groundwater flow model

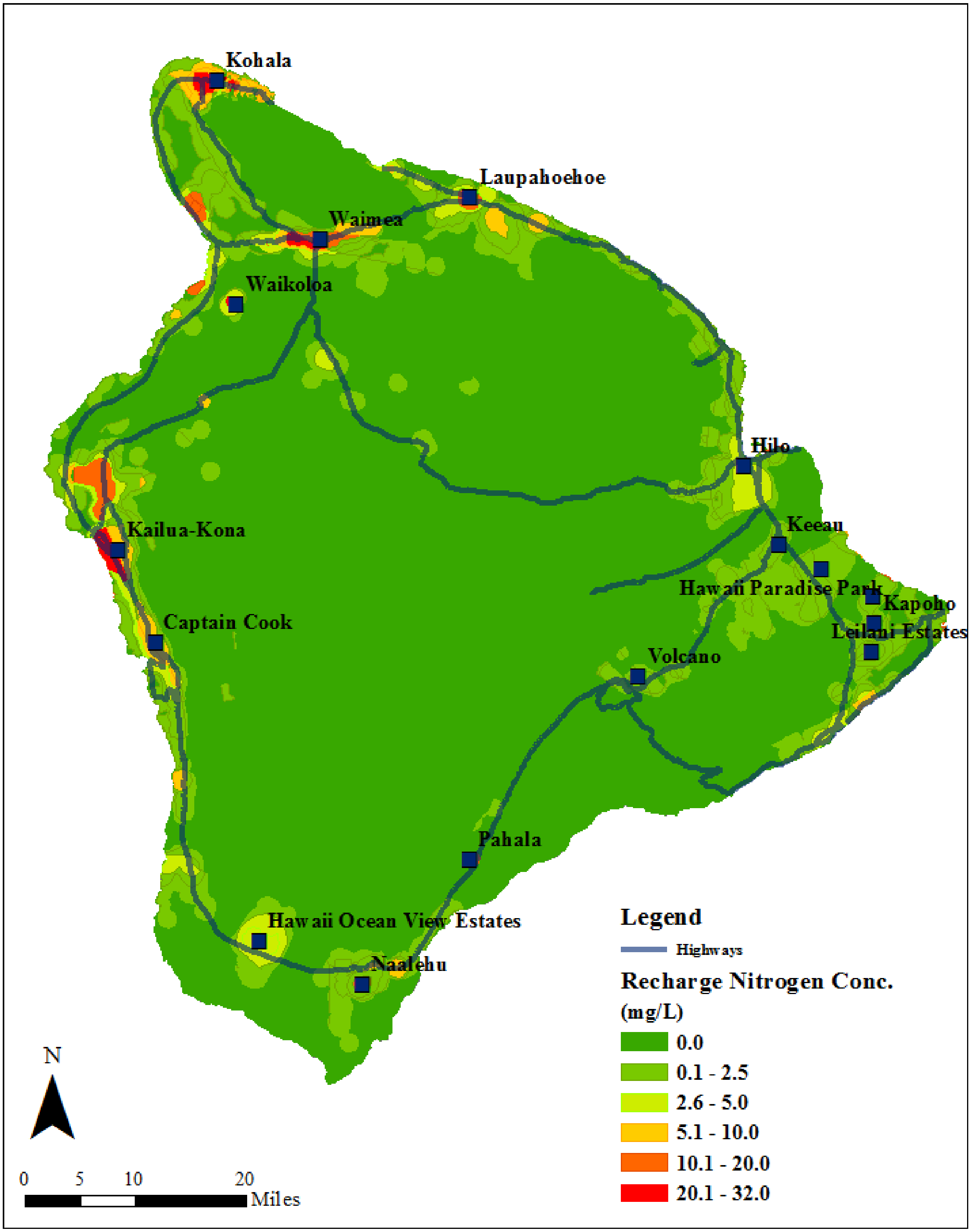

Figure 4-9. The OSDS derived nitrogen concentration for the Hawaii Island transport model

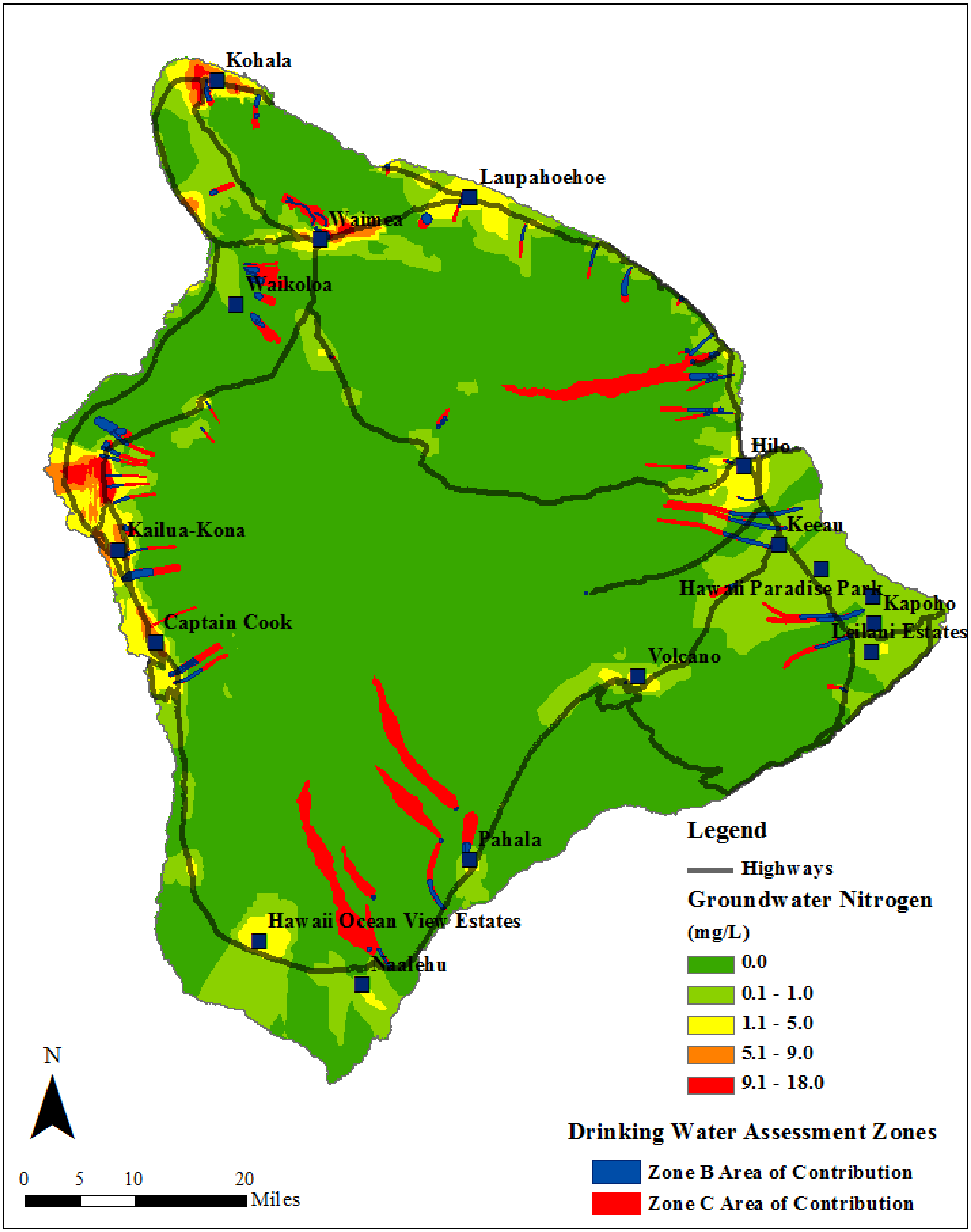

Figure 4-10. The simulated ODGWN concentration for Hawaii Island relative to the drinking water source zones of contribution

4.2.3.2 Kauai

4.2.3.2.1 Kauai Conceptual Model

As with the Hawaii Island model, the groundwater transport model of Kauai was adapted from that used for the initial SWAP assessments (Whittier et al., 2004) by merging three separate models into a single island-wide model. This alleviates problems with overlapping boundaries and the adverse influence of the model boundaries on the capture zones for wells located near the boundaries.

Figure 4-11 shows the boundary conditions and major hydrogeologic features of the Kauai groundwater flow model. Three types of boundaries conditions were used in this model: specified head; specified flux; and no-flow condition. A specified head of 0.0 feet relative to mean sea level was assigned at the shoreline boundary of the model. This was done to capture the influence that the ocean has on the groundwater table elevation at the coast. The upper boundary of the model grid is the topographic surface of Kauai. However, MODFLOW only simulates water flow where the aquifer is saturated so the upper boundary of the numerical model is the water table. Recharge is applied at the upper boundary as a specified flux. A no-flow boundary was assigned to the bottom of the model grid. The elevation of the bottom boundary in the basal aquifer areas is based on the theoretical depth of the mid-point of the freshwater/seawater transition zone using the Ghyben-Hertzberg Principle calculations. For water table elevations up to 25 m, the bottom of the model grid was set at a -40 times the groundwater elevation. Starting at a groundwater elevation of 25 m, the coefficient used to compute the bottom boundary of the model was gradually changed from -40 to -4 times the water table elevations up to 500 m msl (1,640 ft msl). For water table elevations above 500 m msl the elevation of the bottom boundary was -2,000 m (6,560 ft) relative to mean sea level.

Faults and intrusive dikes act as barriers to groundwater flow affecting the groundwater elevation and flow direction. In this model HFBs were used to simulate faults and the boundaries of the dike intruded zones. Faults and dikes act as barriers to groundwater flow resulting in increased groundwater elevations that may rise above the bottom of stream channels. Streams that intersect the water table may draw water from the aquifer. This groundwater/surface water interaction is simulated using the drain feature. The magnitude of the groundwater flow is dependent on the elevation difference between the drain and the water table and the conductance of drain. Conductance is grouped parameter that accounts for the hydraulic conductivity and thickness of the streambed materials.

The aquifers of Kauai are made up of a wide variety of materials resulting in a broad range of hydraulic conductivities. Figure 4-12 shows the values of hydraulic conductivity assigned to the Kauai groundwater flow model. The lowest values of 1.5 to 10 ft/d were assigned to the caldera filling lavas of the Wainiha Valley. Most of Kauai’s geology is dike intruded resulting in a majority of the hydraulic conductivities being less than 50 ft/d. The values used for the dike-intruded lavas ranged from 1.6 to 115 ft/d. The large variation in hydraulic conductivity is a result of the variable dike density, which is the number of dikes present per mile of aquifer transversed. The flank lavas of west Kauai have the highest hydraulic conductivity with values ranging from 500 to 820 ft/d. Southern Kauai has dike free flank lavas of moderate hydraulic conductivity that range from 201 to 500 ft/d.

The distribution of recharge for the Kauai groundwater model was based on a water budget developed by the U.S. Geological Survey in 1995 (Shade, 1995). Values of recharge varied from less than 5 inches per year at the low elevations of west Kauai to greater than 150 inches per year at the highest elevations of Mt. Waialeale. Figure 4-13 shows the recharge distribution used for this model.

4.2.3.2.2 Numerical Model Grid

The finite-difference grid used in this model consisted of 380,580 cells arranged in 278 rows, 270 columns, and three layers. Of these cells only 193,563 were active; the remaining cells fell outside of the boundaries of the conceptual model and were inactive. Each cell was 150 meters on a side. As described above, recharge added 674 mgd of water to grid. Losses of groundwater included 586 mgd discharge at the coastal boundary, 42 mgd in well extraction and 46 mgd of groundwater discharge to streams.

4.2.3.2.3 Current Relative Impact to Kauai Groundwater

The results of the transport model identified the areas where groundwater is expected to be most impacted by OSDS effluent. The transport model accounts for dilution of the OSDS leachate by mixing with the uncontaminated groundwater flow and the cumulative effect of added nitrogen as the groundwater flows beneath a series of OSDS. This results in a displacement downgradient of the maximum ODGWN concentration relative to the recharge nitrogen concentration. The areas that appear to be most heavily impacted by ODGWN are the Poipu area in the south, the Wailua/Kapaa area and Lihue areas in the east, and the Kilauea and Haena areas in the north. All of these areas have simulated ODGWN concentrations exceeding 9 mg/L.

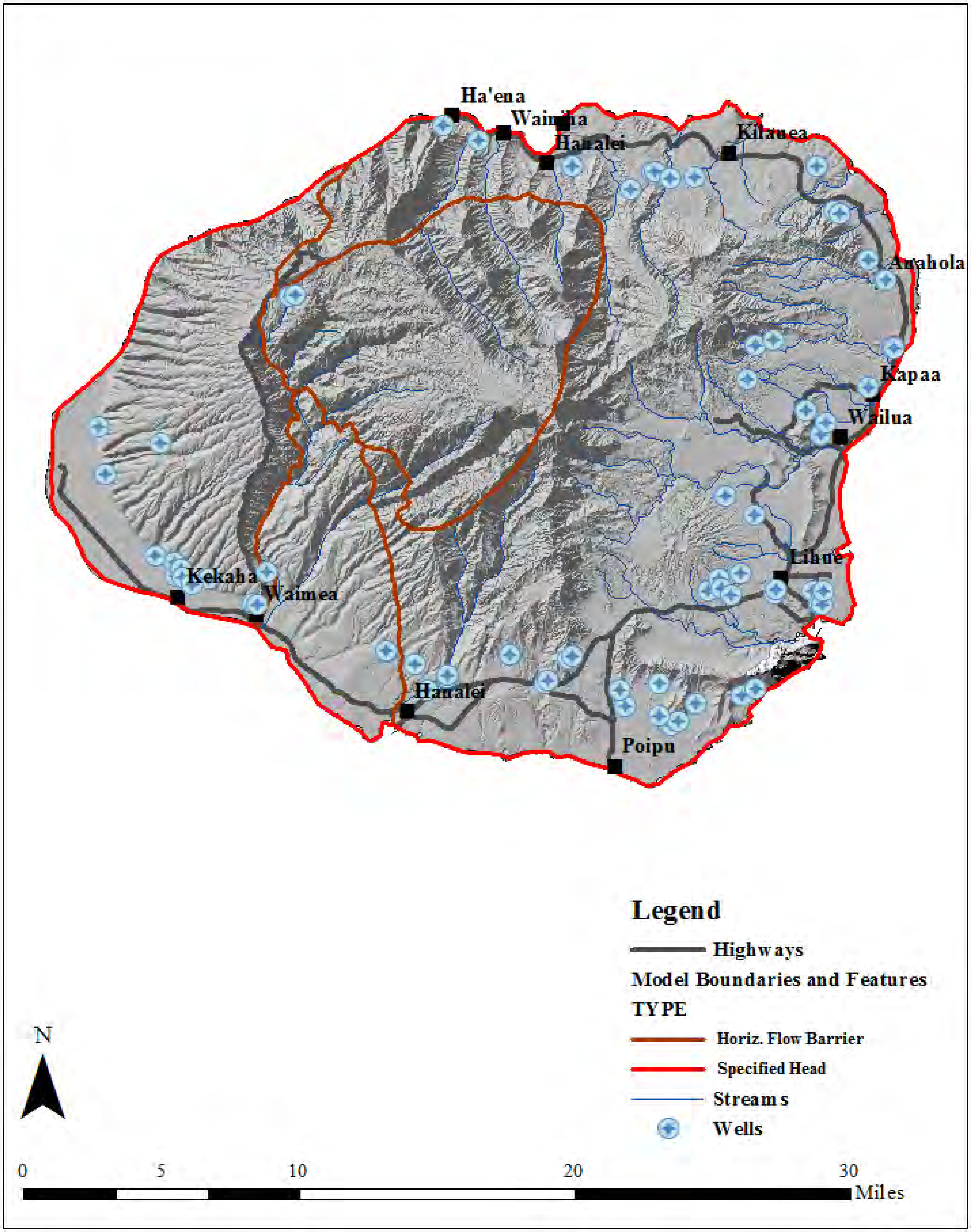

Figure 4-11. Boundary conditions and major features of the Kauai Groundwater Flow Model

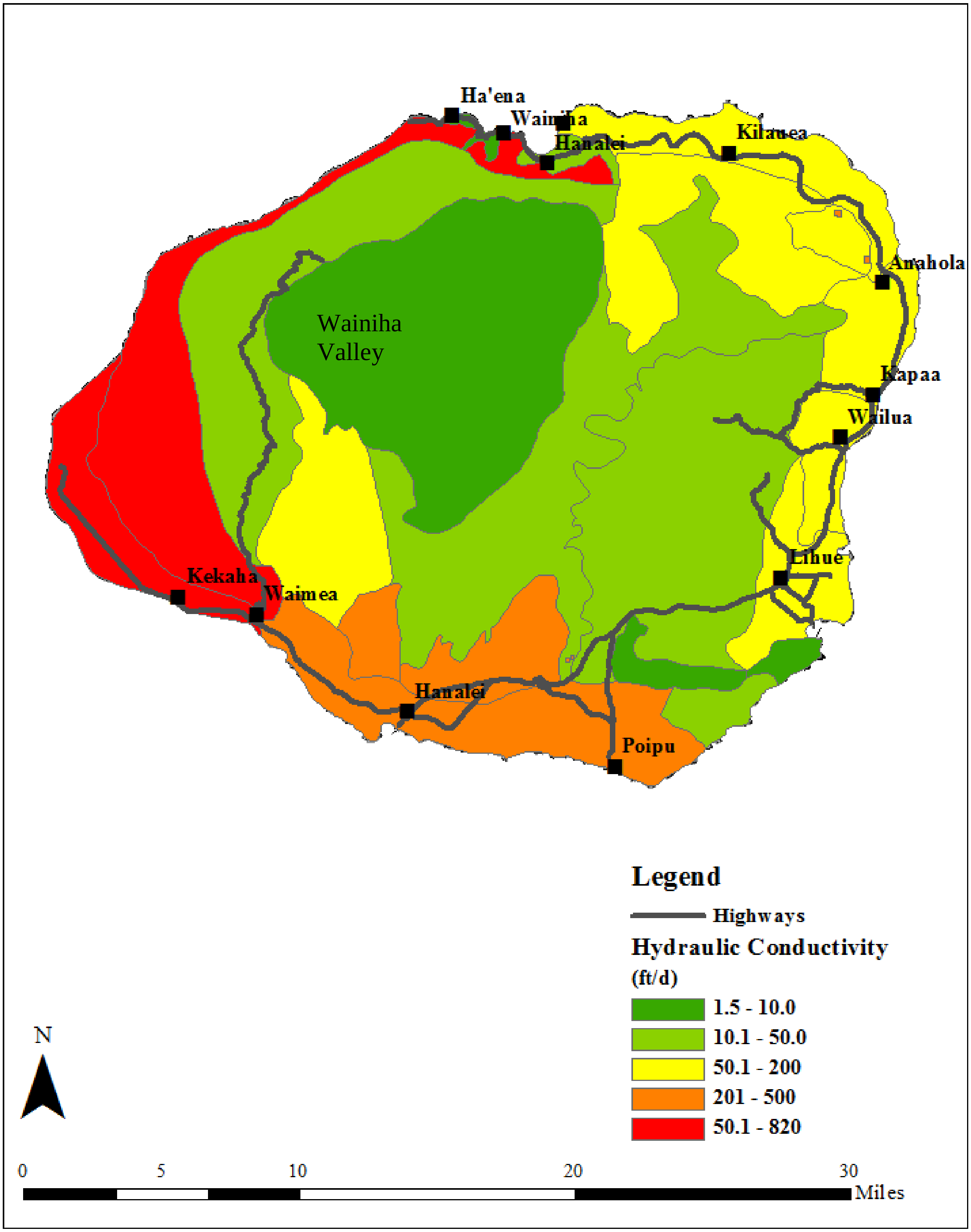

Figure 4-12. The distribution of hydraulic conductivities for the Kauai Groundwater Flow Model

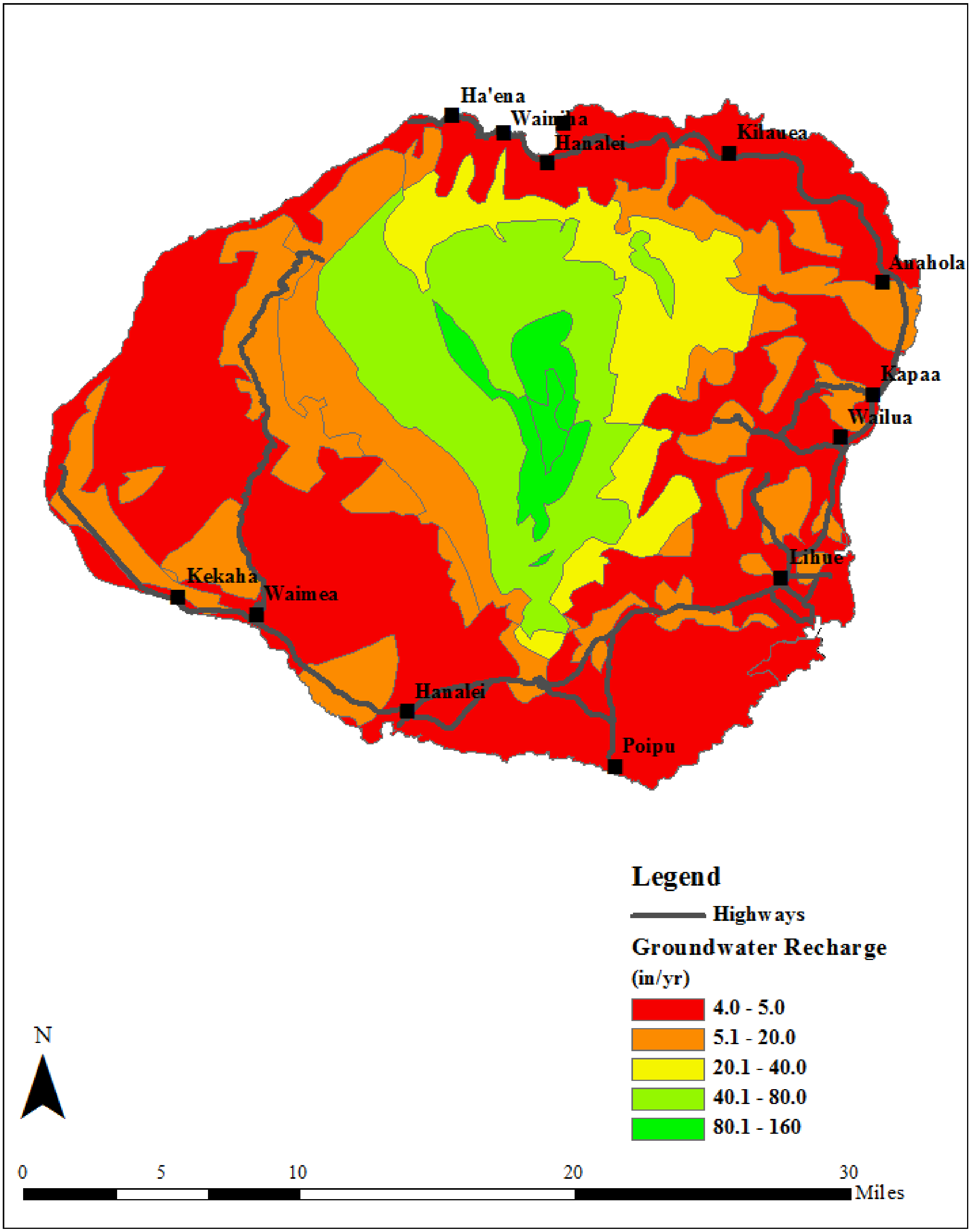

Figure 4-13. The recharge for the Kauai Groundwater Flow Model

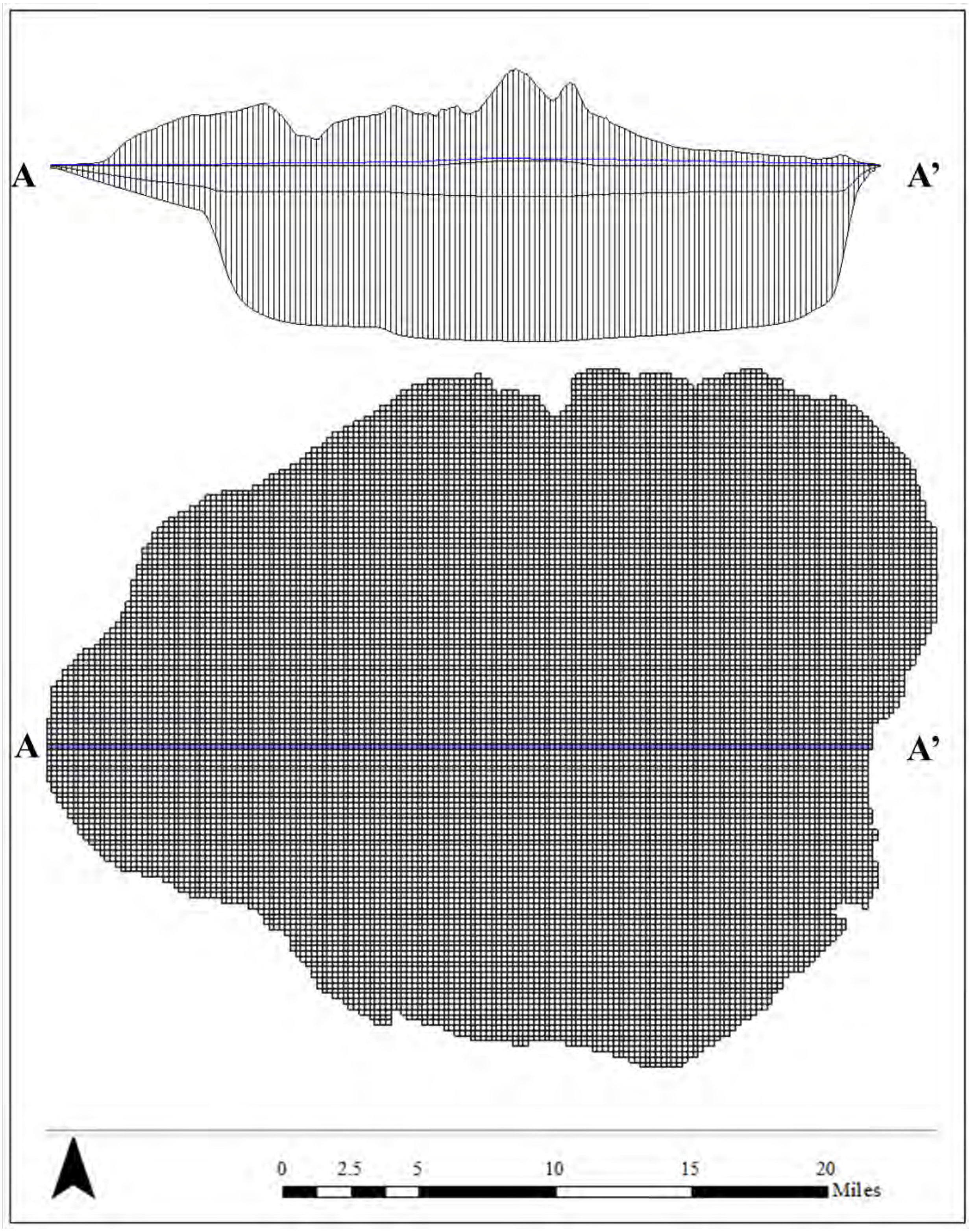

Figure 4-14. Numerical model grid for the Kauai Groundwater Flow Model

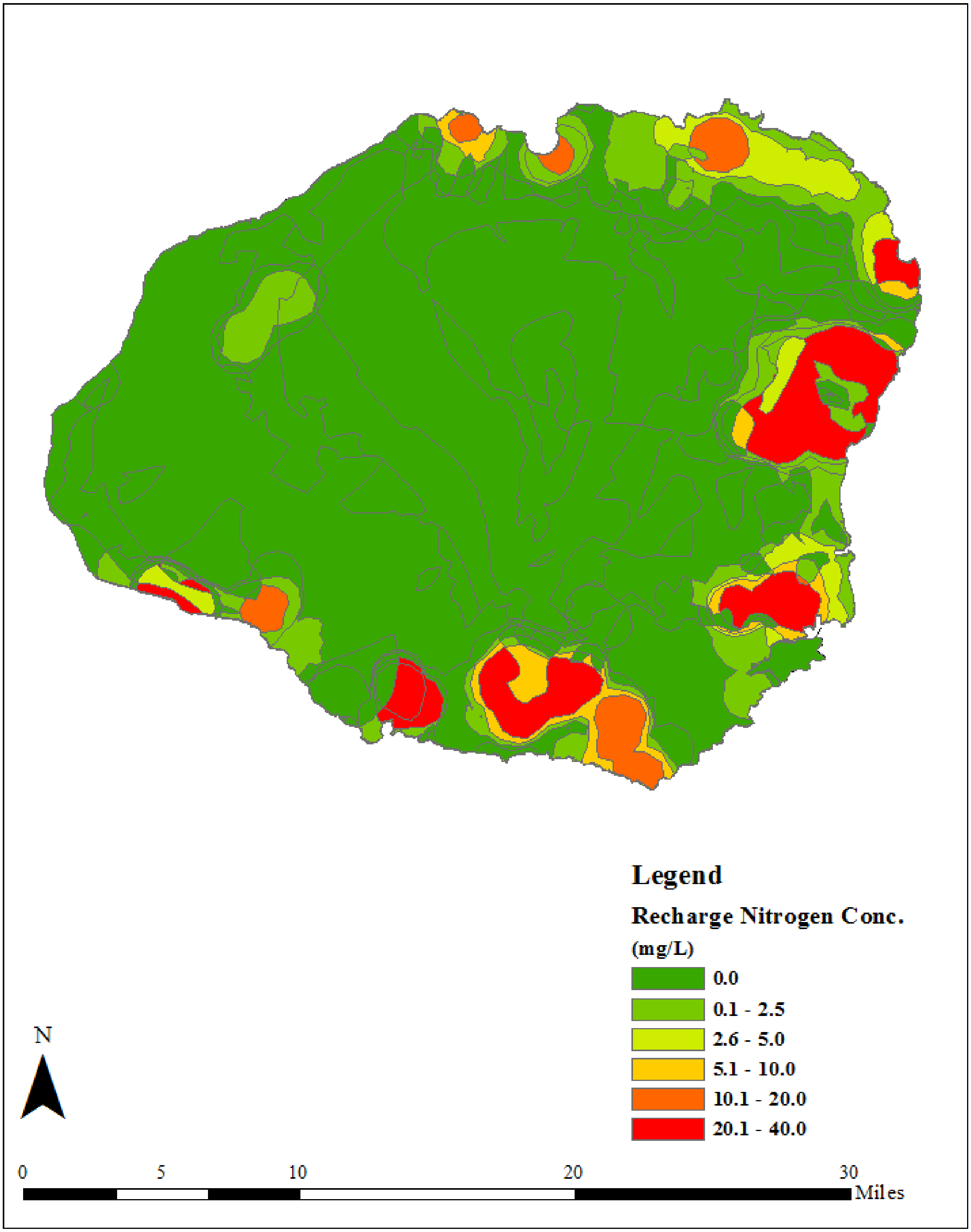

Figure 4-15. The OSDS derived nitrogen concentration in the recharge for the Kauai Contaminant Transport Model

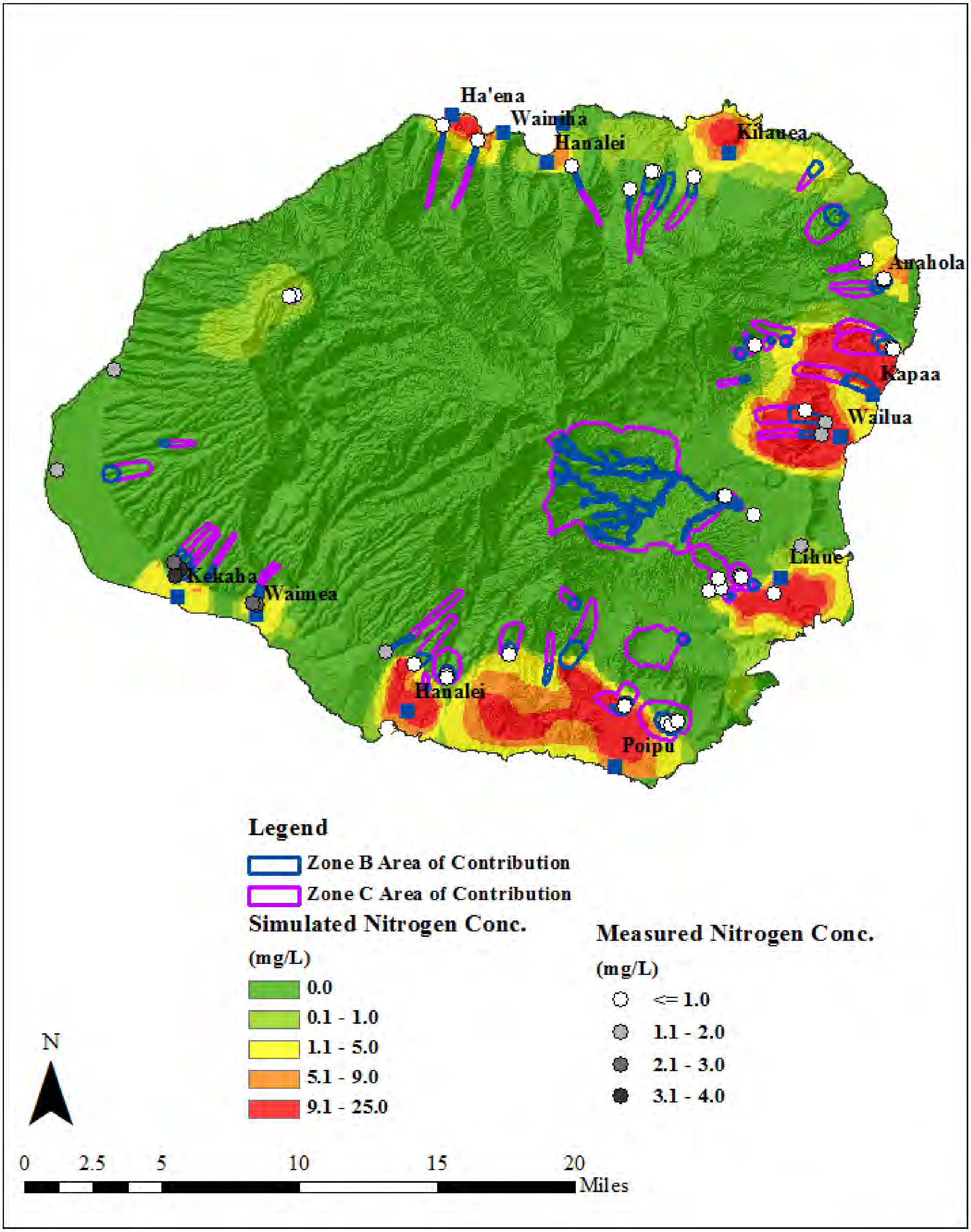

Figure 4-16. The simulated ODGWN concentrations for Kauai

4.2.3.3 Maui

Maui is formed by two volcanoes with an isthmus connecting the two. The nitrogen transport for the island of Maui was done using two different flow models, each centered on the respective volcano that formed east and west Maui. The boundary of each model was extended across the isthmus resulting in some overlap of the models. The first model covered Haleakala and extended west past the narrowest portion of the isthmus. The second model covered the West Maui Volcano and extended eastward again past the narrowest portion of the isthmus.

4.2.3.3.1 East Maui Conceptual Model

Haleakala Volcano makes up the bulk of east Maui and captures the majority of the recharge for the groundwater of this area. Figure 4-17 shows the boundary conditions and major hydrogeologic features for this model. Haleakala volcano has three rift zones: (1) the east rift zone extending from the summit eastward to the coast near Hana; (2) the northwest rift zone that extends from the summit to just west of the northern extend of east Maui; and (3) the southwest rift zone that extends from the summit to the southwest corner of east Maui near Makena. These rift zones were modeled as low hydraulic conductivity formations with HFBs inserted to impose an anisotropy parallel to the axis of the rift zone. The coastline of East Maui was modeled as a specified head of zero. The isthmus boundary to the west was also modeled as a specified head boundary. The assigned head was interpolated using measured water levels.

Figure 4-18 show the distribution of the horizontal hydraulic conductivities that varied from 0.25 ft/d in the rift zones and the high water area of Nahiku to as high as 2,500 ft/d in the flank lavas on the slopes of Haleakala. The hydraulic conductivity of the sediments that form the isthmus varied in hydraulic conductivity of 0.25 to 10 ft/d.

All water entering the model was from groundwater recharge. The assigned recharge was taken from a water budget for East Maui calculated by Shade (1999). Figure 4-19 shows the distribution of recharge that varied from 2.5 in/yr on the leeward slopes of Haleakala to 120 in/yr in the fog drip zone of the windward slope of this volcano. Streams limit the recharge by intercepting the infiltration prior to it reaching the basal aquifer. East Maui has numerous streams that receive baseflow from groundwater discharge. However, the majority of the discharge of groundwater to surface water is from perched water zones (Gingerich, 1999a and 1999b) that intercept the recharge prior to it reaching the basal aquifer. This model only simulated the flow in the basal and high level aquifers and did not include the perched water zones. For this reason, the recharge calculated by Shade (1999) was reduced in the perennial stream watershed areas to account for that perched water that was returned to surface as baseflow for steams. The amount of reduction was that estimated by Gingerich (1999a).

4.2.3.3.2 East Maui Numerical Model

The East Maui model is built on a numerical grid consisting of 125,736 cells arranged in 186 columns, 169 rows, and 4 layers. Of these cells, 95,411 are active with the remainder falling outside of the model boundaries. Figure 4-20 shows the numerical grid for this model in plan view and in cross section. The dimensions of each cell vary from 100 m (328 ft) to 500 m (1640 ft) on a side. The grid was refined to the smaller dimensions at the location of recently installed drinking water wells. The bottom of the grid was set to -40 times the water table elevation beneath the basal aquifer to approximate the mid-point of the freshwater/saltwater transition zone as predicted by the Ghyben-Hertzberg Principle (Freeze and Cherry, 1979). For water table elevations greater than 10 m (32.8 ft) scalar that was progressively changed from -40 to -2 used to compute the model's bottom boundary elevation. This was done to create a smooth transition of the bottom boundary as the aquifer type transitioned from a basal water zone to a high-level aquifer zone. The maximum depth of the bottom boundary was -1000 m (3,280 ft) for water elevations of 500 m and higher. The bottom of Layer 3 was truncated at -200 m. The bottom of the remaining layers was evenly distributed between the water table and the bottom of Layer 3.

4.2.3.3.3 West Maui Conceptual Model

The groundwater in West Maui flows radially from the summit area of the West Maui Volcano to discharge areas at the coast. This model includes the West Maui Mountain and extends eastward past the narrows of the isthmus. Figure 4-22 shows the model coverage, model boundaries, and major hydrogeologic features. At the coast a specified head boundary imposed a defined hydraulic head of 0 m msl (0 ft msl). The isthmus boundary to the east was modeled as a specified head boundary, with the assigned head interpolated from measured groundwater elevations.

The interaction between groundwater and streams plays a significant role in the groundwater flow of west Maui. Groundwater discharges from the high-level groundwater aquifers into streams in the valleys that dissect the interior of West Maui deeply enough to contact the water table. These streams were modeled as drains where the groundwater flowing into the drain is dependent on the elevation difference between the groundwater and the drain, and the hydraulic characteristics of the drain that include the thickness and the hydraulic conductivity of material surrounding the drain. The conductance assigned varied from 0.25 m^2/d/m to 4 m^2/d/m. The values were selected to approximate the baseflow of the major streams. The stream segments that occur outside of the high-level aquifer areas commonly loose water due to infiltration through the streambed. This was accounted for by enhancing the groundwater recharge in the zones adjacent to the streams. Stream valleys also act as barriers to groundwater flow. At the lower elevations the alluvium and weathered rock beneath the streams extend significant distances beneath the water table. HFBs were used to model these obstructions to groundwater flow. HFBs were also used to simulate the fault system that defined the ancient caldera of this volcano (Sherrod et al., 2007). The hydraulic characteristic assigned to the faults was 0.00005 d^{-1}.

The hydraulic conductivity of the lava and other rock and alluvial formations determine the ease with which water flows in the subsurface. Figure 4-23 shows the range of hydraulic conductivities assigned to this model. This volcano does not have a well-defined rift zone, but rather the dike complex that forms the high-level water aquifers occur as an oval in the interior of West Maui. The dike complex was modeled with low hydraulic conductivities that varied from 0.030 to 0.11 ft/d. The majority of the flank lavas (shown in dark green) were assigned a hydraulic conductivity of 5,350 ft/d. The low permeability of the Honolua Volcanics that intersect the water table north of Waihee was assigned a hydraulic conductivity of 161 ft/d. The flank lavas in the Wailuku area (shown in light green) were assigned a hydraulic conductivity of 1,090 m/d. The sediments along the coast that form the isthmus (shown in brown) were assigned hydraulic conductivities that varied from 81 to 161 ft/d.

4.2.3.4 West Maui Numerical Model

The West Maui model was built on a numerical grid consisting of 78,000 cells arranged in 150 columns, 130 rows, and 4 layers. Of these cells, 52,444 are active with the remainder falling outside of the model boundaries. Figure 4-24 shows the numerical grid for this model in plan view and in cross section. The dimensions of each cell are 250 by 150 m (820 by 492 ft) on a side. The bottom of the grid was set to -40 times the water table elevation beneath the basal aquifer to approximate the mid-point of the freshwater/saltwater transition zone as predicted by the Ghyben-Hertzberg Principle (Freeze and Cherry, 1979). For water table elevations greater than 10 m (32.8 ft) scalar that was progressively changed from -40 to -2 used to compute the model's bottom boundary elevation. This was done to create a smooth transition of the bottom boundary as the aquifer type transitioned from a basal water zone to a high-level aquifer zone. The maximum depth of the bottom boundary was -1000 m (3,280 ft) for water elevations of 500 m (1,640 ft) and higher. The bottom of Layer 3 was truncated at -200 m (656 ft). The bottom of the remaining layers was evenly distributed between the water table and the bottom of Layer 3.

4.2.3.4.1 Maui Transport Model

As was done with the previous models, a MT3D transport was used to simulate the transport of ODGWN in the groundwater. The groundwater recharge shapefile was merged with the OSDS and OSDS density shapefiles to model the ODGWN in the recharge water. Figure 4-25 shows the concentrations of the OSDS derived nitrogen in the groundwater recharge. The areas with the highest concentration of nitrogen in the recharge occur in upcountry Maui in the communities of Kula, Pulehu, and Wailea. In West Maui, the highest concentration of OSDS derived nitrogen in the recharge was between Kaanapali and Lahaina. The ODGWN transport simulations were run on both the East Maui and the West Maui model for a period of 50 years to allow the simulated nitrogen concentration to reach a near equilibrium condition. The results of the two models were merged for importation into GIS.

4.2.3.4.2 Current Relative Impact to Maui Groundwater

The ODGWN transport model shows a significant ODGWN impact on the groundwater beneath the western slopes of Haleakala. The unsewered areas between Waihee and Wailuku, and south of Kihei have modeled ODGWN concentrations that exceed 9 mg/L. When added to a background nitrogen concentration of about 1 mg/L, the nitrogen concentrations in these areas could exceed the nitrate MCL of 10 mg/L. The west coast of West Maui does not appear to be significantly impacted by OSDS effluent as evidenced by the low simulated nitrogen concentration in all areas except south of Kaanapali and Kapalua where the model predicted moderate ODGWN concentrations 5 mg/L or less.

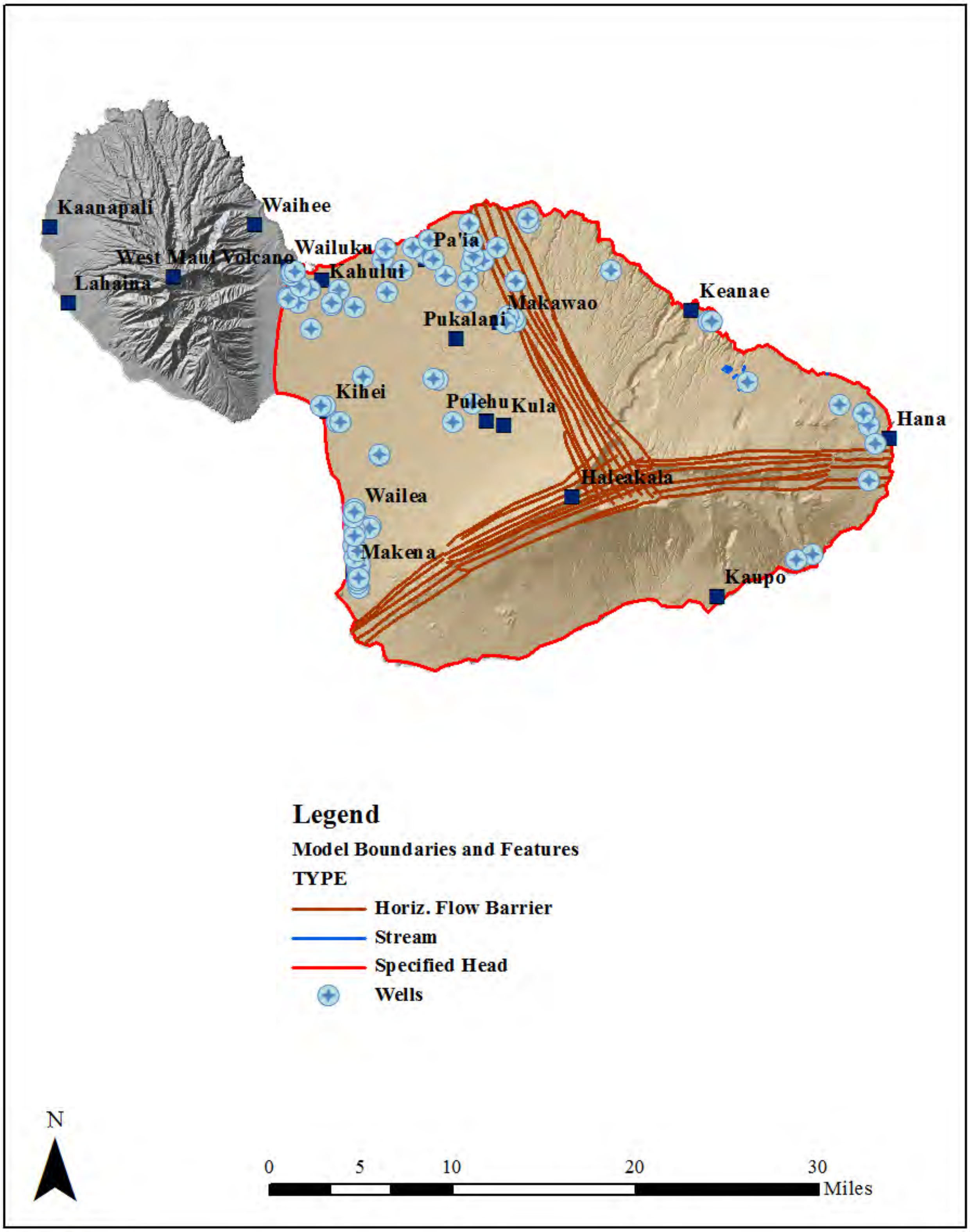

Figure 4-17. The boundary conditions and hydrogeological fatures of the East Maui Groundwater Flow Model

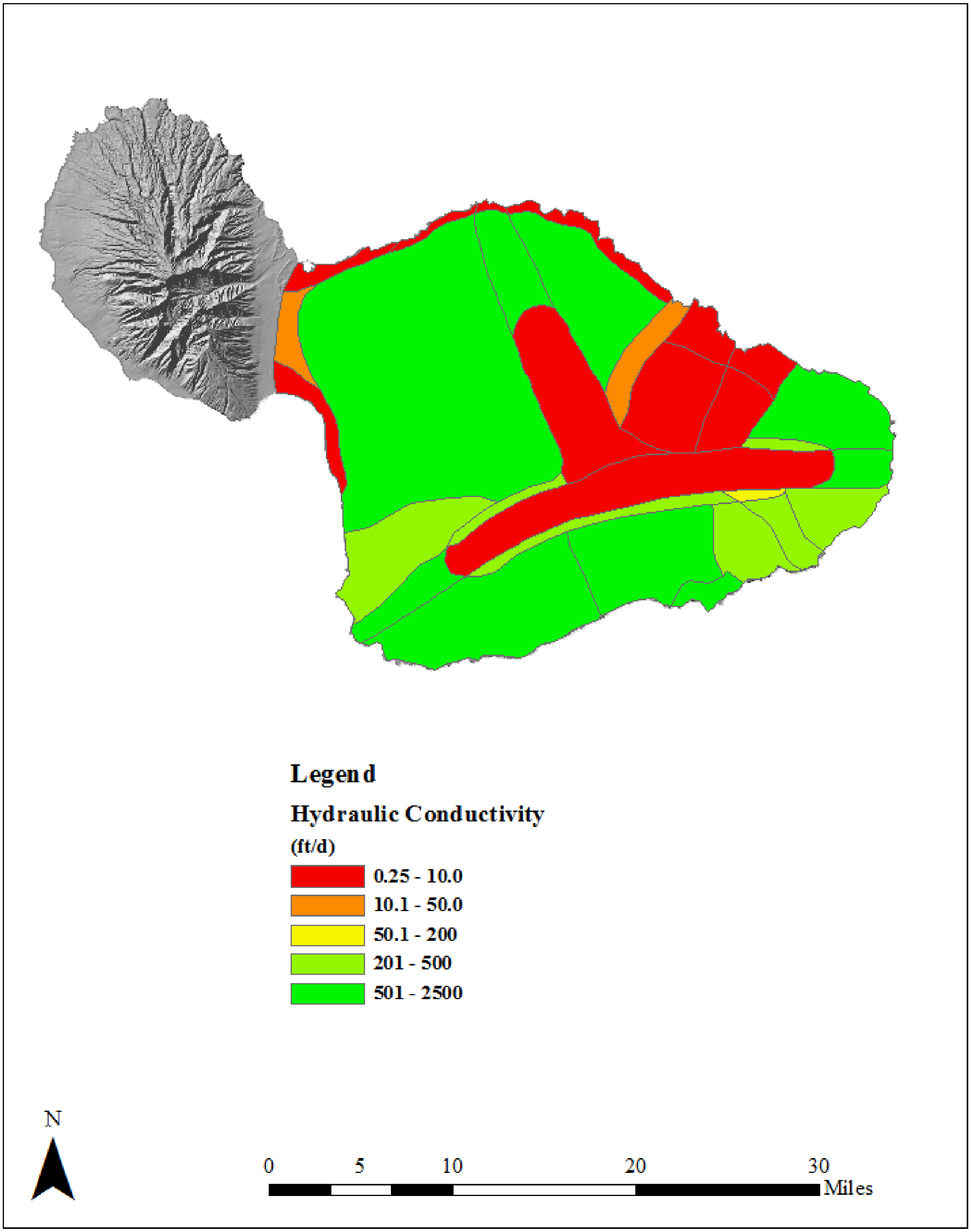

Figure 4-18. The distribution of hydraulic conductivities for the East Maui Groundwater Flow Model

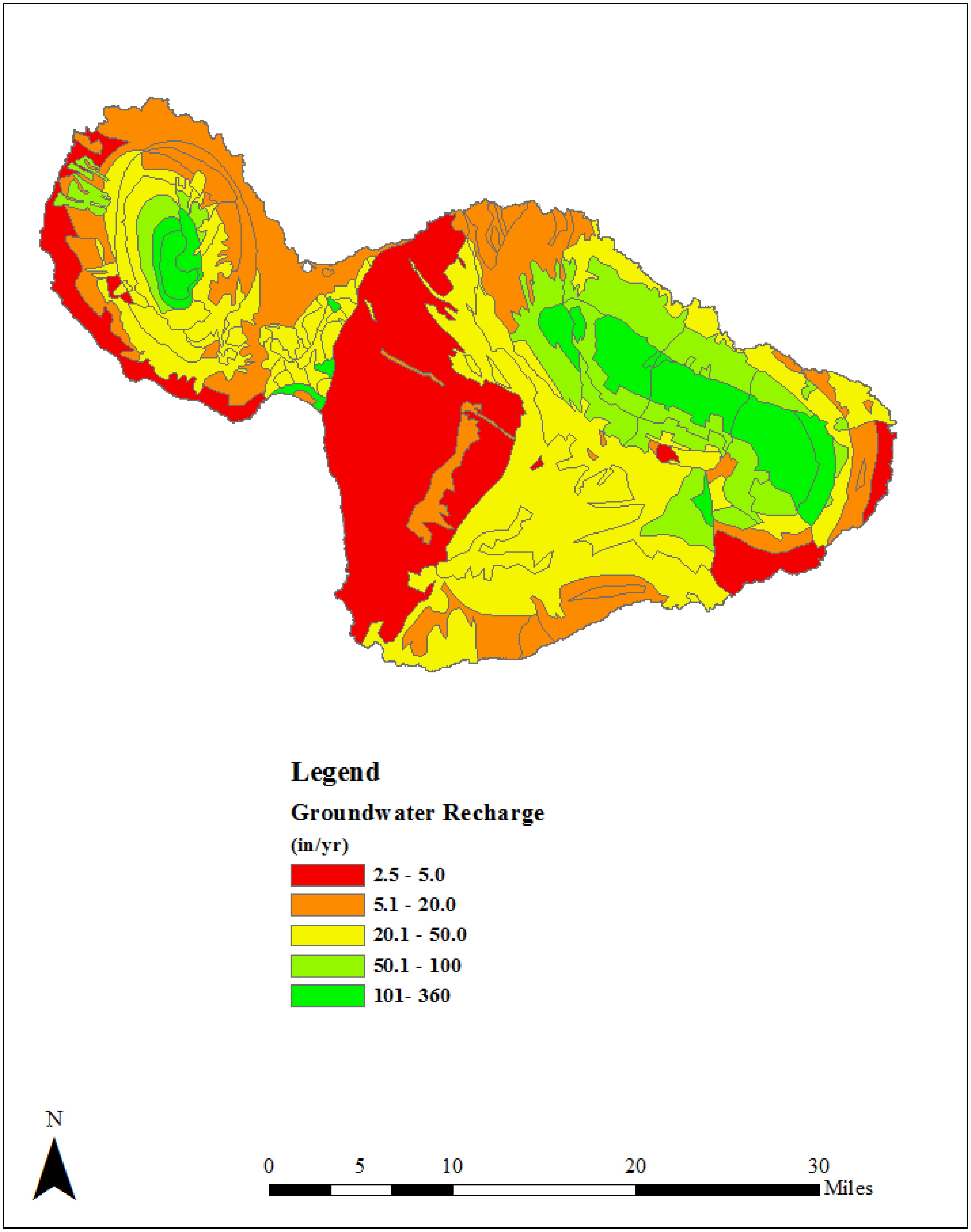

Figure 4-19. The distribution of recharge for the East and West Maui Groundwater Flow Models

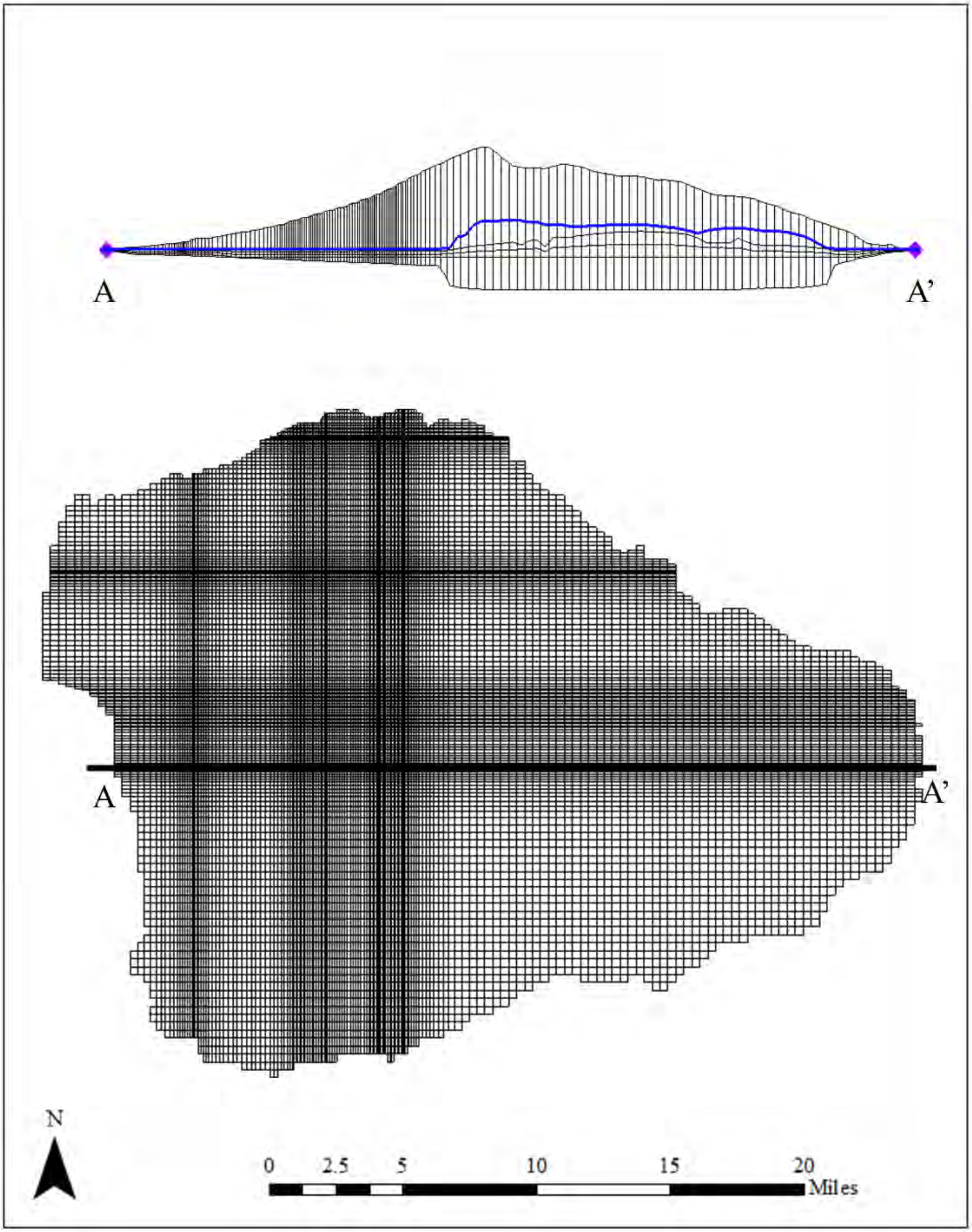

Figure 4-20. The numerical grid for the East Maui Groundwater Flow Model

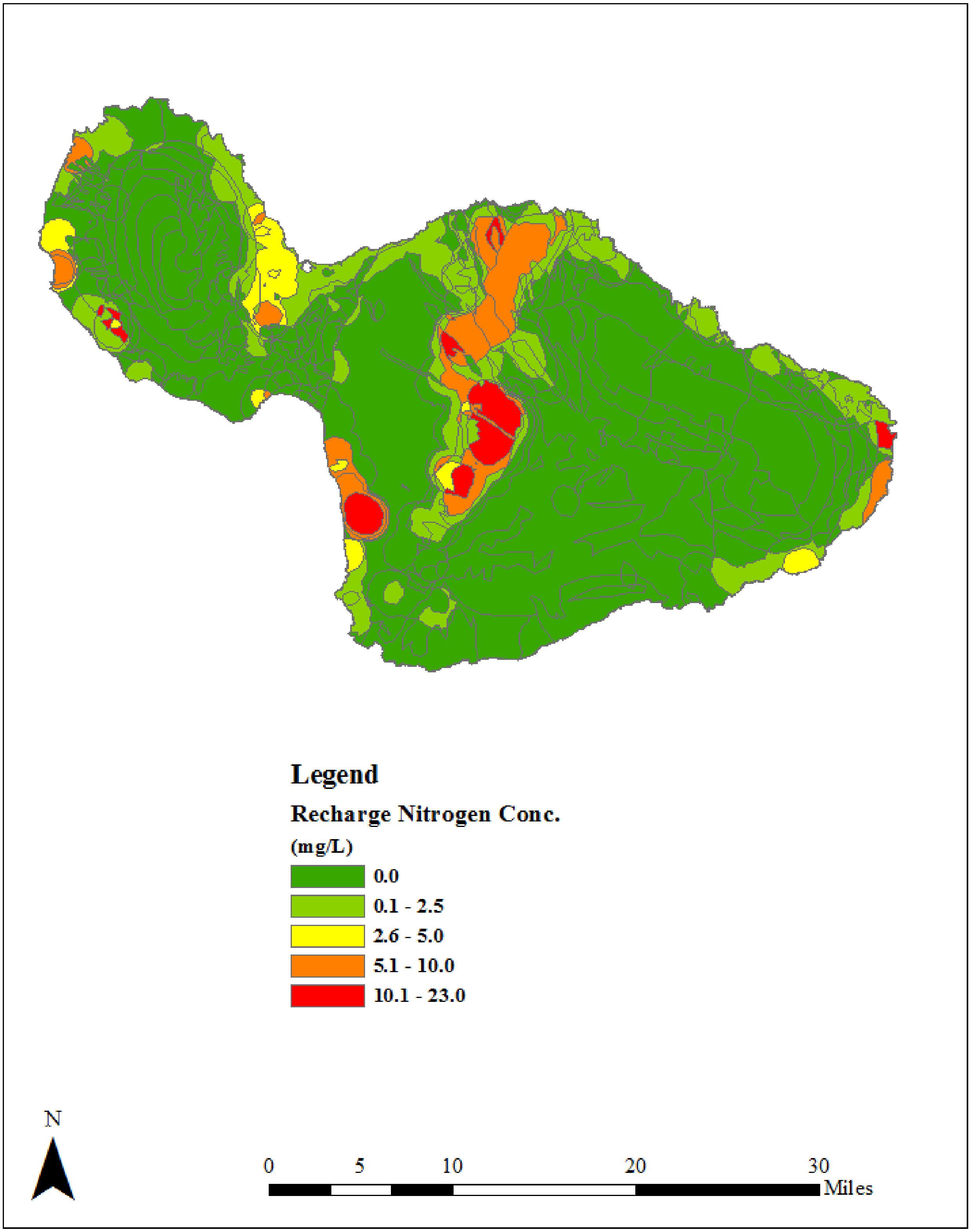

Figure 4-21. The concentration of OSDS derived nitrogen in the recharge for Maui

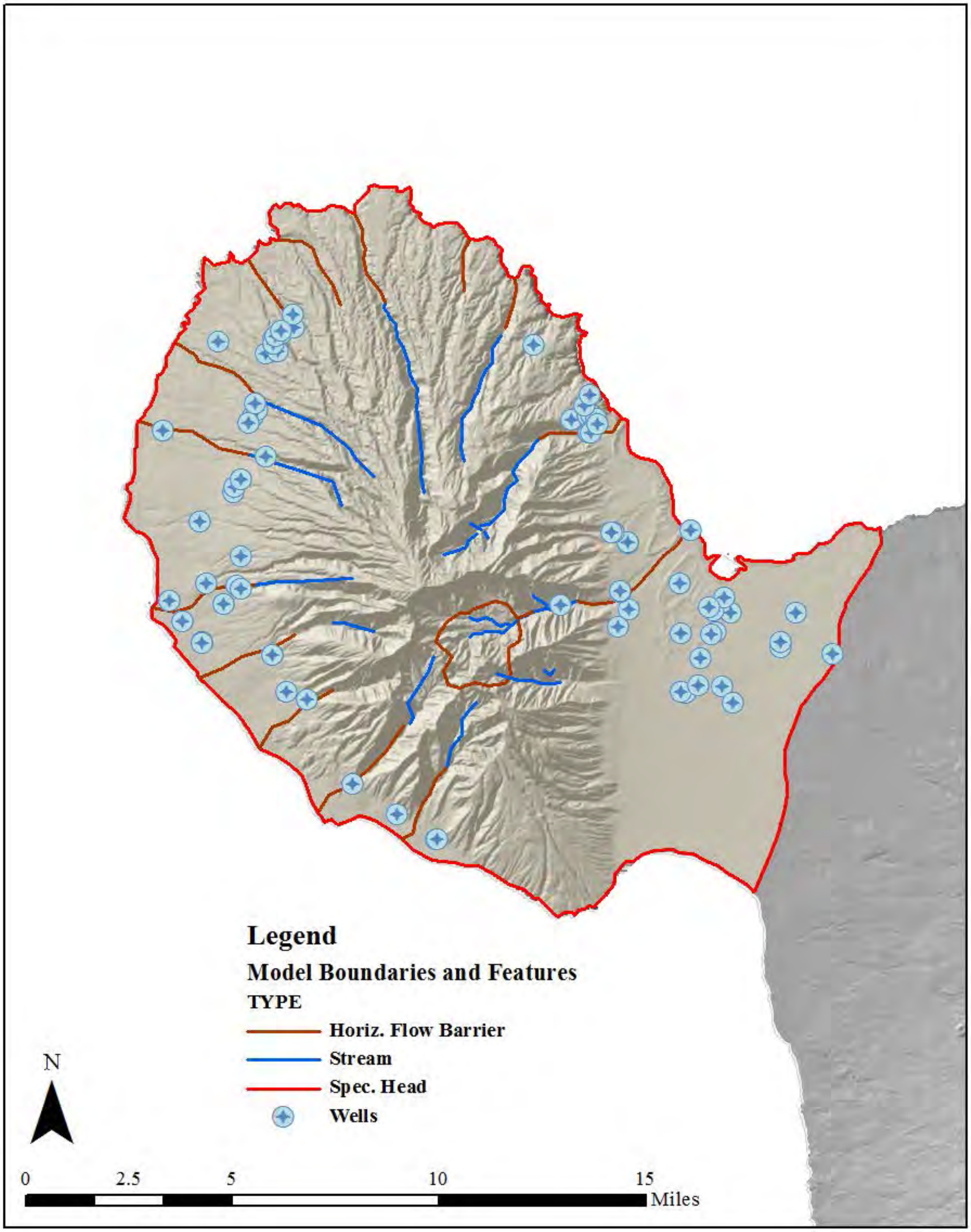

Figure 4-22. The boundary conditions and hydrogeological features for the West Maui Groundwater Flow Model

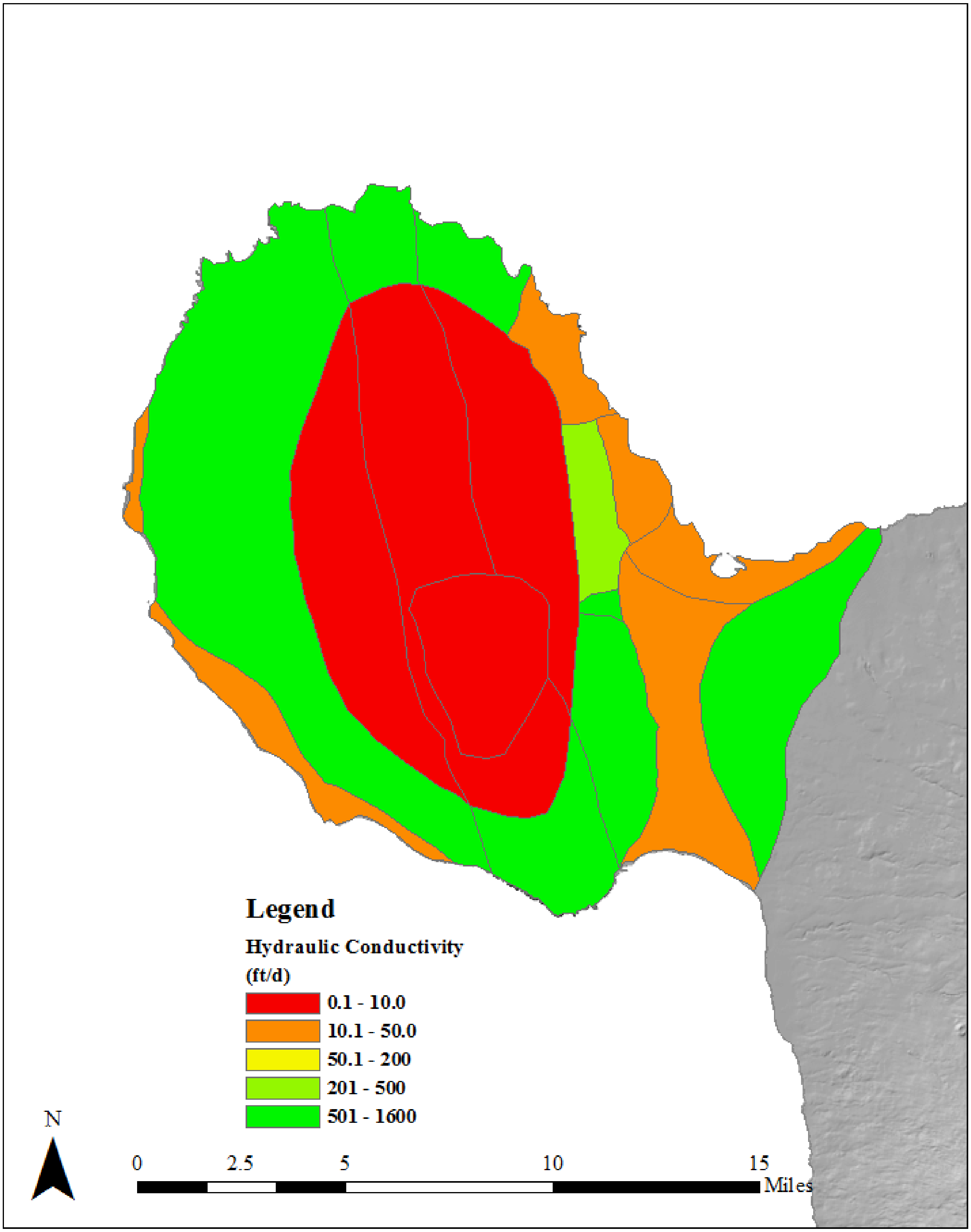

Figure 4-23. The distribution of hydraulic conductivities for the West Maui Groundwater Flow Model

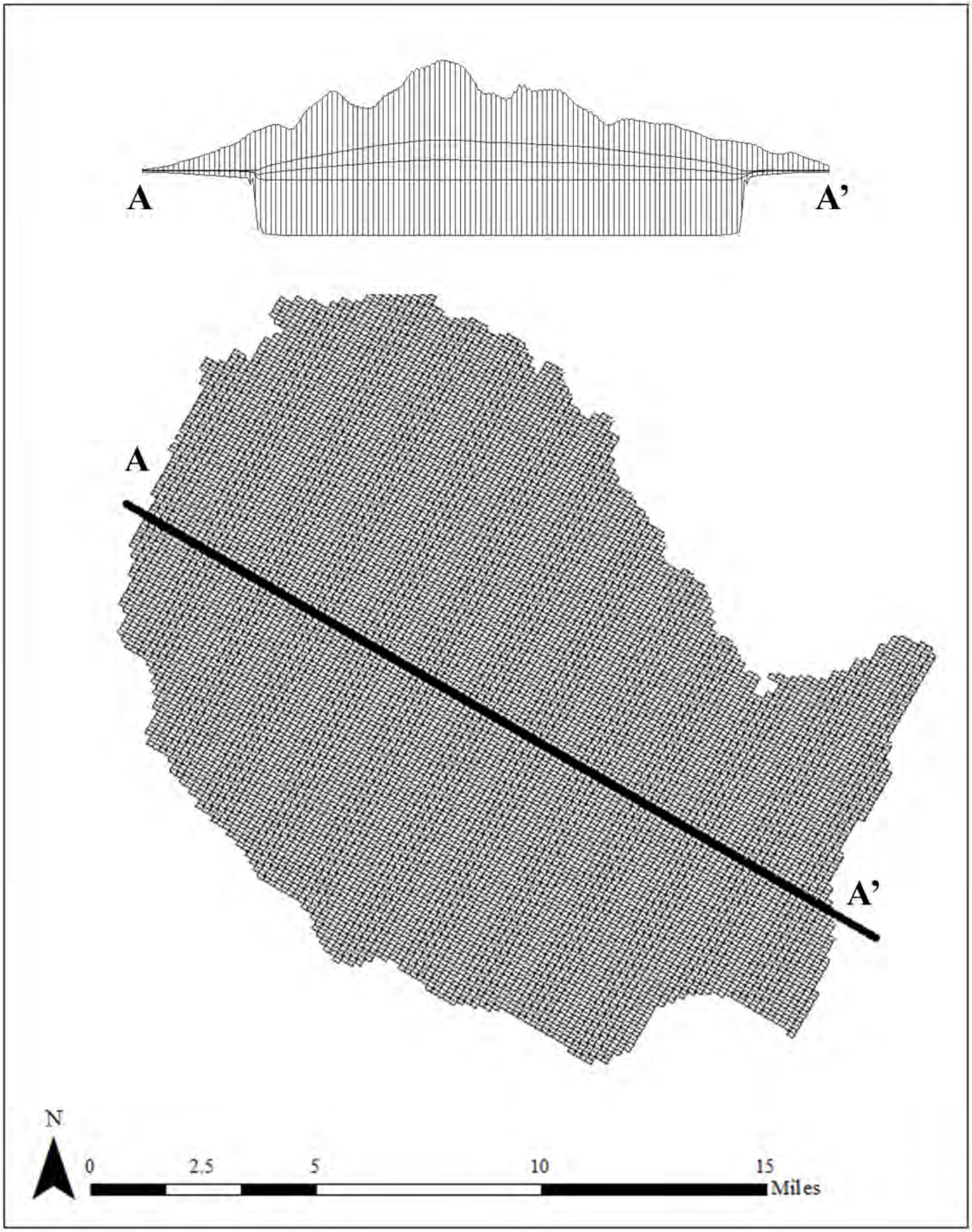

Figure 4-24. The numerical grid for the West Maui Numerical Model

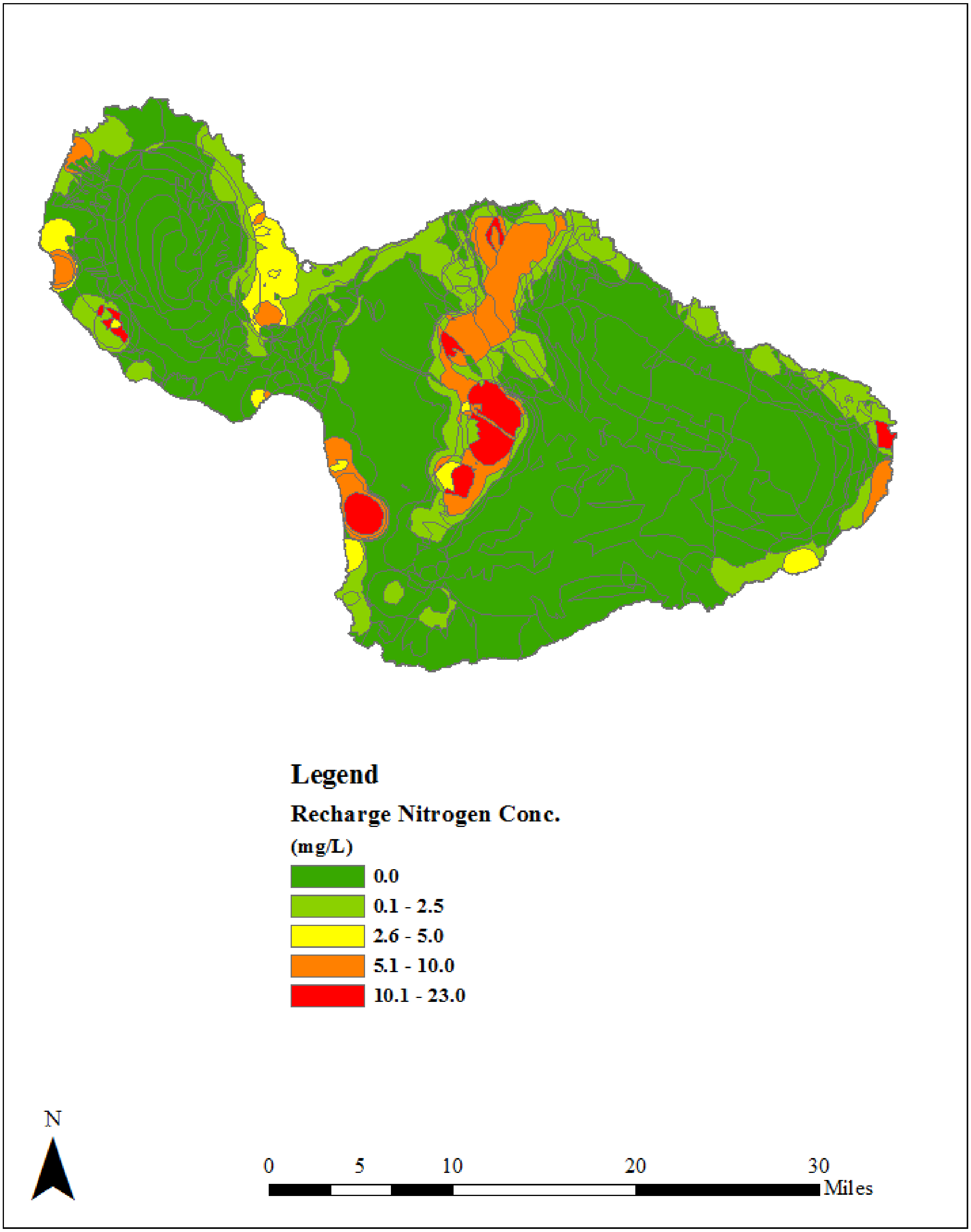

Figure 4-25. The concentration of OSDS derived nitrogen in the recharge for Maui

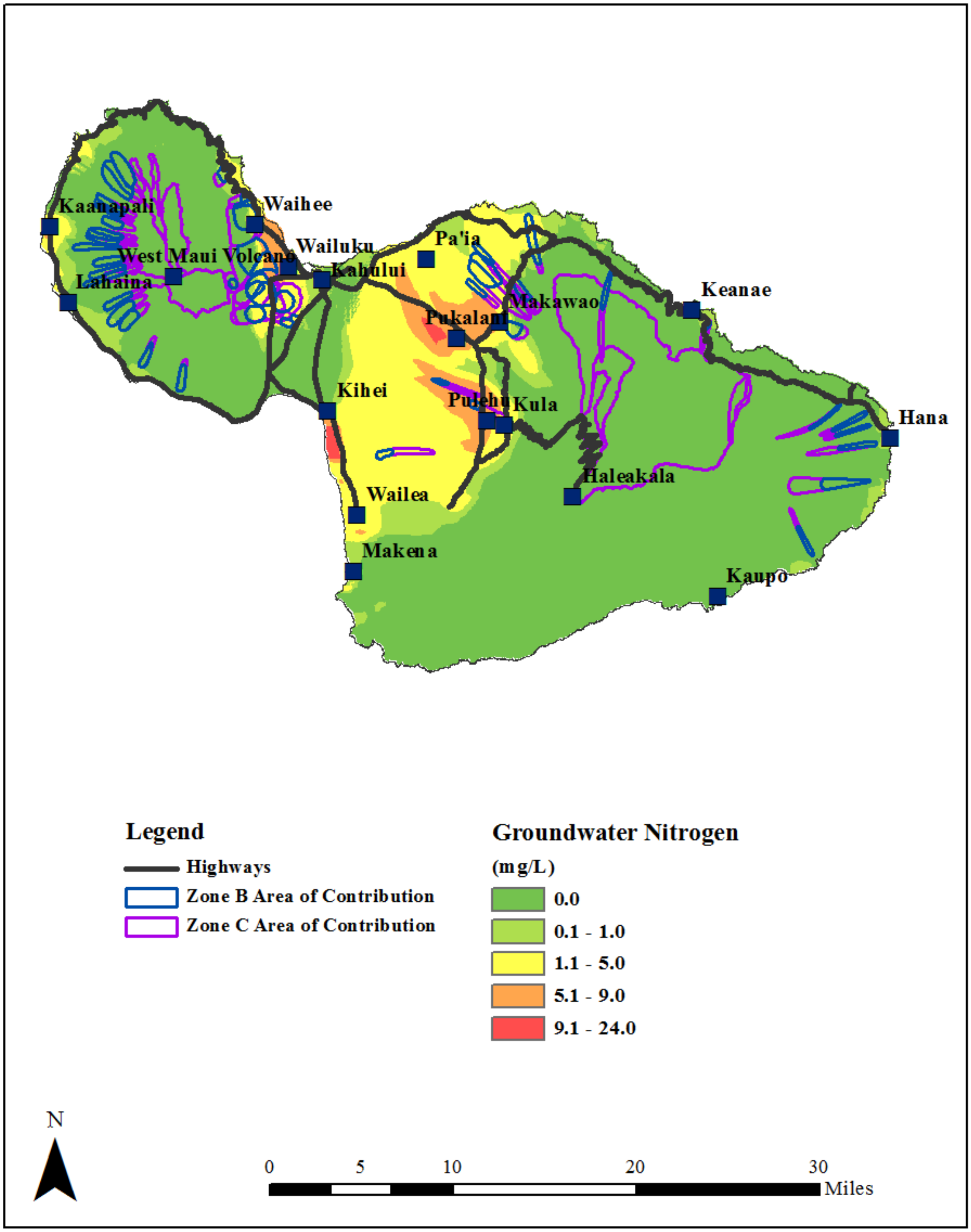

Figure 4-26. The concentration of ODGWN in the groundwater of Maui

4.2.3.5 Molokai

As with the other islands, the model developed for the SWAP (Whittier et al., 2004) was updated and modified to simulate the transport of ODGWN. The modifications included increasing the number of layers from one to three.

4.2.3.5.1 Molokai Conceptual Model

Molokai is made up of two major and one minor volcano. The East Molokai Volcano covers the eastern three-quarters of the island while the West Molokai Volcano that covers the western quarter of the island. Figure 4-27 shows the boundaries of the model and the major features included in the model. The coastline boundary was modeled as a specified head equal to mean sea level. The East Molokai Volcano is separated from the West Molokai Volcano by a HFB that represents the low permeability surface of the older West Molokai Volcano, which is overlapped by the high permeability lavas of the East Molokai Volcano. This feature was included in the top layer only and assigned a hydraulic characteristic of 0.0001. The HFB was used to effectively separate the shallow groundwater of the two volcanoes. Perennial streams in the deep cut valleys that have base flow supported by groundwater discharge were modeled as drains. These drains were assigned a high conductance of 2000 m^2/d/m to allow free drainage from the low permeability dike complex aquifers where the groundwater to surface discharge is most likely to occur. The low hydraulic conductivity of the dike intruded lavas kept the simulated groundwater to surface water discharge rates low and consistent with the actual baseflow amounts.

Figure 4-28 shows the distribution of hydraulic conductivities used for the Molokai groundwater flow model. The central caldera of the East Molokai Volcano is at the northern portion of this feature because much of this volcano was lost during a catastrophic landslide (Moore et al., 1989). Due to the prevalence of dikes in and surrounding the caldera (shown in red in Fig. 4-28) the permeability is very low and was assigned a hydraulic conductivity of 0.08 ft/d. A marginal dike zone (dikes generally number fewer than 100 per mile [Takasaki and Mink, 1985]) lies to the southwest of the dike complex and was assigned a hydraulic conductivity of 115 ft/d. The very permeable flank lavas (shown in green) were assigned a hydraulic conductivity of 650 ft/d. The Kalaupapa Volcano and peninsula were assigned a hydraulic conductivity of 360 ft/d. The two major rifts of the West Molokai Volcano (shown in light blue) were assigned a low hydraulic conductivity of 2.0 ft/d. The permeable flank lavas (shown in dark blue) to of the West Molokai Volcano were assigned a hydraulic conductivity of 490 ft/d.

Groundwater recharge is the source of groundwater entering the aquifers. Figure 4-29 shows the distribution and magnitude of recharge used in this model. The highest recharge of 60 in/yr occurs at the upper elevations of the East Molokai Volcano. The West Molokai Volcano has an elevation much lower than that of the eastern volcano and is much less efficient at capturing rainfall. The groundwater recharge rate for this volcano as well as the western slopes of the East Molokai Volcano and the connecting saddle is less than 5 in/yr. Total recharge into the model was 200 mgd.

4.2.3.5.2 Molokai Numerical Model

The numeric grid for the Molokai model consisted of 185,976 cells of which 108,628 fell within the model boundaries and were active. These cells were arranged in 168 rows, 369 columns, and 3 layers. Figure 4-30 shows the Molokai model grid in plan view and in cross section. Under the high-level aquifers the bottom of layer 3 was truncated at -1800 m msl 5,905 ft msl), while that of layer 2 was truncated at -900 m msl (2,953 ft msl). The bottom of layer 1 was set to -5 m msl (16.4 ft msl) throughout the model. For water table elevations less than or equal to 10 m msl (32.8 ft msl), the bottom of layer 3 was set to -40 times the water table elevation to conform to the Ghyben-Hertzberg principal. As the water table elevation increased, the magnitude of the bottom boundary scalar was gradually decreased so that at a water table elevation equal to or greater than 180 m (590 ft) the bottom boundary of the model was -1800 m msl (5,910 ft msl).

The model estimated that of the 200 mgd of water that was recharged to the aquifer, 153 mgd was discharged to the ocean at the coastal boundary, 36 mgd was became stream flow, and 11 mgd was extracted through pumpage.

4.2.3.5.3 Molokai Transport Model

As with the previous models the recharge, OSDS density, and OSDS shapefiles were spatially joined to compute the OSDS derived nitrogen concentration in the groundwater recharge. Figure 4-31 shows the resulting spatial distribution of this process. The areas with significantly elevated nitrogen concentration (greater than 2.5 mg/L) in the recharge occurred near the coast from Kaunakakai to just west of Halawa with the highest concentrations occurring between Kaunakakai and Kawela. A cluster of OSDS west of Kualapuu also increased the nitrogen concentration in the recharge to concentrations between 5.1 and 10.0 mg/L. Elsewhere, the addition nitrogen is only slightly above background concentrations.

4.2.3.5.4 Current Relative Impact to Molokai Groundwater

Figure 4-32 shows the simulated ODGWN concentrations. The potential impact of OSDS effluent on the Molokai groundwater is less than that on the other islands assessed. The maximum simulated ODGWN concentration was about 7 mg/L west of Kualapuu. The recharged nitrogen in the coastal areas is diluted by non-impacted groundwater flowing from upgradient toward the coast. None of the areas on Molokai had simulated ODGWN that exceeded 9.0 mg/L, which is the concentration that could result in the groundwater exceeding drinking water standards when added to natural nitrogen.

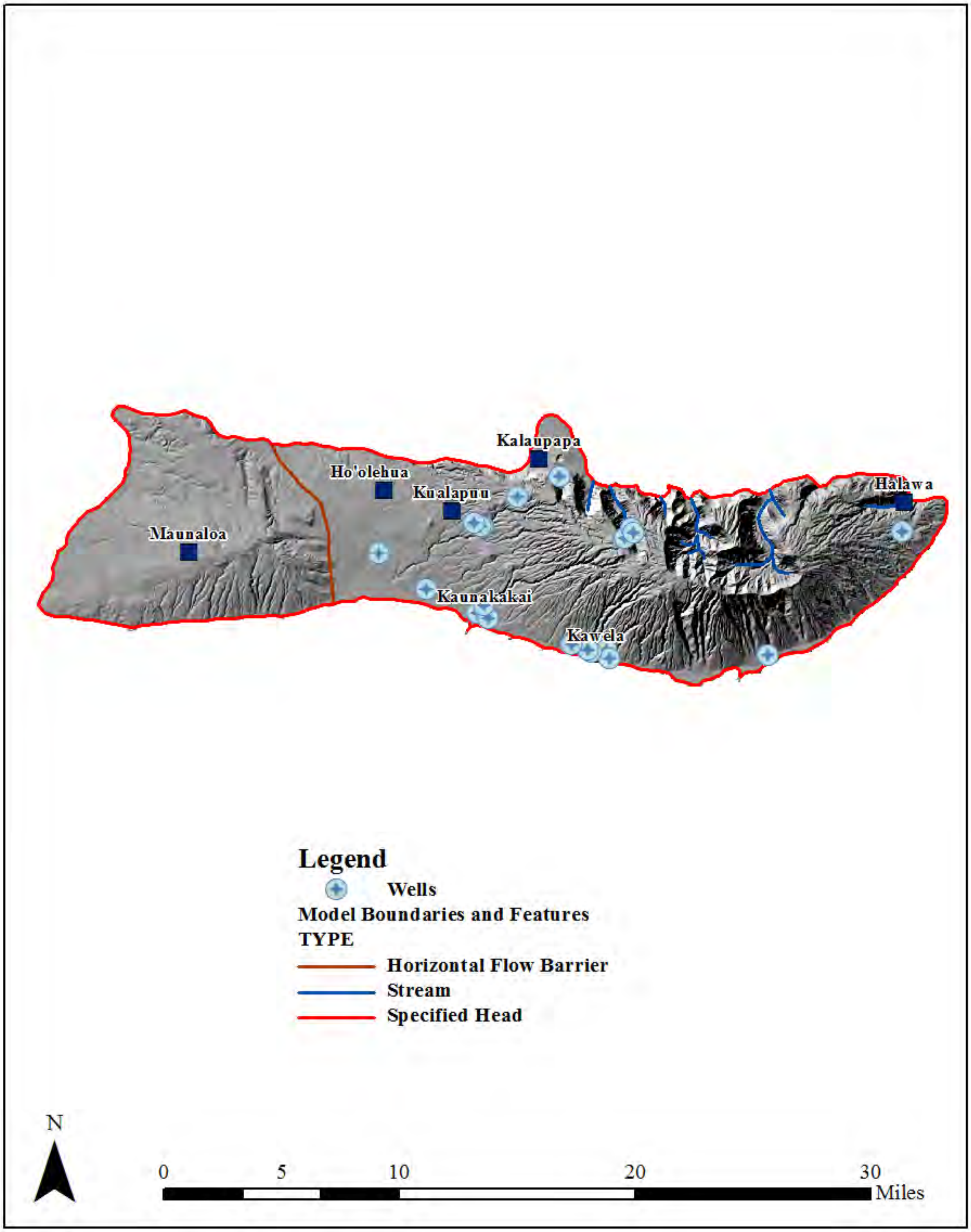

Figure 4-27. The boundary conditions and hydrogeologic features for the Molokai Groundwater Flow Model

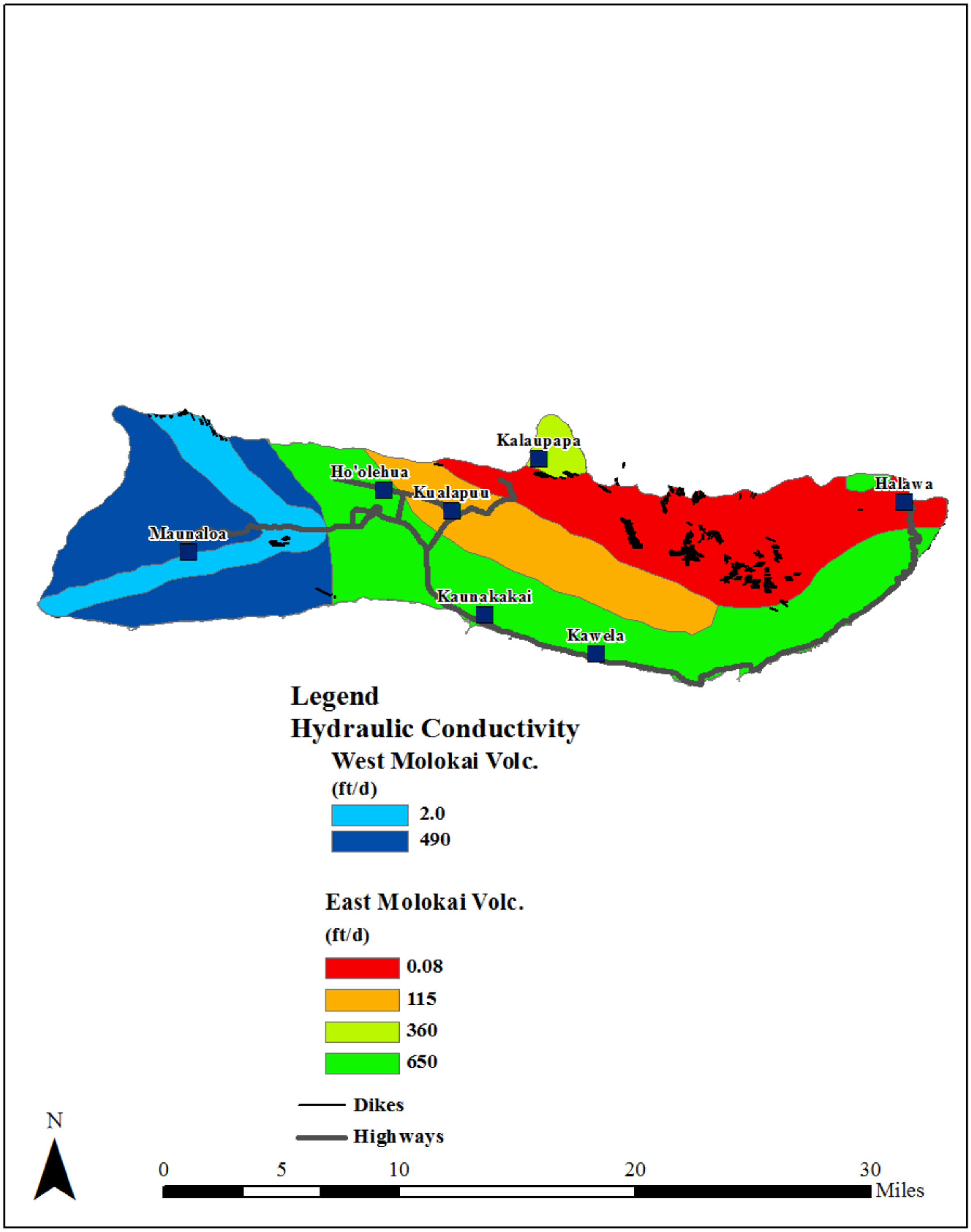

Figure 4-28. The distribution of hydraulic conductivity for the Molokai Groundwater Flow Model

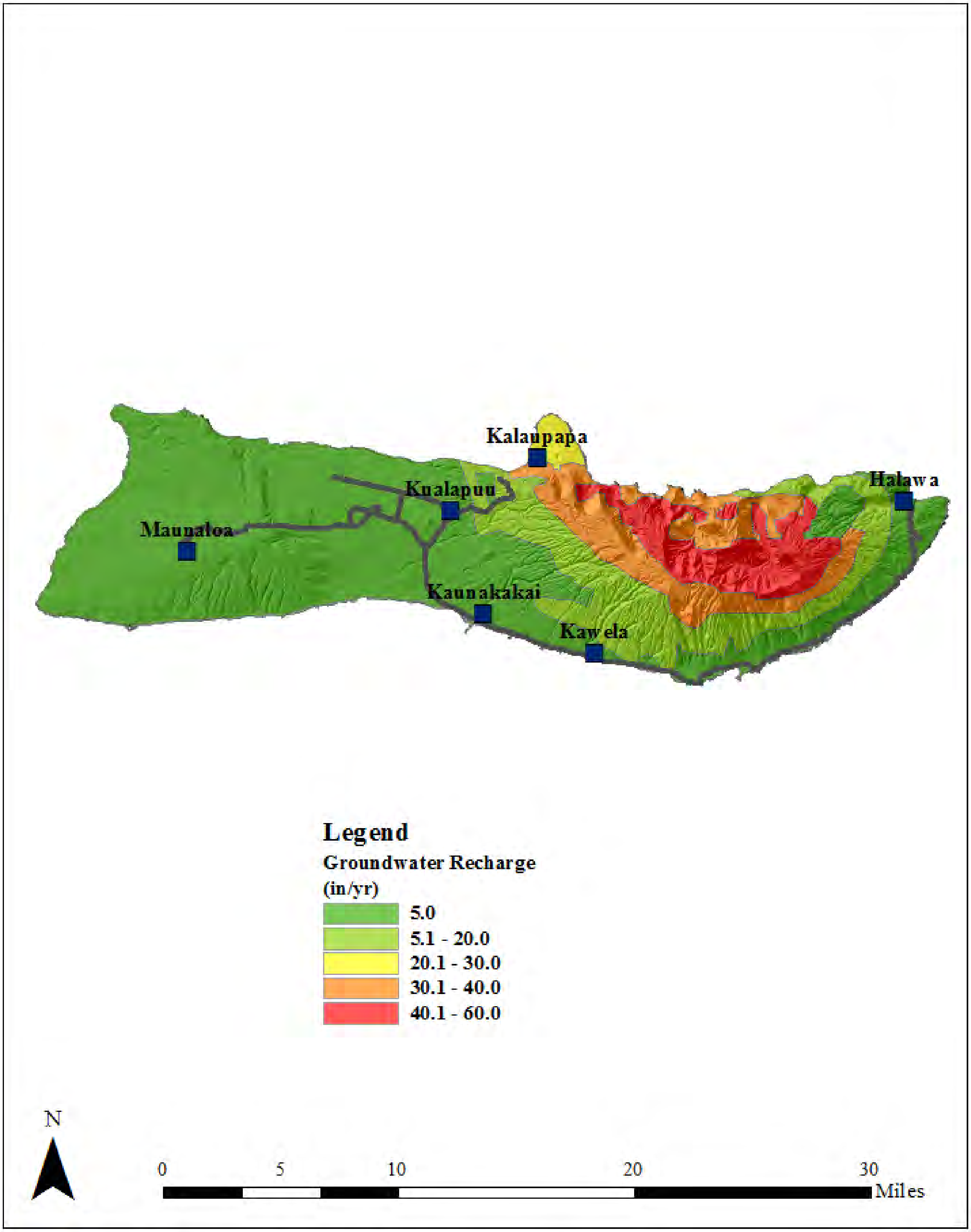

Figure 4-29. The groundwater recharge for the Molokai Groundwater Flow Model

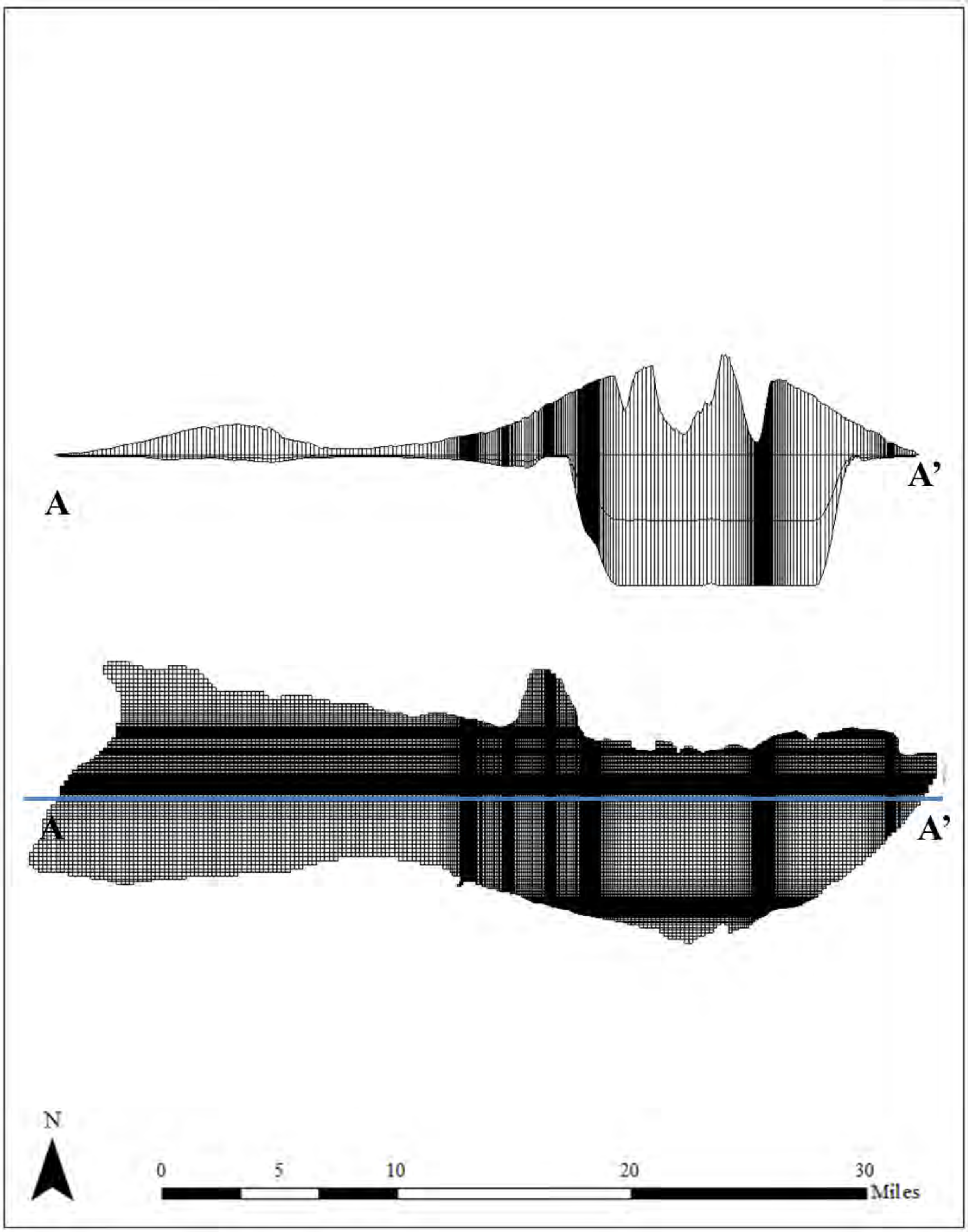

Figure 4-30. The numerical model grid for the Molokai Groundwater Flow Model

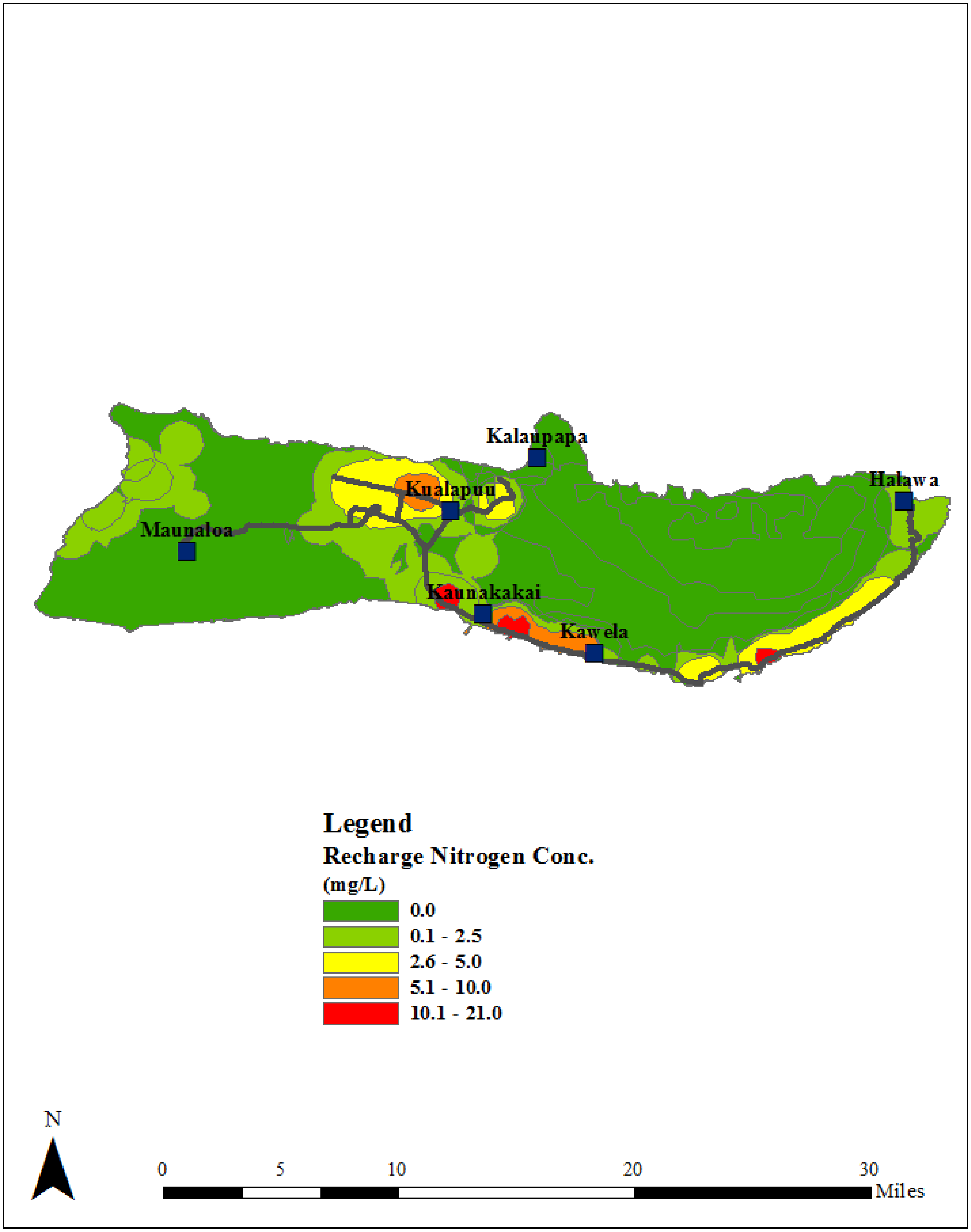

Figure 4-31. The OSDS derived nitrogen concentration in the groundwater recharge for Molokai

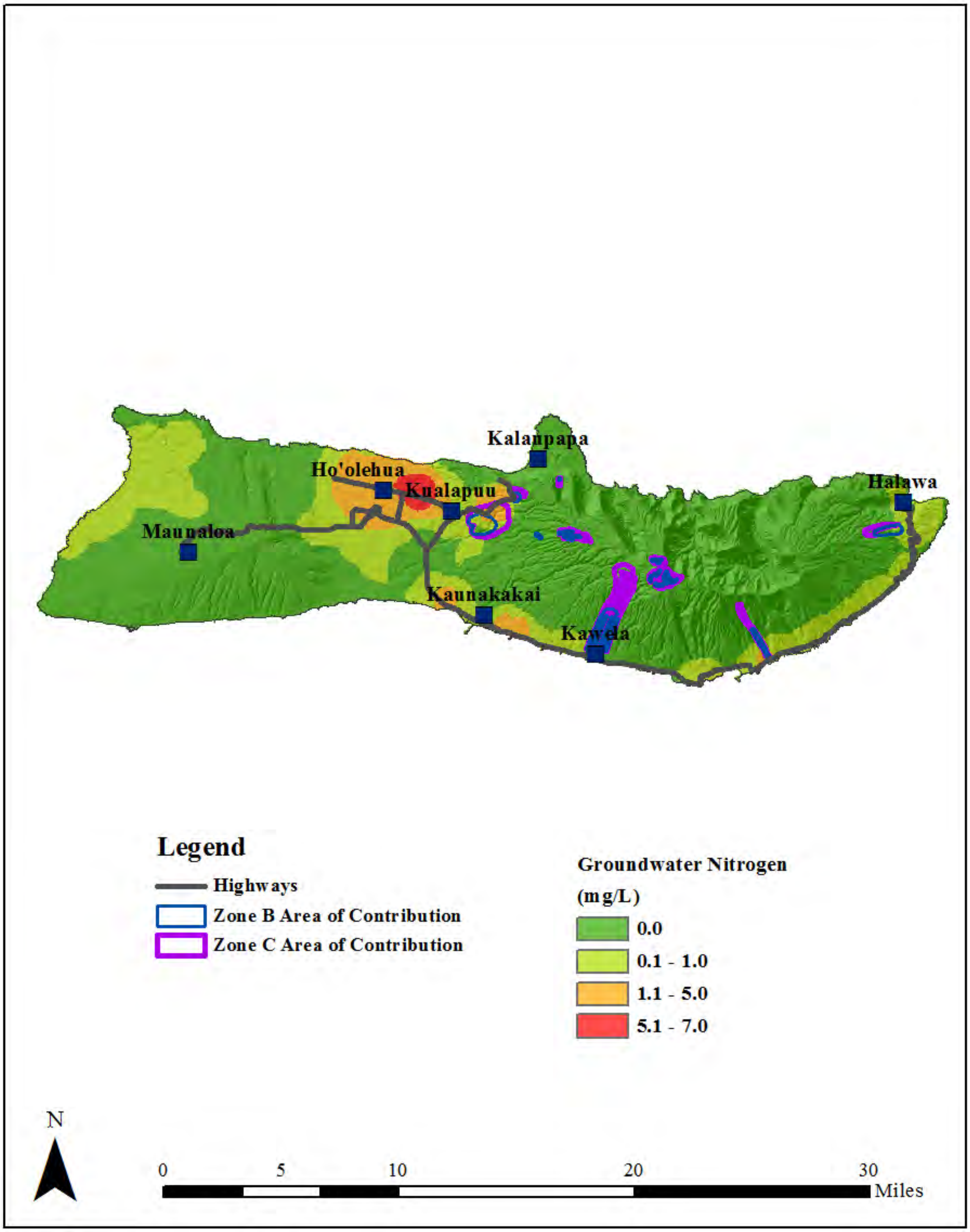

Figure 4-32. The simulated ODGWN concentrations for Molokai

4.3 OSDS GROUNDWATER AND DRINKING WATER RISK SUMMARY

Two types of groundwater OSDS risk assessments were done for the islands of Hawaii, Kauai, Maui, and Molokai. The first assessment focused on the intrinsic susceptibility of groundwater to OSDS leachate contamination. This was done to aid planners and regulators by identifying those groundwater bodies most at risk to OSDS contamination. This assessment considered the hydrologic characteristics of aquifers such as the presence of perched water, depth to groundwater, and presence of a confining layer. We also considered the potential or current use of the aquifers. The primary concerns are the threats to drinking water and critical ecosystems, such as wetlands, that are fed by groundwater. The relative threat was ranked by assigning risk severity scores. The maximum risk score possible was 8. This would apply where there was no intervening perched water between the ground surface and the main aquifer, with a depth to water of less than 25 ft, no confining layer, and within a Zone V CZD of one well and the Zone C CZD of another well.

There were no areas with all of the risk conditions applied, resulting in a maximum risk score of 7. The high risk score of 7 fell exclusively with a two year time of travel to a drinking water well in flank lava aquifers. This condition was present only on Kauai. The hydrogeology of Kauai favored high OSDS groundwater risk scores. Much of the groundwater on Kauai is unconfined with little perched water. The generally lower hydraulic conductivity of lava formations produce high water tables with a reduced depth to groundwater. Hawaii Island has significant areas of perched water that mitigate the OSDS risk to the main aquifers. However, this island does not have any confining formations to protect the underlying aquifer. The maximum risk for Hawaii Island was 6 and occurred in unconfined aquifers where the Zone B delineation for one well intersected the Zone C delineator for another well. This condition was present on the west side of Hawaii Island. Much of Maui's primary groundwater is protected by perched water. However, in most of the northern part of East Maui, the perched water feeds surface water that is utilized for public drinking water sources. The maximum score assigned on Maui was 6 and occurred in the interior regions of West Maui where the depth to groundwater was shallow and fell with the watershed delineation for a public drinking water source supplied by surface water. There were areas on Maui where the aquifer being unconfined was the only risk condition that applied. Molokai had the lowest maximum risk score of 5. This score was assigned to coastal areas west of Kauanakakai where the depth to water was less than 25 ft, the aquifer was both ecologically important and a potential source of drinking water, and the groundwater was unconfined with no intervening perched water between the ground surface and the main aquifer.

The second groundwater risk assessment considered the current risk to groundwater posed by existing OSDS. This risk was evaluated by modeling the transport of OSDS leachate using OSDS derived nitrogen concentration as a risk indicator. The resolution of the recharge coverages for the groundwater flow models was refined by merging the recharge shapefiles with the OSDS density shapefiles. The OSDS effluent discharge was added to the natural and irrigation recharge and a nitrogen concentration was calculated for each recharge polygon. The groundwater flow field for each island was simulated using the USGS groundwater flow model MODFLOW. The output of MODFLOW was used by the transport model MD3D-MS to simulate the concentration of ODGWN in groundwater. Higher concentrations of ODGWN indicate areas where the current impact from OSDS is greatest.

Kauai had the highest modeled ODGWN concentration at about 25 mg/L. This occurred in the areas of Kapaa/Waialua where a very high density of OSDS was present. Other areas of concern on this island were south-central Kauai, the unsewered zones surrounding Lihue, and Kilauea. The areas of highest simulated ODGWN on Hawaii Island were associated with the unsewered developments near the town of Kailua-Kona. Here the model estimated the ODGWN concentration could reach 18 mg/L. The areas near the town of Waimea also had modeled ODGWN concentrations that exceeded 9 mg/L. Upcountry Maui and the area south of Kihei had the highest modeled ODGWN concentrations on Maui. Of particular concern are the OSDS in upcountry Maui because the capture zones for public drinking water wells intersected the areas of high simulated ODGWN concentrations. The maximum ODGWN concentration on Maui was 24 mg/L. Most of Molokai groundwater had very low ODGWN concentrations with a maximum modeled ODGWN concentration of 7 mg/L west of the town of Kualapuu in north-central Molokai. No drinking water wells appear to be impacted by elevated ODGWN concentrations.

SECTION 5. OSDS RISK TO SURFACE WATER

5.1 SURFACE WATER RISK METHODOLOGY

Effluent from OSDS can impact surface water by: introducing pathogens into the streams or increasing the nutrient load, which results in excessive algae growth (Boer, 1995; Carpenter, 2003; Dubrovsky and Hamilton, 2010; Mueller and Spahr, 2006; and Tri-State Water Quality Council, 2005); or introducing pharmaceuticals that cause hormonal and behavioral changes in aquatic species (Milnes et al., 2006; Raloff, 2008 Vajda et al., 2008). The primary pathway for OSDS effluent to enter the aquatic environments is by the discharge of contaminated groundwater to the surface. A secondary pathway is by direct overland flow due to flooding. This section identifies those reaches of perennial streams where groundwater is most likely to contribute to the streams. In this phase of the study, the areas likely to contribute groundwater or floodwater to streamflow were identified. Once the zones of potential stream impact were identified, the relative risk of the streams and watersheds to contamination from currently installed OSDS was ranked.

5.1.1 Delineating Areas of Probable Groundwater Contribution

The first step in assessing the risk OSDS pose surface waters was to identify those areas where groundwater would be most likely to discharge to surface waters. Three conditions were evaluated as supporting groundwater discharge to surface water:

1. Perennial streams have a baseflow component that is usually supplied by groundwater;
2. High-level and perched groundwater occurring in a perennial stream watershed further increases the probability that groundwater discharges to surface water;
3. Stream reaches where the depth to groundwater is shallow, which could result in the discharge of groundwater to surface water; and
4. Fluvial plains exchange water with the stream, which allows OSDS effluent contaminated water to enter the streamflow.

To map the zones of probable groundwater discharge to surface water, the watersheds designated as perennial were extracted from the Department of Aquatic Resources Watershed (DBEDT, 2013) shapefile. The DOH aquifer shapefile was then clipped to the extent of the perennial watershed shapefile and those aquifer sectors designated as high-level or perched were extracted and exported to a new shapefile. The zones where the depth to groundwater was estimated to be 25 ft or less (Section 4.1.1.1) were clipped to the extent of perennial stream watersheds, exported to a new shape file, and a risk score of 1 was applied to each condition that applied.

Effluent from OSDS can enter streams by overland flow if flooding occurs. The possibility of fugitive OSDS effluent due to flooding is addressed in Section 5.1.2. For this section the contribution of groundwater to streams is considered and, more specifically, the contribution of OSDS contaminated groundwater to streams is assessed. The methods are similar to SWAP methodology (Whittier et al., 2004) used to assess the susceptibility of drinking water sources supplied by surface water to contamination.

5.1.2 Delineating Areas of Fluvial Aquifer and Flood Discharge to Streams

OSDS contamination can enter streams from fluvial aquifers along the streams due to leakage from the alluvium surrounding the stream channel. The interaction between the streams and the fluvial aquifer is complex. In some reaches the fluvial aquifer provides water to the streams and other reaches receives water from the stream. The interaction between specific reaches of stream and the fluvial aquifer is beyond the scope of this study to definitively evaluate. A simplified 200 ft setback approach was taken that was consistent with the Zone B SWAP delineations for drinking water sources supplied by surface water (Whittier et al., 2004). The hydraulic conductivity of fluvial aquifers is typically low when compared to thin bedded lavas with a travel path that is oblique to the shorted direction to the stream channels (Woessner, 2000; and TEC, 2001). The oblique travel path lengthens the actual travel path significantly beyond 200 ft allowing for greater pathogen die-off time.

OSDS effluent may also enter streams when flooding occurs by raising the effluent to the surface followed by transport to the stream. To include areas where this may occur, the 200 ft stream setback was merged with Federal Emergency Management Agency 100 year flood risk zones. The 200 ft setback and flood plain delineations were assigned a risk score 1 in addition to the scoring assigned using the methods described in Section 5.1.1.

5.1.3 Current Surface Risk to OSDS Contamination

The primary pathway for OSDS effluent to enter surface waters is by the discharge of OSDS contaminated groundwater to surface water. Section 4 described the numerical simulations that modeled the distribution of ODGWN of the islands evaluated by this study. Those areas within a perennial watershed or within an area where the depth to groundwater was less than 25 ft that had a modeled ODGWN concentration of greater than 5 mg/L were evaluated as posing an increased risk of negatively impacting surface water and were assigned a risk score of 2 bringing the total possible risk score to 6.

To further evaluate the risk to surface water the OSDS database was queried to identify those OSDS that were within a possible zone of contribution to a stream. This zone of contribution consisted of the perennial watersheds overlying high-level or perched groundwater, the 200 ft setback from perennial streams, and the perennial stream reaches in areas where the depth to groundwater was less than 25 ft. The total nutrient load and the nutrient load per unit area were calculated for these zones of contribution to the perennial streams. These nutrient load assessment provided a qualitative indication of the streams currently at most risk to OSDS effluent contamination.

5.2 RESULTS

5.2.1 Hawaii

Young and porous lavas dominate Hawaii Island, resulting in the perennial watersheds being located on the lavas of the older volcanoes of Mauna Kea and Kohala. The only exception is the southernmost perennial watershed that is located on younger Mauna Loa lavas. Figure 5-1 shows that nearly the entire area of the perennial watersheds is underlain by high-level aquifers (blue) where groundwater likely discharges to surface water. Only in a small area near Hawi, Kohala, and Hilo is the water table low enough so that there is little possibility of the groundwater discharging to surface water (shown by the orange-brown shading).

Figure 5-2 shows the ODGWN concentrations in the high-level aquifers located beneath perennial watersheds. The areas near Waimea, Laupahoehoe, and east of Hilo have the greatest potential for

OSDS impacted groundwater to introduce nutrients or pathogens into the streams as indicated by ODGWN concentrations exceeding 1 mg/L. This figure shows where negative impact from OSDS to streams is most likely, but more detailed research would need to be done to determine whether or not this stream degradation is actually occurring.

There are 132 perennial watersheds on Hawaii Island (Table 5-1). There are 19,925 OSDS distributed among 105 of these watershed. These OSDS discharge an estimated 12.4 million gallons of effluent containing about 2,500 kg of nitrogen and 700 kg of phosphorous each day. Table 5-1 shows the results of the OSDS inventory in the perennial watersheds of Hawaii Island. The Wailoa Watershed had the most OSDS with about 10,600 systems in 119,800 acres of watershed. The nitrogen flux density was about 0.011 kg/d/acre. This was the highest nitrogen flux density for watersheds with areas greater than 10,000 acres. The highest nitrogen density flux was in the Haloa Watershed where about 0.048 kg of nitrogen is discharged each day per acre of this watershed. However, this is a small watershed with an area of 680 acres and only hosts 223 OSDS.

Figure 5-3 shows the distribution of these risk severity scores for the surface waters of Hawaii Island. The risk scores varied from 1 to 6. Most of the watersheds are at a moderate risk (score of 2) due to the presence of the high-level groundwater aquifers but no elevated ODGWN concentrations. The low score of 1 only occurred where high-level groundwater was absent within the boundaries of a perennial watershed. A higher score of 4 was located near the towns of Waimea and Laupahoehoe where elevated ODGWN increased the risk OSDS posed to the receiving surface waters. Within the zones of elevated ODGWN, the score increased to 5 within 200 ft of the stream channels. The high score of 6 occurred in a flood zone near Laupahoehoe where the depth to groundwater was less than 25 ft.

Table 5-1. OSDS and nutrient flux inventory for Hawaii Island's perennial watersheds

Watershed Name	Area	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Aamakao	6826	0	1	0	8	9	4,200	0.92	0.26	0.011
Aamanu	533	0	0	0	39	39	21,600	4.94	1.35	0.019
Ahole	233	0	0	0	7	7	3,000	0.69	0.19	0.011
Alakahi	217	0	0	0	16	16	8,000	1.83	0.50	0.006
Aleamai	194	1	0	0	34	35	22,800	5.08	1.39	0.013
Alia	832	3	1	0	23	27	15,800	3.32	0.92	0.009
Alilipali	968	0	0	0	44	44	25,400	5.82	1.59	0.006
Haakoa	3896	0	1	0	56	57	45,200	8.96	2.62	0.003
Hakalau	6346	4	2	0	114	120	84,800	17.28	4.93	0.000
Halawa	1173	0	0	0	25	25	14,600	3.34	0.91	0.003
Halelua	1292	0	0	0	81	81	48,800	11.17	3.05	0.003
Haloa	680	64	3	0	231	298	182,200	32.64	9.18	0.000
Hanaula	1908	5	1	0	93	99	56,900	12.20	3.36	0.000
Hanawi	2728	1	0	0	22	23	12,200	2.66	0.73	0.000
Hapahapai	2465	14	15	1	199	223	126,100	26.51	7.37	0.000
Honokane Iki	1732	0	0	0	0	0	0	0.00	0.00	0.000
Honokane Nui	6715	0	0	0	0	0	0	0.00	0.00	0.000
Honokea	1483	0	0	0	0	0	0	0.00	0.00	0.000
Honolii	10896	0	0	0	18	18	8,800	2.01	0.55	0.000
Honomu	1857	0	1	0	18	19	13,000	2.84	0.79	0.000
Honopue	1659	0	0	0	0	0	0	0.00	0.00	0.000
Kaaheiki	231	1	0	0	8	9	4,400	0.87	0.24	0.000

Table 5-1 (continued). OSDS and nutrient flux inventory for Hawaii Island's perennial watersheds

Watershed Name	Area	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Kaala	4441	0	0	0	2	2	1,000	0.23	0.06	0.000
Kaapoko	114	0	0	0	2	2	1,200	0.27	0.07	0.000
Kaawalii	9049	0	0	0	8	8	4,600	1.05	0.29	0.000
Kahaupu	7007	0	2	0	153	155	95,400	21.68	5.93	0.000
Kahawailiili	9714	1	1	0	130	132	73,600	16.68	4.56	0.000
Kahoopuu	503	0	0	0	0	0	0	0.00	0.00	0.000
Kaieie	1498	0	0	0	82	82	48,600	11.13	3.04	0.000
Kailikaula	521	0	0	0	0	0	0	0.00	0.00	0.000
Kaimu	1083	0	0	0	0	0	0	0.00	0.00	0.000
Kainapahoa	5925	1	0	0	189	190	107,200	24.41	6.66	0.000
Kaiwiki	1406	0	0	0	1	1	600	0.14	0.04	0.000
Kaiwilahilahi	4319	0	0	0	82	82	45,000	10.30	2.81	0.000
Kalaoa	324	0	0	0	14	14	6,800	1.56	0.42	0.000
Kalapahapuu	3852	0	0	0	23	23	13,400	3.07	0.84	0.000
Kalele	43	0	0	0	0	0	0	0.00	0.00	0.000
Kalopa	19633	4	4	0	142	150	84,100	18.35	5.06	0.000
Kaluahine Falls	102	1	0	0	2	3	1,600	0.23	0.07	0.005
Kaohaoha	900	0	0	0	16	16	8,000	1.83	0.50	0.006
Kapehu	1054	1	0	0	23	24	12,000	2.61	0.72	0.000
Kapehu Camp	1142	0	0	0	18	18	9,200	2.11	0.57	0.003
Kapua	642	9	6	0	77	92	62,400	11.99	3.41	0.000

Table 5-1 (continued). OSDS and nutrient flux inventory for Hawaii Island's perennial watersheds

Watershed Name	Area	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Kapue	7200	0	0	0	8	8	3,000	0.69	0.19	0.001
Kapulena	2043	0	0	0	12	12	8,000	1.83	0.50	0.002
Kaula	8694	1	0	0	88	89	54,200	12.27	3.35	0.002
Kaumoali	5816	0	2	0	53	55	30,300	6.91	1.89	0.004
Kawaihae	23558	48	5	1	79	131	79,700	11.15	3.29	0.004
Kawaikalia	1109	1	0	0	23	24	11,600	2.63	0.72	0.031
Kawainui	5296	0	0	0	13	13	7,600	1.74	0.47	0.000
Keahua	1544	0	1	0	79	80	46,800	10.61	2.91	0.003
Kealakaha	2218	0	0	0	8	8	3,800	0.87	0.24	0.002
Kihalani	581	0	3	0	38	41	39,000	7.40	2.22	0.007
Kilau	1684	0	1	0	131	132	77,200	17.62	4.81	0.001
Koholalele	9233	0	1	0	30	31	19,100	4.34	1.19	0.004
Kolealiilii	511	0	0	0	0	0	0	0.00	0.00	0.003
Kolekole	13417	5	0	3	83	91	50,700	10.85	2.98	0.006
Kukaiau	1734	0	0	0	1	1	600	0.14	0.04	0.006
Kukui	486	0	0	0	0	0	0	0.00	0.00	0.001
Kukuilamalamahii	1512	0	0	0	69	69	39,400	9.02	2.46	0.002
Kulanakii	572	0	0	0	5	5	2,800	0.64	0.17	0.001
Kumakua	1845	6	1	0	152	159	89,080	19.63	5.38	0.009
Kupapaulua	1533	0	0	0	1	1	400	0.09	0.02	0.005

Table 5-1 (continued). OSDS and nutrient flux inventory for Hawaii Island's perennial watersheds

Watershed Name	Area	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Kuwaikahi	353	2	9	0	48	59	70,460	9.54	3.05	0.009
Laimi	577	1	0	0	5	6	3,400	0.64	0.18	0.000
Lamimaumau	2376	122	10	0	322	453	284,720	46.75	13.36	0.001
Laupahoehoe	2775	3	0	0	16	19	24,200	2.03	0.66	0.048
Maili	2656	0	3	0	170	173	108,200	24.55	6.73	0.020
Makahanaloa	336	0	0	0	3	3	2,200	0.50	0.14	0.000
Makea	1244	4	1	0	30	35	19,300	3.89	1.08	0.000
Manoloa	985	0	0	0	3	3	1,400	0.32	0.09	0.000
Manowaiopae	1067	2	1	0	58	61	36,900	8.14	2.24	0.000
Manuwaikaalio	282	0	0	0	0	0	0	0.00	0.00	0.000
Maulua	3372	0	0	0	8	8	3,600	0.82	0.22	0.000
Nakooko	579	0	0	0	0	0	0	0.00	0.00	0.001
Naluea	674	0	0	0	0	0	0	0.00	0.00	0.002
Nanue	3486	1	0	0	1	2	1,000	0.14	0.04	0.000
Nienie	3009	2	0	0	106	108	57,000	12.86	3.51	0.008
Ninole	905	0	0	0	13	13	6,000	1.37	0.37	0.001
Niulii	2122	2	0	0	53	55	27,600	6.05	1.66	0.010
Ohiahuea	1346	0	0	0	0	0	0	0.00	0.00	0.008
Onomea	532	0	1	0	22	23	11,200	2.55	0.70	0.027
Opea	1437	0	0	0	7	7	2,600	0.59	0.16	0.013

Table 5-1 (continued). OSDS and nutrient flux inventory for Hawaii Island's perennial watersheds

Watershed Name	Area	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Paauilo	928	1	0	0	34	35	19,400	4.31	1.18	0.002
Pae	392	0	0	0	0	0	0	0.00	0.00	0.002
Paeohe	558	0	0	0	0	0	0	0.00	0.00	0.000
Pahale	2339	0	0	0	9	9	3,800	0.87	0.24	0.002
Paheehee	1970	3	3	0	236	242	160,600	34.76	9.70	0.000
Pahoehoe	4065	0	0	0	35	35	22,600	5.17	1.41	0.000
Pali Akamoa	752	0	2	0	69	71	41,900	9.46	2.60	0.001
Paopao S.	306	0	0	0	0	0	0	0.00	0.00	0.001
Papaikou	125	0	0	0	2	2	1,400	0.32	0.09	0.003
Papuaa	2817	5	6	0	605	616	380,700	86.06	23.55	0.003
Paukaa	423	0	0	0	19	19	14,000	3.20	0.87	0.000
Peleau	727	0	0	0	39	39	23,400	5.36	1.46	0.002
Pohakuhaku	1548	0	0	0	27	27	15,800	3.62	0.99	0.004
Pohakupuka	2514	1	0	0	16	17	9,600	2.06	0.57	0.009
Pololu	3873	0	0	0	4	4	2,600	0.60	0.16	0.000
Poupou	386	0	0	0	9	9	5,400	1.24	0.34	0.007
Pukihae	2188	1	2	0	43	46	31,900	6.76	1.87	0.000
Pukoa	164	0	0	0	0	0	0	0.00	0.00	0.000
Punalulu	808	0	0	0	0	0	0	0.00	0.00	0.007
Puumaile	5988	0	0	0	3	3	2,400	0.55	0.15	0.000

Table 5-1 (continued). OSDS and nutrient flux inventory for Hawaii Island's perennial watersheds

Watershed Name	Area	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Puuokalepa	769	1	2	1	103	107	64,200	14.60	3.99	0.003
Umauma	22265	2	0	0	23	25	12,800	2.66	0.73	0.001
Waiaalala	205	0	0	0	0	0	0	0.00	0.00	0.018
Waiaama	2384	0	0	0	45	45	25,200	5.77	1.57	0.002
Waialeale	631	0	0	0	0	0	0	0.00	0.00	0.001
Waiapuka	457	0	0	0	0	0	0	0.00	0.00	0.002
Waiehu	439	0	0	0	23	23	13,200	3.02	0.82	0.003
Waikaalulu	1919	2	0	0	40	42	21,100	4.80	1.31	0.004
Waikoloa	927	0	0	0	0	0	0	0.00	0.00	0.001
Waikama	2147	5	0	0	40	45	28,300	5.83	1.61	0.003
Waikaumalo	9548	0	1	0	32	33	16,300	3.70	1.01	0.001
Waikoekoe	896	0	1	0	40	41	22,800	5.17	1.42	0.002
Waikoloa	11242	0	0	0	10	10	6,800	1.56	0.42	0.000
Waikoloa/Waiulaula	32008	252	42	1	901	1190	754,040	133.05	37.70	0.005
Waikolu	445	1	0	0	35	36	18,200	4.08	1.11	0.008
Wailoa	119782	1378	123	6	9108	10604	6,742,740	1328.81	369.79	0.001
Wailoa/Waipio	17772	92	7	0	697	796	470,900	94.64	26.24	0.000
Wailuku	142463	69	40	0	676	785	495,200	101.23	28.21	0.005
Waimaauou	801	0	0	0	19	19	8,800	2.02	0.55	0.000
Waimaile	265	0	0	0	0	0	0	0.00	0.00	0.026

Table 5-1 (continued). OSDS and nutrient flux inventory for Hawaii Island's perennial watersheds

Watershed Name	Area	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Waimanu	5442	0	0	0	0	0	0	0.00	0.00	0.007
Wainaia	2955	0	3	0	119	122	74,800	16.91	4.64	0.001
Waipahi	614	0	0	0	0	0	0	0.00	0.00	0.019
Waipahoehoe	808	0	0	0	0	0	0	0.00	0.00	0.002
Waipunahina	10191	0	0	0	46	46	27,200	6.22	1.70	0.003
Waipunahoe	10203	0	0	0	40	40	22,200	5.08	1.39	0.008
Waipunalau	2330	0	5	0	158	163	98,200	22.06	6.07	0.009
Waipunalei	1281	1	0	0	76	77	42,800	9.76	2.66	0.003
Waiulili	16227	20	3	0	359	381	221,200	47.43	13.05	0.011
Total	**----**	**2,144**	**317**	**13**	**17,478**	**19,925**	**12,418,040**	**2,493**	**693**	**----**

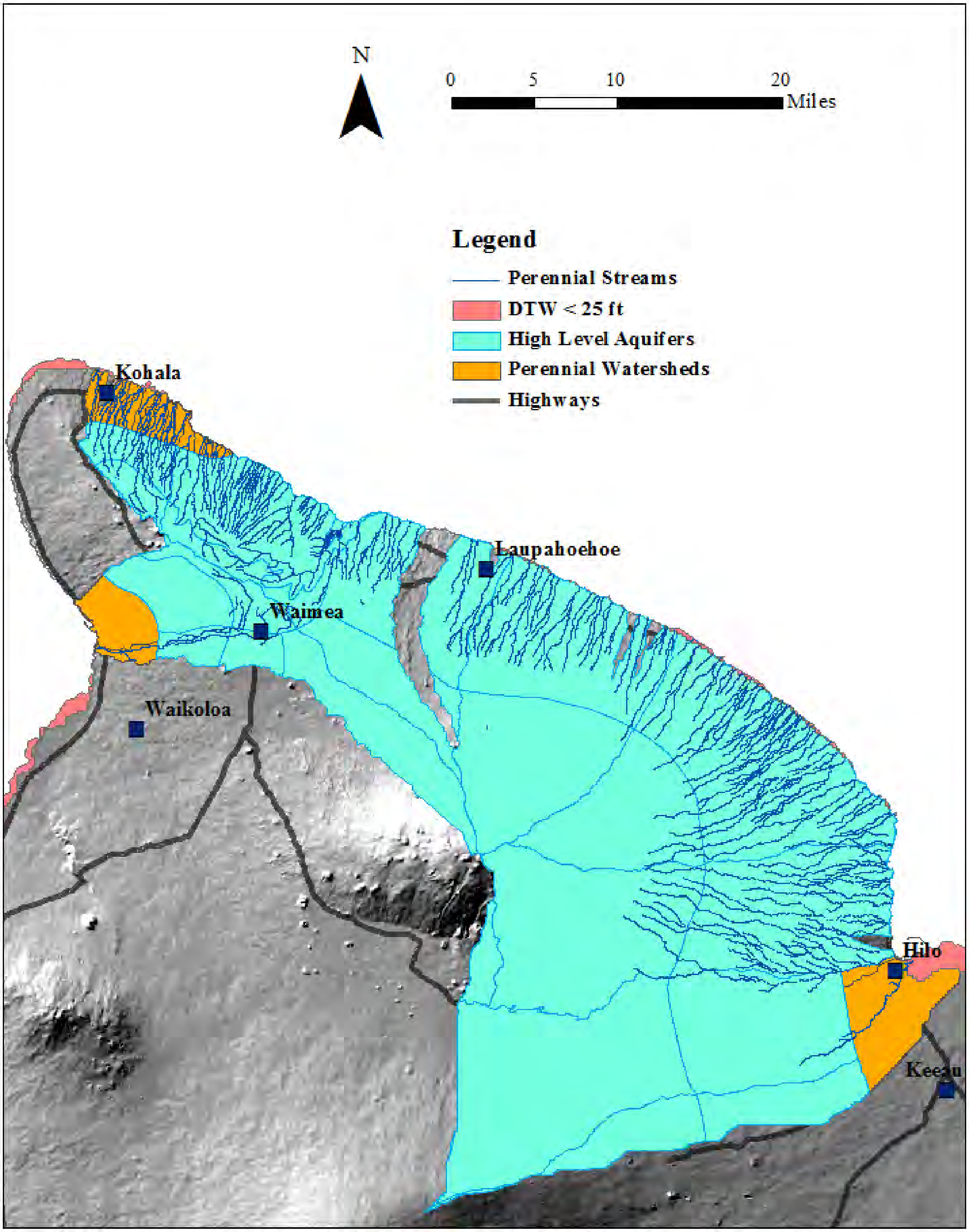

Figure 5-1. High-level groundwater dominates the perennial watersheds on Hawaii Island

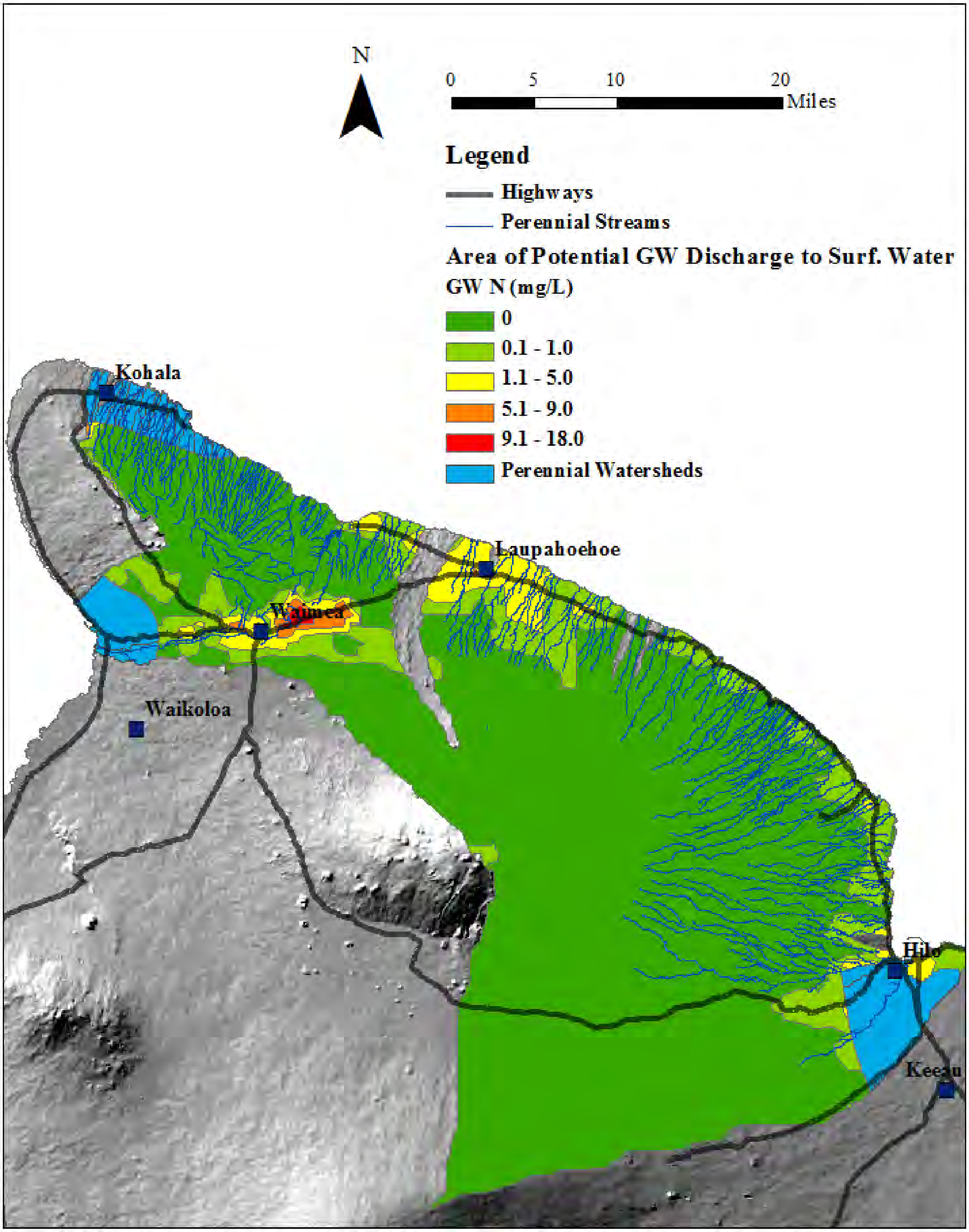

Figure 5-2. The ODGWN concentration distribution in the high-level aquifers located beneath perennial watersheds

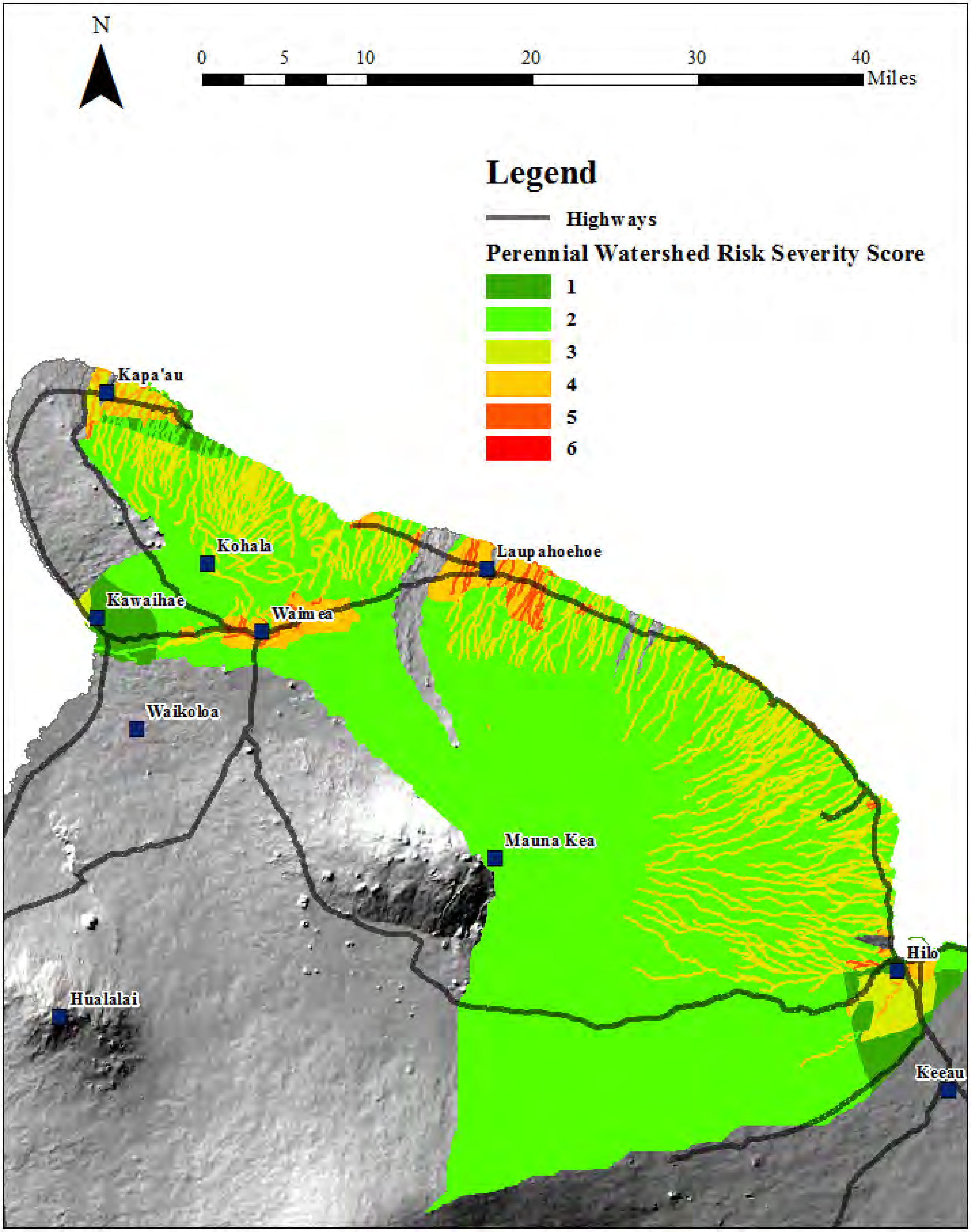

Figure 5-3. The surface water OSDS risk scoring for Hawaii Island

5.2.2 Kauai

Kauai watersheds are particularly vulnerable to OSDS impact on the watersheds because most of the groundwater on this island is classified as high-level groundwater. Figure 5-4 shows the perennial watersheds on Kauai and the status of groundwater within the watersheds. The perennial watersheds are dominated by high-level aquifers, which increases the risk that OSDS contaminated effluent may discharge to the surface water. Near the coast, where a significant portion of the populations lives, the depth to groundwater is less than 25 ft, again satisfying the conditions for groundwater to discharge to surface water. Figure 5-5 shows the ODGWN concentration in those areas of possible groundwater to surface discharge. The concentrations of ODGWN are very high inland of Wailua and Kapaa, and north of Poipu and Hanapepe.

There are an estimated 15,120 OSDS in the perennial watersheds of Kauai (see Table 5-2). Of these, about 11,650 are assumed to be cesspools. Table 5-2 lists the perennial watersheds of Kauai and the OSDS and effluent rates for each watershed. These OSDS discharge about 10.5 million gallons of effluent and about 1,800 and 520 kg of nitrogen and phosphorus, respectively, a day into the environment. The Wailua Watershed has the greatest number of OSDS with an area of 34,000 acres, OSDS population of over 2,500, and a nitrogen flux of 310 kg/d. The watershed with the highest flux density was the Moikeha Watershed with an area 1,500 acres that hosts about 1,760 OSDS that produce about 0.15 kg/acre/d of nitrogen.

The risk of surface water to OSDS effluent contamination was evaluated based on the scoring system described in Section 5.2.1. Figure 5-6 shows the distribution of surface water risk scoring. The values varied from a minimum of one to the maximum possible score of 6. The minimum scored occurred in those portions of the perennial watersheds where there was no high-level aquifer and the depth to groundwater exceeded 25 ft. The high score of 6 occurred within 200 ft of a very limited number of stream segments near Ha‘ena, Wailua, and Hanapepe where there was elevated ODGWN in high-level aquifers and the depth to groundwater is less than 25 ft. Areas where the risk score was 4 to 5 occurred primarily in portions of southern Kauai between Poipu and Hanapepe, in a large area near Wailua/Kapaa, and in limited areas near Kilauea, Hanalei, and Ha’ena. The elevated scores were the result of elevated ODGWN in high-level aquifers.

Table 5-2. OSDS and nutrient flux inventory for Kauai's perennial watersheds

Watershed Name	Area (acres)	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Aakukui	3,353	4	0	0	4	8	7,000	0.9	0.3	0.0003
Anahola	8,763	67	8	0	385	460	330,200	57.6	16.3	0.0066
Anini	1,975	57	1	0	30	88	58,200	4.4	1.5	0.0022
Awaawapuhi	850	0	0	0	0	0	0	0.0	0.0	0.0000
Haeleele	1,492	0	0	0	1	1	400	0.1	0.0	0.0001
Hanakapiai	2,444	0	0	0	0	0	0	0.0	0.0	0.0000
Hanakoa	1,292	0	0	0	0	0	0	0.0	0.0	0.0000
Hanalei	15,125	94	2	0	161	257	196,000	22.9	6.9	0.0015
Hanamaulu	7,303	12	5	0	41	58	29,700	4.1	1.2	0.0006
Hanapepe	17,222	11	0	0	563	574	329,400	73.0	20.0	0.0042
Hoea	10,213	3	0	0	3	6	1,200	0.1	0.0	0.0000
Honopu	1,093	0	0	0	0	0	0	0.0	0.0	0.0000
Hoolulu	182	0	0	0	0	0	0	0.0	0.0	0.0000
Huleia	17,936	15	3	0	93	111	83,600	15.5	4.4	0.0009
Kaawaloa	4,232	0	0	0	0	0	0	0.0	0.0	0.0000
Kalalau	2,748	0	0	0	0	0	0	0.0	0.0	0.0000
Kalihiwai	7,375	141	13	0	82	236	158,000	12.8	4.3	0.0017
Kapaa	10,500	177	55	0	975	1,207	816,600	146.2	41.6	0.0139
Kaulaula	1,666	0	0	0	0	0	0	0.0	0.0	0.0000
Kawailoa	2,388	1	1	0	8	10	5,000	1.0	0.3	0.0004

Table 5-2 (continued). OSDS and nutrient flux inventory for Kauai's perennial watersheds

Watershed Name	Area (acres)	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Kilauea	8,178	183	29	0	357	569	409,600	55.5	16.5	0.0068
Kipu Kai	1,905	0	0	0	4	4	3,000	0.7	0.2	0.0004
Kumukumu	729	8	0	0	1	9	3,800	0.1	0.0	0.0001
Lawai	5,979	240	230	8	1,560	2,038	1,514,000	267.6	77.6	0.0448
Limahuli	1,186	3	0	0	10	13	8,600	1.3	0.4	0.0011
Lumahai	9,095	0	0	0	0	0	0	0.0	0.0	0.0000
Mahaulepu	8,367	7	1	102	9	119	76,000	7.0	2.3	0.0008
Mahinauli	5,547	0	0	0	3	3	1,600	0.4	0.1	0.0001
Manoa	624	19	1	0	40	60	49,200	5.5	1.7	0.0087
Milolii	2,775	0	0	0	0	0	0	0.0	0.0	0.0000
Moikeha	1,503	155	134	1	1,468	1,758	1,222,200	231.6	66.0	0.1541
Moloaa	2,418	59	10	1	44	114	73,400	6.3	2.1	0.0026
Nakeikionaiwi	306	0	0	0	0	0	0	0.0	0.0	0.0000
Nawiliwili	4,014	49	36	1	622	708	479,100	94.6	26.6	0.0236
Nualolo	1,789	0	0	0	0	0	0	0.0	0.0	0.0000
Pohakuao	335	0	0	0	0	0	0	0.0	0.0	0.0000
Puali	1,327	51	11	11	271	344	237,700	43.3	12.2	0.0327
Puukumu	806	53	6	0	74	133	91,000	11.7	3.5	0.0145
Wahiawa	5,173	1	1	0	39	41	25,000	5.5	1.5	0.0011
Waiahuakua	404	0	0	0	0	0	0	0.0	0.0	0.0000
Waikaea	4,564	217	57	3	828	1,105	755,200	125.5	36.0	0.0275
Waikoko	458	3	0	0	1	4	6,200	0.4	0.1	0.0008
Waikomo	5,601	203	94	134	1,420	1,851	1,263,600	225.5	64.2	0.0403
Wailua	34,023	398	95	3	2,013	2,509	1,785,600	310.8	88.5	0.0091
Waimea	55,007	20	1	0	202	223	119,400	23.1	6.4	0.0004

Table 5-2 (continued). OSDS and nutrient flux inventory for Kauai's perennial watersheds

Watershed Name	Area (acres)	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Wainiha	15,157	120	4	0	230	354	259,000	29.8	9.0	0.0020
Waiolaa	225	0	0	0	0	0	0	0.0	0.0	0.0000
Waioli	3,483	34	1	0	100	135	98,800	14.1	4.1	0.0040
Waipa	1,592	3	0	0	4	7	4,800	0.6	0.2	0.0004
Waipao	5,740	1	0	0	2	3	3,600	0.6	0.2	0.0001
Total	**----**	**2,409**	**799**	**264**	**11,648**	**15,120**	**10,505,700**	**1,800**	**516**	**----**

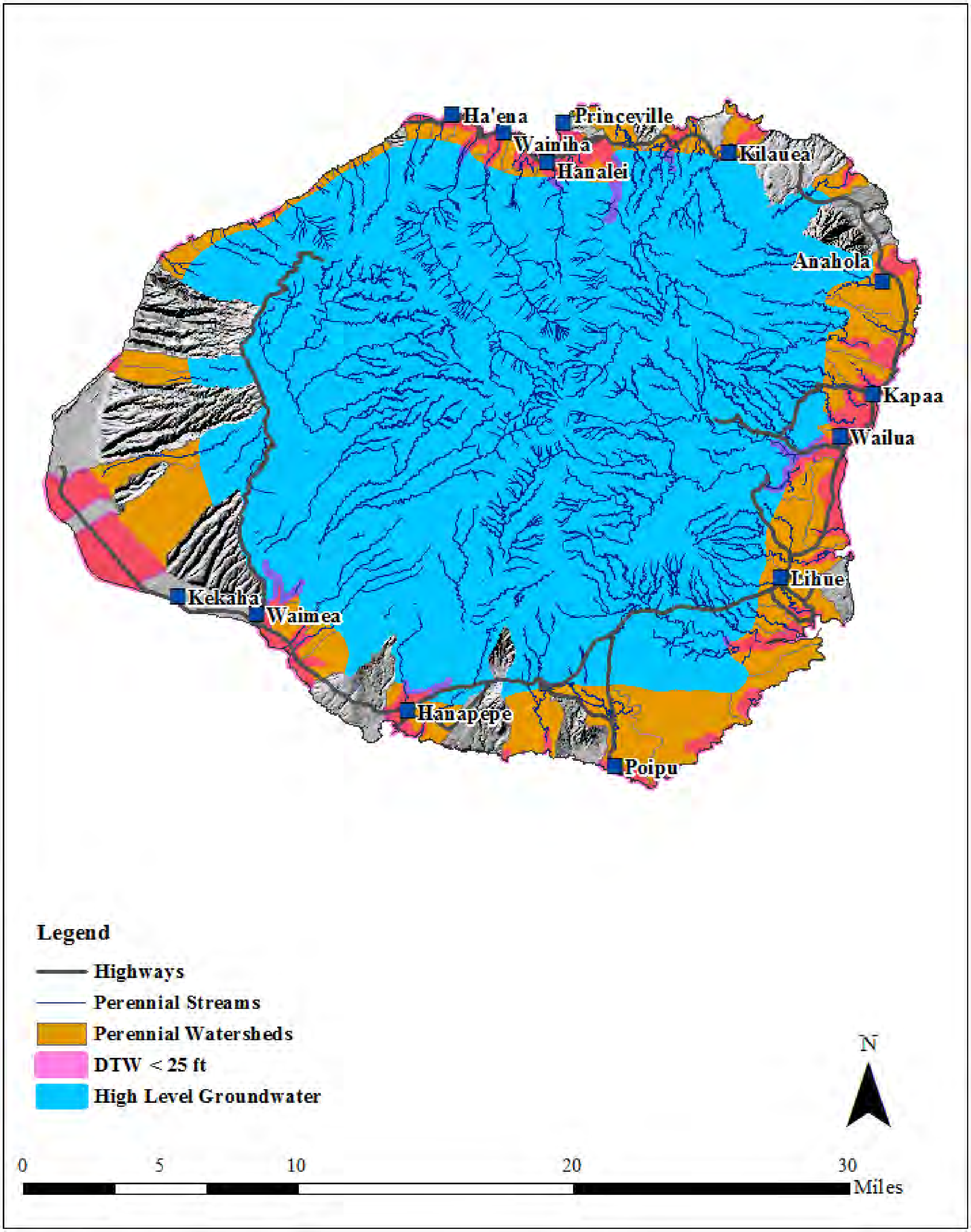

Figure 5-4. Areas of high-level groundwater and shallow depth to groundwater within the boundaries of perennial watersheds on Kauai

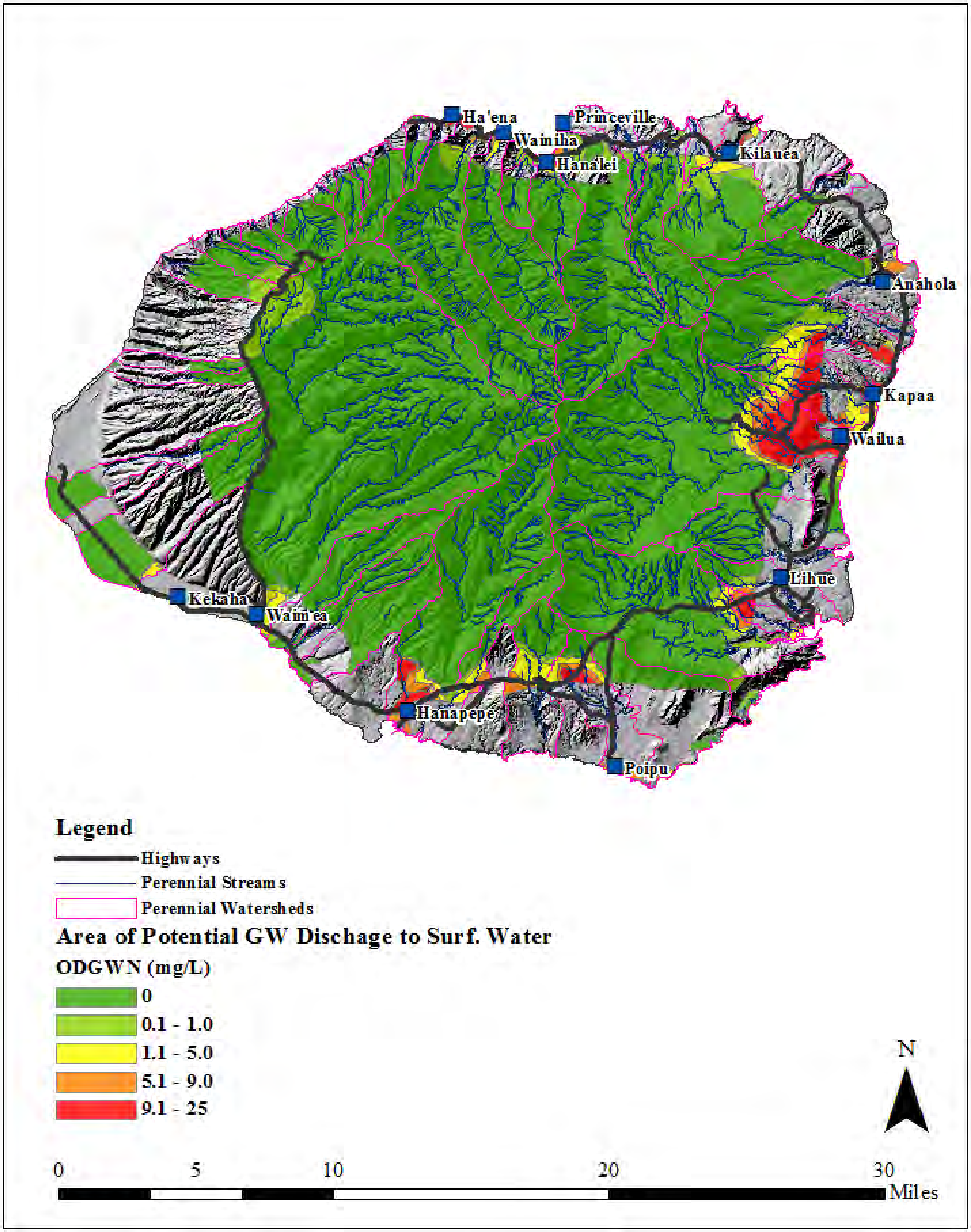

Figure 5-5. The concentration of ODGWN in the groundwater that potentially discharges to the surface water on Kauai

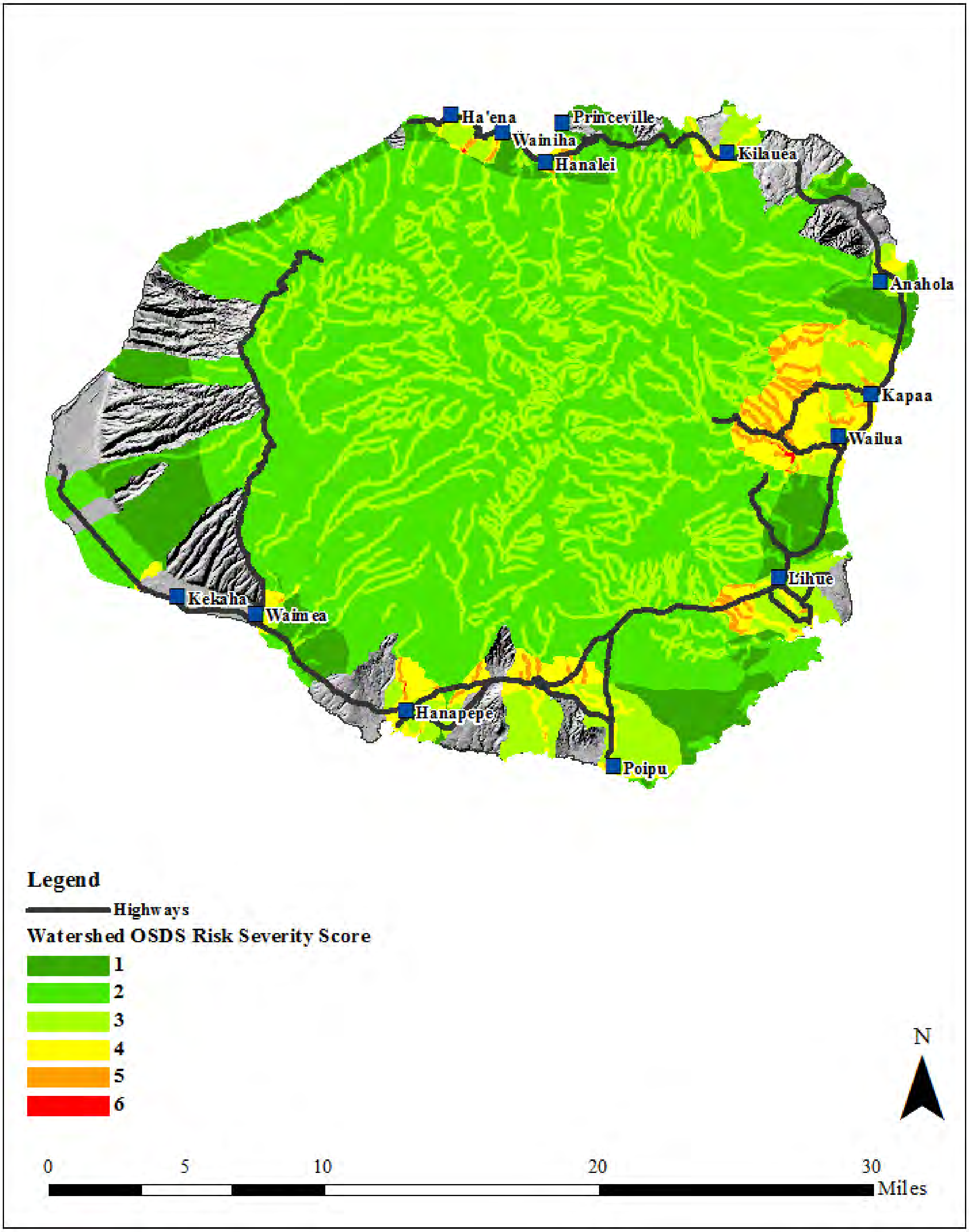

Figure 5-6. The surface water OSDS risk scoring for Kauai

5.2.3 Maui

Unlike northeast Hawaii Island and Kauai, there are significant areas of perennial watersheds where the discharge of groundwater to surface water is unlikely. This condition occurs outside of the central highlands of west and in central Maui. Figure 5-7 shows the extent of the high-level aquifers or perched groundwater that underlie the perennial watersheds. The discharge of high-level or perched groundwater to perennial streams is likely the interior of the West Maui Volcano and throughout the northeast flank of Haleakala. The areas in these watersheds where the depth to groundwater is estimated to be less than 25 ft occur at center of the West Maui Volcano, the coastal areas of West Maui, and near the Keanae region of East Maui.

There are estimated to be 4,600 OSDS in the perennial watersheds of Maui. Of these, about 3,100 are assumed to be cesspools. Table 5-3 lists the perennial watersheds of Maui, and the OSDS quantity and effluent rates for each watershed. These OSDS discharge about 3.3 million gallons of effluent and about 510 and 154 kg of nitrogen and phosphorus, respectively, into the environment each day. The Kiaha Watershed, with an area of 5,235 acres has about 1,450 OSDS and nitrogen flux density of 0.0254 kg/acre/d. This is also the highest nitrogen flux density of all of the watersheds.

The modeled groundwater areas of OSDS impact, as indicated by elevated ODGWN, lie largely outside of the perennial watersheds. Figure 5-8 shows the modeled ODGWN concentration in the perennial watersheds. Areas where the modeled ODGWN concentration was greater than 1 mg/L occurred in the Iao and Waiehu Watersheds in Central Maui and the Kuiaha Watershed in East Maui. Elevated ODGWN in the groundwater that may discharge to surface waters indicates areas where adverse stream impacts are most likely to be occurring.

The OSDS risk scoring for Maui's perennial watersheds is shown in Figure 5-9. For most of the watershed area the risk potential is low (score of 2 or less) to moderate (score of 3) adjacent to the stream channels. A significant risk potential (score of 4 in the watershed and 5 adjacent to the stream) occurs in the Kuiaha Watershed due to the elevated ODGWN. In these areas, effluent from the OSDS throughout the watershed can impact the streams. These scores were mapped to the OSDS to rank the relative risk each unit poses to the streams.

Table 5-3. OSDS and nutrient flux inventory for Maui's perennial watersheds

Watershed Name	Area (acres)	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Alelele	817	0	0	0	0	0	0	0.0	0.0	0.0000
E. Wailuaiki	2436	0	0	0	0	0	0	0.0	0.0	0.0000
Haipuaena	1051	0	0	0	0	0	0	0.0	0.0	0.0000
Hanawana	330	9	2	0	13	24	13,800	1.8	0.9	0.0055
Hanawi	3549	0	0	0	0	0	0	0.0	0.0	0.0000
Hanehoi	674	9	1	0	15	25	10,900	1.4	0.4	0.0021
Hoalua	952	3	1	0	2	6	3,500	0.4	0.1	0.0004
Honokahua	3117	37	9	0	18	56	49,800	5.1	3.0	0.0016
Honokohau	7466	5	0	0	19	24	12,700	2.1	1.1	0.0003
Honokowai	5631	1	0	0	16	17	11,900	2.5	0.7	0.0004
Honolua	3028	21	3	0	2	26	19,700	0.7	0.3	0.0002
Honomanu	4158	0	0	0	0	0	0	0.0	0.0	0.0000
Honopou	1681	22	0	0	10	32	18,600	1.5	0.5	0.0009
Hoolawa	3192	73	6	0	46	125	71,800	4.9	1.7	0.0015
Iao	14479	58	20	10	731	819	553,400	111.6	31.1	0.0077
Kaapahu	323	0	0	0	0	0	0	0.0	0.0	0.0000
Kahakuloa	2680	2	0	0	21	23	14,900	3.1	1.8	0.0011
Kahoma	5189	20	13	0	314	347	268,100	56.1	15.9	0.0108
Kailua	3109	11	0	0	17	28	17,500	2.1	0.6	0.0007
Kakipi	6065	28	2	0	55	85	43,100	6.2	2.1	0.0010
Kalepa	573	0	0	0	1	1	900	0.2	0.1	0.0004
Kapaula	553	0	0	0	0	0	0	0.0	0.0	0.0000
Kauaula	5399	30	0	0	39	69	71,800	5.3	1.8	0.0010

Table 5-3 (continued). OSDS and nutrient flux inventory for Maui's perennial watersheds

Watershed Name	Area (acres)	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Kaupakulua	2421	58	6	0	154	218	119,500	17.6	5.1	0.0073
Kopiliula	3048	2	0	0	0	2	1,100	0.0	0.0	0.0000
Kuhiwa	2319	10	0	0	5	15	6,600	0.4	0.1	0.0002
Kuiaha	5235	447	53	0	946	1446	909,300	128.3	39.5	0.0245
Kukuiula	440	0	0	0	2	2	1,200	0.3	0.1	0.0006
Launiupoko	4085	243	2	0	54	299	430,000	57.1	16.8	0.0140
Makamakaole	1405	7	8	1	6	22	13,600	1.4	0.5	0.0010
Makapipi	2016	1	0	0	24	25	12,300	2.6	1.2	0.0013
Nailiilihaele	2315	0	0	0	0	0	0	0.0	0.0	0.0000
Nuaailua	1015	3	0	0	14	17	9,700	1.8	0.5	0.0018
Nuanuaaloa	2432	2	0	0	6	8	4,300	0.8	0.2	0.0003
Oheo	5672	0	0	0	3	3	1,400	0.3	0.1	0.0001
Ohia	208	1	0	0	2	3	1,600	0.2	0.1	0.0011
Olowalu	5002	17	0	0	3	20	14,900	0.7	0.3	0.0001
Oopuola	820	0	0	0	0	0	0	0.0	0.0	0.0000
Piinaau	13225	2	1	0	4	7	6,800	1.0	0.3	0.0001
Punalau	669	1	0	0	0	1	300	0.0	0.0	0.0000
Puohokamoa	2001	1	0	0	0	1	600	0.0	0.0	0.0000
Ukumehame	5575	22	0	0	17	39	26,900	2.2	0.7	0.0004
W. Wailuaiki	2679	0	0	0	0	0	0	0.0	0.0	0.0000
Wahinepee	3495	0	0	0	1	1	900	0.2	0.1	0.0001
Waiehu	6639	44	8	0	307	359	258,300	50.4	14.1	0.0076
Waihee	4584	28	3	1	47	79	48,000	6.5	1.9	0.0014
Waikamoi	449	0	0	0	0	0	0	0.0	0.0	0.0000

Table 5-3 (continued). OSDS and nutrient flux inventory for Maui's perennial watersheds

Watershed Name	Area (acres)	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Waikapu	9060	11	10	0	123	144	93,900	18.7	5.3	0.0021
Wailuanui	3807	3	0	0	25	28	15,500	3.1	0.9	0.0008
Waiohue	503	0	0	0	0	0	0	0.0	0.0	0.0000
Waiokamilo	1696	3	0	0	4	7	4,100	0.6	0.2	0.0004
Waiolai	678	47	0	0	15	62	48,500	2.2	0.9	0.0033
Waipio	684	31	5	4	38	78	69,400	10.7	3.1	0.0156
Total	**----**	**1313**	**153**	**16**	**3119**	**4593**	**3,281,100**	**512.2**	**154.0**	**----**

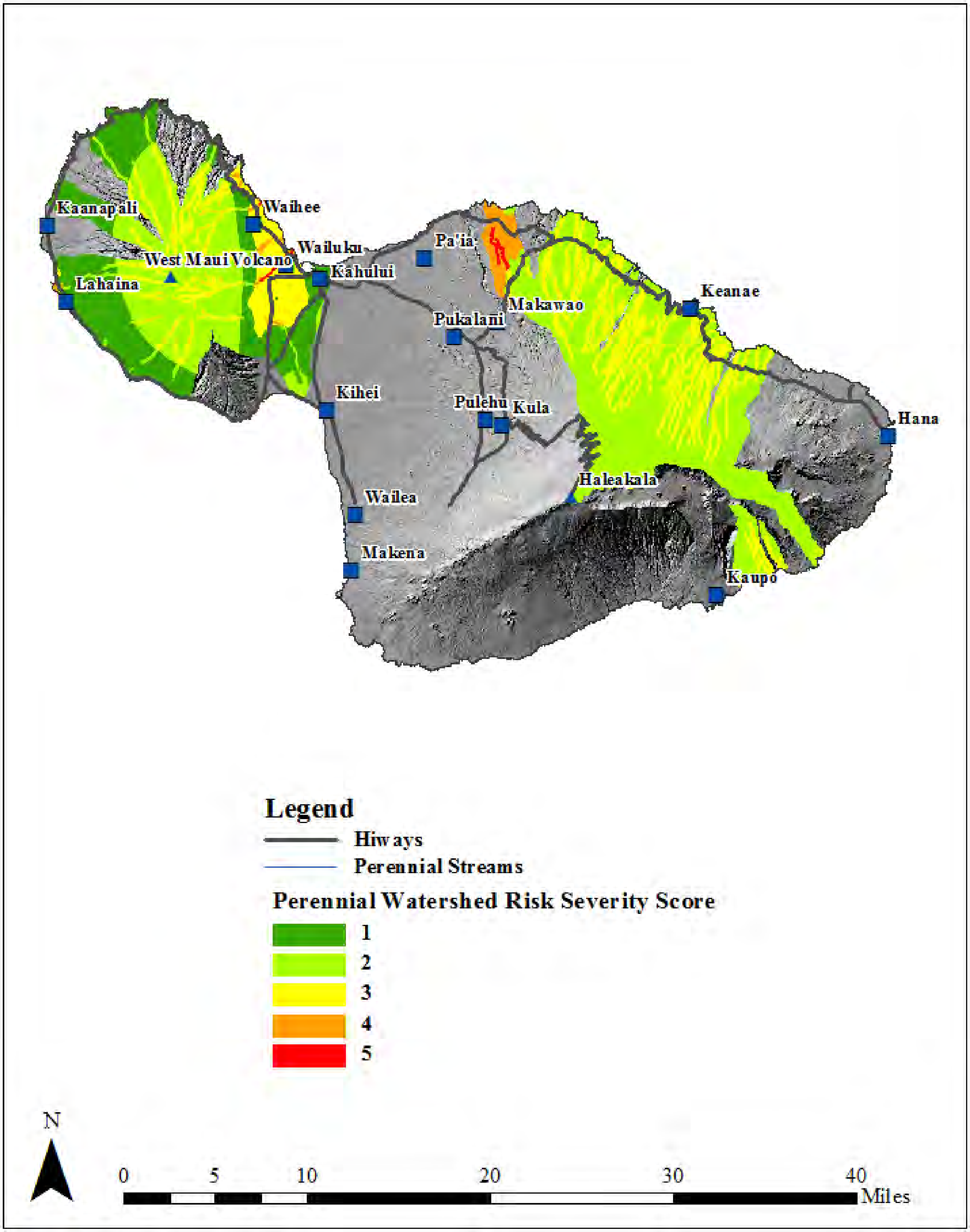

Figure 5-7. Areas of high-level groundwater and shallow depth to groundwater within the boundaries of perennial watersheds on Maui

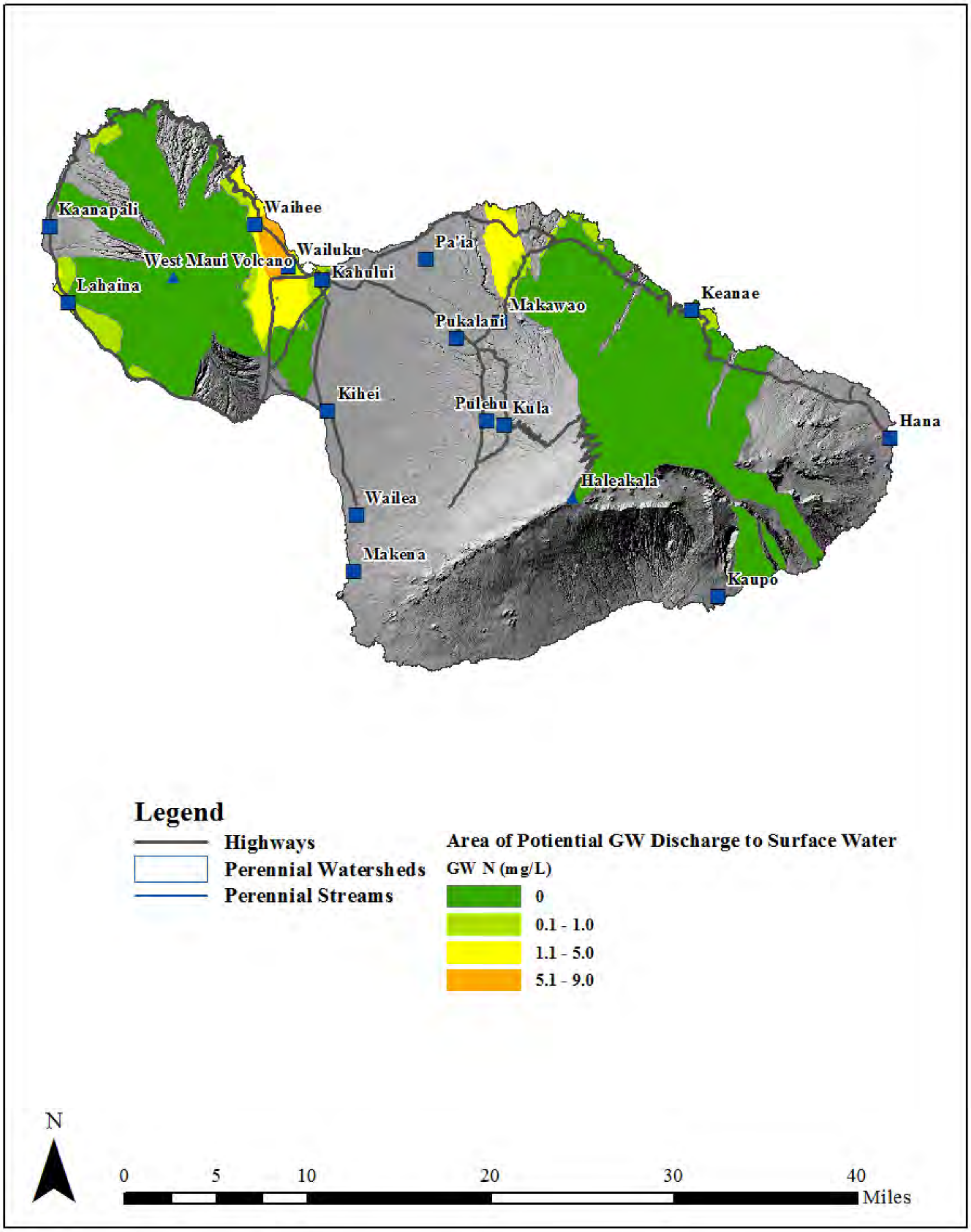

Figure 5-8. The concentration of ODGWN in the groundwater that potentially discharges to the surface water on Maui

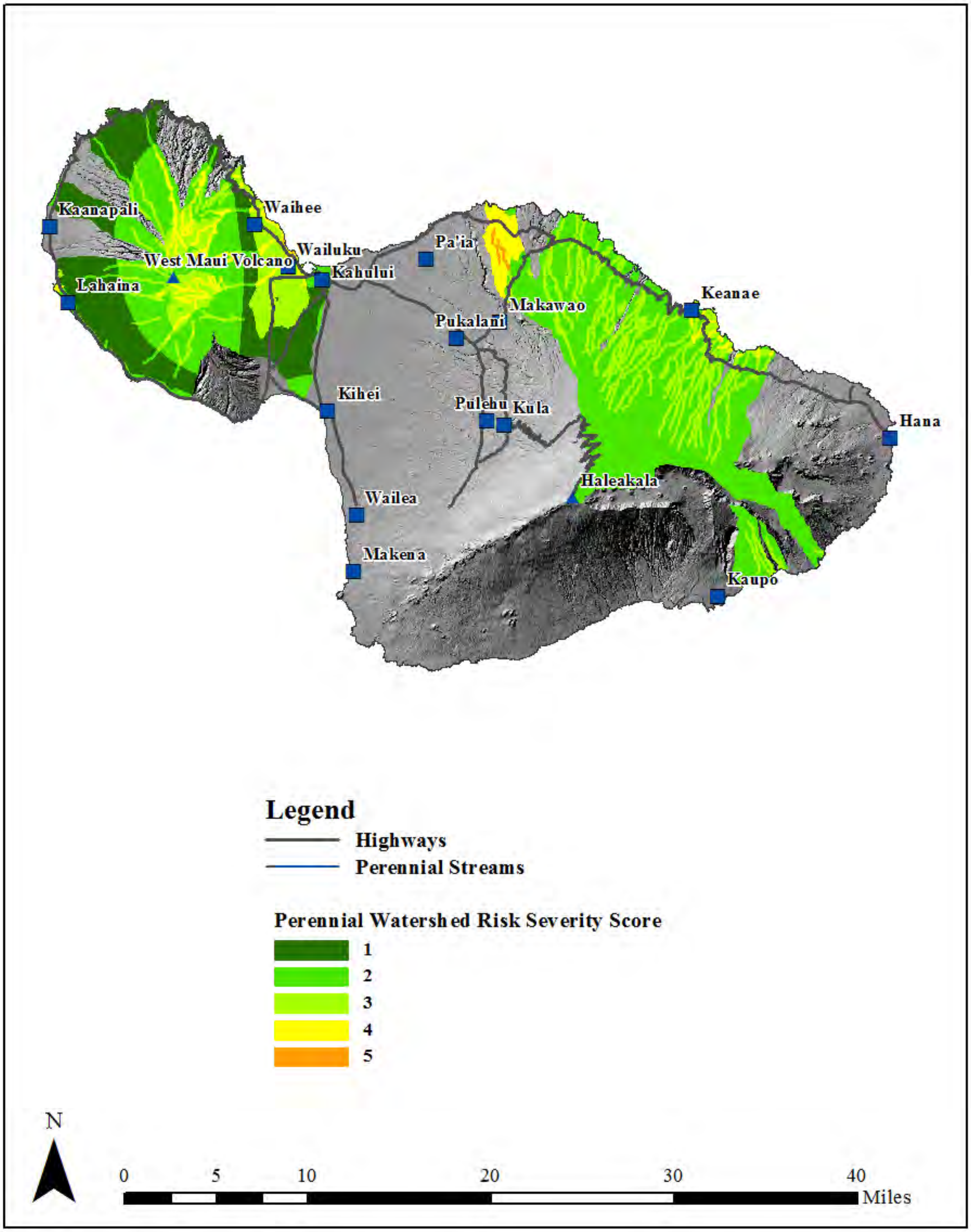

Figure 5-9. The surface water OSDS risk scoring for Maui

5.2.4 Molokai

Perennial watersheds on Molokai are restricted to the eastern third of the island (Figure 5-10). About half of the perennial watersheds occur over high-level groundwater aquifers. There are only very small areas near Halawa and on the south coast of the perennial watersheds where the depth to groundwater is less than 25 ft. This limits the areas where groundwater has the potential to discharge to surface water to the rugged interior of East Molokai.

With only 80 OSDS in the perennial watersheds of Molokai, there appears to very little risk to surface water from these systems. Of these, about 61 are assumed to be cesspools. Table 5-4 lists the perennial watersheds of Molokai and the OSDS and effluent rates for each watershed. These OSDS discharge about 45 thousand gallons of effluent and about 8.4 and 2.4 kg of nitrogen and phosphorus, respectively, a day into the environment. The Honouliwai Watershed, with an area of 1,705 acres has about 31 OSDS and nitrogen flux density of 0.0022 kg/acre/d. This is also the highest nitrogen flux density of the all of the perennial watersheds on Molokai.

The ODGWN in the groundwater underlying the perennial watersheds is very low in ODGWN, which indicates that the current risk to streams is very low. Figure 5-11 shows the ODGWN concentration distribution within the boundaries of the perennial watersheds. In the high-level aquifer areas there is no elevated nitrogen as a result of OSDS effluent discharge. In the coastal areas, the modeled ODGWN concentration within the perennial watersheds does not exceed 1 mg/L.

The risk that OSDS in perennial watersheds is much lower for Molokai than for the other islands evaluated. The majority of the perennial watershed area is underlain by basal rather than high-level water. Additionally, the high topographic relief in these areas limits the areas where the depth to groundwater is less than 25 ft to very small flood plains at the mouth of a limited number so streams. Figure 5-12 shows that the majority of Molokai’s perennial watersheds have the lowest risk severity score of 1. The area maximum risk severity score is 3 within the 200 ft setback from stream channels in the high-level aquifer areas. However, there are currently no OSDS in these areas.

Table 5-4. OSDS and nutrient flux inventory for Molokai's perennial watersheds

Watershed Name	Area (acres)	CLASS I	CLASS II	CLASS III	CLASS IV	Total OSDS	Effluent Flux (gpd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)	Nitrogen Flux Density (kg/d/acre)
Kawainui	2,348	0	0	0	0	0	0	0.000	0.000	0.0000
Kahiwa	124	0	0	0	0	0	0	0.000	0.000	0.0000
Halawa	4,748	0	0	0	6	6	4,100	0.939	0.256	0.0002
Waiahookalo	156	0	0	0	0	0	0	0.000	0.000	0.0000
Wailau	7,689	1	0	0	0	1	200	0.001	0.002	0.0000
Papio	1,206	0	0	0	1	1	400	0.092	0.025	0.0001
Honouliwai	1,705	6	1	0	24	31	19,800	3.735	1.047	0.0022
Waialua	2,122	7	1	0	17	25	11,900	1.859	0.538	0.0009
Kainalu	984	3	0	0	13	16	8,900	1.768	0.490	0.0018
Total	**----**	**17**	**2**	**0**	**61**	**80**	**45,300**	**8.39**	**2.36**	**----**

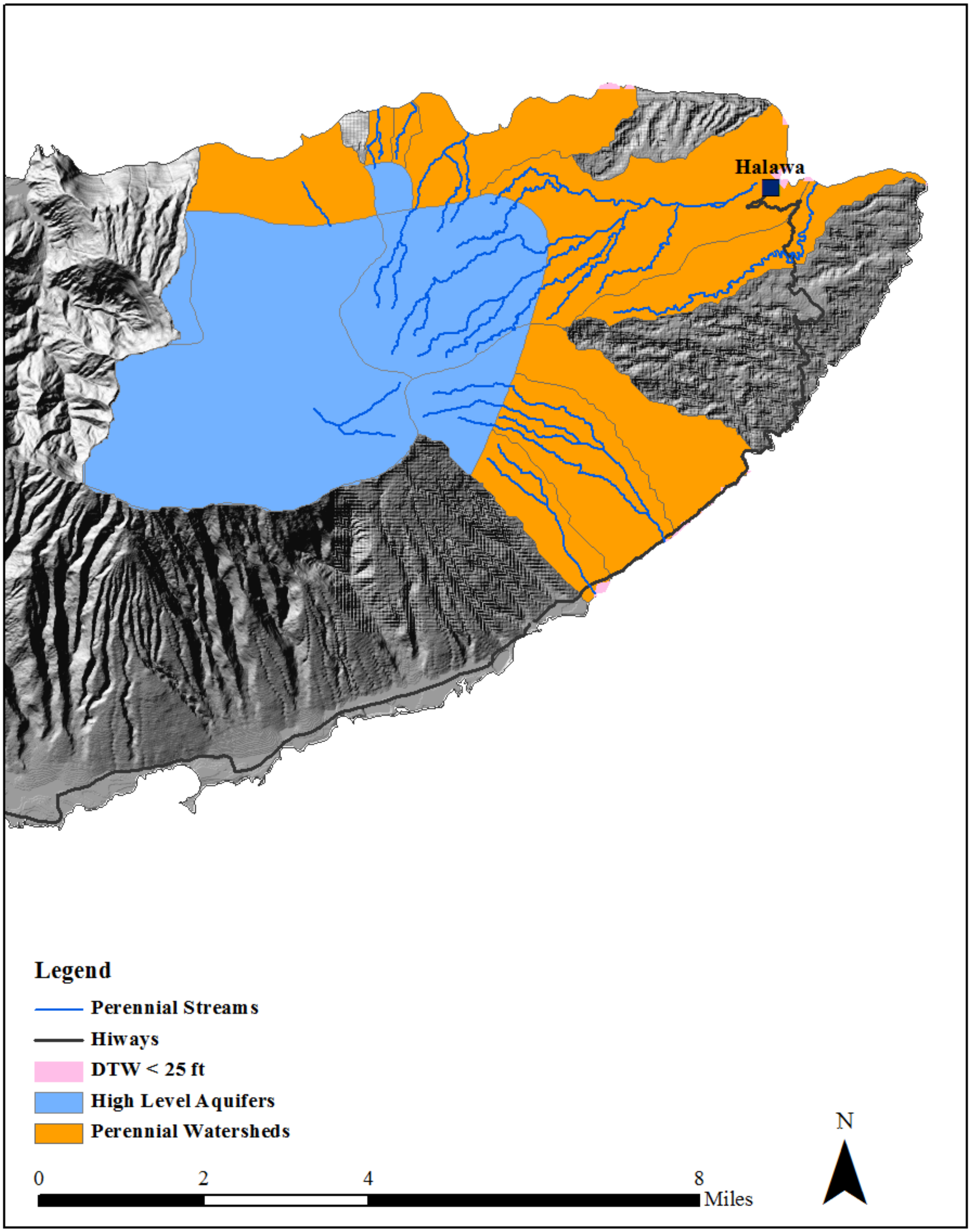

Figure 5-10. Areas of high-level groundwater and shallow depth to groundwater within the boundaries of perennial watersheds on Molokai

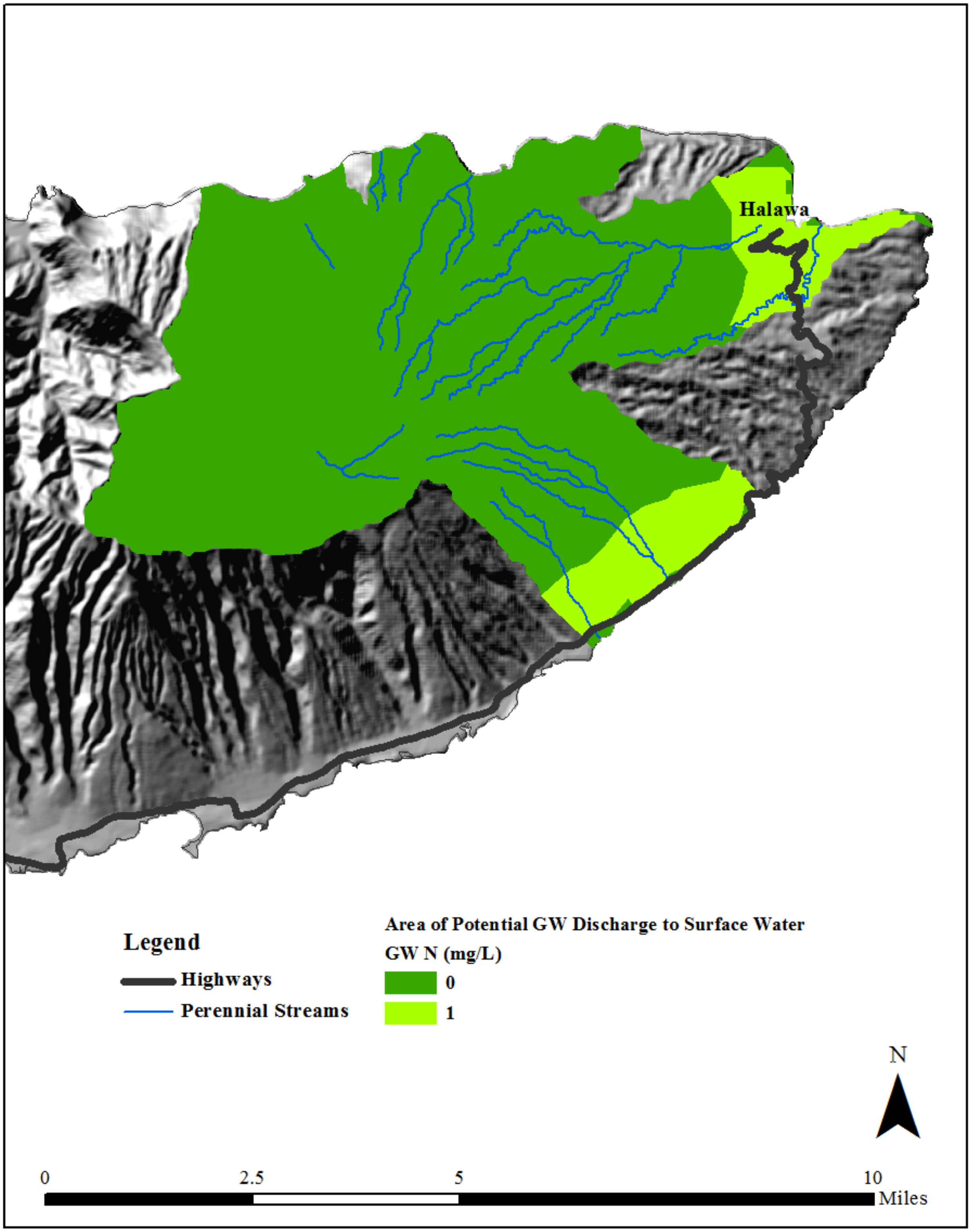

Figure 5-11. The concentration of ODGWN in the groundwater that potentially discharges to the surface water on Molokai

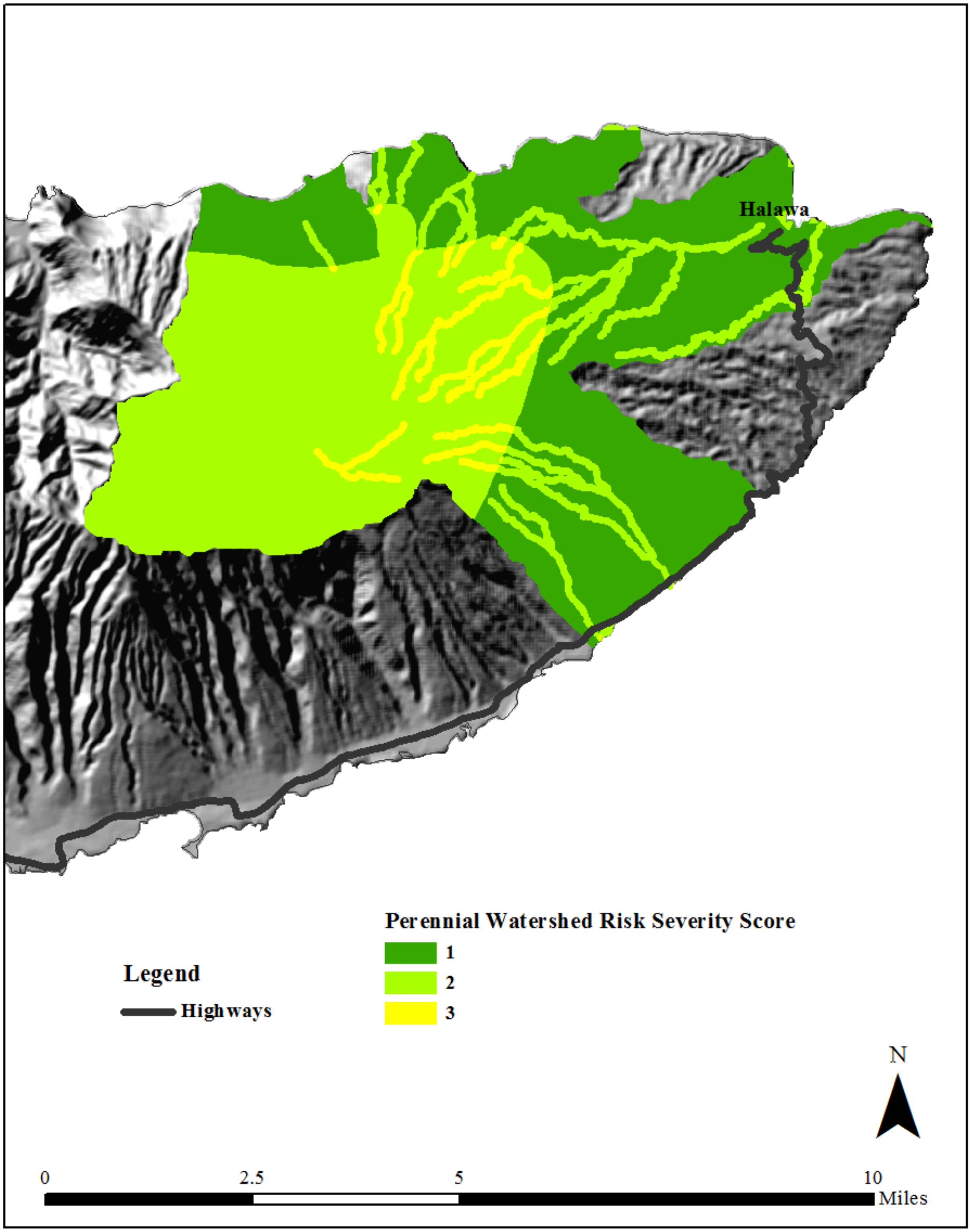

Figure 5-12. The surface water OSDS risk scoring for Molokai

SECTION 6. COASTAL ZONE WATERS

This section describes the delineation zones adjacent to the coast where the presence of OSDS could adversely impact the nearshore marine environment. This section further describes the methodology employed to classify the relative risk posed by OSDS located within these zones. Finally, the OSDS database in Section 3 was queried to tabulate those OSDS located within the delineated zones and estimate the nutrient load to the coastal waters.

The discharge from OSDS eventually migrates to the ocean. The OSDS effluent migrates vertically to the water table and is carried with the groundwater flow to submarine groundwater discharge points. This type of discharge is not regulated under the Clean Water Act considering that there is no direct surface connection between the OSDS and the stream or ocean. However, it can still negatively impact human health and the environment. Pathogens derived from OSDS in the nearshore recreational waters can result in direct contact between these disease causing organisms and humans (Calderon et al., 1991; Jones et al., 2011). The effluent also contains high-levels of nutrients, which increases the nutrient load to coastal waters (Giblin and Gaines, 1990; Jones et al., 2011; and Reay, 2004; Postma et al., 1992; and Valiela and Costa, 1988).

6.1 ZONES OF CONSIDERATION FOR COASTAL WATERS

To evaluate the potential impact of the OSDS on coastal zone waters, two setback areas were delineated. One setback zone was a fixed distance while the other was a time of travel delineation. The setback considerations were used to delineate and rank those areas where OSDS pose the most immediate threat to the coastal waters. The ODGWN within or adjacent to these zones identified those areas where adverse impact to coastal waters from existing OSDS is most likely occurring.

6.1.1 Fixed Setback

The OSDS immediately adjacent to the coastal zone waters pose the greatest risk. To reflect the increased risk posed by these systems, a 200 ft setback from the shoreline was delineated for each island assessed by this study. This approach is consistent with the Zone B methodology used for drinking water sources supplied by surface water. This setback was used to identify those OSDS that had the greatest potential to contribute pathogens to the coastal zone waters.

6.1.2 Time of Travel Considerations

A two-year TOT setback was delineated to identify those OSDS that pose the greatest nutrient loading risk to the coastal zone environment. The effluent from OSDS located within this zone has little opportunity for natural recharge to dilute the nutrients and limited time for pathogen die-off or inactivation.   A two-year TOT setback was selected because it is consistent with the SWAP methodology. The delineations were based on the flow fields generated by the SWAP groundwater models of each island. The MODPATH particle transport code was used to identify those areas within a two-year TOT of the shoreline using the reverse tracking option with the virtual particles inserted at the modeled shoreline.

6.1.3 Assessing Potential Impact From OSDS Outside of the Two Year Time of Travel

OSDS located outside of the coastal two-year time of travel delineation have the potential to deliver problematic nutrient loads to the nearshore environment if insufficient dilution occurs. Sources of dilution are low nutrient recharge and hydrodynamic dispersion. The nitrogen transport model described in Section 4.2 was used to evaluate reduction in ODWGWN concentration from both of these processes. The areas adjacent to the two-year TOT where the simulated ODGWN exceeded 1 mg/L, which occurred in areas of OSDS density, were annexed to the setback zone.

6.2 RISK SCORING FOR THE COASTAL ZONE

This study combined the setback delineations with the ODGWN model results to rank the relative risk to coastal waters. The area evaluated for the coastal risk assessment included those zones described in Sections 6.1.1 through 6.1.3. Each zone was assigned a risk score for each condition that applied as follows: (1) areas within a two-year time of groundwater travel from the coast were assigned a score of 1; (2) areas within 200 ft of the coast were assigned a score of 2; and areas where the simulated ODGWN concentration was greater than 5.0 mg/L were assigned a score of 2.

The maximum possible risk score of 5 was assigned to zones of elevated ODGWN concentrations within 200 ft of the coast. The minimum risk score of 1 was assigned to zones within a two-year time of groundwater travel to the coast, further than 200 ft inland from the shore, and with no elevated ODGWN concentrations. Areas outside of the two-year TOT, but within a zone of elevated ODGWN concentration, were assigned a score of 2.

6.3 RESULTS

Table 6-1 lists the inventory of OSDS in the coastal setback zones. This study estimated that there are nearly 42,000 OSDS within the coastal setback zones. Of these OSDS, over 34,000 are cesspools. These OSDS discharge an estimated 26.5 mgd of effluent that includes 4,800 kg/d and 1,400 kg/d of nitrogen and phosphorus, respectively. It is also estimated that over 1,100 OSDS are located within 200 ft of the shoreline on the four islands assessed by this study.

6.3.1 Hawaii

This study estimated that there are nearly 28,000 OSDS within a two-year TOT of the coast and the areas of elevated ODGWN adjacent to and upgradient of this zone (see Table 6-1). Of these OSDS nearly 24,000 are likely Class IV. This study further estimates that there are about 512 OSDS within 200 ft of the shoreline on this island. A significant length of the shoreline of the island of Hawaii is at risk from adverse impact OSDS impact due to the large number of these systems within a two-year time of travel to the coast. Figure 6-1 shows the distribution of OSDS risk scores in the coastal setback zones for Hawaii Island. Those areas are defined as having a risk score of 5 are shown in red. Most of the northeast coast of this island falls into this category as well as the northern tip of the Kohala Peninsula and the much of the coast of West Hawaii. In West Hawaii, the urban core of Kailua-Kona, Waikoloa Village, and the resort areas are served by sewer service. Outside of these areas, OSDS are the primary means of wastewater disposal. This results in elevated ODGWN concentrations in a large area beneath the west slope of Hualalai that is inland but adjacent to the coastal two-year TOT setback. This zone of elevated ODGWN was annexed to the coastal two-year TOT delineated zone. Smaller areas of concern are associated with the communities of Hawaii Ocean View Estates, Naalehu, Pahala, and the developments on the eastern extent of the island (Hawaiian Beaches and Hawaii Paradise Park for example).

6.3.2 Kauai

Kauai, the second smallest island assessed, had the second greatest number of OSDS within the coastal setback zones. We estimate that more than 7,400 OSDS, of which over 5,500 are Class IV OSDS, are located within a two-year TOT of the coast or adjacent to areas of elevated ODGWN concentrations (see Table 6-1). The coastal areas of southern and eastern Kauai were most adversely impacted by OSDS. A score of 5 was assigned to the 200 ft setback zone of southern Kauai from Hanapepe to Poipu due to the elevated ODGWN levels. This includes the communities of Kaleheo, Lawai, and Koloa. In eastern Kauai, the most susceptible to adverse impact from OSDS are the non-sewered parcels south of Lihue, Wailua and Kapaa, and Anahola. Smaller zones of significant impact are indicated by a coastal score of 5 surrounding the communities of Kilauea and Haʻena. Areas inland of the two-year TOT in Hanapepe to Poipu, and Nawiliwili and Wailua/Kapaa were annexed due to elevated ODGWN concentrations.

6.3.3 Maui

The number of OSDS estimated to be within the coastal setback zones for Maui was less than that of the previous two islands even though its length of coastline is significantly greater than that of Kauai. We estimate that over 5,400 OSDS, of which nearly 3,800 are estimated to be Class IV OSDS, were within the coastal setback zones (see Table 6-1). These OSDS discharge an estimated 4.9 mgd of effluent and about 620 and 190 kg/d of nitrogen and phosphorus, respectively. Figure 6-3 shows the coastal zones' risk severity scores for Maui. The areas that have the greatest potential to be negatively impacted by OSDS are: West Maui between Kaanapali and Lahaina; Central Maui from Waihee to Wailuku; East Maui from Kihei to Makena; and East Maui from the isthmus to the northernmost extent of Haleakala. The OSDS located outside of the two-year TOT that may contribute significant nutrient loads to the coast include those in upcountry Maui in the unsewered zones of Pukalani, Makawao, and nearby communities and the unsewered areas in the Wailuku to Waihee. Groundwater transport simulations show that the effluent discharge from the OSDS in these areas is capable of producing an ODGWN plume of greater than 1 mg/L that extends to the two-year TOT boundary. Elsewhere, the Maui coastline has little impact from OSDS effluent as indicted by the minimum risk score of 3 for the zone within 200 ft of the shoreline.

6.3.4 Molokai

Molokai has the least number of OSDS, which means it has the lowest length of potentially impacted shoreline of the islands assessed. We estimate that there were only about 1,300 OSDS within the coastal setback zones (see Table 6-1). The majority, 883, were Class IV OSDS. Most of the shoreline within the 200 ft setback zone has the minimum risk score of 3. The areas with a risk score of 5 are the shoreline north of Hoʻolehua and small sections on the southern coast east of Kaunakakai. The groundwater transport simulations indicate that the OSDS in Hoʻolehua and the surrounding areas, although outside of the two-year TOT setback, produce sufficient effluent to increase ODGWN concentrations to above 1 mg/L at the shoreline. The largest section of shoreline that may be potentially contaminated by OSDS effluent is north of Hoʻolehua. The remainder of the Molokai shoreline shows little potential impact from OSDS effluent.

Table 6-1. Inventory results for OSDS within the coastal zone setback areas

	OSDS	Class I	Class II	Class III	Class IV	Effluent (mgd)	Nitrogen Flux (kg/d)	Phosphorus Flux (kg/d)
Hawaii								
Shoreline two-year TOT	27,639	3,398	293	49	23,928	16.6	3,276	913
Shoreline 200 ft Setback	512	185	5	8	317	0.29	42	12
Kauai								
Shoreline two-year TOT	7,438	1,355	323	235	5,525	5.2	848	244
Shoreline 200 ft Setback	317	91	5	14	207	0.24	31	9
Maui								
Shoreline two-year TOT	5,401	1,373	194	39	3,795	3.85	618	187
Shoreline 200 ft Setback	148	33	6	8	101	0.14	26	8.4
Molokai								
Shoreline two-year TOT	1,308	391	31	3	883	0.83	123	35.9
Shoreline 200 ft Setback	160	41	1	0	118	0.092	15.9	4.50
Total								
Shoreline two-year TOT	41,786	6,517	841	326	34,131	26.5	4,865	1,380
Shoreline 200 ft Setback	1,137	350	17	30	743	0.76	115	34

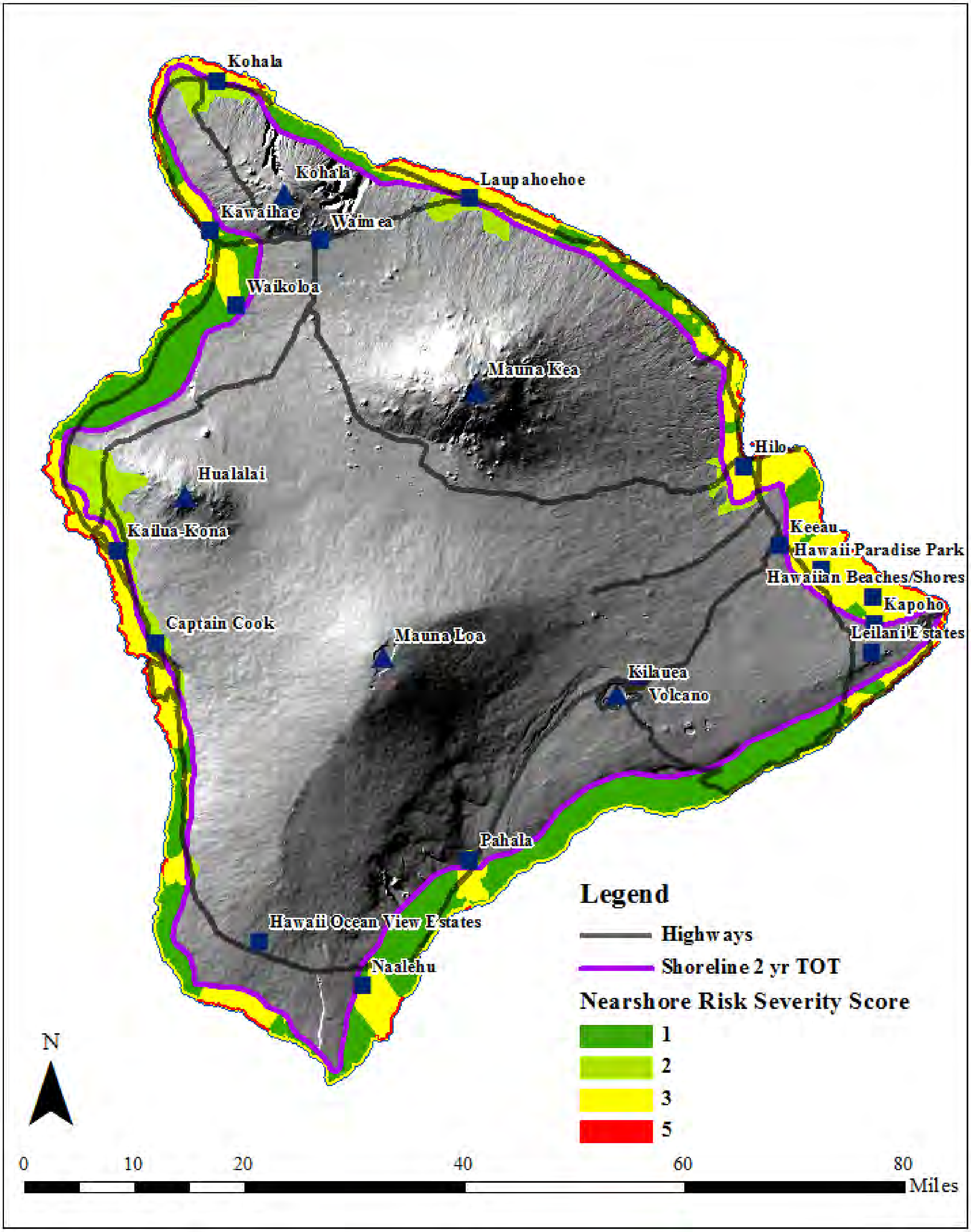

Figure 6-1. The coastal zone OSDS risk severity scores for Hawaii Island

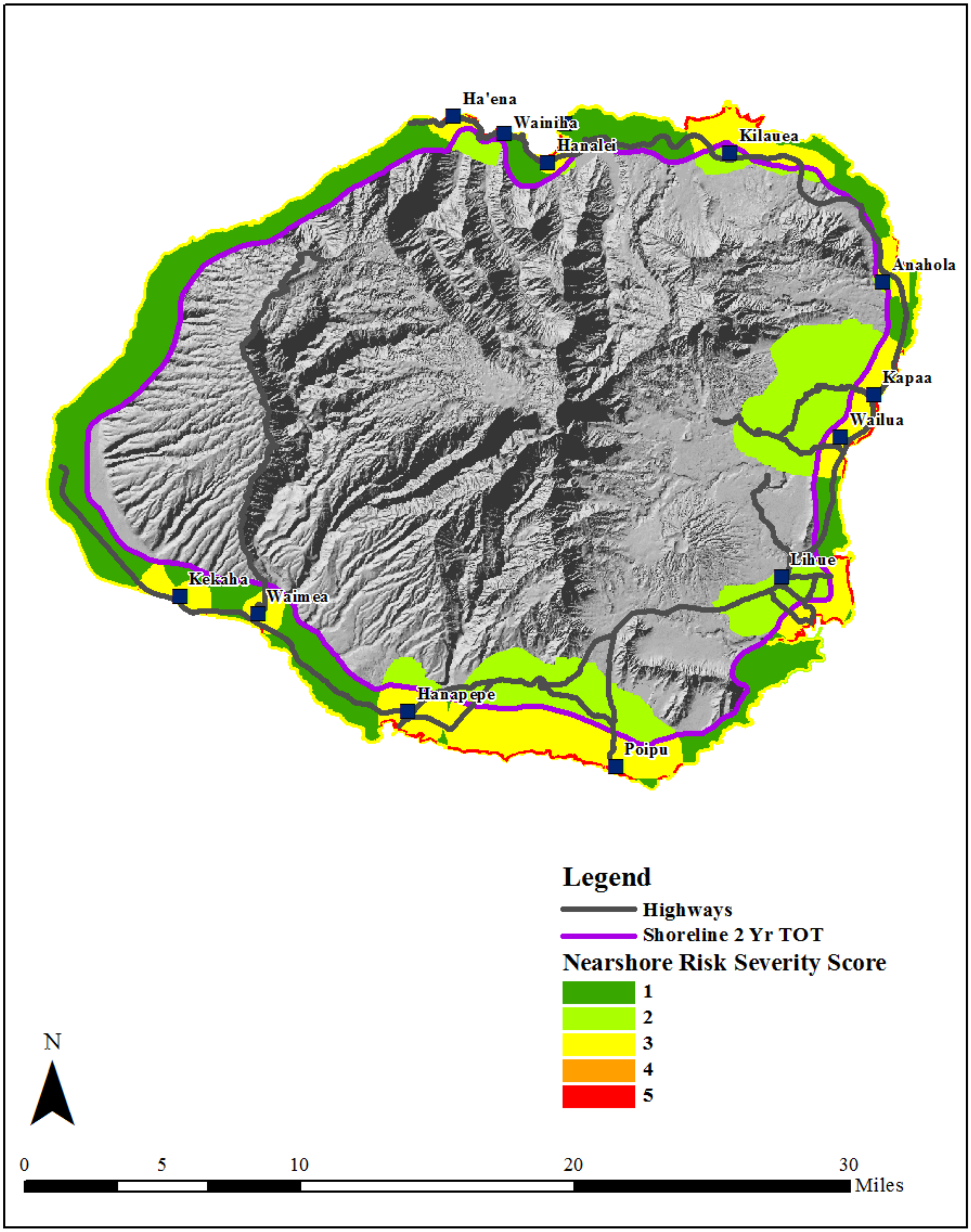

Figure 6-2. The coastal zone OSDS risk severity scores for Kauai

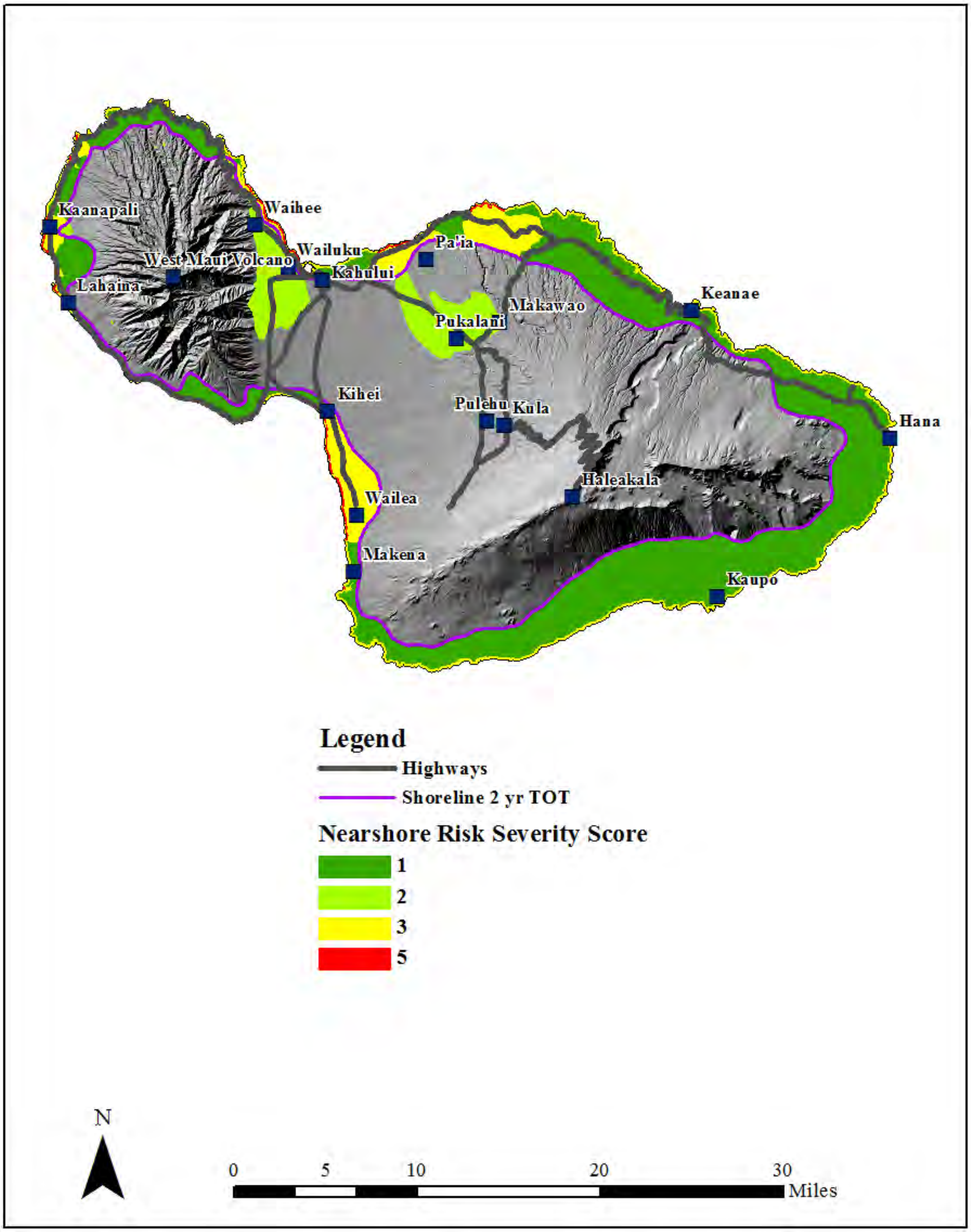

Figure 6-3. The coastal zone OSDS risk severity scores for Maui

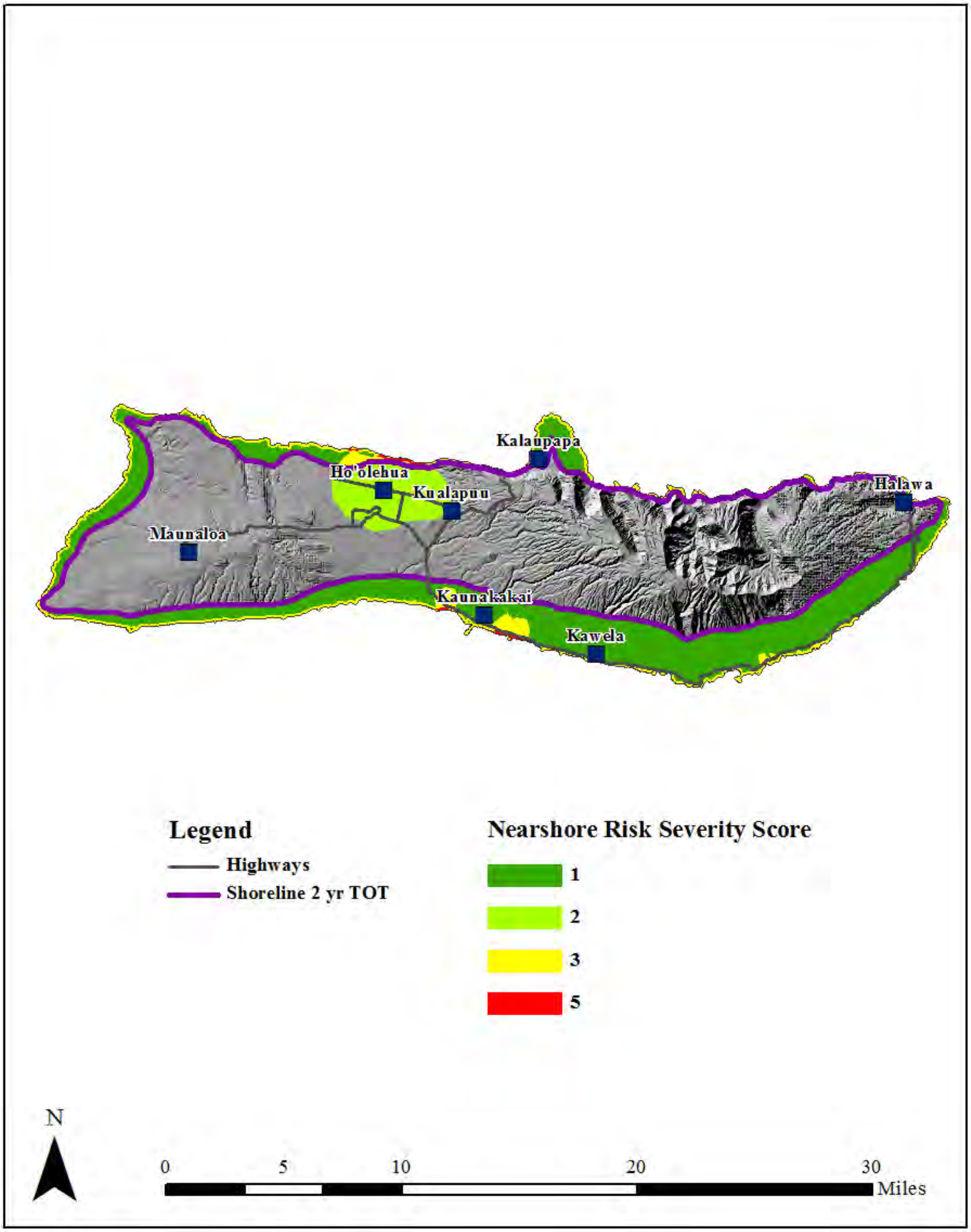

Figure 6-4. The coastal zone OSDS risk severity scores for Molokai

6.4 SUMMARY AND CONCLUSIONS

This study did an assessment of the environmental and health risks posed by OSDS to receptors in the coastal waters. The health risk is primarily through the introduction of pathogens into recreational coastal waters. Nutrient loading from OSDS effluent that may cause reef damaging algae growth is the principal environmental risk. The approach included delineating risk zones using a 200 ft fixed setback to consider those areas that had the greatest pathogen risk to coastal waters. The nutrient loading risk zones included a two-year TOT setback and adjacent areas where the modeled ODGWN concentration exceeds 1 mg/L. The zones of high ODGWN inland of but adjacent to the two-year TOT setback were included because the natural dilution of the OSDS nutrients is not sufficient to mitigate harm to the coastal waters.

The island of Kauai had the greatest proportion of its coastline evaluated as being at an increased OSDS risk potential. The areas of Wailua/Kapaa have a particularly high risk of negative impact from OSDS. Hawaii Island had greatest absolute length of coastline at elevated risk from OSDS. The long coastline has few urban centers with centralized wastewater collection systems. Consequently, the smaller communities near the coast must rely on OSDS for wastewater disposal. By contrast Molokai, another island with few urban centers with centralized wastewater collection, has very little of its coastline at elevated risk to OSDS impact. The low population density on this island results in low OSDS density and thus low impact to the coastal waters. On Maui the zones of highest risk included Waiehu/Wailuku and the area between Kahului and Paia where there is a heavy reliance on OSDS upgradient of the coast.

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SECTION 7. SOIL AND SEPTIC SITING SUITIBILITY

7.1 SOIL RISK FACTORS

Soil is the primary medium that remediates residential wastewater. Small pore sizes in many soils filter out pathogens; clay particles act as sorption sites for nitrate and other nutrients. Also, bacteria in the soil can convert contaminants such as reactive nitrogen species into inert nitrogen gas. However, for adequate treatment to occur the soil must be permeable enough to prevent saturated conditions, but also have a small enough pore throat diameter to filter pathogens from the effluent. As described in later sections, processes such as filtering characteristics of the soil and attenuation of pathogens are considered in the risk assessment of OSDS. The primary functions that soil performs are to prevent the migration of pathogens to surface water or to groundwater, retard and reduce contaminants, and provide a barrier against direct human contact with the effluent. Of these functions, the prevention of pathogen migrations is the most important. As described in previous sections, waterborne diseases, of which wastewater contamination is a significant cause, is a serious threat even in developed countries.

Soil grain size is an important factor in determining the pathogen retarding characteristics of soil. Fine-grained soils can prevent migration of larger pathogens such as the pathogenic protozoa by filtering. Sorption is also a significant remediation process in preventing the migration of smaller pathogens such as bacteria and viruses. Pathogens tend to cling to a solid surface especially when the intergranular pore space is not filled with water. During unsaturated flow the water forms a film on the soil grains, forcing close contact between the pathogens and the soil matrix, a condition that enhances the sorption process. When the soil is saturated, a larger intergranular pore space is available for pathogen reducing the effectiveness of sorption. Viruses are particularly troublesome because they are more persistent in the soil and, due to their small diameter, are not filtered by porous media. Sorption becomes the primary process that retards the migration of these pathogens (USEPA, 2002).

Studies have shown that soils are efficient in filtering pathogens and that the effective life span of bacteria and viruses in soil is less than six months (Yates, 1985; Tanimoto et al., 1968, Tasato and Dugan, 1980; and Oki et al., 1992). Studies also indicate that properly functioning soil-based treatment systems remove or attenuate most pathogens, and significantly reduce the nutrient load within infiltration distances (Field et al., 2007; Van Cuyk et al., 2001). Dawes and Goonetilleke (2003) showed that most of the improvement in effluent quality occurred in the first 3 ft of infiltration with very little improvement after that depth. Thus the soil characteristics of the first three feet below the leach field discharge point are critical in assessing the potential OSDS impact to the environment.

Soil is critical to pathogen removal. Viruses are particularly mobile once they reach the water table so the span of the unsaturated zone is very important in protecting against these pathogens. In the saturated zone, viruses have documented travel distances of up to 220 ft vertically and 1338 ft horizontally before dying or otherwise becoming benign (USEPA, 2002). In unsaturated soil, virus mobility and survivability are greatly reduced. A properly functioning soil treatment process of sufficient thickness can effectively prevent the migration of viruses and other pathogens to the water table. Two feet of fine sand effectively removed all viruses at eight monitored septic systems in Florida (USEPA, 2002; Anderson et al., 1991). A field experiment in Massachusetts showed that 99 percent of a tracer virus population was removed in the first one ft of soil and a 99.9 percent removal (10^3) in the first five feet of a sandy soil (Higgins et al., 2000).

7.2 NATIONAL RESOURCES CONSERVATION SERVICE (NRCS) SOILS DATABASE

The soil information source for this study is the online soils database of the Natural Resources Conservation Service (NRCS, 2011). The soils database includes a polygon shape file of the soil taxonomy and tables of the soil characteristics. The Access database in the soils database was set up to generate interpretive reports that provide the suitability of each soil map unit for various purposes. Included is the option to generate a sewage disposal report that provides two suitability assessments. The first assessment evaluates the soil suitability for septic tank absorption fields and the second evaluation is for siting sewage lagoons. This study used septic tank absorption field suitability assessments to evaluate the soil factors that influence the environmental and human health risk posed by OSDS. A printout of the NRCS Sewage Disposal Report for each island evaluated is available in Appendix A of this report. The soils database states that this interpretation only evaluates the soil between depths of 2 to 5 ft. A more complete description of the criteria used for this study is contained in the NRCS Soil Survey Manual (NRCS, 1993).

7.3 EVALUATING THE ROLE OF SOIL IN OSDS RISK

Soil is the primary treatment medium for OSDS effluent. Even the leachate from cesspools undergoes some natural remediation if a sufficient thickness of soil exists between the bottom of the cesspool and the water table. The suitability of soil for siting a septic system is one of the many soil properties evaluated by the NRCS in their soil surveys. This suitability is based on the degree of limitation of eight factors that control the treatment and infiltration of septic system leachate, and the ease of leach field installation. These factors are as follows:

- Depth to bedrock or cemented pan;
- Degree to which the soil is subject to flooding or ponding;
- Filtering characteristics of the soil;
- Rate of water infiltration through the soil;
- Rate of seepage out of the bottom layer of the soil;
- Topographic slope;
- Amount of subsidence the soil is likely to undergo after the leach field installation; and
- Fraction of rock fragments in the soil.

The NRCS soils database lists the degree of septic system siting limitation and shows the highest degree of limitation for any of the previously described limitation properties. The limitations fall into three categories: Very Limited; Somewhat Limited; or Not Limited. Figure 7-1 shows the distribution of the septic siting limitation severity for Hawaii Island. Nearly all of Hawaii Island was rated as Somewhat (7.8% land area) or Very Limited (74% of the land area). Only a very small area on the south tip of the island was evaluated as Not Limited (0.3% of the land area). This indicates that on Hawaii Island at least one of the soil properties was classified as Very Limited on 74% of the land area. Because the majority of the inhabitable land area was evaluated as having Very Limited ability to remediate OSDS effluent, the basic NRCS septic siting suitability limitation field does not provide sufficient data for planners and regulators. To provide more concise data about the limitations of soil to remediate OSDS effluent each of the primary soil properties or groups of properties described in Section 7.3 were mapped individually. The sum of the scores was also mapped to provide a ranked spatial distribution of limitations of the soil to remediate OSDS effluent.

Table 7-1 in this report lists the Interpretive Soil Properties from Table 6-1 in the Soil Survey Manual (NRCS, 1993) and provides the parameter values for the limitation severity class. The limitation severity scores assigned to the parameters ranged from 0 to 1.0, with 0 indicating no limitation and 1.0 indicating a severe limitation. For example, a depth to cemented pan or bedrock limitation was assigned a score of 0 for values greater than 6 ft (no limitation) and assigned a score of 1.0 for a value less than 3.3 ft (severe limitation). Some parameters had values that were equal to either 0.0 or 1.0. In this study these values were indicated on the maps as “No Limitation” or a “Severe Limitation”, respectively. For those parameters were evaluated with a sliding scale using values between and including 0.0 and 1.0 the severity limitation rating was divided into the following categories.

- A score of 0.0 was designated as “No Limitation”.
- Scores greater than 0.0 but less than or equal to 0.33 were designated “Slight Limitation”.
- Scores greater than 0.33 but less than or equal to 0.66 were designated as “Moderate Limitation”.
- Scores greater than 0.66 were designated as “Severe Limitation”.

This study mapped the distribution and limitation severity of the first four factors individually based on the NRCS soils database. The last four factors were lumped together and evaluated as a single factor that deals primarily with degree of difficulty encountered when installing a septic system. To evaluate the overall distribution of the soil limiting factors, the score of each of the four individual factors and the average of four installation factors were multiplied by 100. The expanded score of all five categories was then spatially averaged so that the maximum score possible would be 100. To attain a score of 100, all of the limiting factors must all be the most severe. Because not all of the categories were the most limiting together at a single location, the maximum scores resulted in a score of 45. The spatial averaging of the scores provided a qualitative ranking of the soil limitations for septic siting that varied from 0 to the maximum of 45. The limitation severity rating used is as follows:

- A score of zero was designated as “No Limitation”;
- Scores up to 15 and greater than zero were designated as “Slight Limitation”;
- Scores up to 30 and greater than 15 were designated as “Moderate Limitation”; and
- Scores greater than 30 were designated as “Severe Limitation”.

Table 7-1. Soil risk characteristics

Soil Property	Limitation Class			
	None	***Slight***	***Moderate***	***Severe***
Depth to Bedrock or Cemented Pan (ft)	>6	----	3.3-6	<3.3
Flooding or Ponding	None	Rare	Occasional	Frequent
Filtering Capacity (soil hydraulic conductivity (ft/d)	----	----	----	>12
Slow Water Movement (ft/d)	>12	4-12	1.2-4	<1.2
Soil Suitability Factors – Scored Together				
Seepage From Bottom Layer (ft/d)	>2.8	----	1.1-2.8	<1.1
Total Subsidence (ft)	<=2	----	----	>2
Slope (percent)	<8	----	8-15	>15
Percent Rock Fragments > 3”	<25	----	25-50	>50

7.4 RESULTS

This study produced maps showing the relative degree limitation of the soil properties to treat OSDS effluent. Maps were produced for each property or property group assessed as well as for the total septic siting soil limitation score (TSSLS). Table 7-2 summarizes the results of the limitation scoring for each island. The average score varied from a low 22 for Maui to a high of 27 for Kauai. On Kauai, low permeability is the soil property with the highest average limitation score of 67. The range of most scores for each property is quite large, spanning from 0 to 100 in most cases. The soil properties for flooding and ponding, and insufficient filtration are frequently the least limiting properties because Hawaii soils are generally dominated by silt with clay size particles with good drainage properties. When combined, these characteristics reduce the chance of flooding and ponding while allowing for sufficient filtration.

Table 7-2. The results of the soil remediation-limitation severity scoring by property and island

Island	Statistic	Low Permeability	Flooding or Ponding	Insufficient Filtration	Insufficient Depth to Rock	Other	Total
Hawaii	Minimum	0	0	0	0	0	0
	Average	36	2	14	42	30	24
	Maximum	100	50	100	100	75	55
	Standard Deviation	42.0	9.0	34.8	46.7	21.6	10.9
Kauai	Minimum	0	0	0	0	0	5
	Average	67	19	10	18	20	27
	Maximum	100	100	100	100	100	80
	Standard Deviation	42.5	37.2	29.6	38.4	17.1	11.6
Maui	Minimum	0	0	0	0	0	0
	Average	48	6	10	21	24	22
	Maximum	100	100	100	100	75	54
	Standard Deviation	44.7	18.2	29.9	38.8	21.8	10.6
Molokai	Minimum	0	0	0	0	0	0
	Average	58	11	8	20	18	23
	Maximum	100	100	100	100	75	46
	Standard Deviation	45.4	22.8	27.5	39.5	16.7	9.3

7.4.1 Hawaii

Hawaii Island is the youngest of the islands evaluated. The minimum, average, maximum, and standard deviation for limitation severity scores are included in Table 7-2, the spatial distribution of the limitation severity scores are mapped in Figures 7-2 through 7-6, and distribution of the septic siting limitation severity (the average of limitation severity scores) is shown in Figure 7-7. The soil survey for the island of Hawaii does not include the Hawaii Volcanoes National Park. Due to this lack of data, the limitation severity for the various soil factors was not mapped. However, a worst-case limitation score for this area for septic siting limitation severity could be assumed. The lavas in the Hawaii Volcanoes National Park would have very little OSDS remediation potential. For example, because the majority of this area consists of recent volcanics the depth to rock limitation, filtering capacity, and rock fragment limitations would be most severe. A worst-case assumption may not be appropriate for flooding and ponding, subsidence, slow water movement, and flow out of the bottom layer limitations. Because there is minimal development in the park the only areas of significant wastewater discharge will be the visitor's center, Volcano House, Kilauea Military Camp, and Hawaii Volcanoes Observatory.

The following is a brief description of the major soil limitation factors and distribution of their severity on the island of Hawaii. Figure 7-2 shows the distribution of the depth to rock limitation. Of the areas evaluated, all had either moderate to severe depth to rock limitation, which means that there is not a sufficient thickness of soil to adequately treat the wastewater effluent. This is only directly applicable to the Class I OSDS, however, because only these systems rely on soil treatment. From a practical perspective, the depth to rock is important to all systems because the soil between Class IV OSDS (cesspools) and the rock will treat the effluent (Field et al., 2007).

The Island of Hawaii is the youngest of the island group with moderate topographic relief, and shallow and porous soils. The most limiting soil property for remediation of OSDS effluent is the thin soil cover, as shown in Figure 7-2. The thin soil minimizes the occurrence of flooding and ponding (Figure 7-3). Flooding and ponding only pose severe limitations to OSDS siting in areas near the saddles between the major volcanoes such as Mauna Kea and Mauna Loa, Mauna Loa and Kohala, and small patches on the central portion of the West Hawaii coastline.

If the permeability of the soil is too low the downward percolation of the effluent is not sufficient to keep up with the effluent discharge rate. Figure 7-4 shows that slow soil percolation is a severely limiting property for much of northeast Hawaii and the southwest slope of Mauna Loa. Elsewhere this property is assigned a ranking of "moderate limitation". Figure 7-5 shows that the ability of the soil to provide proper filtration is sufficient throughout much of Hawaii Island. The limitation distribution of the grouped soil properties (seepage from the bottom layer, total subsidence, excessive slope, and percent of rock fragments) is generally less severe on the slopes of the Mauna Kea and Kohala Volcanoes. The group property limitation for the younger volcanoes (Hualalai, Mauna Loa, and Kilauea) is predominantly moderate to severe (Figure 7-6). The septic siting limitation severity for Hawaii Island when all of the pertinent soil properties are considered was generally moderate (Figure 7-7). The soil siting limitation score was mapped to the OSDS and became part of OSDS risk ranking evaluation for each system.

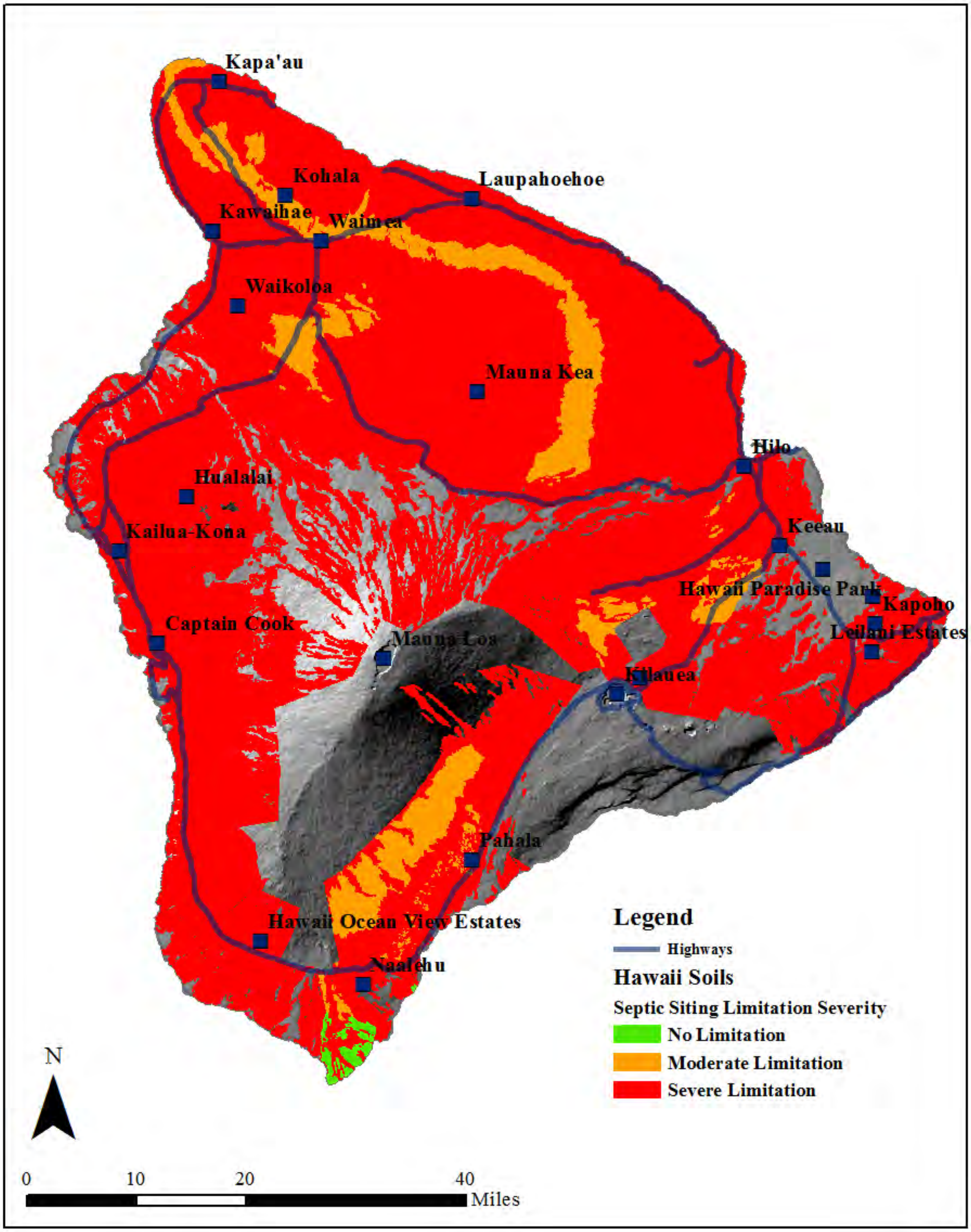

Figure 7-1. The severity of soil property limitations for Hawaii Island based on the dominant limiting property

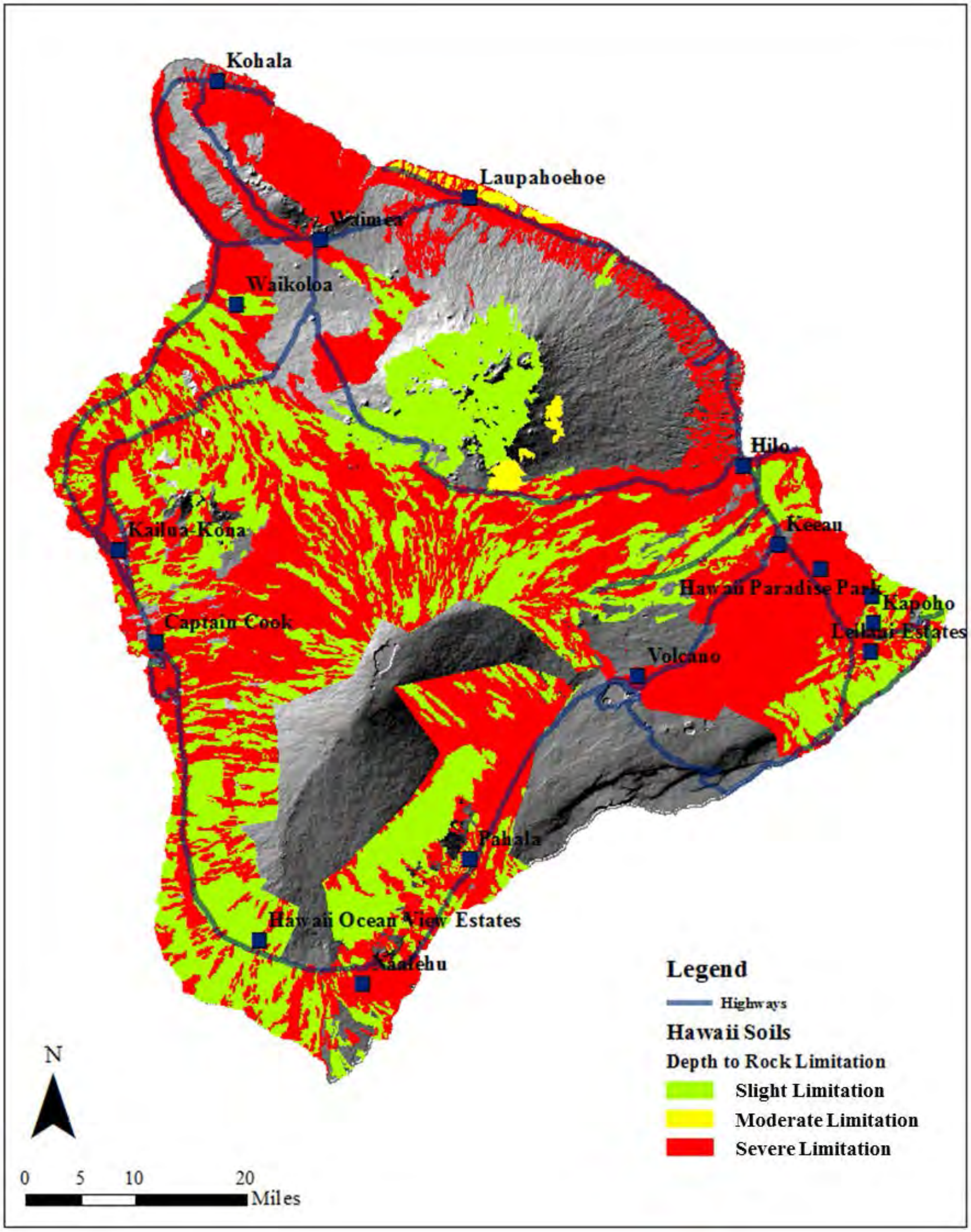

Figure 7-2. The severity distribution of the depth to rock limitation on Hawaii Island

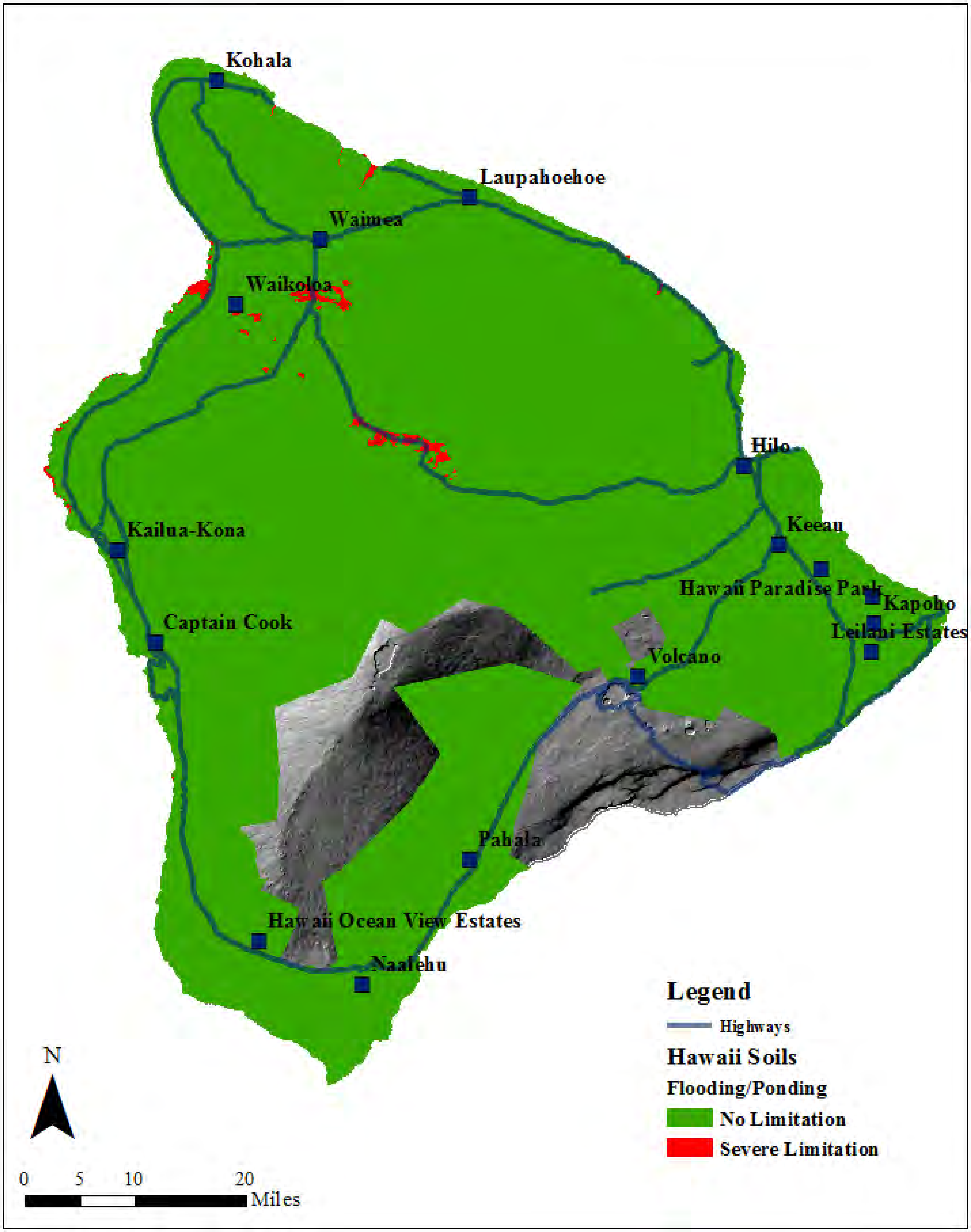

Figure 7-3. This distribution and severity of the flooding and ponding limitation on Hawaii Island

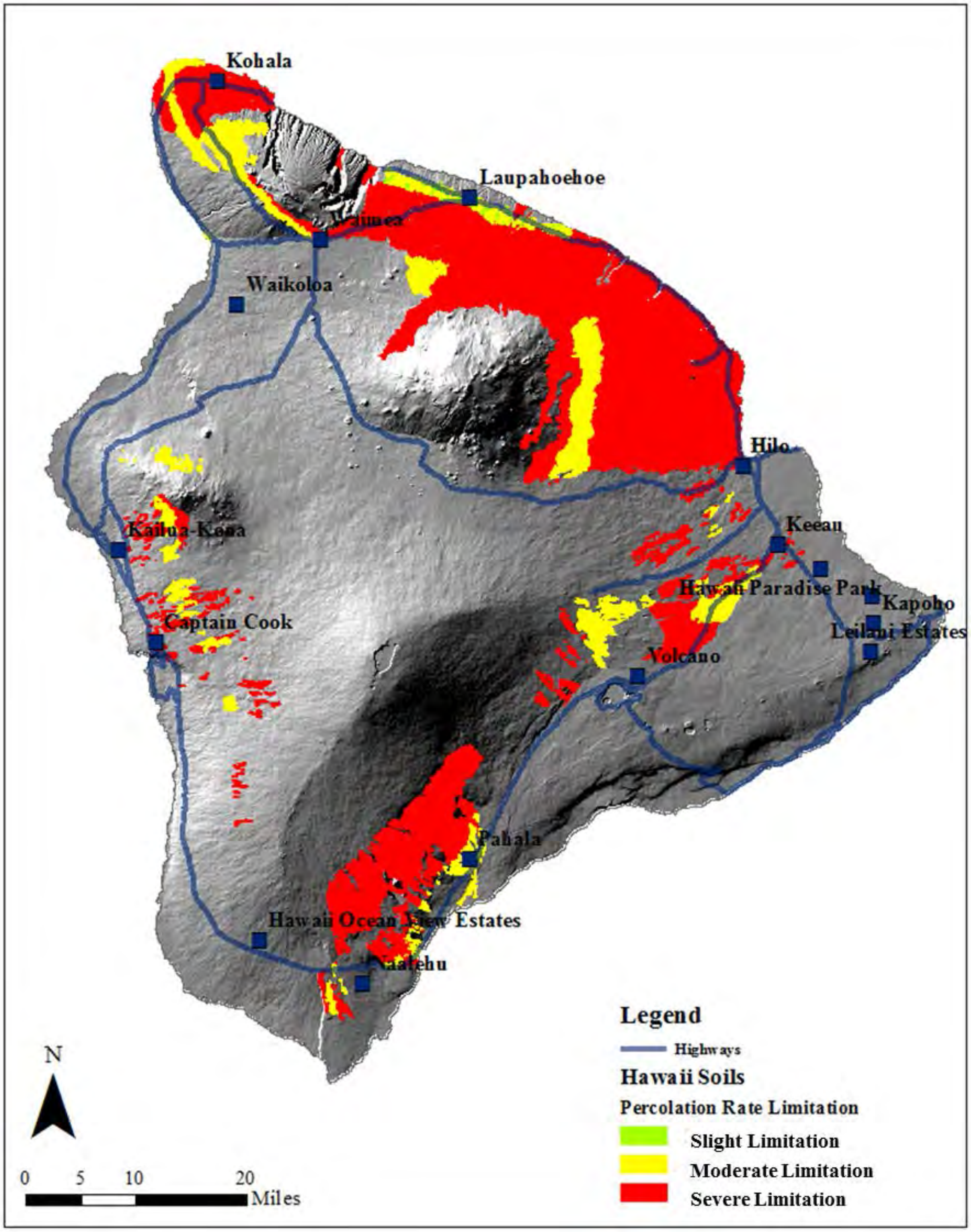

Figure 7-4. The distribution and severity low permeability limitation on Hawaii Island

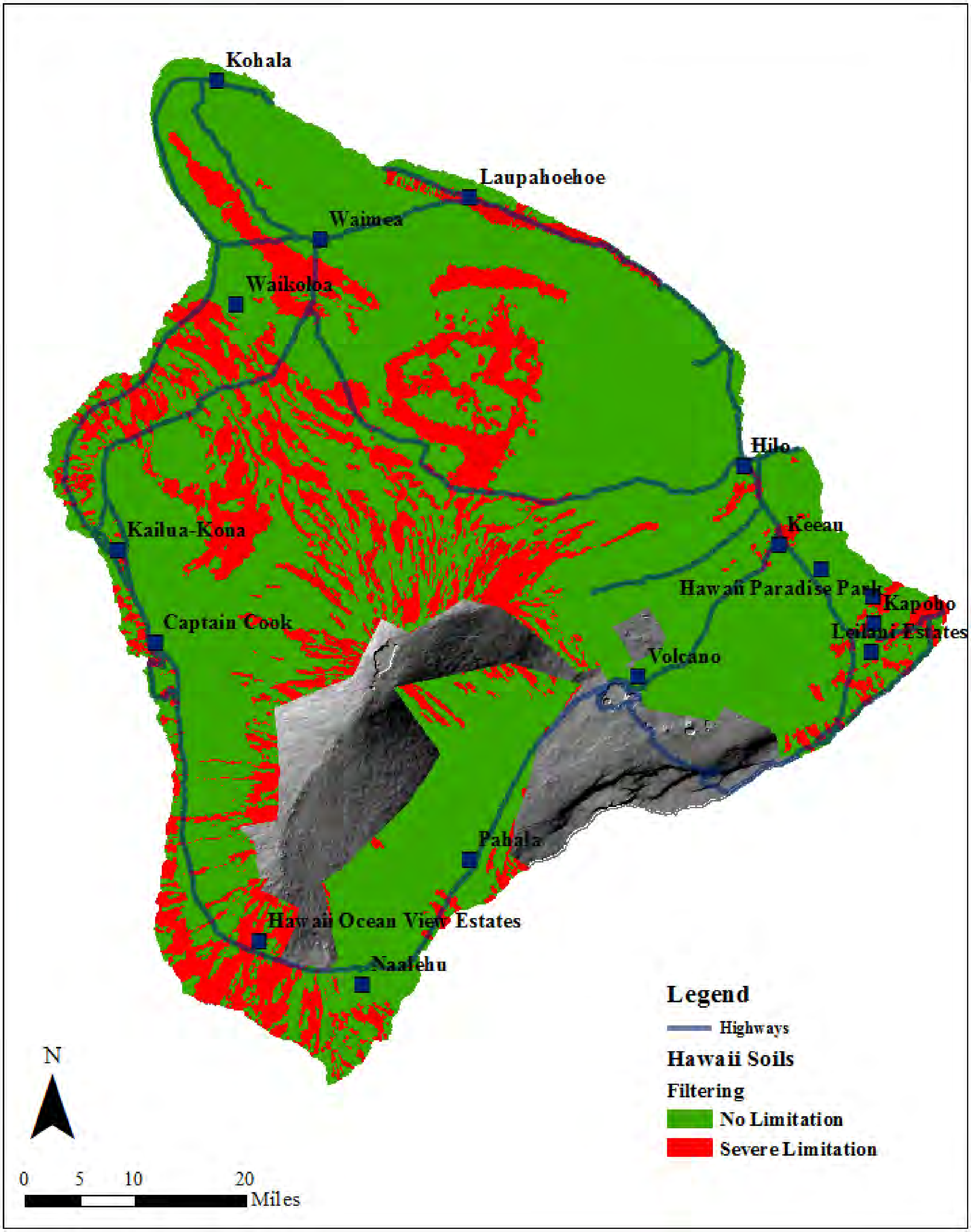

Figure 7-5. The distribution and severity of the soil filtration limitation on Hawaii Island

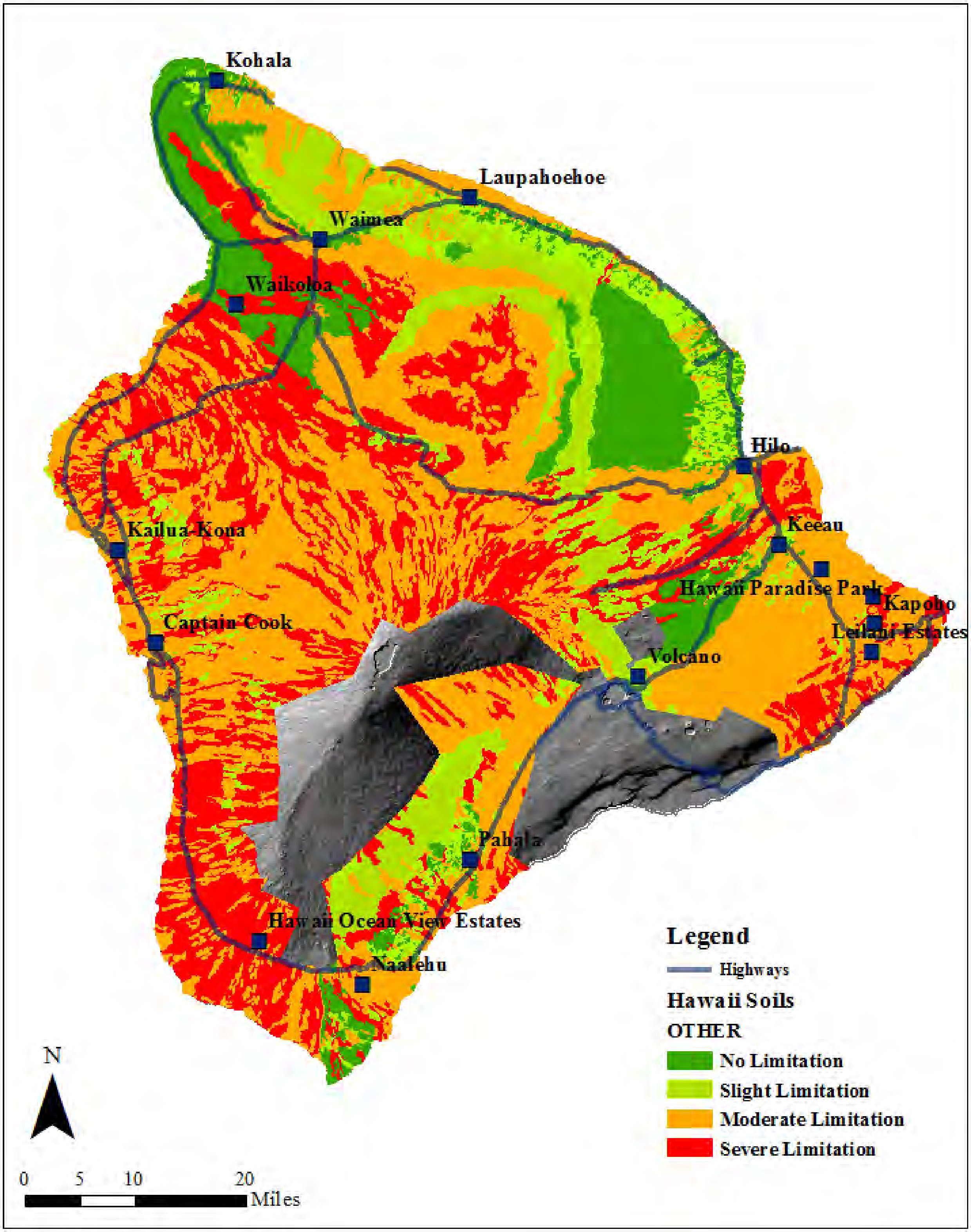

Figure 7-6. The composite of limitations that include seepage from the bottom layer, total subsidence, excessive slope, and the percent of rock fragments on Hawaii Island

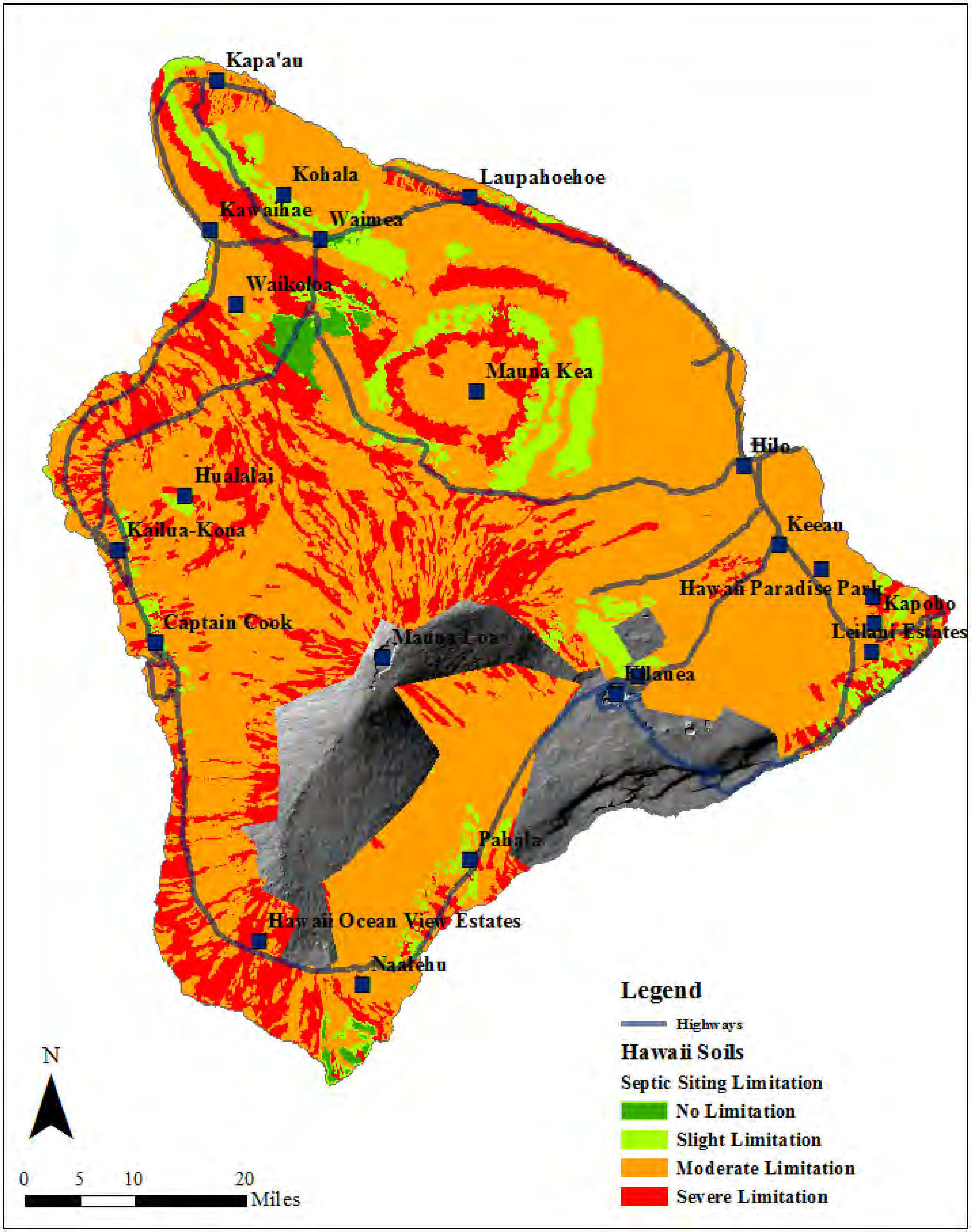

Figure 7-7. The distribution of the TSSSLS on Hawaii Island

7.4.2 Kauai

Kauai is the oldest island evaluated by this study and, therefore, has had more time for a thicker soil cover to develop. The thicker soil results in a smaller fraction of the land area being evaluated as having a severe depth to rock limitation when compared to Hawaii Island (see Figure 7-8). With regard to the other soil parameters, evaluated flooding and ponding are the least limiting while low permeability is the most limiting. The flooding and ponding are evaluated as a moderate to severe limitation for the Mana Plain and the flood plains of the major streams on Kauai; elsewhere this soil parameter is not limiting (Figure 7-9). The slow water percolation limitation is evaluated as moderate to severe for much of the island except for the interior highlands, the coastal areas of the Mana Plain, and Poipu (Figure 7-10). The filtration capability of the soil is sufficient throughout all of Kauai except for small coastal areas and very small areas of the island interior (Figure 7-11). The limitation distribution of the grouped soil properties (seepage from the bottom layer, total subsidence, excessive slope, and percent of rock fragments) is generally not or only slightly limiting except in the interior and northern highlands. When all of the properties are considered, 43 percent of Kauai's land area is evaluated as having a moderate limitation for septic siting suitability and 54 percent is evaluated as severely limiting.

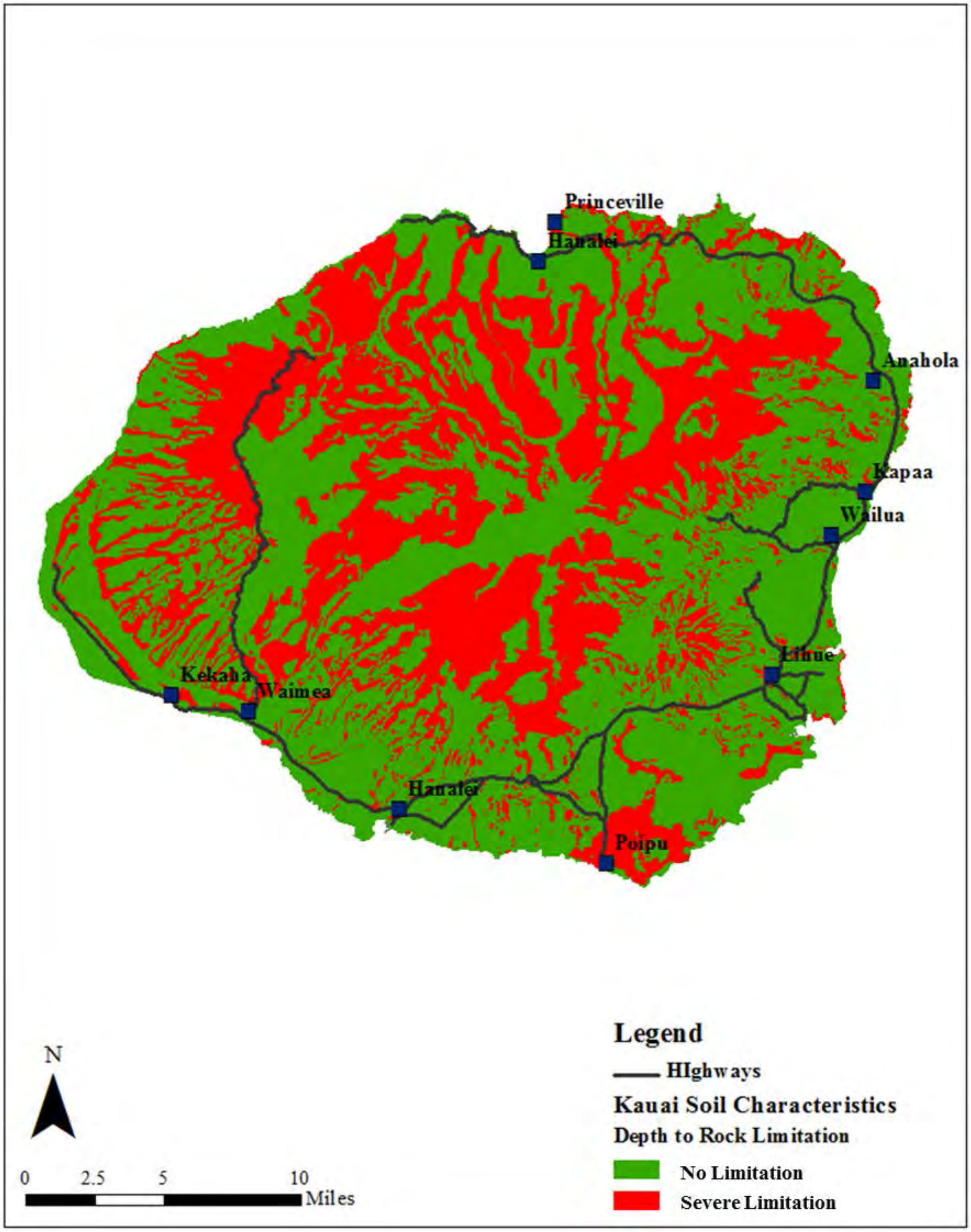

Figure 7-8. The severity distribution of the depth to rock limitation on Kauai

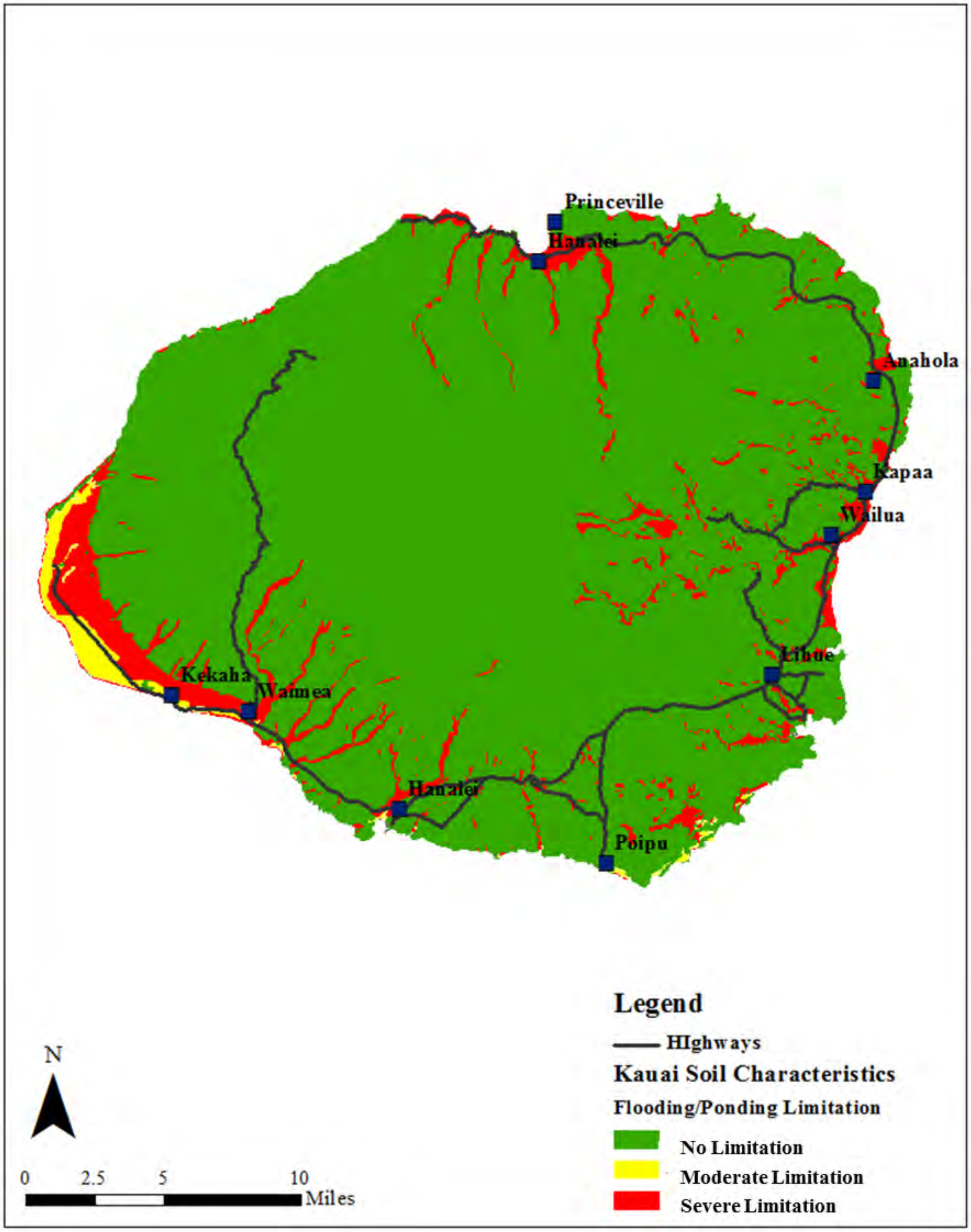

Figure 7-9. This distribution and severity of the flooding and ponding limitation on Kauai

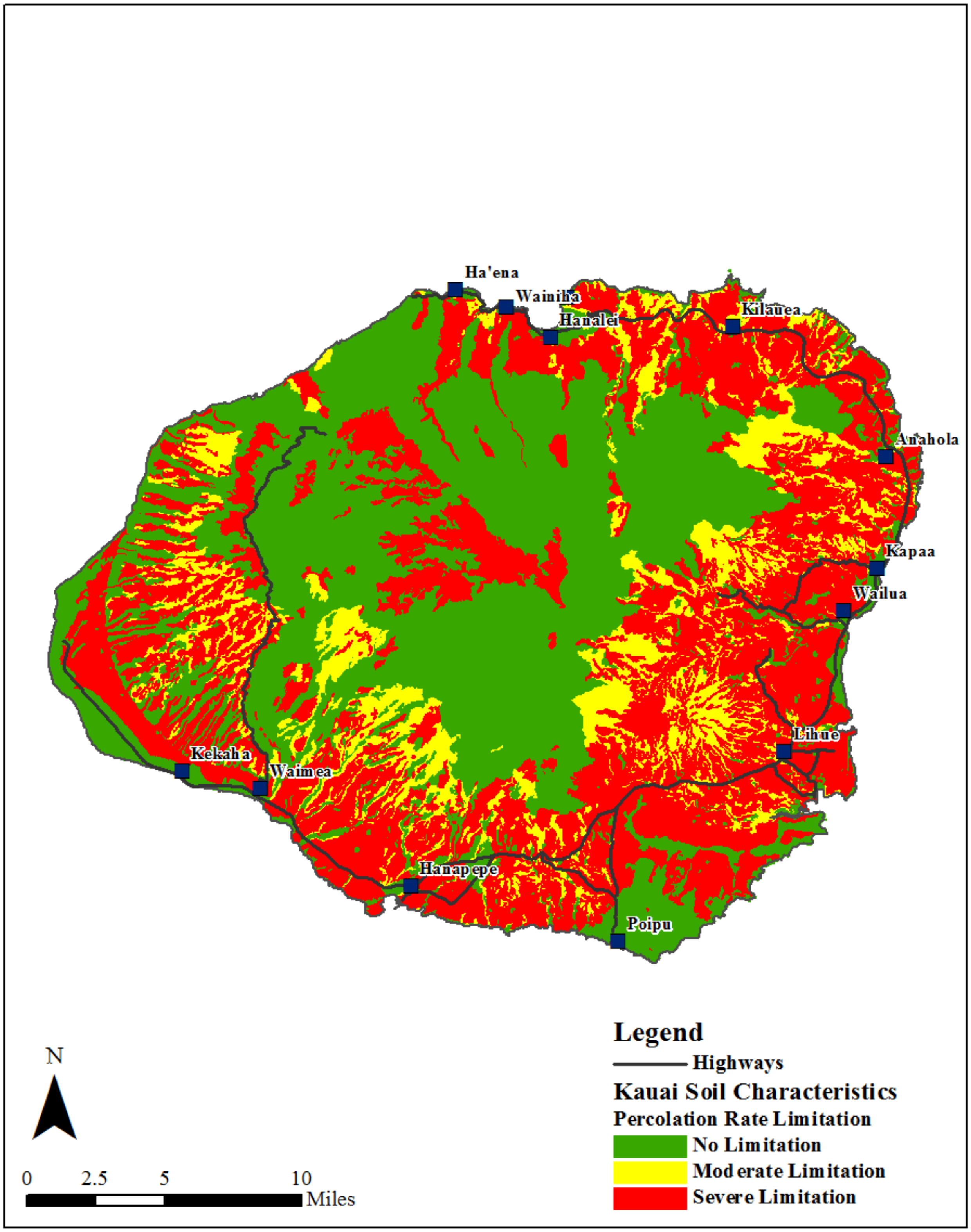

Figure 7-10. The distribution and severity low permeability limitation on Kauai

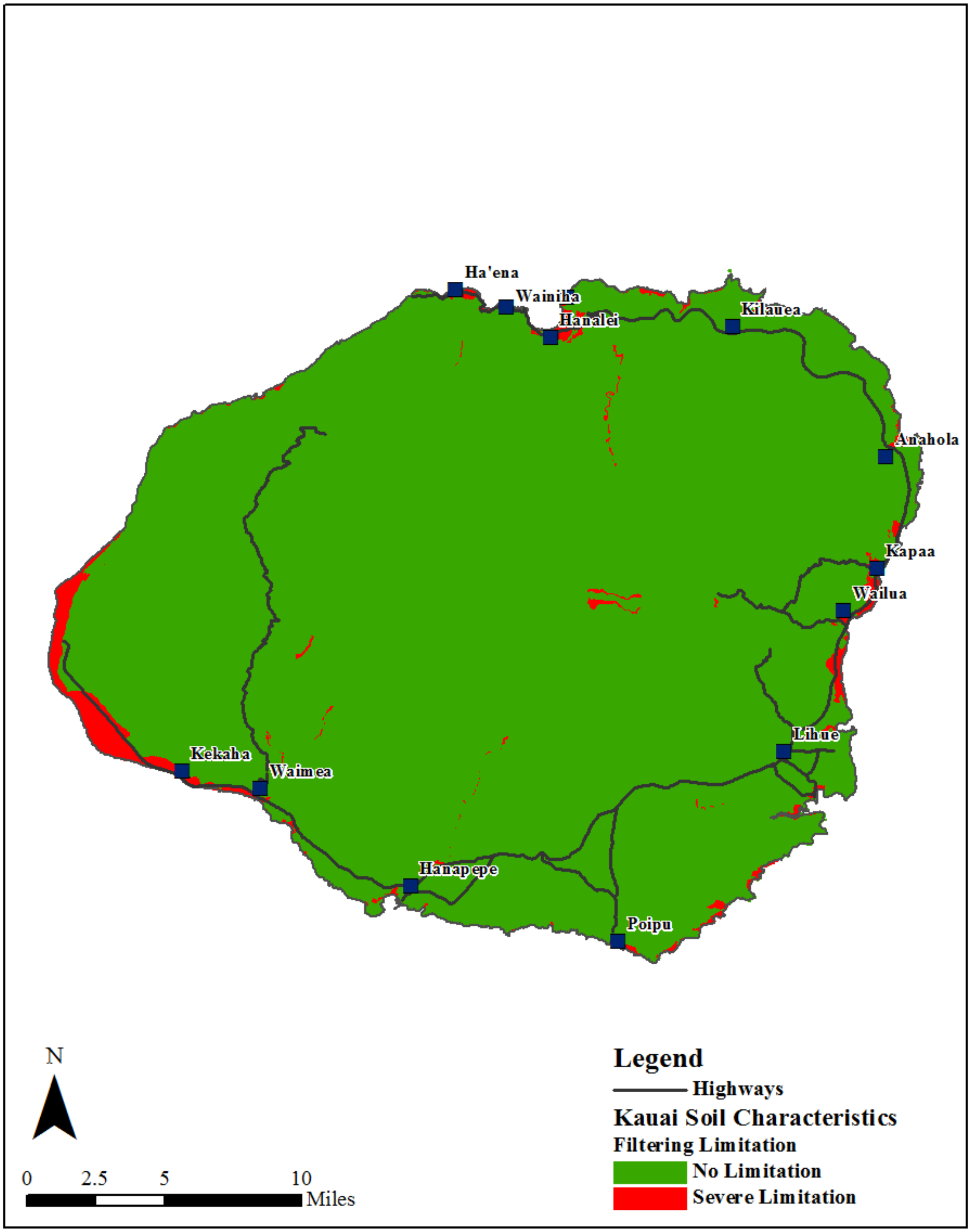

Figure 7-11. The distribution and severity of the soil filtration limitation on Kauai

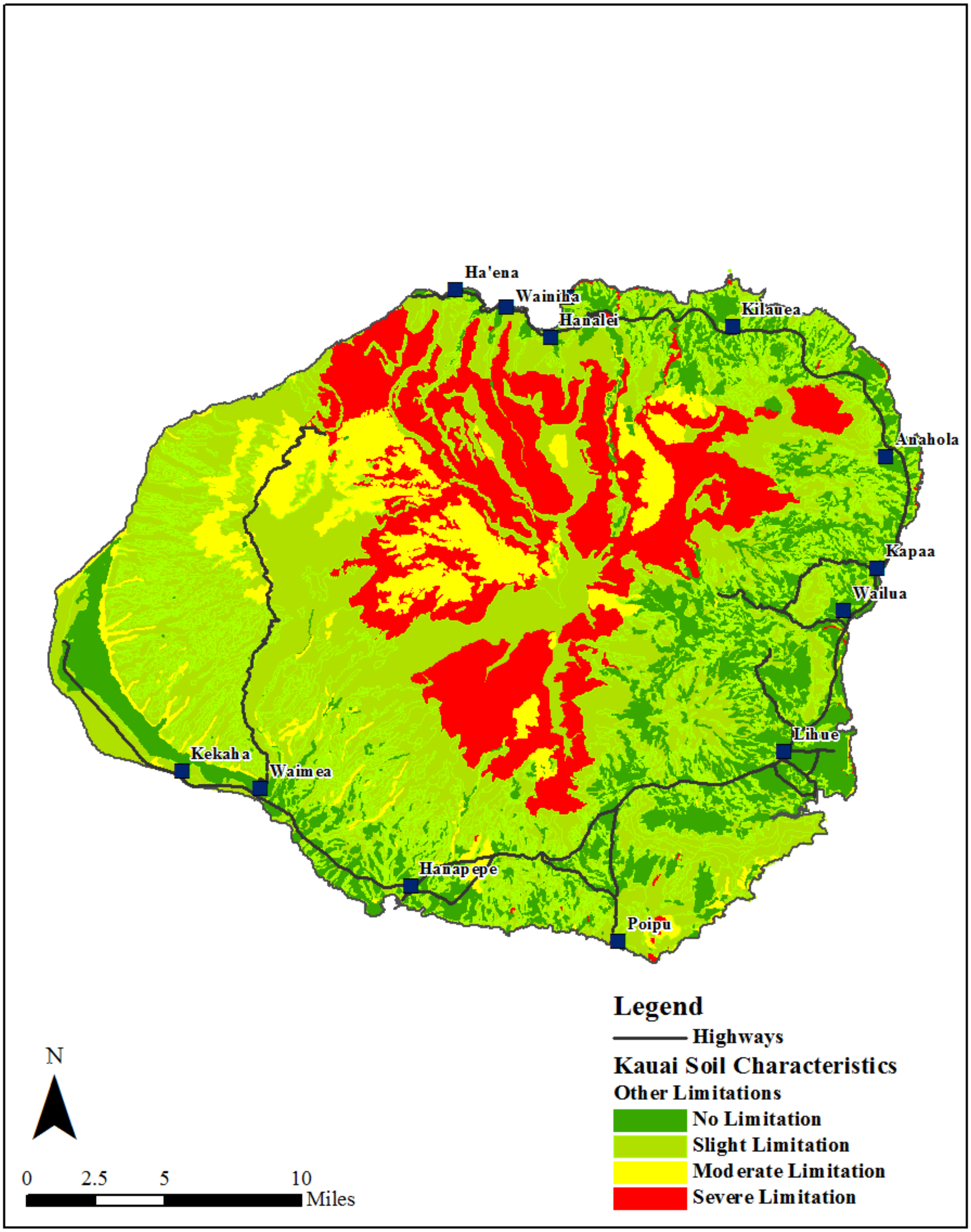

Figure 7-12. The composite of limitations that include seepage from the bottom layer, total subsidence, excessive slope, and the percent of rock fragments on Kauai

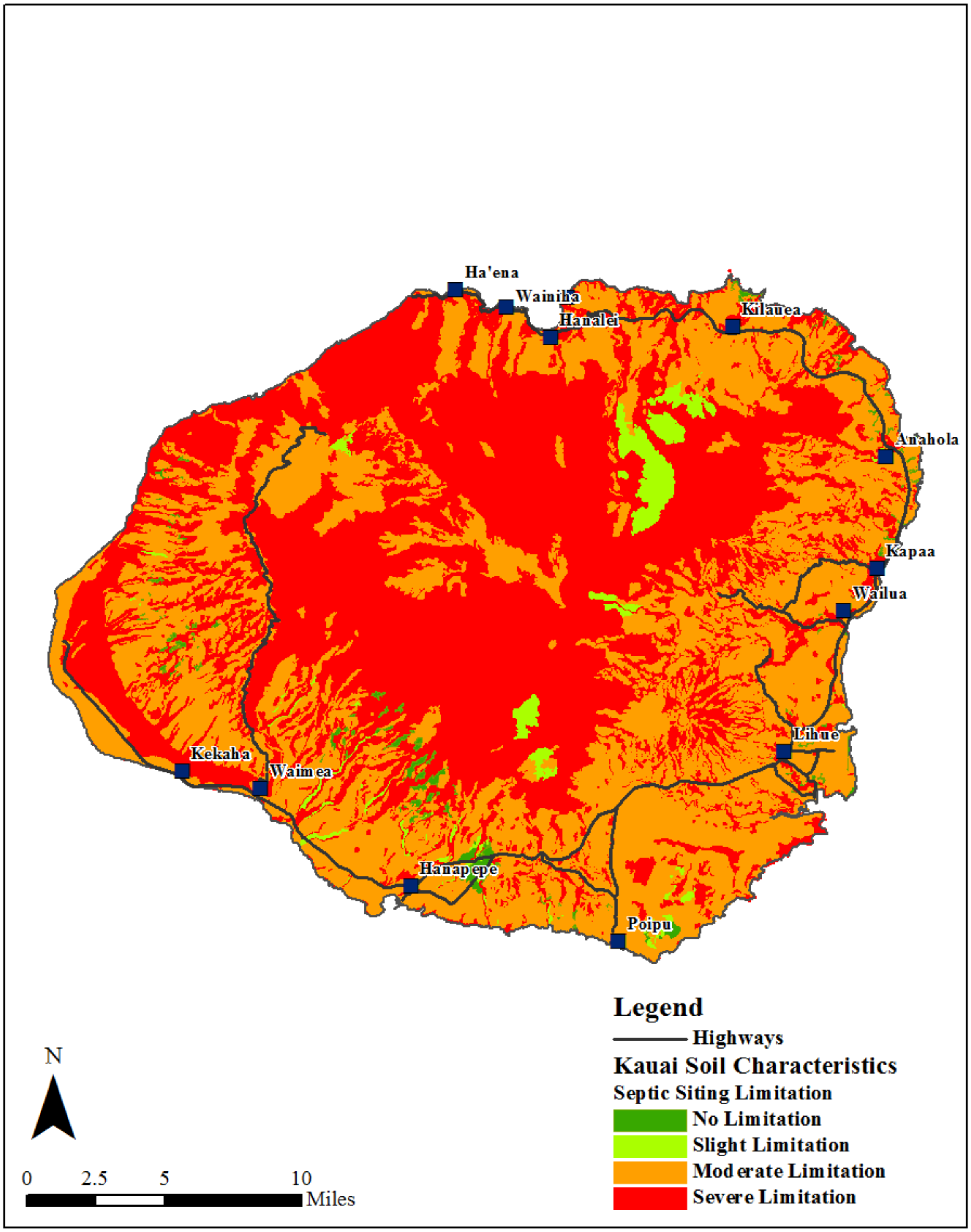

Figure 7-13. The distribution TSSSLS on Kauai

7.4.3 Maui

The soil properties on Maui are generally more favorable for OSDS septic siting suitability than on Hawaii Island and Kauai. The average septic siting suitability score of 22 (the evenly weighted average of the soil property scores) was the lowest score of all the islands studied (see Table 7-1). Taking the soil parameter limitations individually, Maui's scores generally fell in the mid-range, ranking second or third. Figures 7-14 through 7-18 show the limitation severity of the soil properties that remediate OSDS effluent. The depth to rock property limitation is moderate to severe throughout most of West Maui and over a significant fraction of East Maui (Figure 7-14). Flooding and ponding are limiting properties in South-Central Maui and a few locations elsewhere (Figure 7-15). Slow water percolation is a very limiting property for most of Upcountry Maui on the northwest slope of Haleakala and on the peripheral slopes of West Maui (Figure 7-16). Inadequate filtration is only limiting on the south slopes of Haleakala and in the Hana region of East Maui (Figure 7-17). The composite limitation severity rating for seepage from the bottom layer, total subsidence, excessive slope, and percent of rock fragments is shown in Figure 7-18. Excessive slope and insufficient seepage from the bottom layer are the soil properties that resulted in moderate to severe limitation rating for the combined factors.

As stated above, the overall limitation rating for Maui is the lowest of the islands evaluated. Figure 7-19 shows the distribution of the evenly weighted average of the five limitation categories of soil parameters used to evaluate the soils ability to remediate OSDS effluent. A shallow depth to rock (Figure 7-14) and slow water percolation (Figure 7-17) are the soil properties that resulted in moderate to severe limitations for septic siting suitability (Figure 7-19). The limitation severity for most of West Maui is rated either moderate or severe. Central Maui and most of the eastern slopes of Haleakala are rated as having a slight limitation. However, the populated regions on the east slopes of Haleakala are evaluated as having a severe limitation.

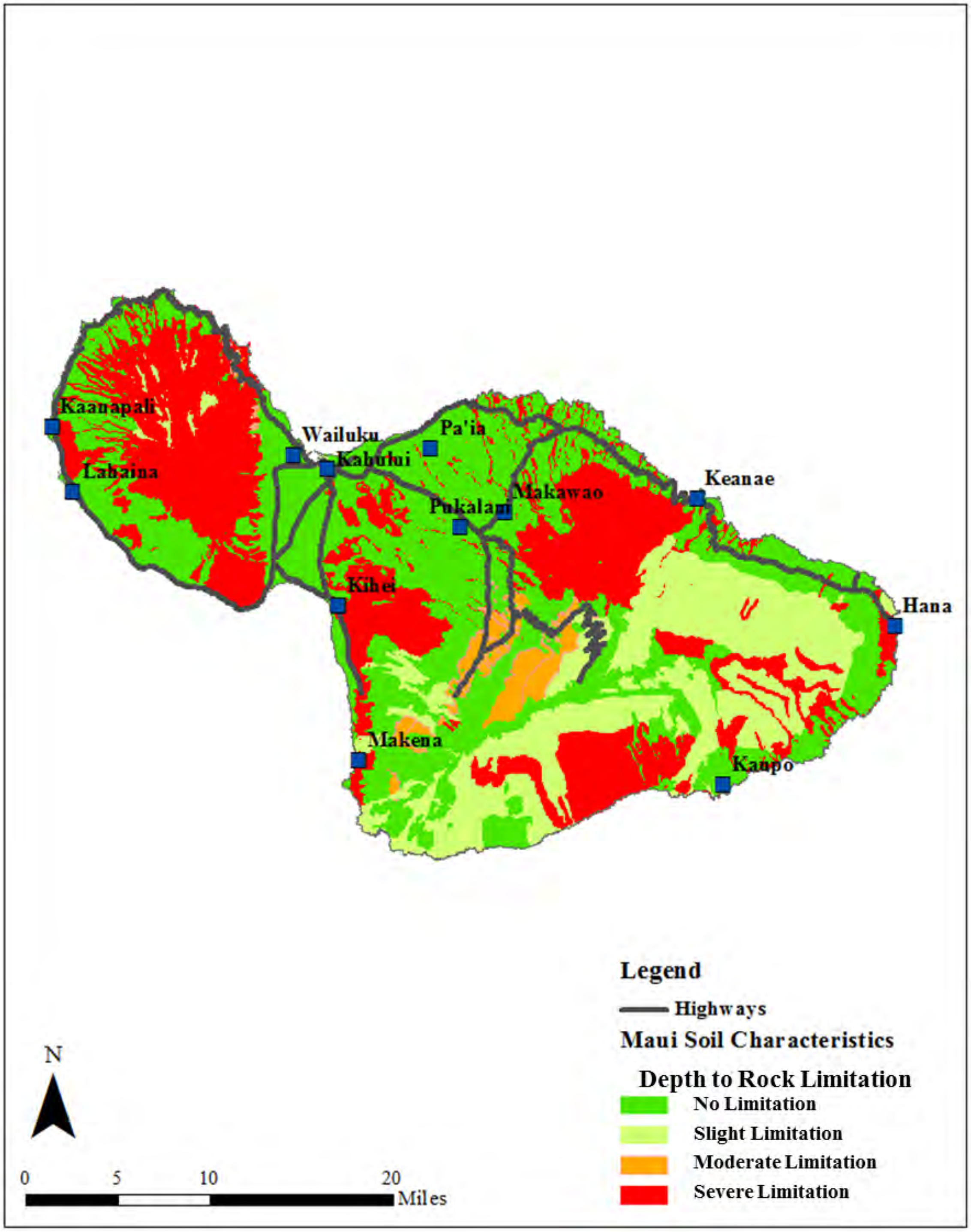

Figure 7-14. The severity distribution of the depth to rock limitation on Maui

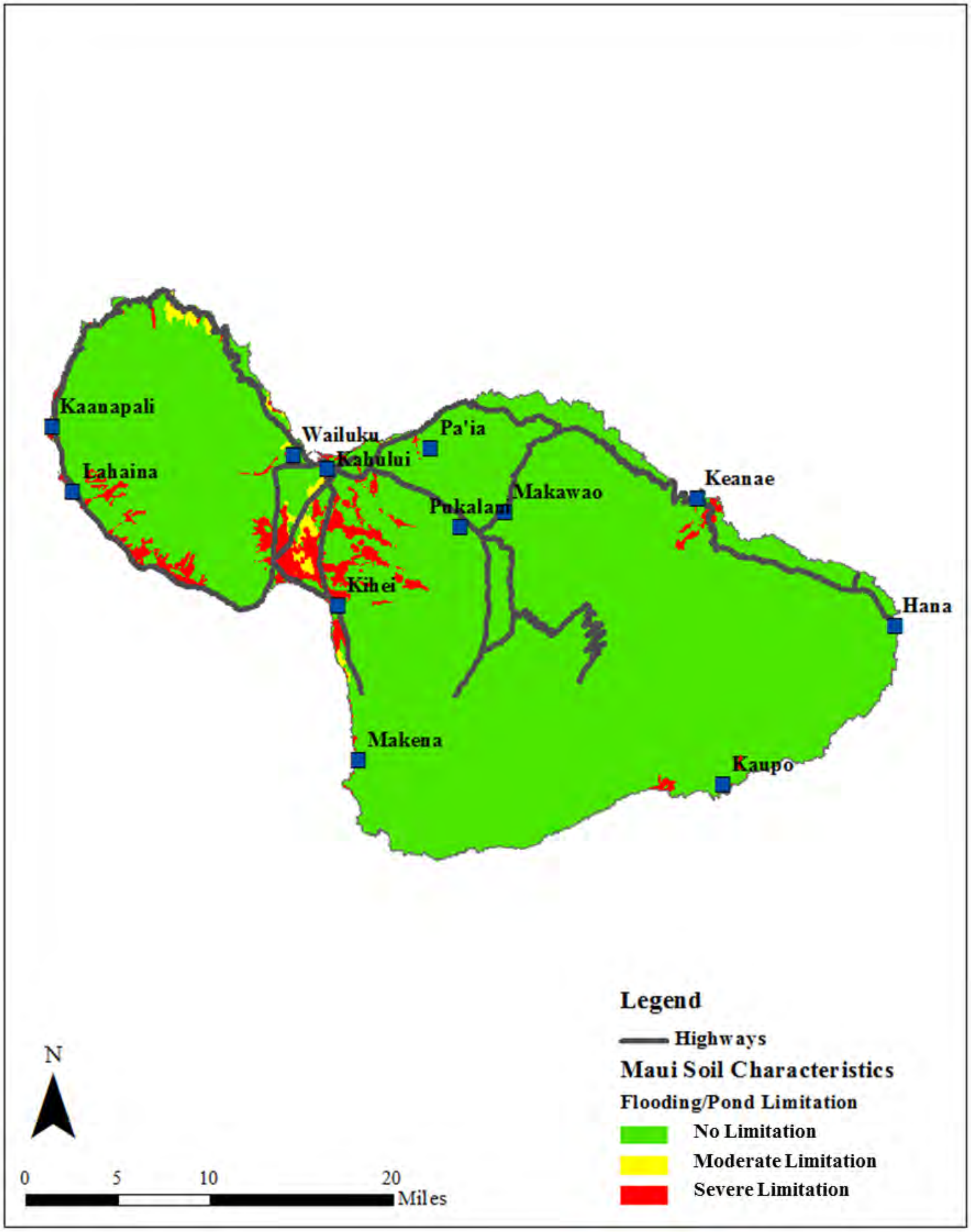

Figure 7-15. This distribution and severity of the flooding and ponding limitation on Maui

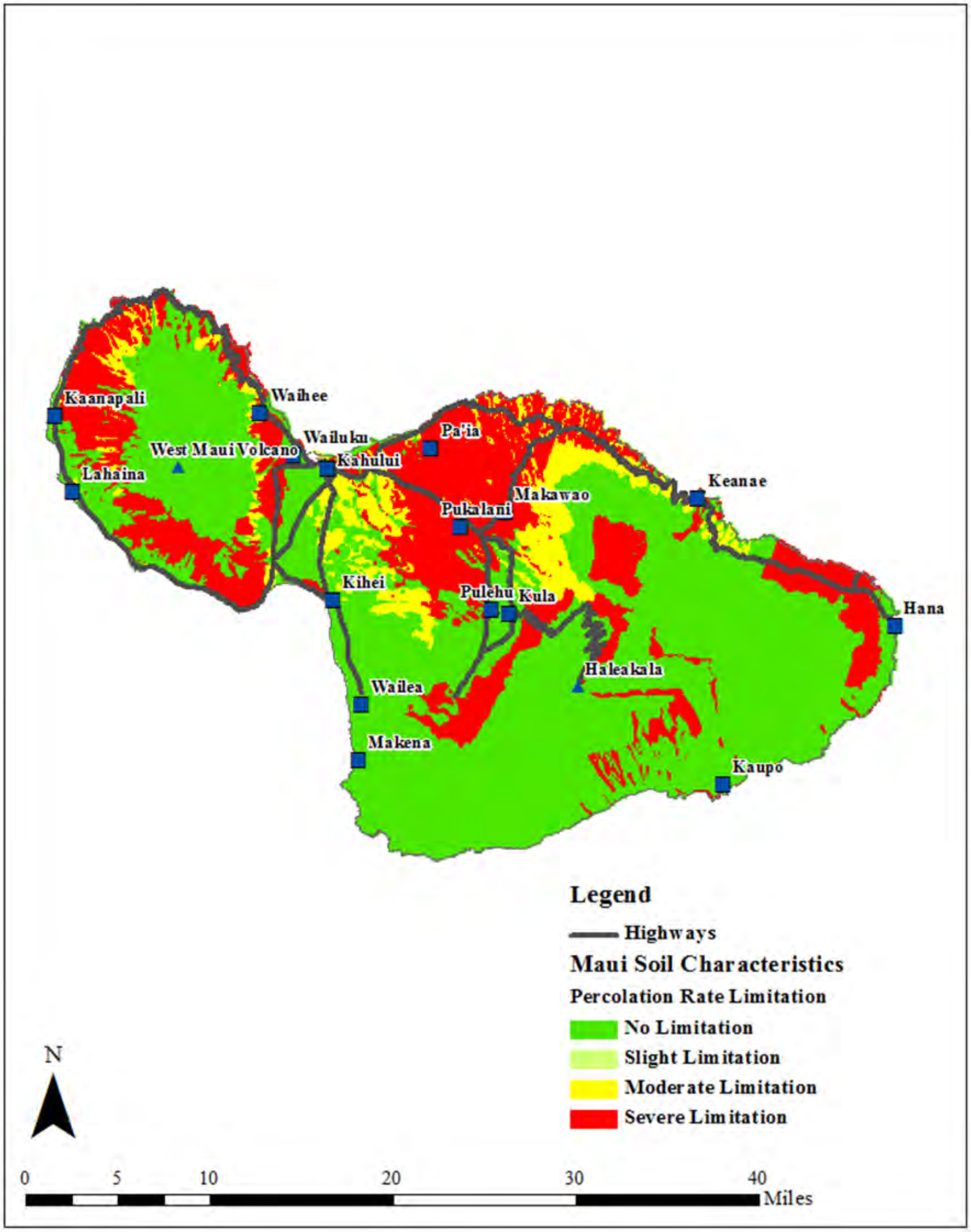

Figure 7-16. The distribution and severity low permeability limitation on Maui

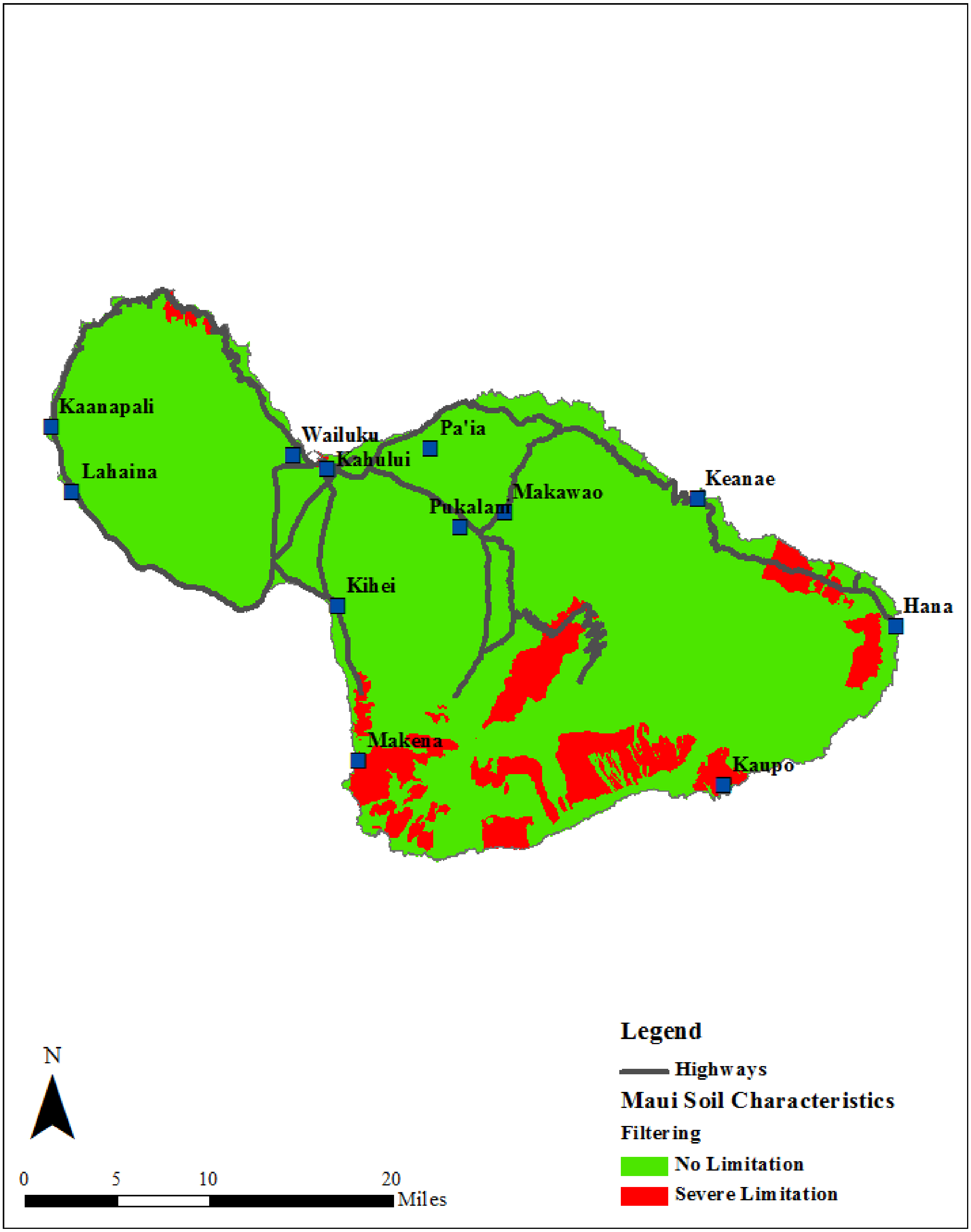

Figure 7-17. The distribution and severity of the soil filtration limitation on Maui

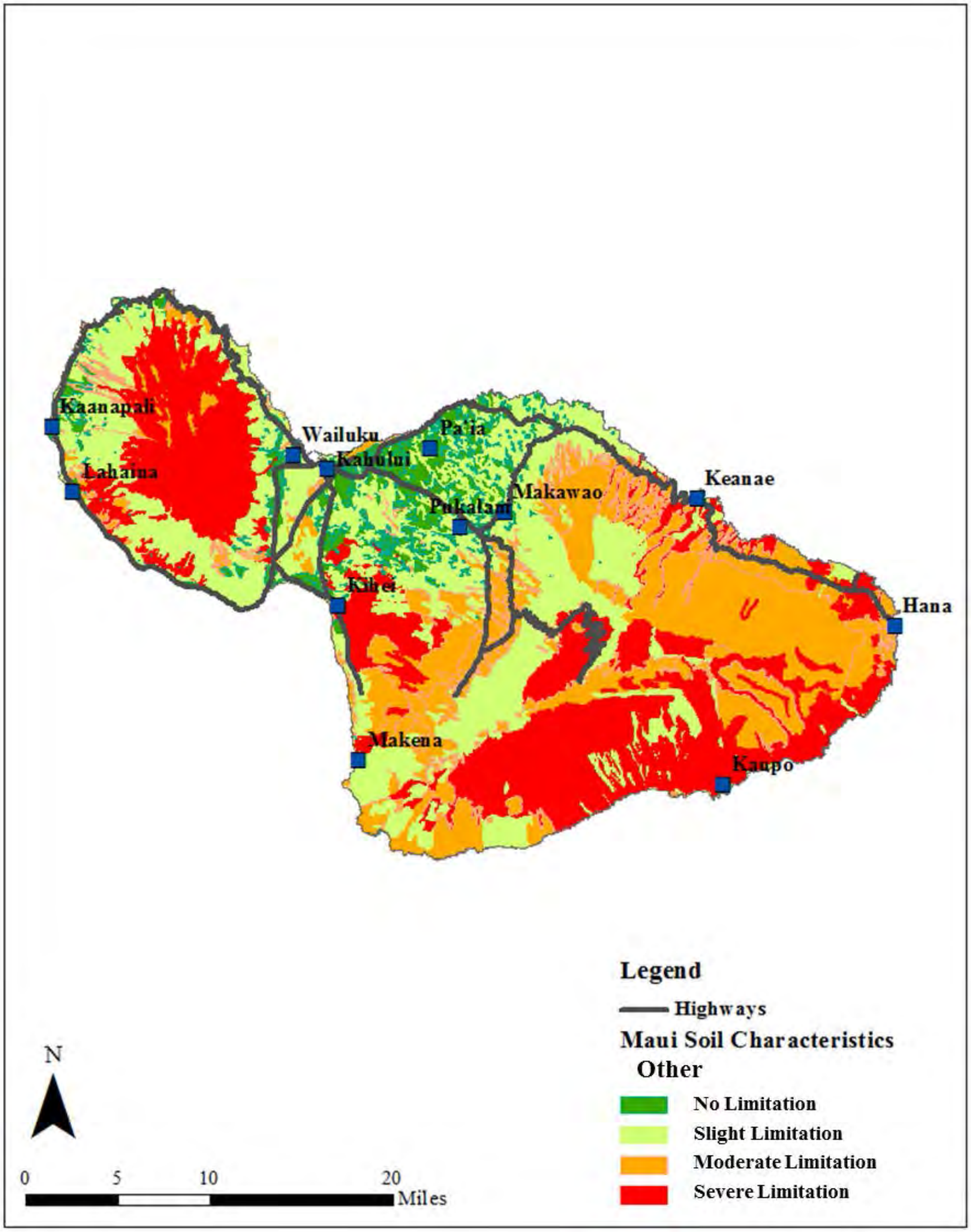

Figure 7-18. The composite of limitations that include seepage from the bottom layer, total subsidence, excessive slope, and the percent of rock fragments on Maui

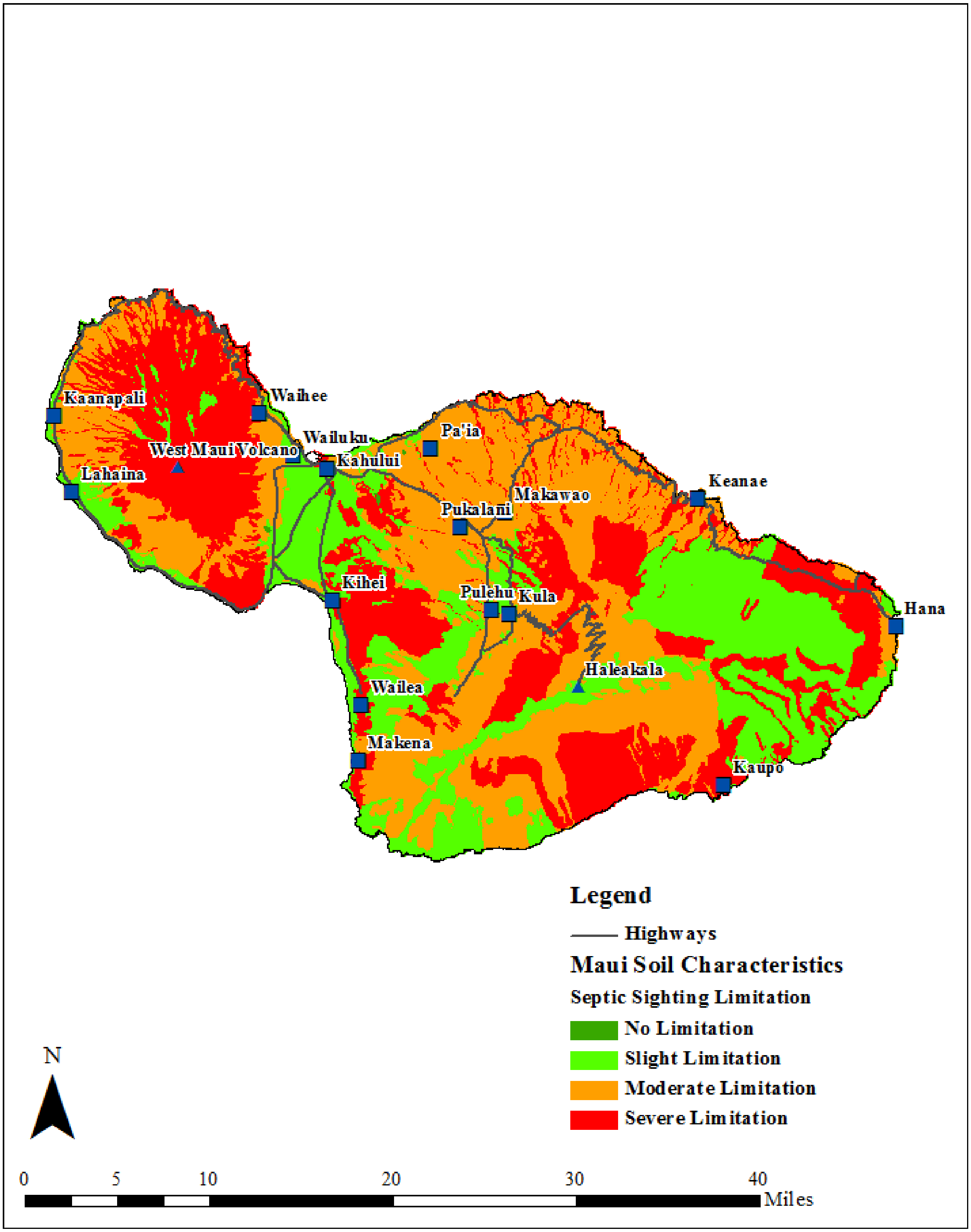

Figure 7-19. The distribution of the TSSSLS on Maui

7.4.4 Molokai

The overall suitability of Molokai's soils siting septic systems is very close to that of Maui when all of the soil properties were considered. The total septic siting limitation score was 23, compared to 22 for Maui and 24 for Hawaii Island (Table 7-2).

Figures 7-20 through 7-24 show the limitation severity distribution for the OSDS related soil properties for Molokai. The majority of East Molokai has a shallow soil cover, which explains the severe limitation rating for this property (Figure 7-20). This property is also rated as having a severe limitation in much of the coastal areas of West Molokai. As with the other islands, flooding and ponding are only limiting along a small coastal fringe of southern and western Molokai (Figure 7-21). Slow water percolation is rated as severely limiting in most of West Molokai and along the southeast coastal areas of East Molokai (Figure 7-22). The soils of Molokai provide sufficient filtration of OSDS effluent except for small areas along the southern and western coasts where limitation of this property is evaluated as severe (Figure 7-23). The limitation of the combined soil properties that include seepage from the bottom layer, total subsidence, excessive slope, and excessive percentage of rock fragments are rated as moderate to severe over much of East Molokai and south Molokai (Figure 7-24). Excessive slope, inadequate seepage from the bottom layer, and excessive occurrence of rock fragments combined to make the limitation of the combined properties severely limiting in the highland areas of East Molokai. Excessive slope and occurrence of rock fragments resulted in the moderate limitation rating for the southern and western regions of Molokai.

When all soil properties are considered, the septic siting suitability for much of East Molokai, the southern part of the saddle between East and West Molokai, and near the western coast of West Molokai is evaluated as severely limiting (Figure 7-25). The shallow depth to rock and severe limitation rating for the "combined" soil factors resulted in an overall severe rating for East Molokai. The shallow depth to rock and slow percolation rate resulted in the moderate limitation rating for much of West Molokai and severe limitation rating for the western coastal areas of West Molokai.

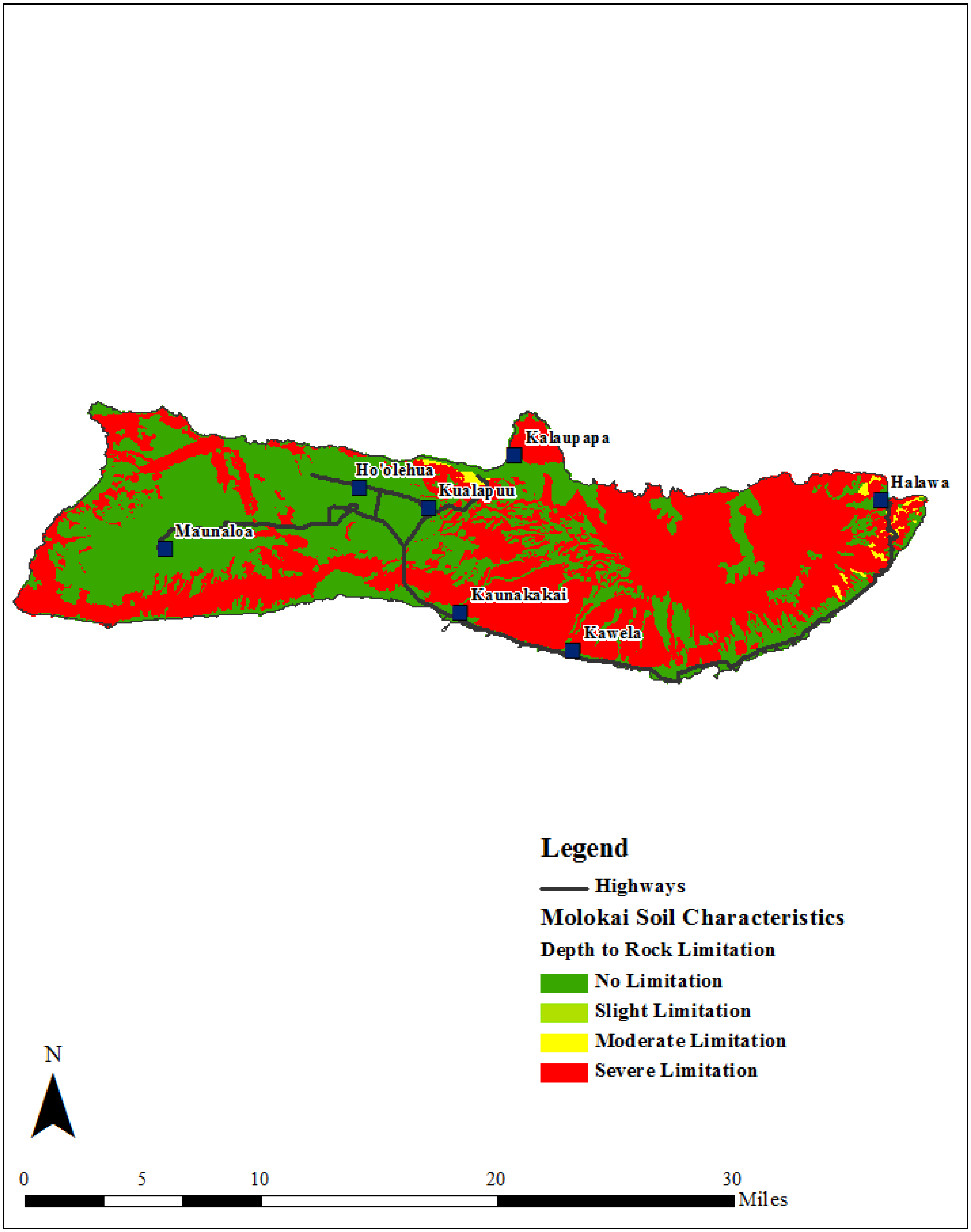

Figure 7-20. The severity distribution of the depth to rock limitation on Molokai

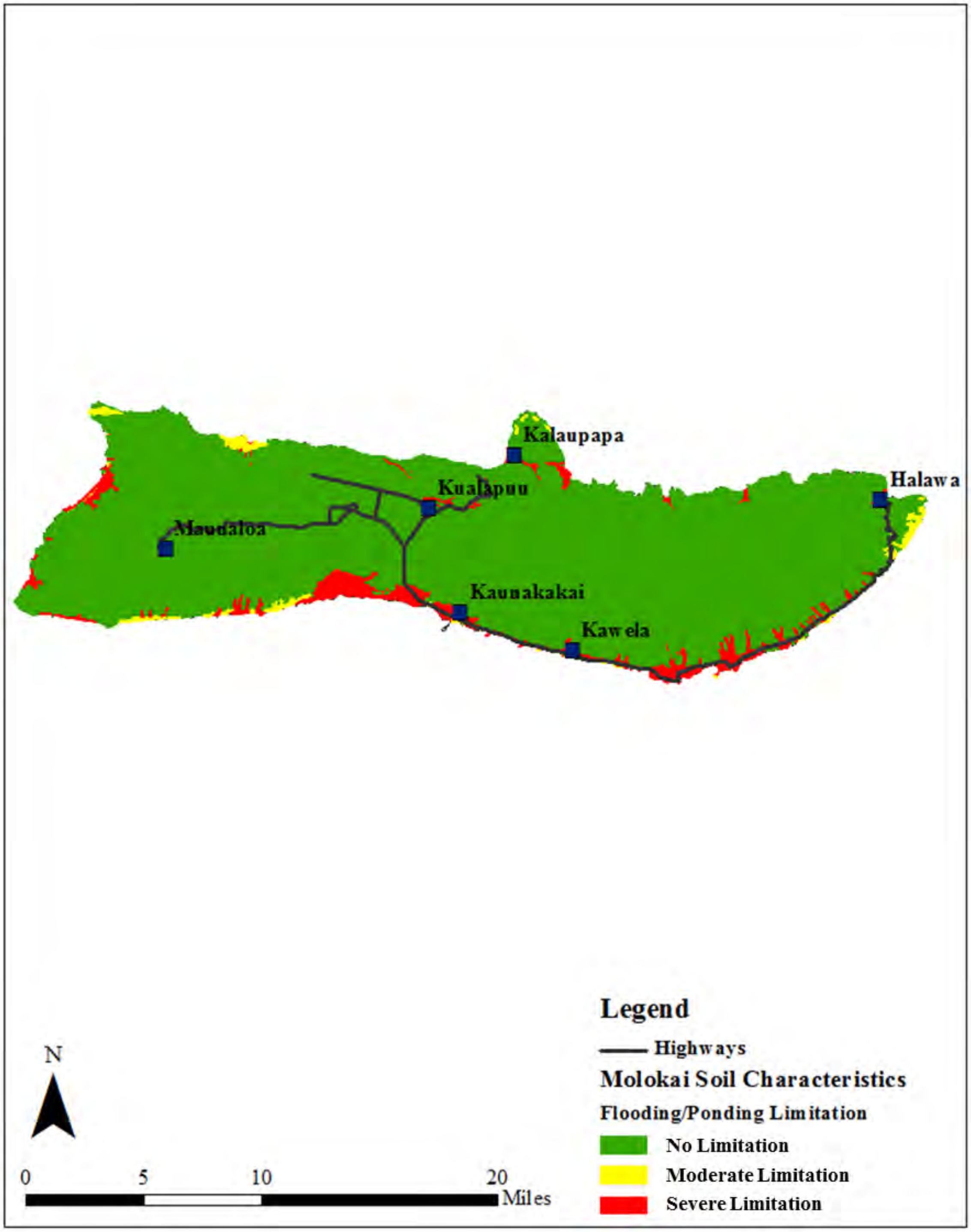

Figure 7-21. This distribution and severity of the flooding and ponding limitation on Molokai

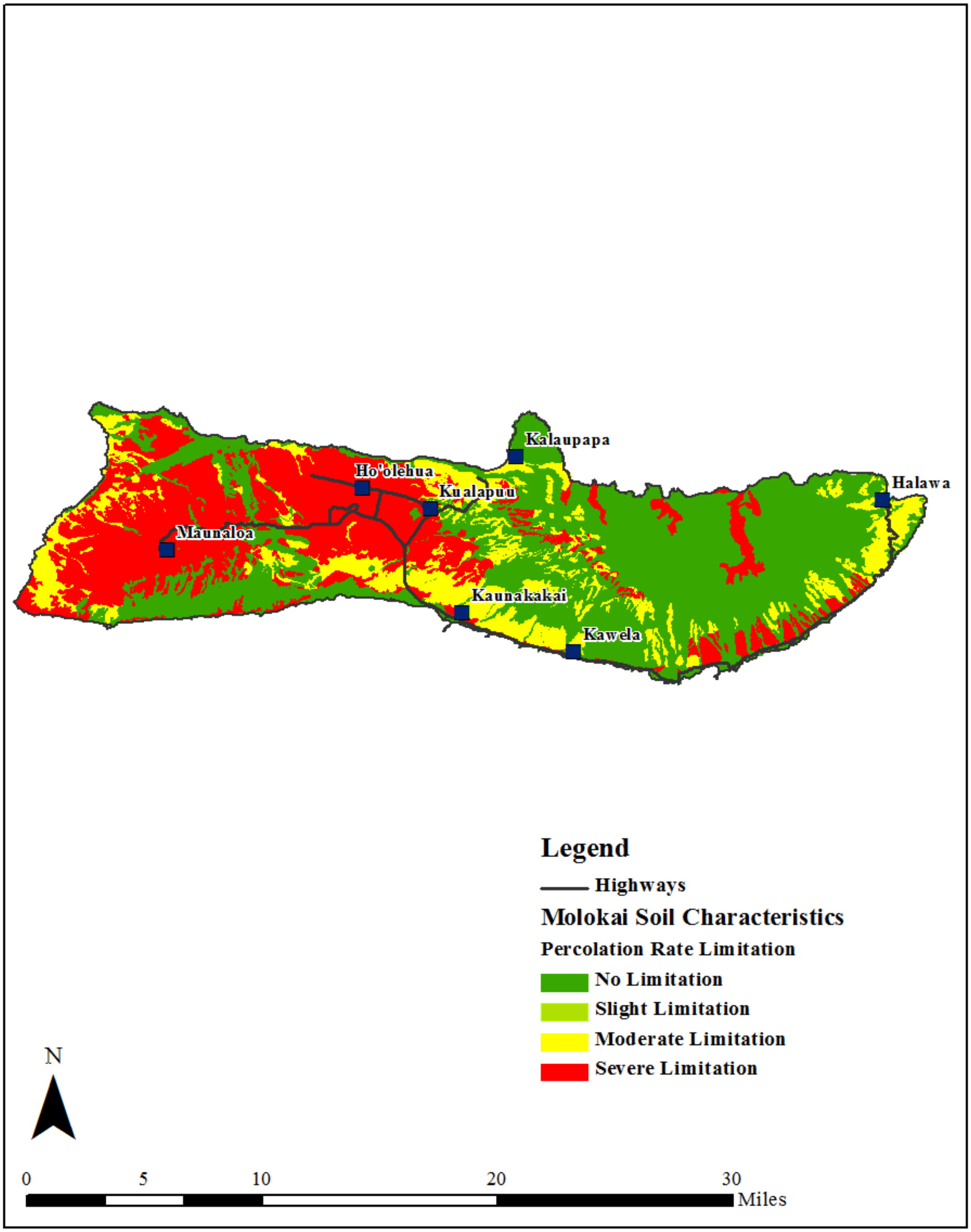

Figure 7-22. The distribution and severity low permeability limitation on Molokai

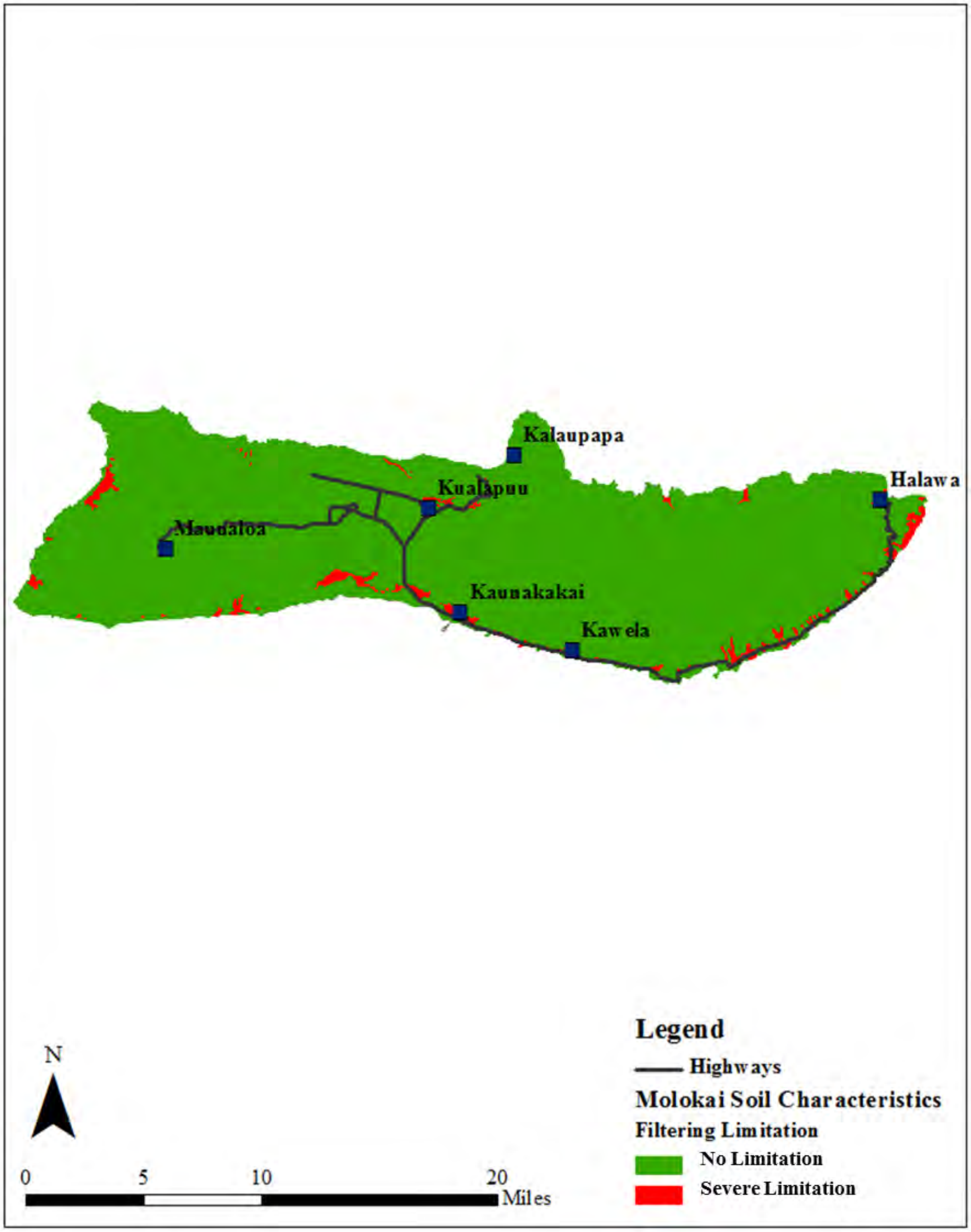

Figure 7-23. The distribution and severity of the soil filtration limitation on Molokai

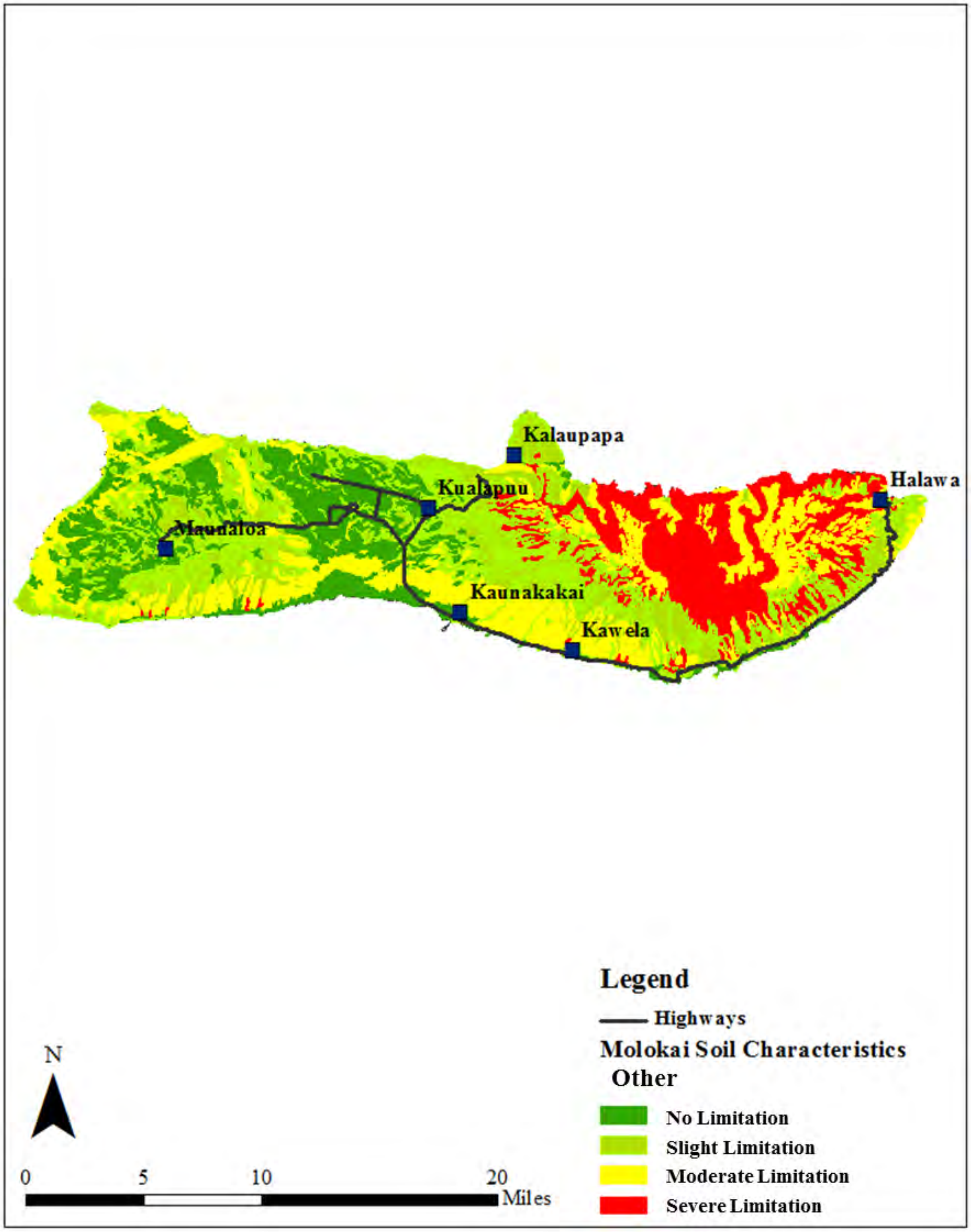

Figure 7-24. The composite of limitations that include seepage from the bottom layer, total subsidence, excessive slope, and the percent of rock fragments on Molokai

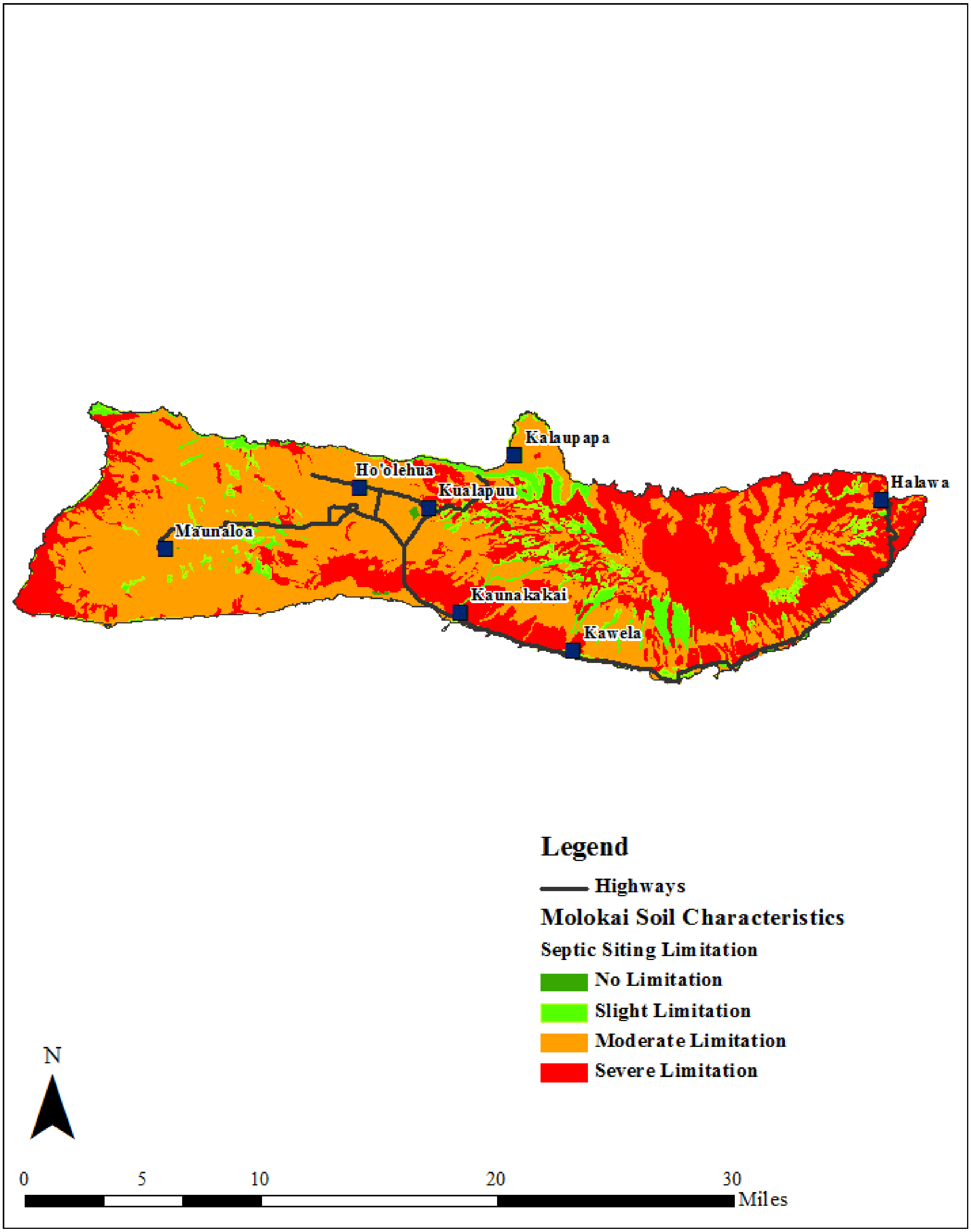

Figure 7-25. The distribution TSSSLS on Molokai

SECTION 8. ON-SITE SEWAGE DISPOSAL SYSTEM RISK RANKING

A primary goal of this study is to rank the risk posed by individual OSDS. In previous sections, the risk faced by each ROC to OSDS contamination and the current impact of OSDS effluent on the groundwater were considered. In this section, a relative risk ranking of the OSDS is estimated by considering the individual susceptibility scoring for each ROC, whether or not the effluent is treated, and the characteristics of the soil where the OSDS is located. This goal was slightly modified because a TMK parcel is the smallest spatial element considered by this study. A single TMK parcel may host multiple OSDS. Where multiple OSDS are located on a single TMK parcel there is the risk that the same score was assigned to all OSDS within a single parcel. To reflect the fact that the scores are assigned at the parcel level rather than to the individual OSDS the term "OSDS parcel" will be used.

8.1 METHODS

The OSDS risk severity score reflected the hydrologic characteristics of the OSDS location and the characteristics of the OSDS itself. A single risk score was assigned to each OSDS parcel by summing ROC risk scores, scaling and adding the TSSSLS, and adding a term for Class IV OSDS (i.e., cesspools). Table 8-1 lists the terms used in the OSDS risk ranking scoring and the values used for each risk category. This table includes the different parameters considered in each risk category, risk severity value assigned, and total risk severity score for each category. A description of each term in the final OSDS risk score is summarized in the following sections. Included in the description is any modification made to the individual risk score terms prior to the final risk summation.

A risk severity score is computed for each ROC, as described in Section 4 (groundwater and drinking water), Section 5 (stream and watershed risk), and Section 6 (coastal waters risk). The risk severity score for drinking water sources is computed separately from that for groundwater to more concisely evaluate the risk to human health posed by the individual OSDS. As shown in Table 8-1, the risk severity score components for groundwater included depth to water, confined/unconfined status of the aquifer, presence or absence of perched water, and whether or not the aquifer was a potential drinking water source or of ecological importance. The criteria used to compute the drinking water risk severity score (refer to Table 8-1) included whether the OSDS is within a drinking water CZD, and the modeled ODGWN concentration at the location of the OSDS. Incorporating the modeled OSGWN concentration reflected the increased risk to drinking water posed by groupings of OSDS. Drinking water and watersheds are assigned a higher maximum score to reflect the greater seriousness of OSDS contamination to these two ROCs. OSDS contamination of drinking water is considered serious because of the direct risk to human health while contamination of watersheds is also considered serious because of the lesser ability of streams to dilute OSDS effluent compared to that of the coastal waters. The summing of the individual ROC scores reflects the increased probability of harm to human health or the environment posed by an OSDS that is located in close proximity to multiple ROCs.

As described in Section 2, the quality of effluent released to the environment from an OSDS varies with the amount of treatment it receives. Systems utilizing soil treatment (Class I OSDS) can attain nitrogen removal rates of greater than 90 percent (refer to Table 2-3). The effluent from cesspools, the Class IV OSDS, receives no treatment and thus no reduction in nutrients and pathogens prior to release to the environment. To reflect the greater risk to human health and the environment posed by Class IV OSDS, OSDS parcels in which a cesspool is located was assigned a type risk score of 3. Class II OSDS (septic systems discharging to a seepage pit) have nutrient removal rates similar to that of cesspools. However, Class II OSDS account for less than 2.5 percent of the total number of OSDS so no elevated risk score was assigned to this class of systems.

As described in Section 7, the characteristics of the soil where an OSDS is located plays an important role in the mitigation of OSDS risk. The soil at each OSDS location was assigned a score that varied from 0 to a maximum possible score of 100. The magnitude of the soil risk severity score was scaled to a maximum value of 6, similar to that of the ROC risk severity scores. The scaling was done using the follow breakdown.

- A soil score of 0 was assigned a scaled score of 0.
- A soil score greater than 0, but less than or equal to 10 was assigned a scaled score of 1.
- A soil score greater than 10, but less than or equal to 20 was assigned a scaled score of 2.
- A soil score greater than 20, but less than or equal to 30 was assigned a scaled score of 3.
- A soil score greater than 30, but less than or equal to 40 was assigned a scaled score of 4.
- A soil score greater than 40, but less than or equal to 50 was assigned a scaled score of 5.
- A soil score greater than 50 was assigned a scaled score of 6.

The maximum-scaled risk value stopped at 6 because only very small areas on Kauai had a soil risk severity score that exceeded 60.

The risk scores were combined with soil suitability scores to generate a composite risk severity score for each OSDS. This risk ranking is an overall evaluation of the relative risk posed by each OSDS or groups of OSDS in a single TMK. However, the risk that an OSDS poses to a single ROC class may be much higher than the total risk score assigned to the OSDS. For example, when evaluating the risk a group of OSDS pose to coastal waters, the risk score specific to that ROC type should be used.

Table 8-1. OSDS Risk Scoring

Risk Category	Parameter	Score Assigned
Type Score	**Class IV OSDS within the TMK**	**3**
Groundwater	Depth to water >= 25 ft	1
	Primary aquifer unconfined	1
	Lack of perched water overlying the primary Aquifer	1
	Aquifer is potential source of drinking water	1
	Aquifer is of ecological importance	1
	Maximum possible score	**5**
Drinking Water	OSDS located with a Zone B area of contribution	2
	OSDS located within a Zone C area of contribution	1
	ODGWN	
	>1, but <=5	1
	>5, but <=9	2
	>9	3
	Maximum possible score	**6**
Perennial Watersheds	Perennial watershed	1
	Portion present in a high-level aquifer	1
	Area within 200 ft of a stream	1
	Areas where depth to groundwater is < 25 ft	1
	Areas where the ODGWN is >1 mg/L	2
	Maximum Possible Score	**6**
Coastal Zone	Areas within a two-year groundwater time of travel to the coast	1
	Areas within 200 ft of the shoreline	2
	Areas within or adjacent to the two-year groundwater time of travel to the coast where the modeled ODGWN is >1 mg/L	2
	Maximum possible score	**5**
Soil	**Maximum possible score**	**6**
Total maximum possible OSDS risk severity score		**31**

8.2 RESULTS

The ROC and related parameters needed for risk evaluation were identified for the 81,844 OSDS parcels on Hawaii Island, Kauai, Maui, and Molokai that host an estimated 96,896 OSDS. Because the TMK parcel was smallest spatial element considered by this study, each OSDS within an individual TMK was assigned the same risk score. Table 8-2 summarizes the results for the four islands and Table 8-3 breaks the scoring results down by the individual parameters used to compute the final risk score. Figure 8-1 is a histogram displaying the OSDS risk severity scores in increments of 5 for each island.

The OSDS risk severity scores varied from 1 to 26, with Kauai having the highest maximum and average risk severity scores followed by the island of Hawaii. The maximum risk severity scores for Maui and Molokai are significantly lower than that for Kauai and Hawaii, while the average risk severity scores for Molokai and Maui are moderately less than that for Hawaii. Figure 8-1 shows that most of the scores fell within the expected mid-range from 5 to 15, with Kauai having more scores falling in the higher segment of 10 to 15. The majority of the scores for Hawaii Island, Molokai, and Maui fell in the lower 5 to 10 segment. Kauai had notably more scores higher than 15 than the other islands. Kauai is also the only island to have any scores in the greater than 25 segment. When comparing OSDS risk severity scores it is important to note that this score is only part of the overall risk assessment. This OSDS risk severity score applies to individual parcels on which OSDS are located and to risk posed by these systems to the island as a whole. For example, Molokai has a slightly higher average OSDS risk severity score than Maui. This means that the risk posed by the individual OSDS on Molokai on average is slightly higher than that on Maui due to such factors as less suitable soil conditions and the absence of perched groundwater. However, Maui has nearly 17,000 OSDS with an average of 23 OSDS per mi^2 compared to less than 2,000 on Molokai with a density of 7.5 OSDS per mi^2. When evaluating OSDS risk to an island or to an ROC we look at the total number and density of OSDS in conjunction with and the risk severity score assigned to the individual OSDS parcels.

In general, the risk posed by OSDS is greatest on Hawaii Island and Kauai. Hawaii Island and Kauai have the highest average OSDS Type Score, which reflects the higher percentage of cesspools on these two islands. On Hawaii Island and Molokai, more OSDS are located where there is a limited ability of the soil to remediate OSDS effluent and the risk to groundwater. On Kauai the OSDS risk to groundwater and watersheds elevated the score for this island above that of the other islands assessed. The higher groundwater risk on Kauai is due to little perched water over the main aquifers, shallow depth to groundwater in many areas, and high ODGWN. On Kauai perennial watersheds dominate, which allows groundwater with its entrained OSDS contaminants to discharge to surface water.

By risk type, the soil suitability for OSDS siting is the parameter with the highest average score for all of the islands, except Kauai. The average drinking water risk score was the lowest of the parameters evaluated on all of the islands, which reflects the small amount of land area that falls within the zones of contribution to drinking water sources.

Table 8-2. OSDS Risk Severity Statistics

Island	Total OSDS	OSDS Parcels	OSDS Density (per mi^2)	Minimum	Average	Maximum	Standard Deviation
Hawaii	58,982	53,530	14.6	3	10.5	22	2.6
Kauai	19,075	13,883	32.5	3	12.7	26	2.8
Maui	16,883	12,780	23.2	1	8.6	18	2.9
Molokai	1,956	1,651	7.5	3	9.7	16	2.7
Total	**96,896**	**81,844**	**-----**	**-----**	**-----**	**-----**	**-----**

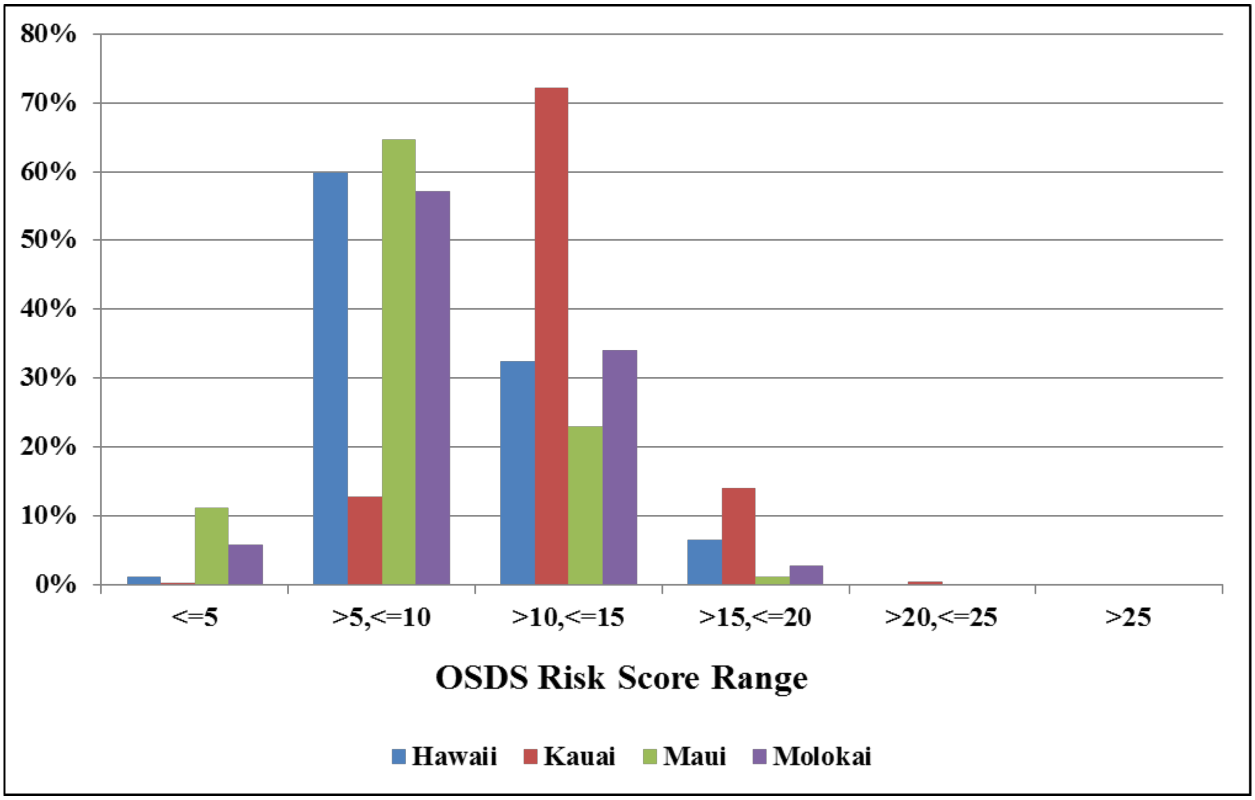

Figure 8-1. Histogram of the OSDS risk severity scores by island

Table 8-3. OSDS risk scoring statistics by island and category

ROC or Parameter	Hawaii			Kauai			Maui			Molokai			Max. Score Possible
	Min.	Avg.	Max.	Min	Avg.	Max.	Min	Avg.	Max.	Min.	Avg.	Max.	
Type Score	0.0	2.5	3.0	0.0	2.5	3.0	0.0	2.2	3.0	0.0	2.2	3.0	3.0
Groundwater	2.0	2.9	4.0	2.0	3.0	5.0	1.0	2.1	4.0	0.0	2.9	5.0	5.0
Drinking Water	0.0	0.1	5.0	0.0	0.3	6.0	0.0	0.3	4.0	0.0	0.1	3.0	6.0
Watershed	0.0	1.0	5.0	0.0	2.9	5.0	0.0	0.8	5.0	0.0	0.1	2.0	6.0
Coastal Zone	0.0	0.9	5.0	0.0	1.3	5.0	0.0	0.7	5.0	0.0	1.4	5.0	5.0
Soil	0.0	3.0	6.0	0.0	2.6	6.0	0.0	2.5	6.0	0.0	3.1	5.0	6.0

8.2.1 Hawaii

Hawaii Island had the second highest maximum and average risk severity scores of the four islands evaluated by this study. This island is currently growing due to on-going volcanic eruptions. The geologically recent eruptions have laid down lava on the ground surface with little time for the rock to weather to soil. Other factors contributing to the higher OSDS risk on this island are the higher rate of Class IV OSDS, the dominance of perennial streams and high-level aquifers in the northeast portion of the island, and a significant abundance of OSDS on western-drier side of the island. This distribution of higher risk is shown in Figure 8-2. The areas of highest risk are located in Northeast Hawaii Island from Hilo to Kapaʻau where perennial streams dominate and Southwest Hawaii Island from Kawaihae to the southernmost point of the island where groundwater recharge is low.

On Hawaii Island, 49,344 out 58,982 or 84 percent of the OSDS were Class IV systems. This is the highest of any island. Because Class IV systems were assigned an OSDS type score of 3, the higher incidence of OSDS on this island contributed to its higher score. There are 3,578 OSDS on this island with a risk severity score that exceeds 15. All are located in the northeastern or western areas of the island. This is an area with perennial watersheds and high-level aquifers. This increases the risk that OSDS pose to perennial watersheds due to conditions that favor groundwater discharge to surface water. Of the 53,530 OSDS parcels, 34 percent or 17,942 are located in perennial watersheds. This percentage is higher than the other islands except Kauai. On Maui and Molokai only 27 percent and 4 percent, respectively, of the OSDS parcels were located within perennial watersheds.

West Hawaii is also an area where the OSDS risk is elevated. Nearly 15,500 OSDS or greater than 25 percent of these systems on Hawaii Island are located in the dry southwest area from Kawaihae to southernmost point of the island. The lower rate of recharge to dilute the OSDS effluent increases the ODGWN concentration.

The younger age of this island appears to be a significant factor in the higher soil risk severity score because an insufficient depth to rock resulted in moderate to severe limitation rating for this parameter. The combined septic siting unsuitability factors (excessive slope, high percentage of rock fragments, seepage out of the bottom soil horizon, and excessive subsidence) score was also much higher for this island than the others. Hawaii Island has a soil risk severity score that is second only to Molokai. Because this island is the youngest of the islands assessed, this is expected.

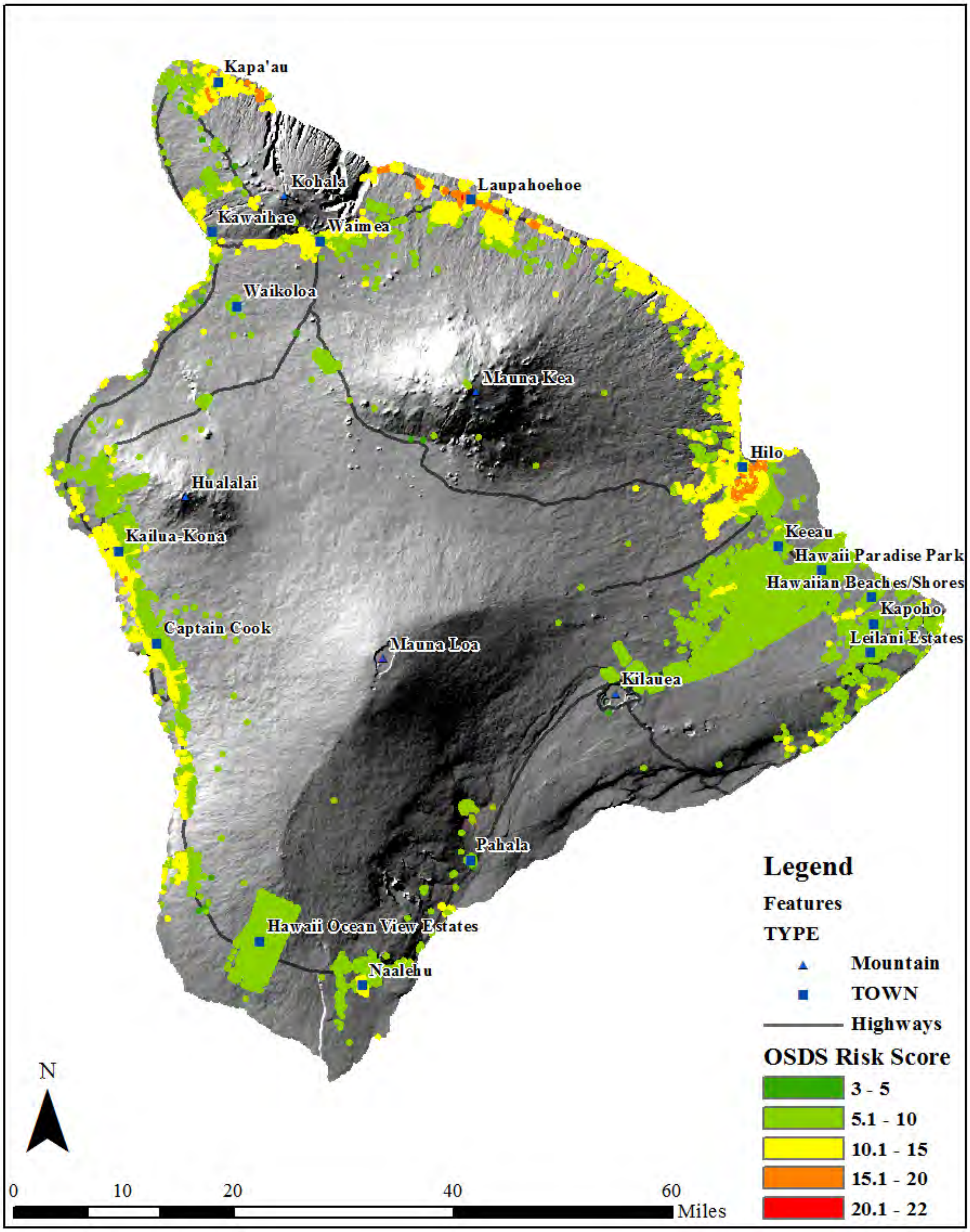

Figure 8-2. OSDS risk severity score distribution of Hawaii Island

8.2.2 Kauai

Kauai had the highest OSDS risk severity score of the islands assessed. Kauai has a maximum OSDS risk severity score of 26 and average OSDS risk severity score of 12.7, which were the highest of the islands evaluated by this study (see Table 8-2). Figure 8-1 shows that Kauai is over represented in the higher risk score segments compared to the other islands with majority of the scores falling the 10 to 15 and 15 to 20 range. Table 8-3 shows that the average watershed risk severity score on Kauai is significantly higher than on the other islands. Eight-four percent of the TMKs that have OSDS are located within a perennial watershed. Nearly the entire area of Kauai's perennial watersheds is classified as high-level groundwater. This makes discharge of groundwater to the surface water probable throughout the majority of perennial watershed area. Kauai also has the highest simulated ODGWN concentration. The combination of the high ODGWN concentration and dominance of high-level aquifers in the perennial watersheds greatly increase the probability that OSDS effluent may degrade the stream water quality on Kauai.

The high ODGWN concentration in Kauai's groundwater also elevates the risk to drinking water sources and to the coastal eco-systems. On Kauai nearly half of the drinking water CZDs have elevated ODGWN. This indicates that OSDS contaminated groundwater may be captured by drinking water wells. The elevated nitrogen in the groundwater also increases the coastal zone risk severity score, which indicates a greater potential for coastal environmental degradation by OSDS compared to that of the other islands evaluated. The combined potential adverse impact of OSDS on streams, drinking water, and the coastal waters resulted in an OSDS risk severity score of 26, higher than that of the other three islands evaluated.

Figure 8-3 shows the distribution of the OSDS risk severity scores for Kauai. The Lihue area near Nawiliwili and Wailua/Kapaa had OSDS with a risk severity score in the highest range (i.e., greater than 20). The areas surrounding all of the towns shown on the map with the exception of Kekaha had OSDS risk severity scores in the mid- to high ranges of 11 to 15 and 16 to 20. As described earlier, Kauai's unique hydrogeology and hydrology typified by an elevated groundwater table and the dominance of perennial watersheds make this island more susceptible to adverse impacts from OSDS effluent. An area of particular concern appears to be the Wailua/Kapaa area where there is a large number of OSDS near a perennial stream that also fall with the zones of contribution of drinking water wells.

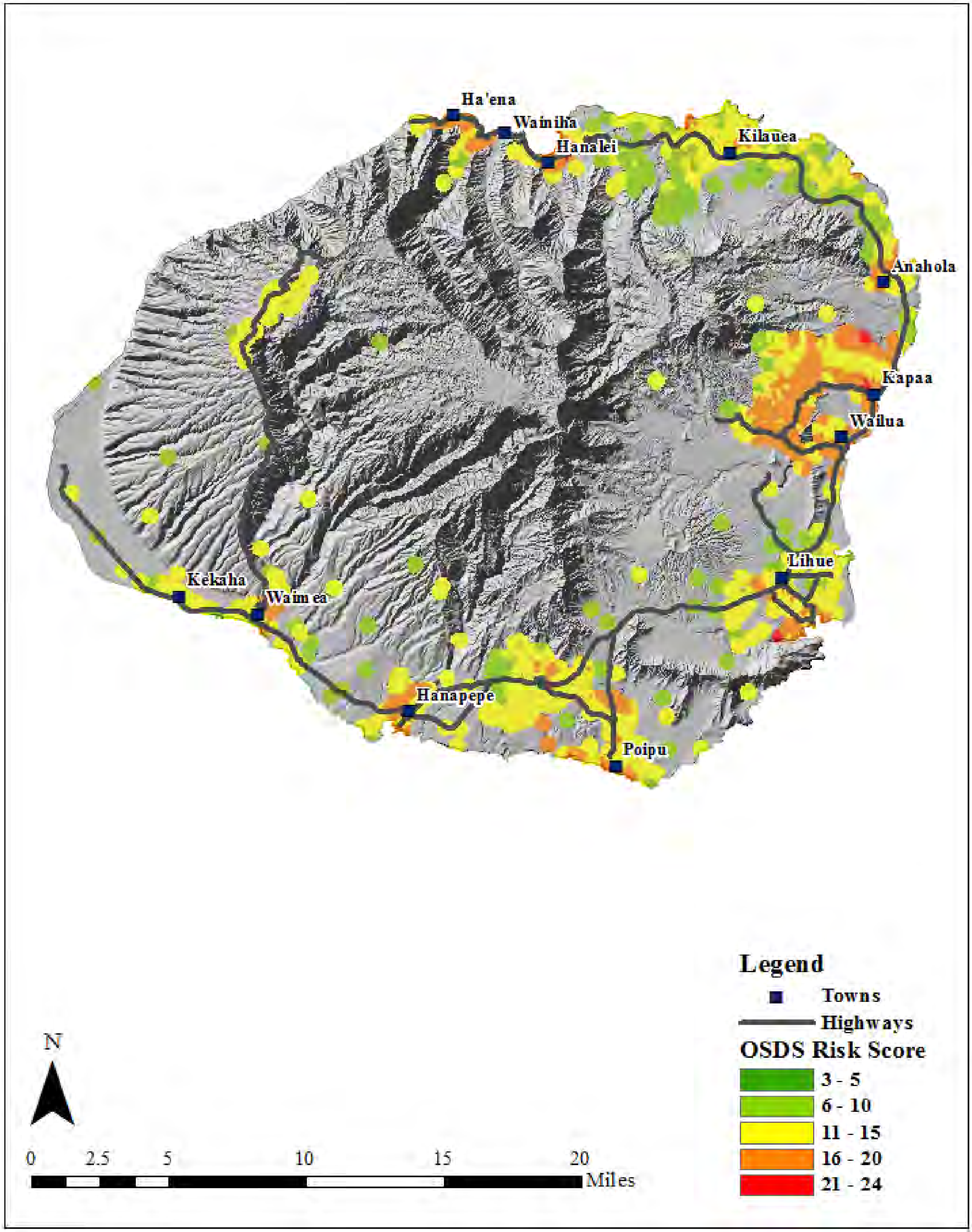

Figure 8-3. The distribution of the average OSDS risk score

8.2.3 Maui

For Maui the estimated risk that OSDS pose to human health and the environment is the lowest of the islands evaluated. Maui has an average OSDS risk severity score of 8.6 and a maximum score of 18, which is significantly lower than that of Hawaii and Kauai (see Table 8-2). The category where the evaluated risk on Maui is high relative to other islands except Kauai is drinking water. The maximum score of 4 is lower than that of Hawaii and Kauai, but the average score is 0.3 higher than that of Hawaii and Molokai. Figure 8-4 shows the distribution of OSDS risk severity scores for Maui. The areas of highest OSDS risk (score of 16 or greater) occurred predominantly in north-Central Maui and on the north slope of Haleakala. Upcountry Maui has many OSDS, but the risk severity scores were in the 1 to 5 and 6 to 10 range due to the likely presence of perched water between the ground surface and the primary aquifer, and absence of perennial streams.

There is no category where the average OSDS risk on Maui was higher than that of the other islands studied (see Table 8-3). Maui has the lowest average risk severity scores for OSDS type, groundwater, coastal zone, and soil suitability. However, Maui has a risk to drinking water equal to that of Kauai. As with Kauai, the relatively high drinking water risk severity score average is driven by potentially high ODGWN concentrations. The maximum simulated ODGWN concentration on Maui is 24 mg/L, only slightly lower than that on Kauai. Elevated ODGWN concentrations fell within the zones of contribution for numerous drinking water wells in upcountry east Maui and the Iao region of central Maui. Also contributing to the elevated drinking water risk severity score is the higher incidence of OSDS in the Zone B area of contribution. On Maui, 5.9 percent of the OSDS are located within a Zone B area contribution. The next highest rate of OSDS in the Zone B area of contribution is 3.1 percent on Kauai, which is significantly lower than on Maui.

Factors contributing to Maui's OSDS risk severity score being less than that of Hawaii and Kauai are the lower rate of Class IV OSDS and the lower soil risk severity score. On Maui, 73 percent of the OSDS were Class IV, less than that of the other islands. The average soil OSDS risk severity score for Maui was 2.5, lower than that of the other islands evaluated. Major factors contributing to the low soil limitation score were filtration qualities that favor effluent treatment and the low rate of soil subject to flooding.

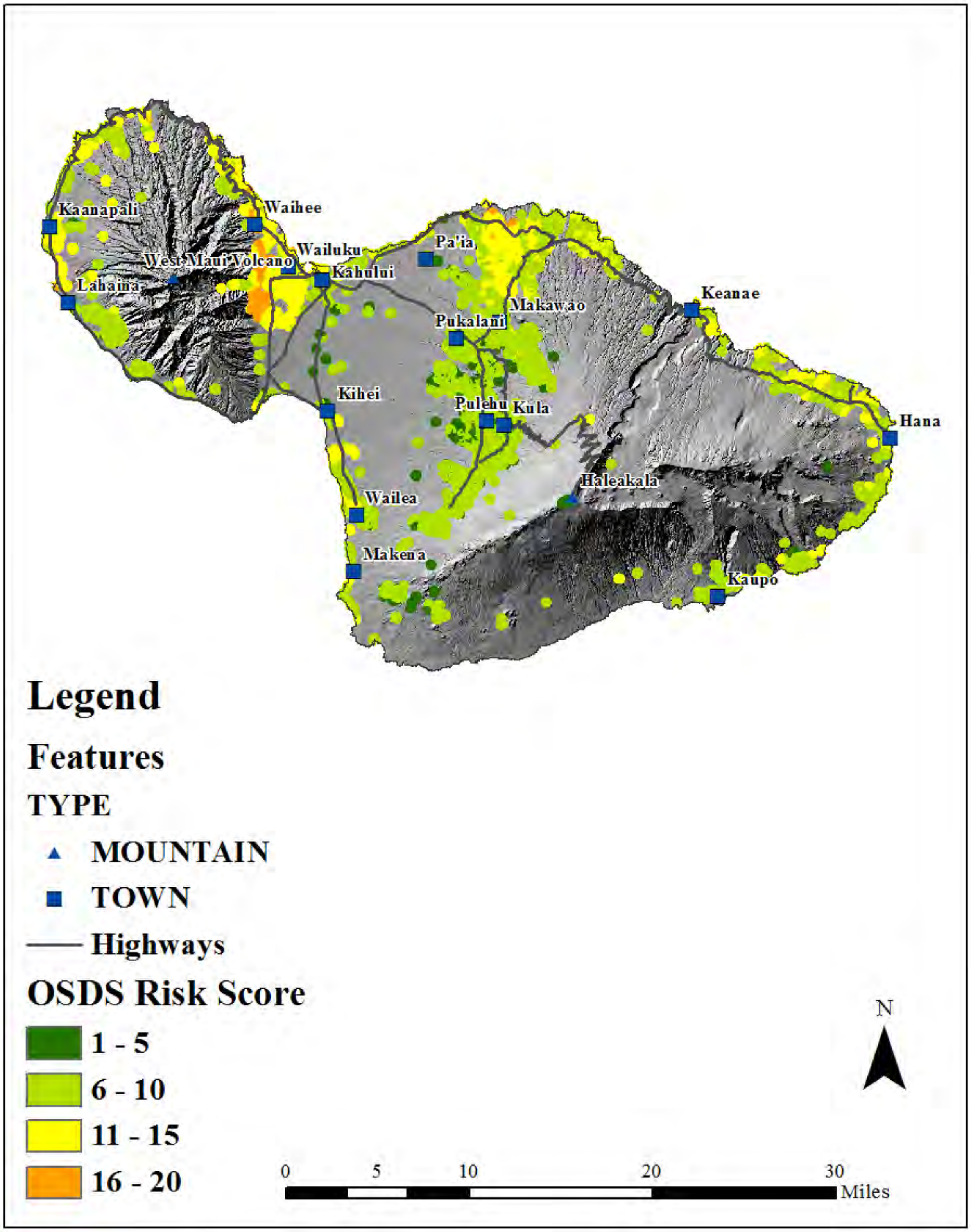

Figure 8-4. The distribution of the average OSDS risk score.

8.2.4 Molokai

Molokai has the lowest population density of the islands evaluated by this study. The low population density decreases the OSDS density, which results in a low risk to human health and the environment. Molokai has the lowest maximum OSDS risk severity score of the islands assessed by this study. The average OSDS risk severity score for this island is also low, but slightly greater than that of Maui. This island has a lower percentage of Class IV OSDS (74 percent) than the other islands, except Maui, and a lower number of OSDS in the Zone B area of contribution (1.6 percent) than all of the other islands assessed. This resulted in low OSDS Type Scores and a low drinking water risk severity score. The simulated maximum ODGWN concentration of 7.0 mg/L was significantly less than that on any other island. The low ODGWN reflects the low impact OSDS have on Molokai groundwater compared to the other islands evaluated. Overall the primary factor resulting in the low OSDS Risk Severity Score is the low population of this island, which results in a low need for OSDS.

Figure 8-5 shows the distribution of OSDS risk severity scores for Molokai. As Figure 8-2 shows, the majority of Molokai's OSDS risk severity scores fall in the 6 to 10 and 11 to 15 range. Also, Molokai is second only to Maui in the fraction of OSDS with a risk severity score of 5 or less. The areas of highest OSDS risk severity are along the southern coastal plain. The only category where the risk score for Molokai exceeded that of the other islands is the soil septic siting suitability score. The average score for Molokai was 3.1 while that for Hawaii, the island with the next highest score, was 3.0. It is important to point out that the overall soil septic siting suitability score described in Section 7.4.4 reflects soil conditions for the entire island while the score in Table 8-3 reflects the soil conditions where the OSDS are currently located. Many of the OSDS are located on the southern coastal plain where flooding and ponding, and the depth to rock are limiting. Other areas of significant OSDS density are the saddle area between the two volcanoes that form Molokai and West Molokai. The soil in these two areas is limited by a slow percolation rate.

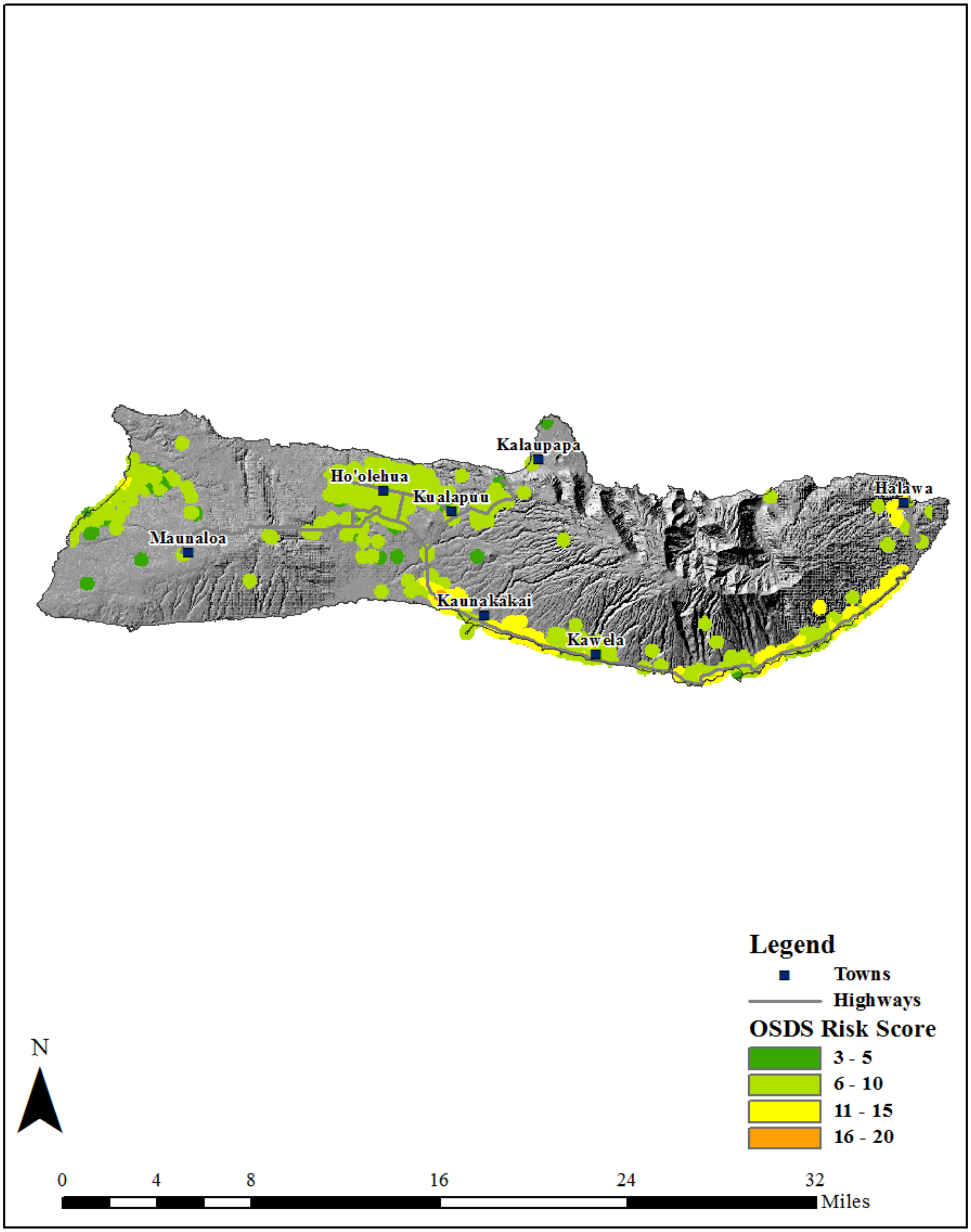

Figure 8-5. The distribution of the average OSDS risk score for the island of Molokai

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SECTION 9. INDICATORS OF OSDS IMPACT AND RECOMMENDATIONS

9.1 INDICATORS OF OSDS IMPACT

Wastewater is a complex mixture of natural occurring and anthropogenic substances and compounds. Constituents that are unique or enriched in wastewater can be used as tracers to evaluate wastewater impact on natural systems. These tracers include: microbes and pathogens, such as fecal coliform bacteria (Hyer, 2007); ions that are enriched in wastewater such as boron, chloride, bromine, and nitrates and nitrites (Hunt and Rosa, 2006; Hyer, 2006; and Miller and Ortiz, 2007); and synthetic compounds such as plasticizers, fragrances, pharmaceuticals, and caffeine (Hunt and Rosa, 2006; Hyer, 2007; Miller and Ortiz, 2007). There are also atomic weight differences in some constituents in water that can indicate a sewage contribution. Among these are the relative atomic weight proportions of dissolved nitrogen. A higher proportion of the nitrogen with an atomic weight of 15 relative to the more common atomic weight of 14 is a strong wastewater indicator (Dailer et al., 2010 and 2012; Hunt and Rosa, 2009; Kendall, 1998).

This study did not perform any field sampling but instead utilized data from the HDOH drinking water sampling program or published in previous studies. Two tracers were selected based on the spatial extent and availability of the data. These were the nitrate/nitrite concentration in the groundwater and the ratio of ^{15}N to ^{14}N ($\delta^{15}N$) along the coastal waters of Maui and West Hawaii Island. The HDOH Safe Drinking Water Branch regularly analyzes water samples collected from public drinking water wells throughout the State of Hawaii for the National Primary Drinking Water Regulation contaminants (HDOH, 2013). This list of contaminants includes nitrate plus nitrite and is available from approximately 250 drinking water wells. The $\delta^{15}N$ data are available from coastal coral reef health assessment surveys. As part of the Hawaii Coral Reef Initiative, Dailer et al. (2010, 2012 and 2013) surveyed the $\delta^{15}N$ using algal assays over entire accessible coastline of Maui and the west coast of Hawaii Island.

9.1.1 Groundwater Nitrogen

This study modeled the ODGWN concentration based on the estimated quantity, location, effluent discharge, and effluent nitrogen chemistry of OSDS on the islands studied. The modeling predicted groundwater nitrogen concentrations exceeding 20 mg/L in some areas of high OSDS density. This approach did not consider any effluent remediation that occurs after the OSDS leachate leaves the zone of treatment (i.e., the zone of treatment is the soil immediately adjacent to a leach field and primary treatment is the process that occurs in a septic tank). Therefore, the modeled ODGWN would likely overestimate the actual groundwater nitrogen concentration. However, some correlation would be expected between the model and measured groundwater nitrogen concentrations. The modeled ODGWN and the HDOH drinking water database nitrate concentrations were compared to determine if any spatial correlation exists between the two.

Figures 9-1 through 9-4 compare the modeled ODGWN concentration to the measured groundwater nitrogen concentration in the wells for which data were available. All islands showed some zones of elevated groundwater nitrogen concentrations. For example, a well in the Waimea area of Hawaii Island had groundwater nitrogen concentrations between 1.6 to 2.5 mg/L (Figure

9-1). Many of the wells with elevated groundwater nitrogen were located outside of the areas where modeling predicted that elevated ODGWN concentrations would occur. For example, the wells with the highest groundwater nitrogen concentrations in West Hawaii Island were located north of where the model predicted elevated ODGWN concentrations would occur. This was also the situation for the other islands assessed in this study. Wells that had elevated nitrate concentrations coincided more closely with agricultural areas. On Kauai (Figure 9-2) there were no wells with elevated groundwater nitrogen concentrations except for a single well north of Lihue. In the Wailua/Kapaa area the model predicted highly elevated ODGWN over a large area. A well located in the middle of this area showed no elevated groundwater nitrogen concentrations. Maui has numerous wells with elevated groundwater nitrogen concentrations (Figure 9-3). Several of these wells were located within areas that the model predicted elevated ODGWN concentrations would occur. For example, a well located on the north slope of Haleakala had an average nitrate concentration of 4.6 mg/L that correlated with the model predicted ODGWN concentration of approximately 5 mg/L. However, this well is located in an agricultural zone and the elevated groundwater nitrogen concentration is more likely from fertilizer leachate. In West Maui the wells with elevated groundwater nitrogen concentrations were upgradient of the area where the model predicted elevated ODGWN concentrations would occur. Molokai (Figure 9-4) had no wells sampled that had elevated groundwater nitrogen concentrations.

The comparison of the modeled ODGWN concentrations with the groundwater nitrogen concentrations measured at public drinking water wells indicates that groundwater nitrogen concentration alone is a poor indicator of wastewater impact. This approach could be improved by sampling domestic wells and environmental monitoring wells. Public drinking water wells tend to be screened deep in the aquifer to capture the higher quality groundwater (Hunt, 2004). Leachate from OSDS in residential areas would preferentially impact the groundwater near the top of the water table. Domestic and monitoring wells with their shallow well screens could more efficiently capture the groundwater at or the near the water table. Also the use of stable isotopes should be considered in any OSDS impact study. The stable isotopes of nitrogen can help differentiate between fertilizer and wastewater sources of nitrogen. The next section compares coastal $\delta^{15}N$ surveys with the modeled ODGWN concentrations in the adjacent aquifers.

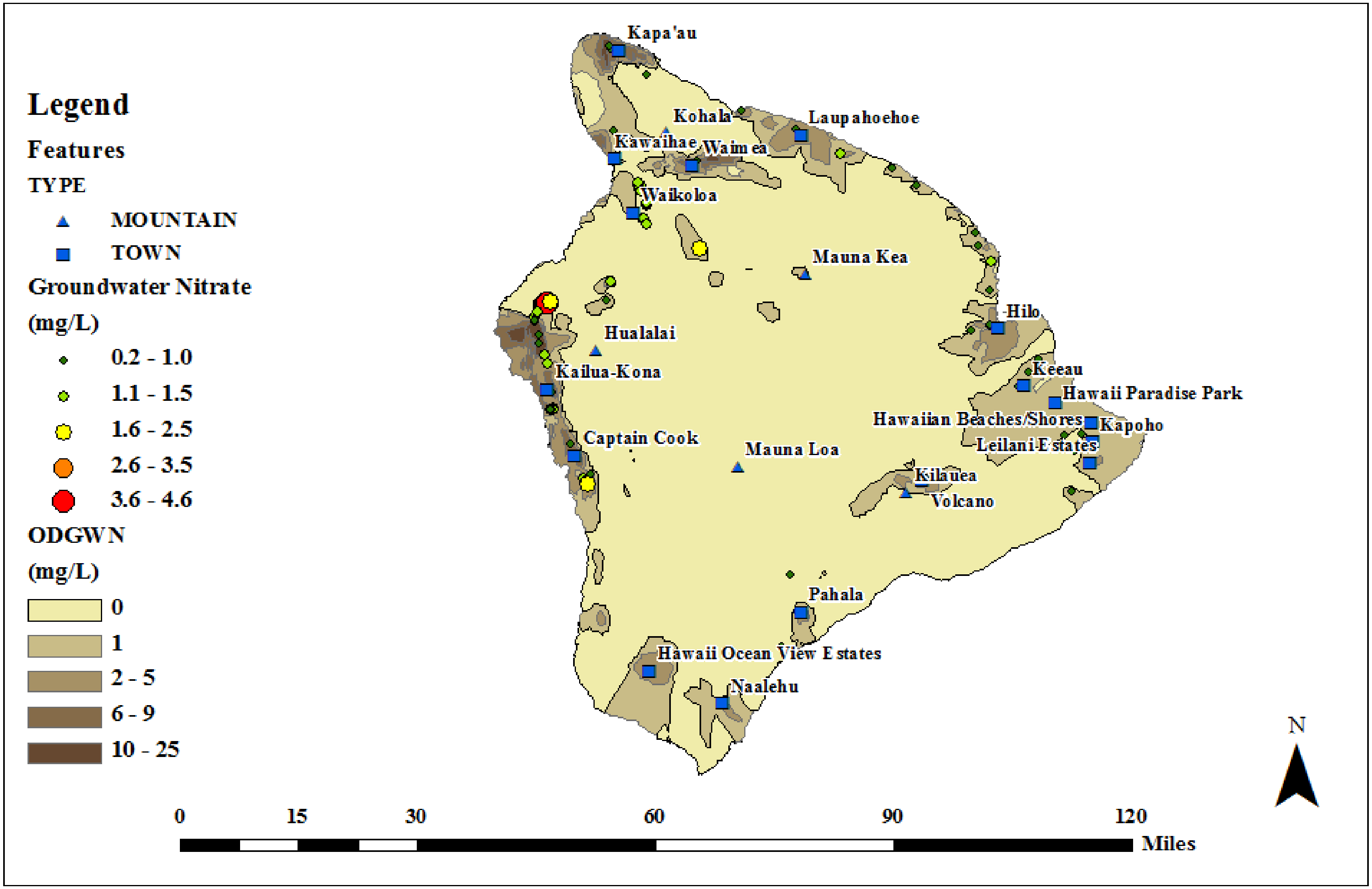

Figure 9-1. Drinking water well nitrogen concentrations compared to the modeled ODGWN for Hawaii

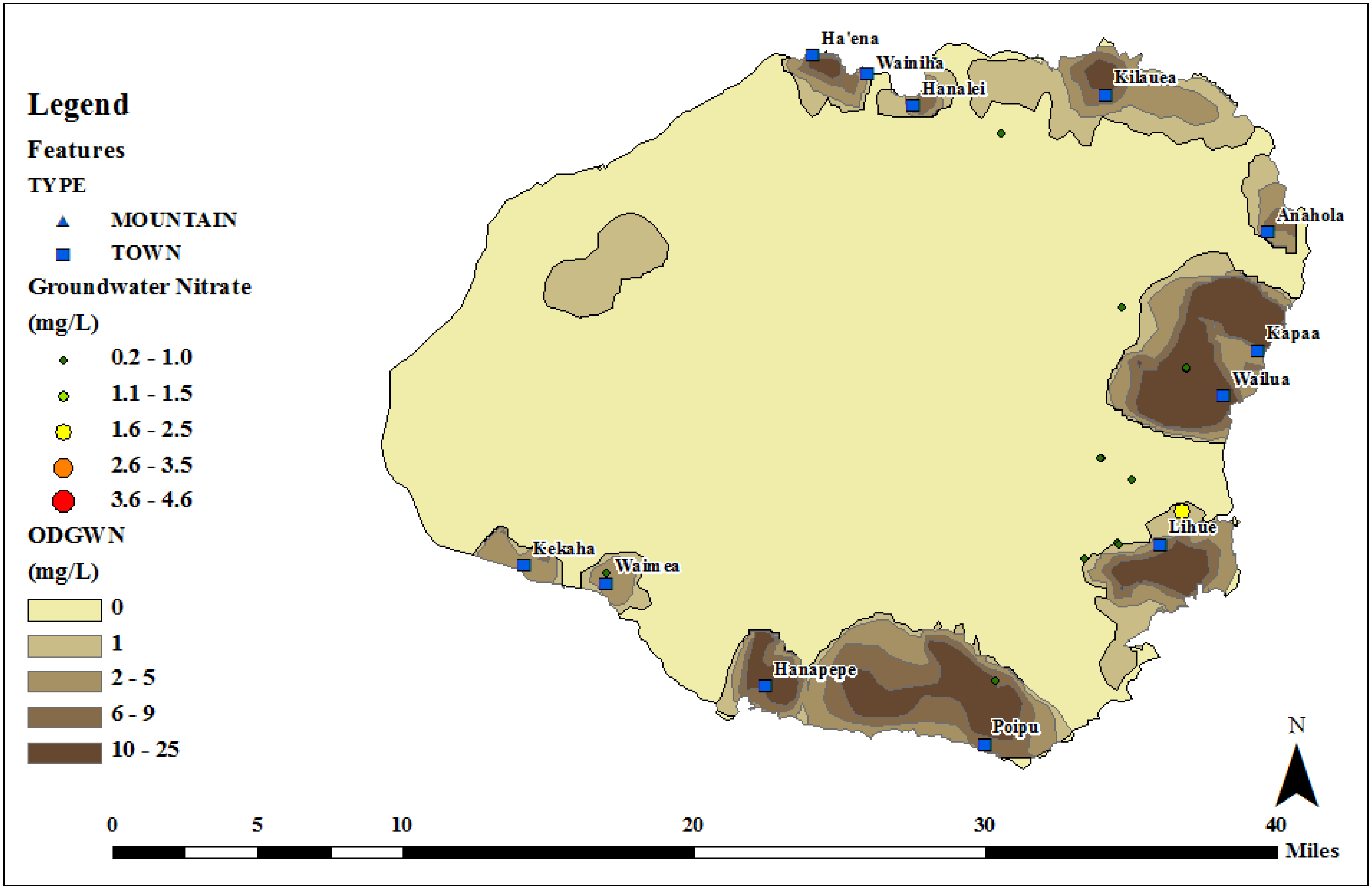

Figure 9-2. Drinking water well nitrogen concentrations compared to the modeled ODGWN for Kauai

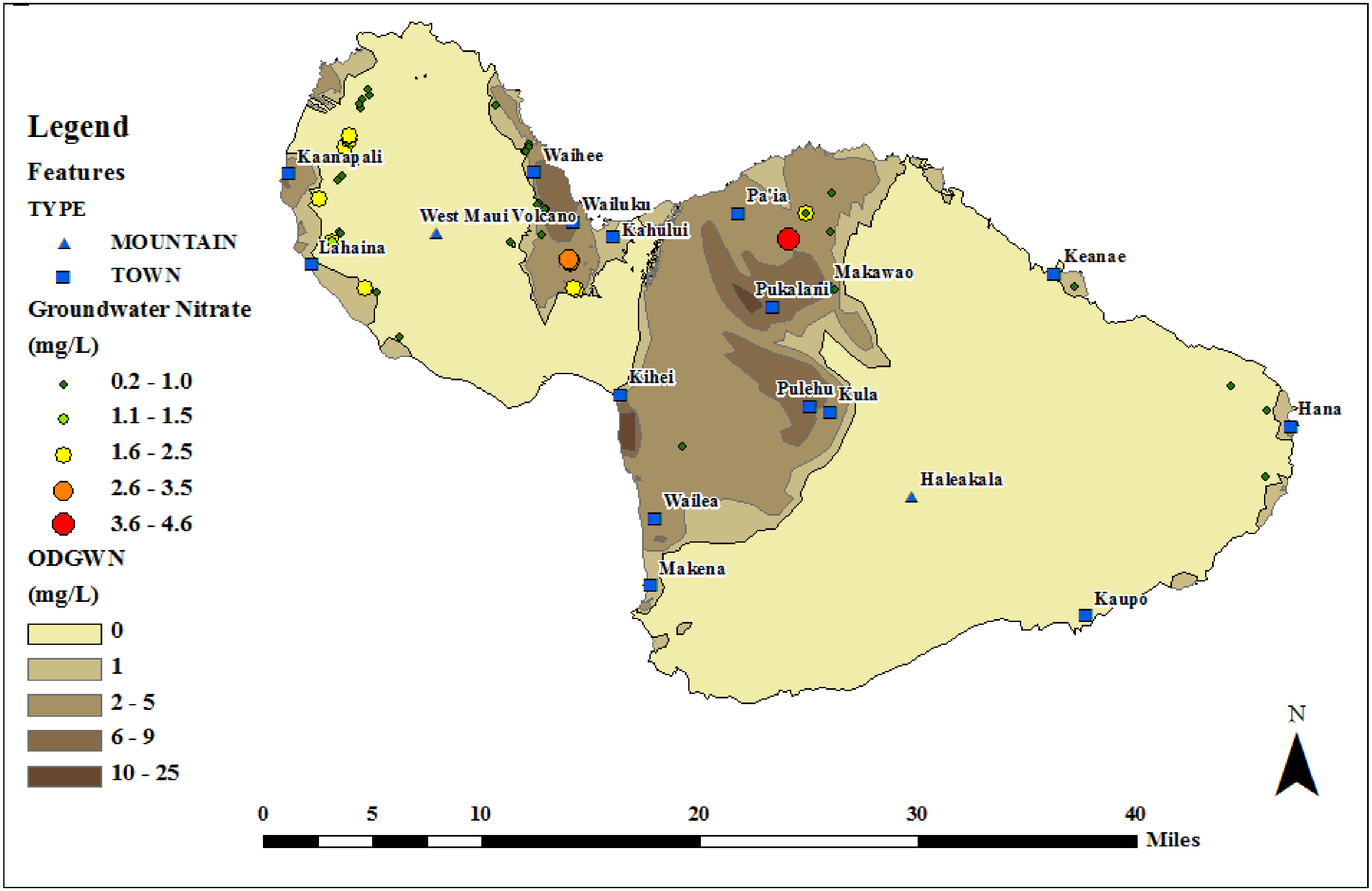

Figure 9-3. Drinking water well nitrogen concentrations compared to the modeled ODGWN for Maui

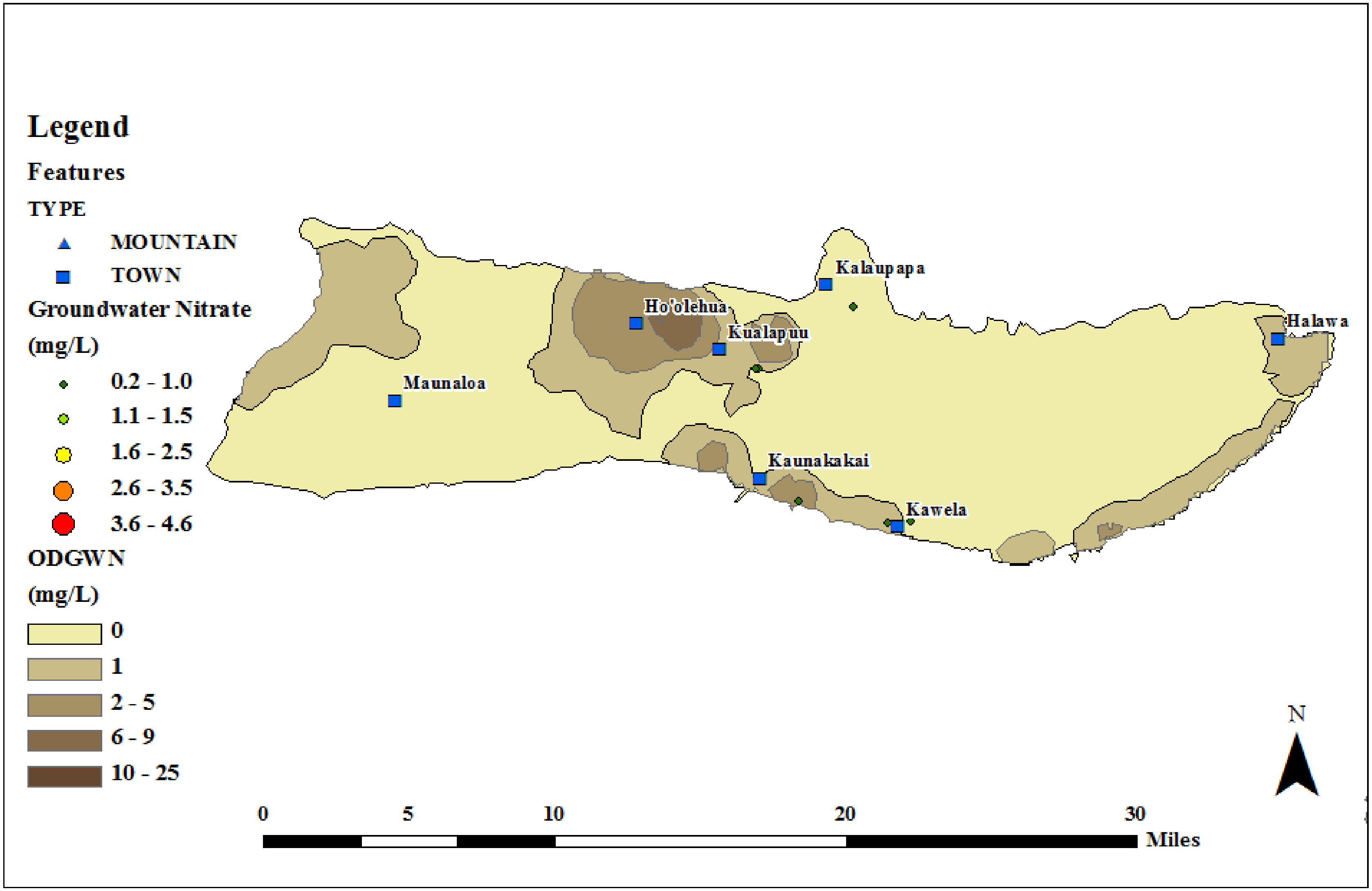

Figure 9-4. Drinking water well nitrogen concentrations compared to the modeled ODGWN for Molokai

9.1.2 ODGWN and Coastal $\delta^{15}N$

As described in Section 9.1.1, groundwater nitrogen concentrations alone are a poor indicator of OSDS impact on an aquifer. The ODGWN signature appears to be overwhelmed by nitrogen leaching from agricultural fields. Agricultural leaching of nitrogen will continue for the foreseeable future so other methods need to be considered to confirm any impact that OSDS may have on groundwater. Nitrogen derived from wastewater sources differs isotopically from agricultural nitrogen. Nitrogen from mammal waste sources is enriched in the ^{15}N isotope. The enrichment is presented as the ratio of ^{15}N:^{14}N in the water being evaluated compared to the same ratio for seawater (Kendall, 1998) and expressed as $\delta^{15}N$ in units of parts per thousand ($^{o}/_{oo}$). Natural sources of nitrogen have $\delta^{15}N$ value that varies from -4 to 4$^{o}/_{oo}$. The range for fertilizers is commonly from 0.0 to 4.0$^{o}/_{oo}$. Wastewater values are enriched in ^{15}N with a $\delta^{15}N$ of 7.0 to 38$^{o}/_{oo}$ (Dailer et al., 2010; Kendall, 1998). Dailer et al. conducted a coastal survey of marine nitrogen isotope distribution for Maui (Dailer et al., 2010, 2012) and West Hawaii (Dailer et al., 2013) using algal bioassays. We compared the results of these studies to the modeled distribution of coastal ODGWN. The $\delta^{15}N$ values were broken down into two categories: (1) values less than or equal to 7$^{o}/_{oo}$; and (2) values greater than 7$^{o}/_{oo}$, indicating a probable wastewater contribution.

Factors that affect the utility of using $\delta^{15}N$ as an indicator of OSDS impact include coastal groundwater flux, loading from other sources of nitrogen, oxidation/reduction (redox) condition of the groundwater, coastal preferential flow paths, and magnitude of the ocean currents. In areas of low coastal groundwater flux the $\delta^{15}N$ signal can quickly become diluted in by the lower isotopic weight nitrogen of a large oceanic reservoir. Unlike municipal injection of wastewater where a large volume of heavy isotope nitrogen enters the aquifer in small area, the effluent flux from communities utilizing OSDS distributes the effluent over a much larger area. These communities commonly occur in former or current agriculture land. The location of OSDS in these types of areas complicates that evaluation of OSDS impact on groundwater. Leaching of fertilizer nitrogen may overwhelm the nitrogen isotope signal from the OSDS effluent. The redox condition of the aquifer can cause the fertilizer nitrogen isotopic signature to mimic that of wastewater. Under anoxic or suboxic conditions, nitrogen in the form of nitrate is reduced through a series of chemical reactions to nitrogen gas (Wilhelm et al., 1994). During the conversion from nitrate to nitrogen gas the bacteria preferentially utilize the lighter nitrogen isotopes, thus enriching the remaining effluent in ^{15}N (Kendall et al., 1998). This results in a heavy nitrogen isotope signature such as was encountered is the submarine discharge points for the Lahaina Wastewater Reclamation Facility injected wastewater. Under oxidizing conditions, there is no enrichment of ^{15}N due to denitrification, making the $\delta^{15}N$ signal from wastewater easier to detect.

On Maui the elevated $\delta^{15}N$ ratios occur in three primary areas: Waiehu/Wailuku/Kahului area; Kihei to Makena area; and the Kaanapali area of West Maui. Figure 9-5 shows the distribution of algal $\delta^{15}N$ and the ODGWN for Maui. At each of the three elevated $\delta^{15}N$ locations municipal wastewater treatment plants inject treated wastewater into the brackish or saline zones of the groundwater. Much of the elevated algal $\delta^{15}N$ is due to this wastewater injection (Hunt, 2006; Hunt and Rosa, 2009; Glenn et al., 2012 and 2013). There are however; areas of elevated algal $\delta^{15}N$ that occur closer to the zones of elevated ODGWN than to the location of a municipal wastewater injections. For example, Figure 9-6 shows the algal $\delta^{15}N$ and ODGWN for the Waiehu/Wailuku/Kahului region. There are three locations with $\delta^{15}N$ values greater than 7. Two are located near the Kahului Wastewater Reclamation Facility injection well. The third was located adjacent to an area with modeled ODGWN concentrations that were above background levels (greater than 1 mg/L). In the Kaanapali/Lahaina area, there were five elevated algal $\delta^{15}N$ values (Figure 9-7). The two highest values result from the submarine groundwater discharge of treated wastewater from the Lahaina Wastewater Reclamation Facility (Glenn et al., 2013). Three other elevated algal $\delta^{15}N$ values occur south of the treated wastewater impact zone. These points correlate well with a zone of elevated ODGWN from cesspools in the Wahikuli area. In the Kihei to Makena area (Figure 9-8) there were three elevated $\delta^{15}N$ values. The one near Kihei is adjacent to an area of elevated ODGWN. Further south, an elevated $\delta^{15}N$ value occurred near the injection wells for the Kihei Wastewater Reclamation Facility. An elevated $\delta^{15}N$ value also occurred in the Makena area. The reason for the third elevated $\delta^{15}N$ value is not known because there is no wastewater injection well or elevated ODGWN near that location.

A similar study was done along the west coast of the island of Hawaii (Dailer et al., 2013). Figure 9-9 shows the algal $\delta^{15}N$ sampling locations. Figure 9-10 shows the extent of the elevated $\delta^{15}N$ values and the ODGWN in the North Kona area while Figure 9-11 shows the same for the South Kona area. In North Kona all $\delta^{15}N$ values that exceeded $7^{o}/_{oo}$ are located near wastewater injection wells, such as the injection well near Kawaihae. In the South Kona area the elevated $\delta^{15}N$ values also occur near wastewater injection wells. There are zones of high ODGWN just north of Kailua-Kona, where modeling predicted ODGWN concentrations of 6 to 9 mg/L, but there were no corresponding elevated $\delta^{15}N$ sample locations. Unlike on Maui, there is no correlation between $\delta^{15}N$ values indicative of wastewater and the modeled ODGWN concentrations greater than 1 mg/L. Disposal of wastewater into injection wells is the most likely cause of the elevated $\delta^{15}N$ values along the coast of West Hawaii Island.

The spatial correlation between elevated algal $\delta^{15}N$ and ODGWN is mixed. On Maui there did appear to be a correlation between elevated ODGWN concentrations predicted by the modeling with elevated $\delta^{15}N$ values collected from algal bioassays. However, on Hawaii Island no such correlation was found. There is a good spatial correlation between wastewater injection wells and elevated algal $\delta^{15}N$ on both islands. There are, however, even exceptions to this correlation. A series of wastewater injection wells in the Maalea area of Maui (Figure 9-5) and near Captain Cook (Figure 9-11) on Hawaii Island have no corresponding elevated $\delta^{15}N$ values at the coast. In summary, there is some correlation between the algal $\delta^{15}N$ values and the modeled ODGWN concentration, however, the correlation seems to be island specific to Maui. There are areas such Waiehu, Maui where nitrogen in effluent from OSDS is the most likely cause of the elevated algal $\delta^{15}N$. On the island of Hawaii elevated $\delta^{15}N$ values correlated most strongly to wastewater injection wells. Even in areas where modeling predicted highly elevated ODGWN concentrations, there was no elevated $\delta^{15}N$ unless wastewater injection was occurring nearby. However, even in the vicinity of the injection wells, there are low $\delta^{15}N$ values interspersed with elevated $\delta^{15}N$ values. This could be the result of the injectate taking preferential flow paths to the coast. This hypothesis is strengthened by the TIR surveys that were done over West Hawaii showing point zones of higher ground flux (Johnson et al., 2008). Areas where groundwater preferentially discharges reduces the seawater dilution effect and increases the likelihood of detecting an isotopic signature indicative of wastewater effluent.

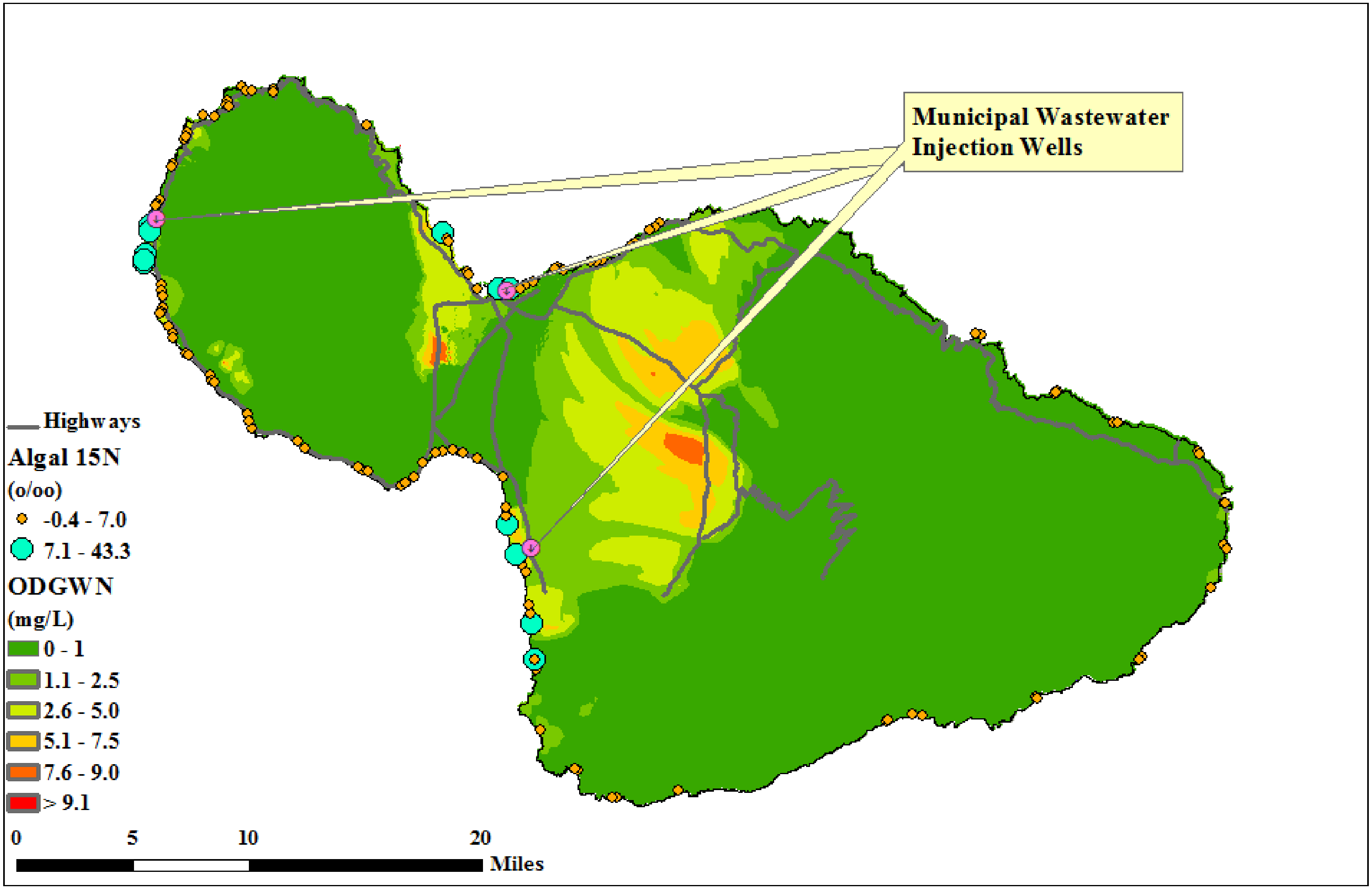

Figure 9-5. The algal $\delta^{15}N$ and ODGWN distribution for the island of Maui

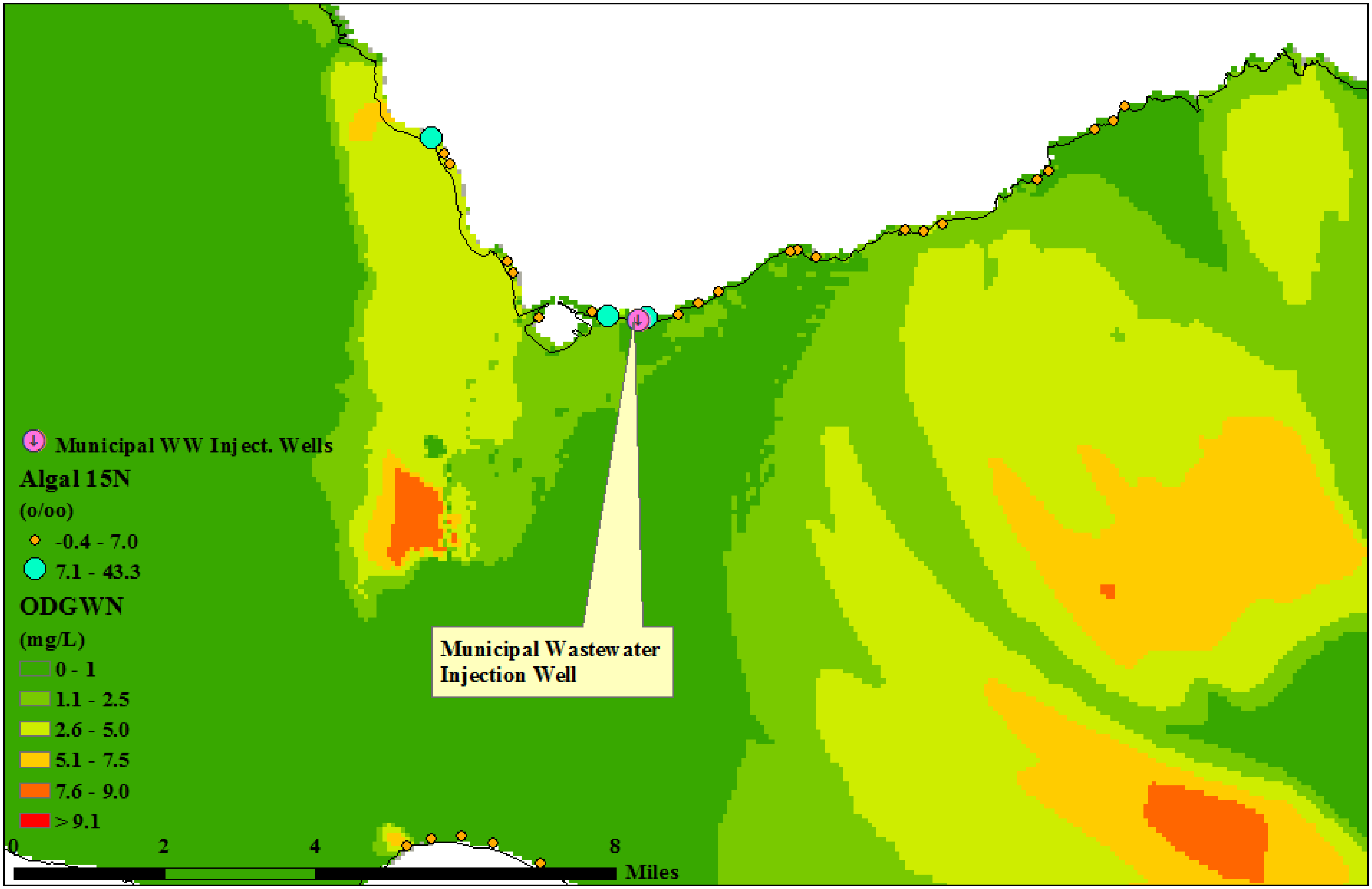

Figure 9-6. The algal $\delta^{15}N$ and ODGWN distribution for the Waiehu/Wailuku/Kahului region of Maui

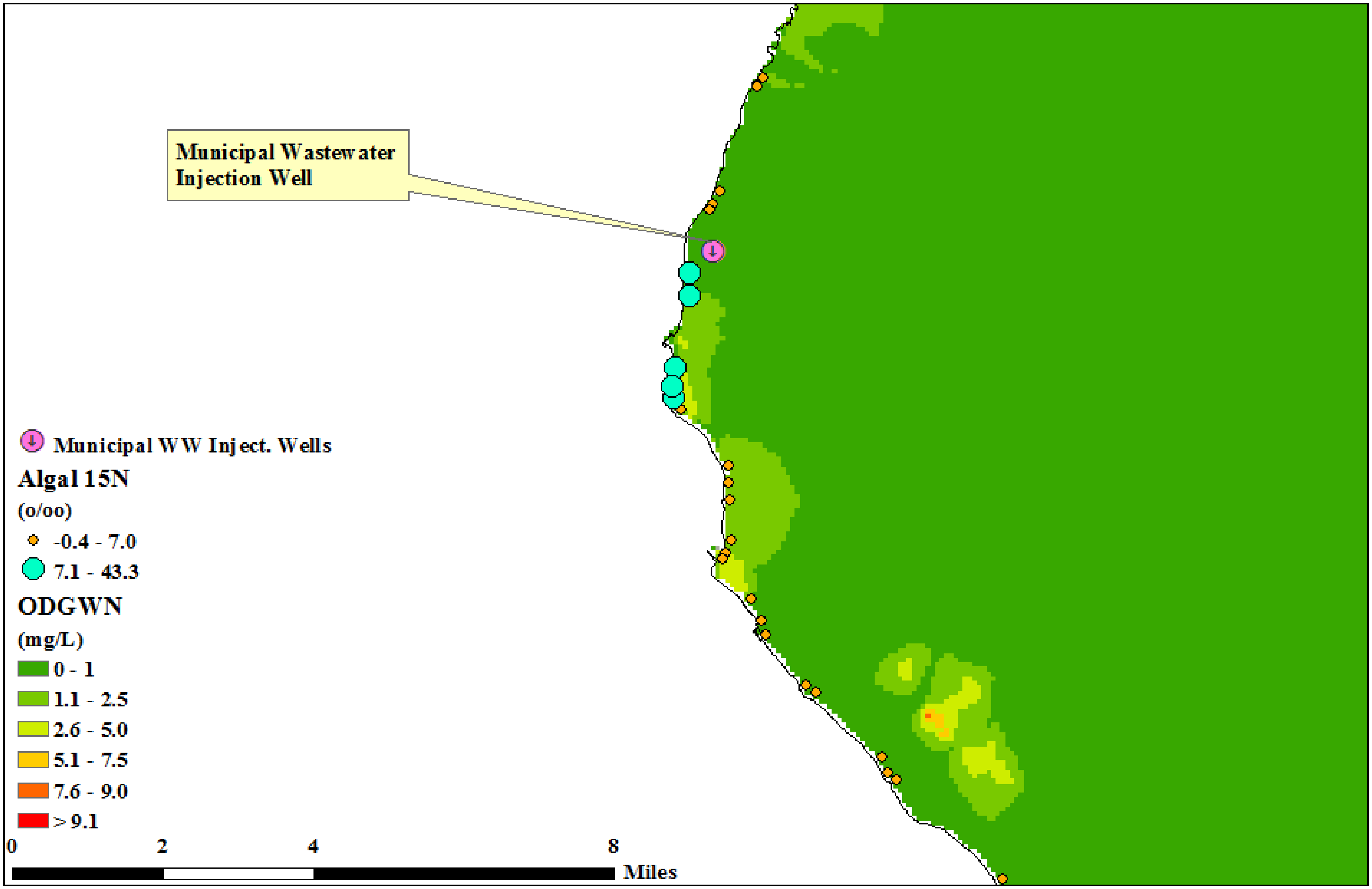

Figure 9-7. The algal $\delta^{15}N$ and ODGWN values for the Kaanapali and Lahaina regions of Maui

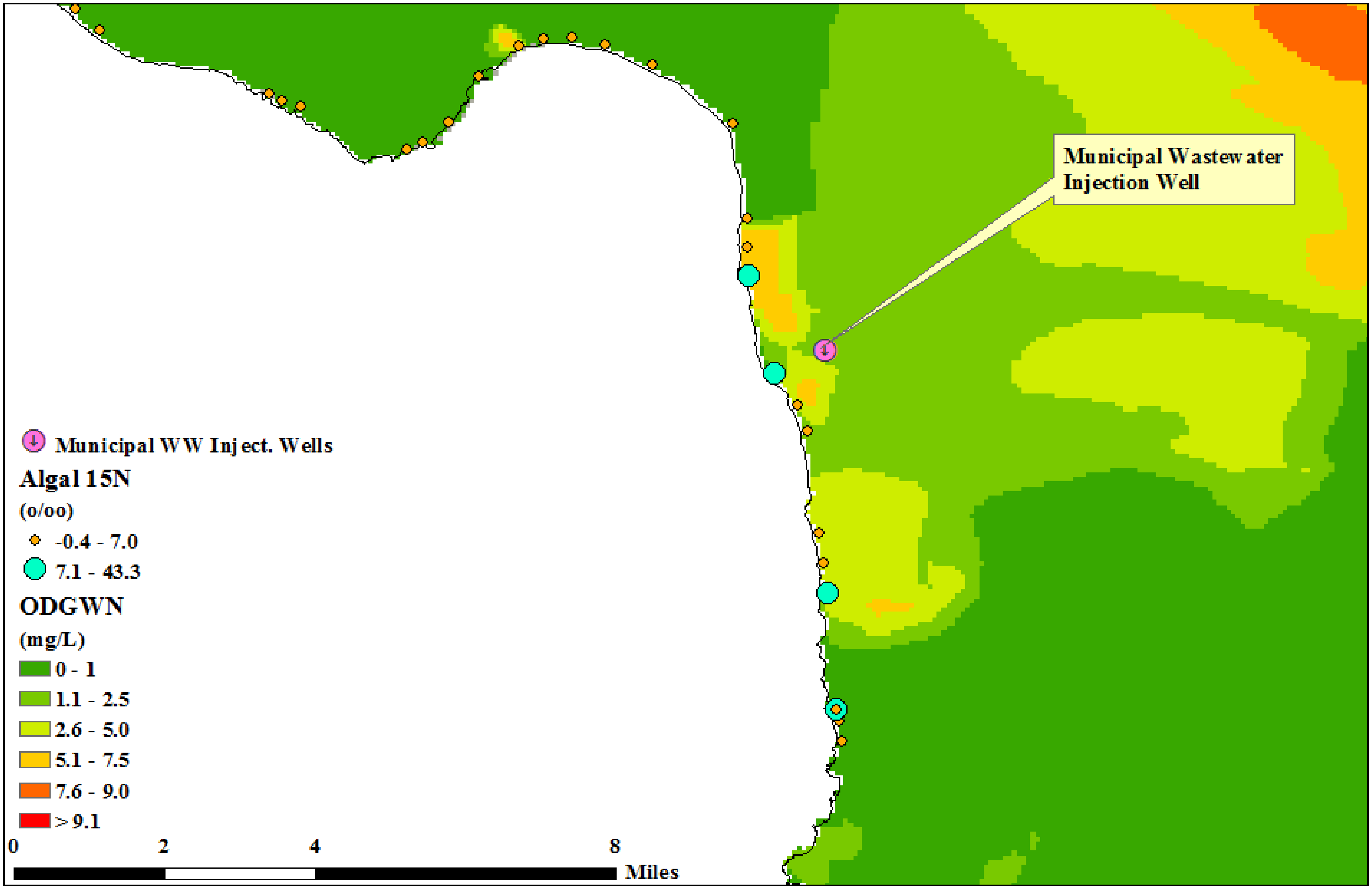

Figure 9-8. The algal $\delta^{15}N$ values for the Kihei to Makena area of Maui

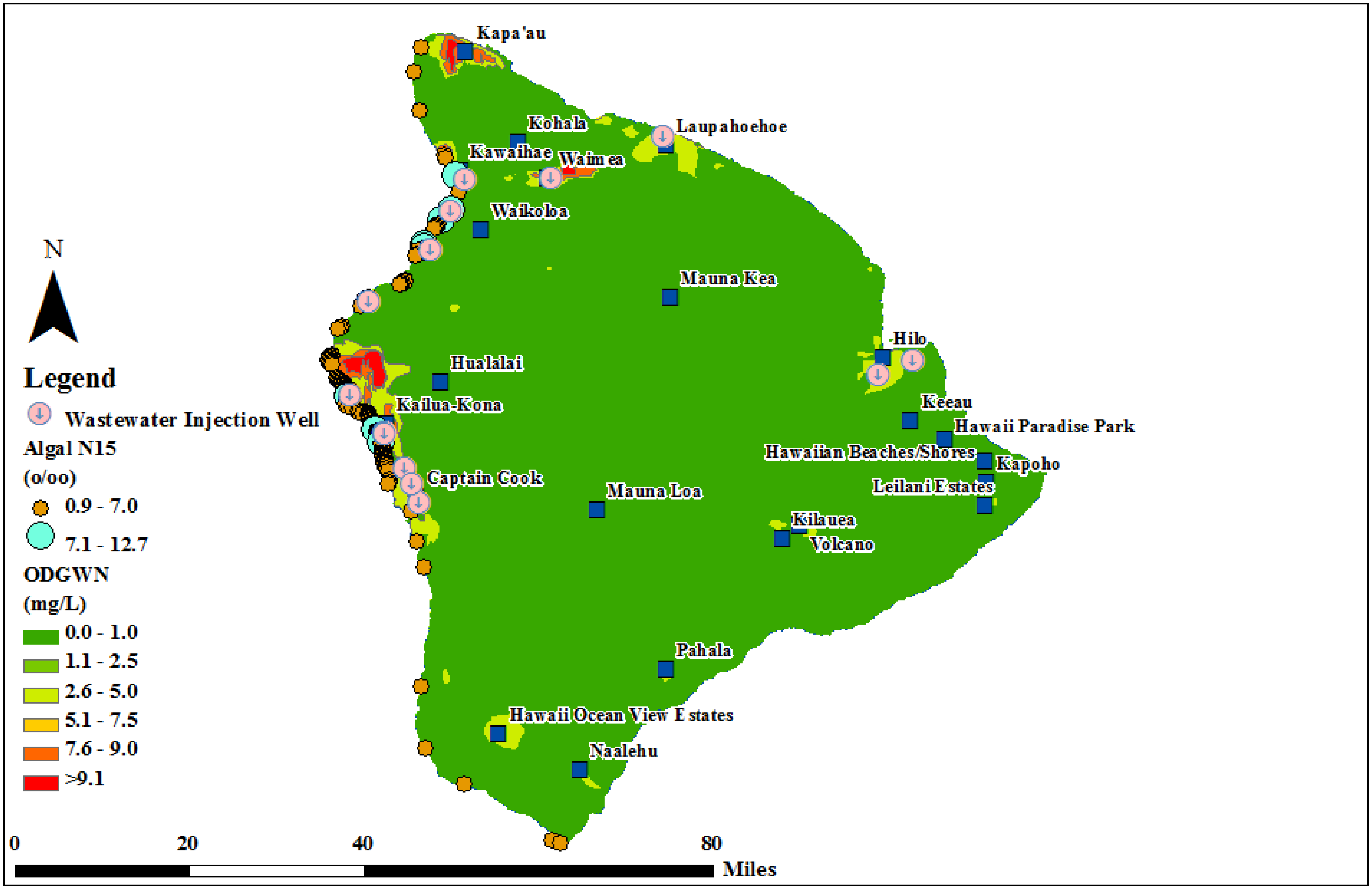

Figure 9-9. The ODGWN concentration and $\delta^{15}N$ distribution for Hawaii Island

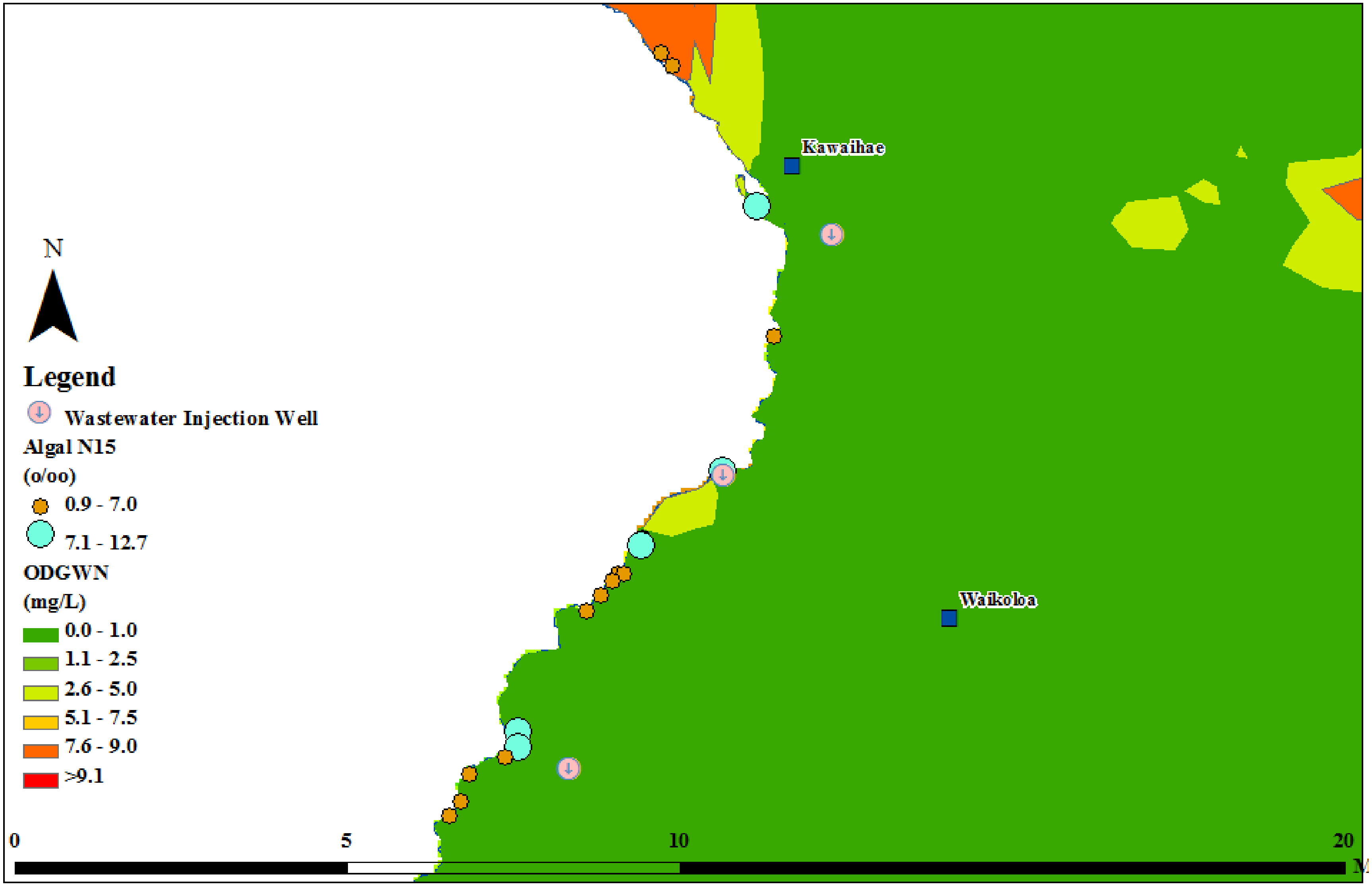

Figure 9-10. The algal δ^{15}N sampling locations and the ODWGN in the North Kona area

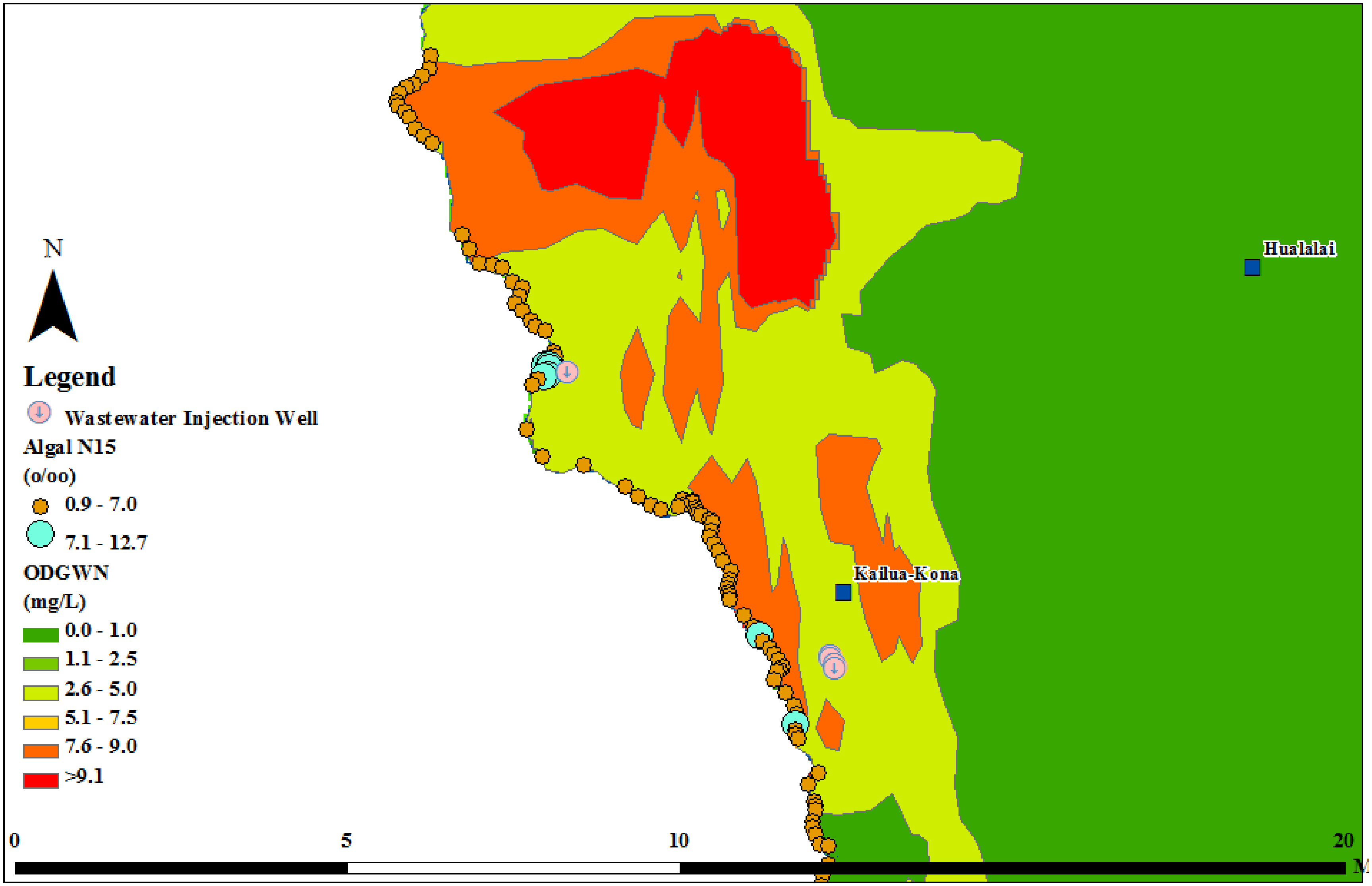

Figure 9-11. The algal δ[15]N sampling locations and the ODWGN in the South Kona area

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9.2 CONCLUSIONS

Conclusion 1. The potential for OSDS effluent to adversely impact human health and the environment is significant.

This study estimated that nearly 70 mgd of wastewater effluent is discharged to the environment with no or limited treatment. This study identified areas with high concentrations of OSDS that have significant potential for health and environmental risk. The groundwater modeling indicates that dilution by natural groundwater flow is not sufficient to reduce the nutrient concentrations to acceptable levels. Problematic levels are defined as nitrogen concentrations resulting from OSDS effluent discharge that can result in an exceedance of drinking water standards or the Clean Water Standards. This study assumed no natural remediation of the OSDS effluent once it leaves the zone of treatment. This is a conservative assumption, because there are many areas with thick soil cover where the effluent from cesspools will undergo natural remediation as it infiltrates down to the water table (Dawes and Goonetilleke, 2003). A review of actual groundwater nitrogen data and coastal $\delta^{15}N$ algal samples showed mixed results with some correlation between the modeled ODGWN and actual groundwater nitrogen and elevated $\delta^{15}N$ ratios. The disparity between the modeled and actual water chemistry may be due to natural attenuation of the effluent that was not accounted for in the models, or due to the long travel time between the points of effluent release and arrival at a sampling point. Consequently, the core of the effluent plume may not have reached the point of sample collection. Thus it is important to subject the water in the modeled high ODGWN areas to increased surveillance to detect and possibly correct any degradation of groundwater quality due to OSDS leachate.

Conclusion 2. Groundwater modeling can be used to identify areas most at risk from adverse OSDS impacts.

The adverse groundwater impact from OSDS may be mitigated by dilution from upgradient groundwater flux or from other recharge. The ROCs that receive contaminated groundwater may be significant distances away from the OSDS location that is the source of the contamination. Groundwater modeling accounts for dilution by recharge and the inflow of upgradient groundwater, and identifies the travel path and points of groundwater emergence to the surface. The source location, travel path, dilution, and point of emergence are critical in identifying impacted ROCs and in identifying the OSDS responsible for that impact. The ODGWN transport can assist environmental managers and planners when prioritizing OSDS mitigation efforts.

Conclusion 3. Physical evidence for adverse OSDS impact is inconclusive and a comprehensive chemical survey should be done for areas with the highest modeled OSDS impact.

Groundwater modeling can identify areas where adverse environmental impact is likely to occur, but more research is needed to assess to what degree OSDS effluent is negatively affecting the environment. The groundwater modeling shows a significant potential for adverse OSDS impact with ODGWN concentrations high enough to exceed drinking water standards and cause problematic nutrient loading in surface and nearshore waters. A primary factor for the inconclusive link between OSDS and degraded groundwater quality is the limited data sets used. However, limited positive correlation exists between measured groundwater nitrogen and modeled ODGWN and between coastal $\delta^{15}N$ in bioalgal assays and the nearshore modeled ODGWN. Due to the potential for adverse impact from OSDS leachate, a more comprehensive chemical survey should be done to investigate any OSDS caused groundwater degradation in the high impact areas delineated by this study.

9.3 RECOMMENDATIONS

This study identified those areas where OSDS have greatest potential adversely impact the groundwater. A field study should be undertaken to investigate to what degree the groundwater is being degraded by OSDS leachate. Preference should be given to following areas:

- where the OSDS density is high;
- where this high density has existed for a significant time making the time of travel in the unsaturated zone less of a factor;
- where there is no intervening perched water to intercept the leachate or if perched water is present, that there are sufficient sampling points in the perched water zone;
- where a sufficient number of sampling points exist (an area with domestic wells should meet this criteria);
- that have background sampling point(s) unaffected by OSDS leachate; and
- where the agricultural contribution to groundwater is minimal so the chemical signature of the OSDS leachate is not masked.

This type of study requires that many samples be taken, necessitating a tiered approach to control cost. Analysis costs for many of the wastewater tracers are expensive. The key tracers with high costs include pharmaceuticals and isotopic composition, limiting the number of samples that can be analyzed for these parameters. To optimize the resources invested, a phased approach should be taken includes:

- broad based field screening program that would include primary water quality parameters (pH, specific conductivity, oxidation/reduction potential, and temperature, optical brighteners, and chloride);
- based on the field screening, submit samples for laboratory analysis that would include all major ions, boron, nutrients, and fluorescent scans; and
- from the results of the previous two analysis suites, select samples (that will include background) for advanced analysis that will include, at a minimum, $\delta^{15}N$ and pharmaceuticals.

Finally, this study assessed the limitations of the ability of the soil to properly remediate OSDS effluent. Consideration should be given to incorporating the results of the OSDS soil limitation evaluations in the review process for OSDS permits. Areas where the soil can’t properly remediate the OSDS effluent would benefit from more treatment requirements for their systems.

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APPENDIX A: On-Site Sewage Disposal Shapefiles for Kauai, Maui, and Molokai

Provided on Compact Computer Disk