HUMAN AND ENVIRONMENTAL RISK RANKING OF ONSITE SEWAGE DISPOSAL SYSTEMS

Final

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ACRONYMS

^{o}C	Degrees Celsius
d	day
DBEDT	Department of Business, Economic Development, and Tourism
DEWALT	
ET	evapotranspiration
FEMA	Federal Emergency Management Agency
ft	feet
ft msl	Feet above mean sea level
gpd	gallons per day
GWUDISW	Groundwater under the direct influence of surface water
HAR	Hawaii Administrative Rules
HDOH	Hawaii Department of Health
IWS	Individual Wastewater System
in/yr	Inches per year
mi^2	square mile
MCL	maximum contaminant level
mgd	Millions gallons per day
mg/L	milligrams per liter
NO_3	nitrate
NO_3-N	nitrate as nitrogen
NRCS	Natural Resources Conservation Service
OSDS	on-site sewage disposal system
OSWTCS	Off-site wastewater treatment and collection system
ROC	receptor of concern
SWAP	Source Water Assessment Program
TMDL	Total maximum daily load
TMK	tax map key
TOT	time of travel
USEPA	U. S. Environmental Protection Agency

USGS	U.S. Geological Survey
WRRC	Water Resources Research Center
yr	year

EXECUTIVE SUMMARY

This study evaluated the human health and environmental risk posed by on-site sewage disposal systems (OSDS). Oahu, Hawaii, was chosen as the study area for this project to develop and implement the methodology that will be applied to other islands in the future. The specific objectives of this study were to:

- Estimate the quantity and types of OSDS on Oahu;
- Estimate the effluent load discharged to the environment by these systems;
- Identify which individual critical receptors (drinking water sources, streams and near shore waters) are most impacted by OSDS;
- Identify other factors contributing to potential risk of OSDS;
- Develop a risk scoring scheme based on various factors to assist regulatory managers in prioritizing inspection efforts for OSDS; and
- Assign a risk score to each OSDS.

INTRODUCTION

The risk that sewage effluent released to the environment poses to human health and the environment is well documented. Studies assessing human health risks from wastewater include Hrudey and Hrudey (2007) who reviewed cases of waterborne disease outbreaks in developed countries tabulating 75 outbreak cases. Wastewater contamination was identified as the major cause in 40 of those cases. Typical of these cases was an outbreak that involved an OSDS occurred at the Washington County Fair, New York State in 1999 (Novello, 2000) resulting in two deaths. The suspected source of the pathogens was a septic tank seepage pit located 38 feet (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 or *Camplyobacter jejuni* (C. jejuni) were confirmed and a follow-up survey indicated that at least 2,800 people were infected. 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.

OSDS effluent can degrade the environment by increasing the biologic productivity in streams and near shore waters. Nitrate and phosphate, both enriched in OSDS effluent, are the most common limiting nutrients in these 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). Excessive growths of macroalgae that covered the reef slopes and the outer reef flats in

Kaneohe Bay decreased substantially 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 have concluded that sewage related sources are a significant factor in algae blooms off Kihei and Lahaina, Maui (Honolulu Advertiser, 2009). Although the Kihei and Kaneohe Bay examples involve municipal waste water, 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.

STUDY AREA

Located between 157^{o} 39' and 158^{o} 17' west longitude, and 21^{o} 15' and 21^{o} 45' north latitude, Oahu lies near the middle of the Pacific Ocean far from any continental land mass, and is part of an island chain that is formed as the Pacific Tectonic Plate passes over a mid-ocean hotspot. Oahu was formed by two volcanoes, the Koolau Volcano to the east and the Waianae Volcano to west. The lavas of these volcanoes coalesced forming the Central Oahu corridor, a broad saddle between mountains formed by these volcanoes.

Oahu is the State of Hawaii's major urban center, having a population of nearly 900,000 out of a state wide population of approximately 1,200,000 (Department of Business and Economic Development and Tourism [DBEDT], 2004). The majority of Oahu's population is concentrated along southern coastal plain from east end of the island to the Ewa Plain on the southwest portion of Oahu. There are smaller urban centers elsewhere on the island with such as Mililani and Waipio where former sugar cane and pineapple lands were converted to residential development. These urban areas are served by sewer systems, but smaller urban areas and rural communities utilize on-site disposal of wastewater. Figure ES-1 shows those areas served by sewer systems in green while those where no sewer service is available are shown in red.

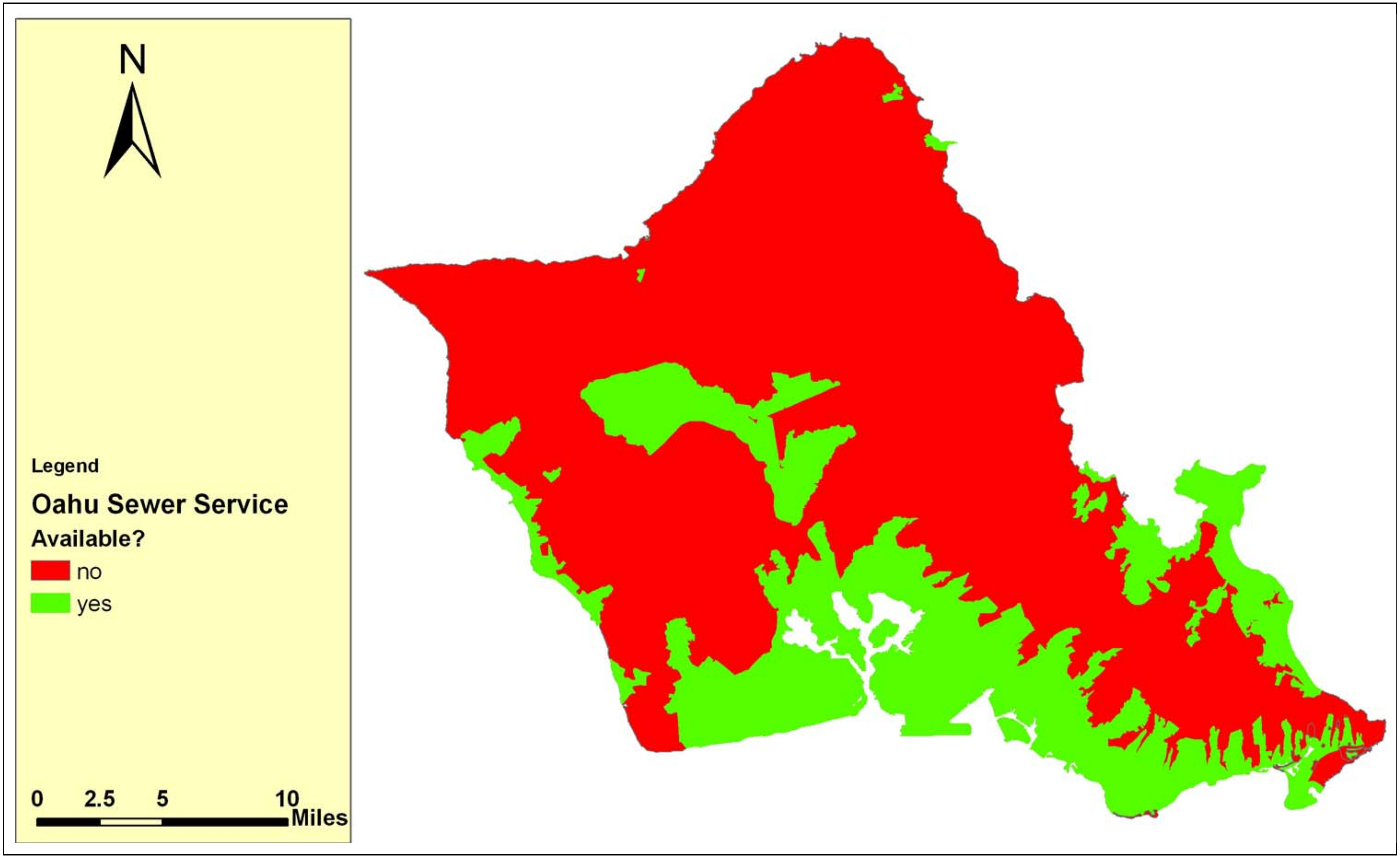

Figure ES-1. Map of Sewer Status on Oahu

EVALUATION OF FACTORS AFFECTING OSDS ENVIRONMENTAL AND HEALTH RISK

The five steps used to evaluate OSDS risk included:

1. quantifying the effluent characteristics of each major category of OSDS;
2. identifying areas where risk to human health or degradation of the environment would occur if OSDS effluent constituents were present;
3. delineating buffers around potential risk areas;
4. tabulating the number and types of OSDS in the buffers; and
5. evaluating the ability of the environment to mitigate the risk posed by OSDS effluent.

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 and the overwhelming majority have not been transferred to an electronic database. The sheer numbers of cards and obsolete records make using this data set impractical for accurately estimating the numbers identifying types of systems. The number and spatial distribution of OSDS were estimated by utilizing data directly from available electronic sewage disposal databases and indirectly from Tax Map Key (TMK) information, sewer, Honolulu Board of Water Supply billing, and parcel/structure databases. The TMK number was the common field in each data set and was used as the key identifier for this study.

The next major data source was the electronic records of approved Individual Wastewater System (IWS) permits. IWS permit information was obtained from the Department of Health Wastewater Branch's database. 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, and TMK where OSDS is to be constructed or upgraded. This information was joined to the TMK parcel information using the 8-digit TMK as the common field. Table ES-1 correlates the OSDS class used by this study to the IWS classifications in the database. 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.

Table ES- 1. OSDS Class 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.
Class III	Aerobic units discharging to a seepage pit.
Class IV	All cesspools

Using these categories of OSDS, concentrations of nitrogen, phosphorus, and fecal coliform bacteria were estimated based on data in the Onsite Wastewater Treatment Survey and Assessment (Water Resources Research Center [WRRC] and Engineering Solutions, 2008). Table ES-2 gives a summary of effluent characteristics based on OSDS type.

Table ES- 2. Effluent Characteristics by OSDS Class

OSDS Class	Typical Nitrogen Concentration (mg/L as nitrogen)	Typical Phosphate Concentration (mg/L as phosphorus)	Typical Fecal Chloroform Concentration (colony forming units [CFU]/100 mL)	SOURCE (WRRC and Engineering Solutions, 2008)
Class I	1	2	13	Soil treatment, Table 4-1, page 4-6
Class II	36	13	1.00E+06	Septic Tank to seepage pit, Page 5-9
Class III	24	8	1.00E+06	Aerobic unit, seepage pit disp., Page 5-15
Class IV	60.5	16.5	1.00E+06	Cesspool, Table 4-1, page 4-6

Based on available data, this study estimated the total number of OSDS on Oahu and listed them by type and location. The number of potential OSDS sites was estimated at 13,684. However, many parcels host more than one OSDS which increased the number to an estimated total of 14,606 units. This study also estimates that nearly 10 mgd of sewage is released to the environment, the majority of which reaches the groundwater. Of the estimated quantity of OSDS, cesspools accounted for 77 percent of the total with an estimated release of nearly 7.2 mgd of untreated sewage effluent. Nearly 96 percent of potential nitrogen release from OSDS comes from cesspools (1,660 kg/d out of 1,732 kg/d). Table ES-3 shows the results of this inventory, the effluent volume, and the nutrient discharge flux for each type of OSDS.

Table ES- 3. Estimated Quantities of OSDS on Oahu and the Daily Effluent Output

OSDS Type	Quantity	Daily Effluent (mgd)	Daily N Flux (Kg/d)	Daily P Flux (Kg/d)
Class I	2,620	1.96	7.6	14.9
Class II	534	0.38	51.4	18.5
Class III	199	0.15	13.4	4.5
Class IV	11,253	7.19	1660.0	462.6
Total	**14,606**	**9.67**	**1732.1**	**500.4**

Risk factors include OSDS's position relative to receptors of concern (ROCs), groundwater contamination, soil characteristics, flooding, depth to the water table, and OSDS density. The ROCs considered by this study were drinking water sources, streams, and near shore waters. ROCs can provide a pathway for ingestion of pathogens and contaminants to humans or damage plant and harm coral growth due to an excessive nutrient load. Buffers were delineated around these ROCs using time of travel (TOT) and fixed setback techniques used by the Source Water Assessment Program (SWAP) (HDOH, 1999; and Whittier et al., 2004). Figure ES-2 shows the buffer zones delineated for drinking water sources, while Figure ES-3 shows the buffer zones for streams and near shore areas. Risk was estimated in this study based the distance of the OSDS relative to the buffer zone. Table ES-4 list the quantities of OSDS in each type of ROCs.

Table ES- 4. Summary of OSDS Located in ROCs

	Drinking Water CZD		Stream Buffer	Shoreline	
	Zone b	Zone c		200 ft setback	Two Yr TOT
Class I	80	113	1,058	291	1,908
Class II	15	52	157	39	319
Class III	14	6	64	29	132
Class IV	730	845	3,932	1,110	6,967
Total OSDS	**839**	**1,016**	**5,211**	**1,469**	**9,326**

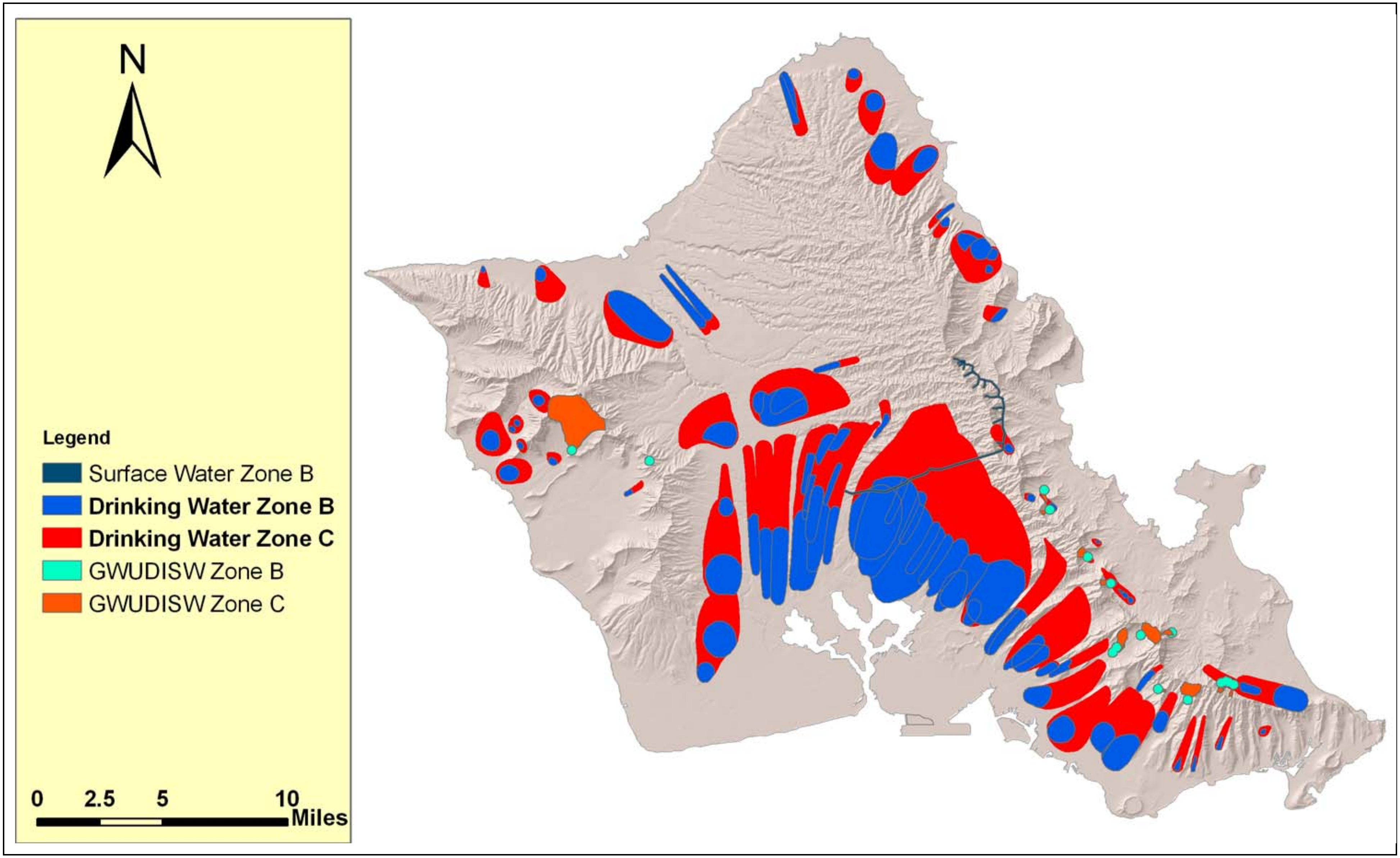

Figure ES-2. Zone B and Zone C Source Area Delineations for Drinking Water Sources

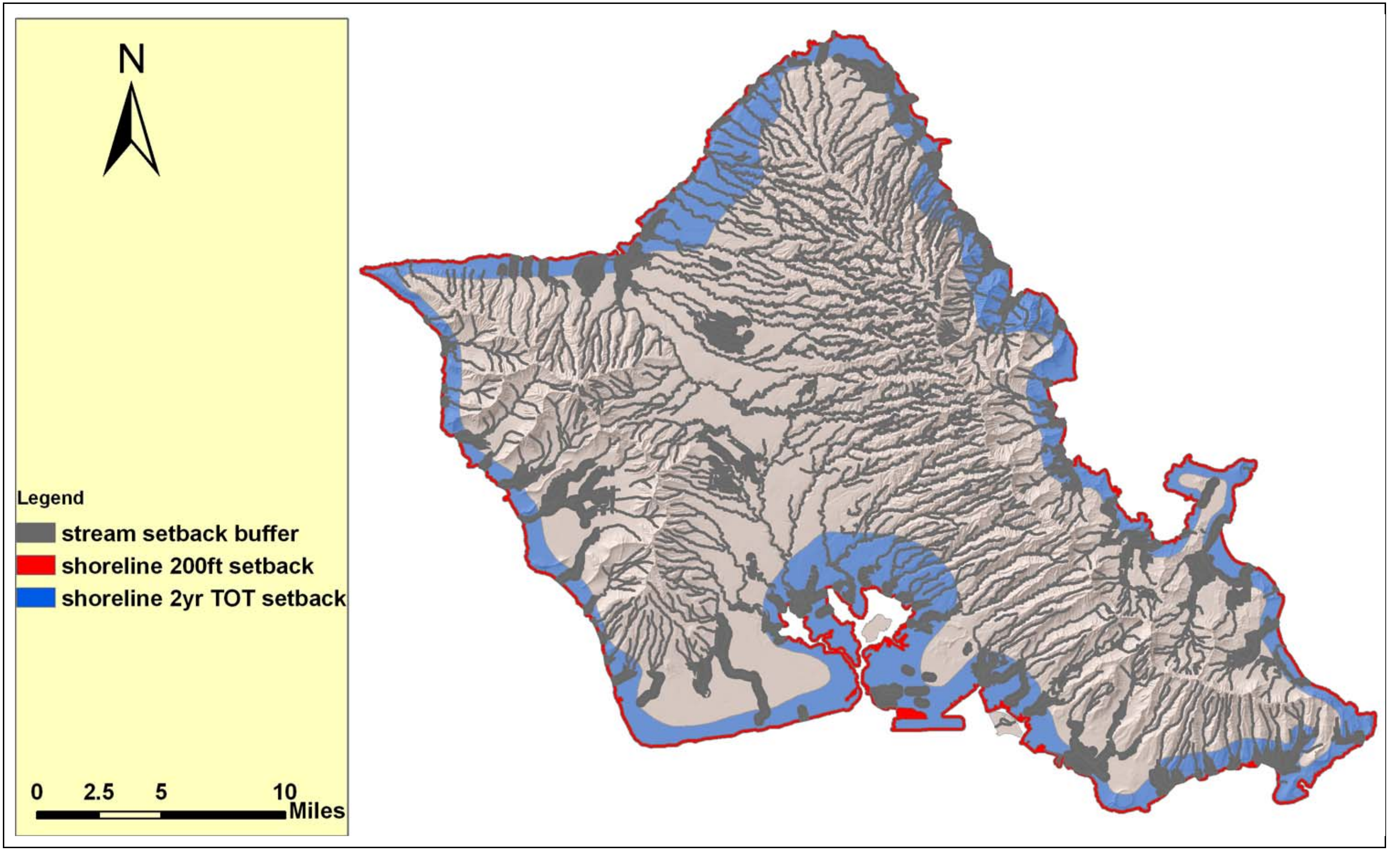

Figure ES-3. Stream and Near Shore Buffer Zones

Groundwater models were used to assess the risk for contamination, using nitrate concentration as a risk indicator. The study estimated a maximum potential increase in nitrate concentration due to OSDS of about 11 mg/L above existing or background values. More importantly, this indicates that OSDS effluent can produce groundwater concentration of nitrate that exceeds the EPA MCL of 10 mg/L for drinking water. Areas of concern on Oahu are Waianae, Waialua, Diamond Head, and the Mokapuu Peninsula where the concentration can exceed the MCL.

Soil provides the primary media for mitigating the undesired impacts of OSDS. Main factors include soil filtration ability and soil thickness. Most of the soils on Oahu provide adequate filtration of OSDS effluent, with the exception of coastal areas, stream valleys, and some inland areas, including Tantalus, Mokuleia, and the Mokapuu Peninsula. This should be alarming considering that these areas include a significant number of OSDS. On the other hand, soil thickness is not a limiting factor regarding the OSDS effluent treatment for most of Oahu. But severe limitations occur in most of the mountain ridge areas. With the exception of eastern Oahu, there are few OSDS located on the mountain ridges. Areas where the soil thickness is inadequate are also located in the Ewa plain and some leeward valleys, and the Kaiwi area of eastern Oahu, where numerous OSDS exist. In addition to soil filtration ability and thickness, other soil risks are related to the ease of water movement, slopes in excess of 6.5 percent, large stone content, and seepage out of the bottom of the soil layer. Nearly all of Oahu shows a limitation due to one or more of these factors. The areas on Oahu of least suitability, as with the other soil factors, are the mountain slopes. The areas of greatest suitability are the Honolulu and Ewa coastal plains. However, as described earlier, the suitability of these areas for OSDS effluent disposal is limited by soil thickness and depth to water considerations.

Flooding can damage septic tanks by buoying tanks, causing structural damage, and more seriously, leading to a mixing of OSDS effluent with flood waters that may result in direct human contact. The areas where the OSDS are most at risk from flooding include much of the southern coastal plain area (Honolulu and Ewa), Waianae Valley, Waialua, the coastal plain in the Kahuku area, and low lying areas in the Kaneohe, Kailua, and Waimanalo districts.

A vertical distance between the ground surface and groundwater (the thickness of the unsaturated zone) greater than 25 ft is needed for proper treatment of the OSDS effluent. Nearly all of the coastal plains, areas of high OSDS density, fail to meet this condition.

The areas with the highest OSDS density on Oahu are Waianae, Waialua, Hauula/Punaluu, Kahaluu, Waimanalo, Honolulu, and Ewa Beach. These areas were identified based on an estimated OSDS density that exceeds 40 units/mi^2, a density estimated by the EPA to have an adverse environmental impact. Honolulu and Ewa Beach are served by sewers, but during the inventory process it could not be confirmed that numerous parcels in these areas were actually connected to the sewer system. Additional investigative effort is needed to clarify this uncertainty.

The spatial distribution of OSDS risk was assessed using a weighted overlay. This was done by "stacking" each of the individual risk rasters, assigning a weight to each factor, then summing the risks in each vertical column of cells. For the resulting grid, the sum was scaled to the span of values from zero, indicating no adverse risk, to a maximum possible score of ten, indicating a location that was evaluated as having the highest risk for all factors considered. There were 12 risk raster data sets created for this model. The factors that assess the risk to human health were given the highest weight. These included drinking water source buffers and stream and shoreline setbacks. Table ES-5 gives the weighting values for each factor. Many of the risk factors were ‘yes-no’ type evaluations represented by a zero for no risk and 100 if a mitigation threshold was not attained. For example, areas where the depth to water was greater than 25 ft were assigned a risk score of zero, while areas where the depth to water was less than 25 ft were assigned a risk score of 100. Other risks were divided into sub-classes. For example, groundwater risk score was assumed to be proportional to the modeled OSDS nitrate concentration.

Table ES- 5. Risk Scoring Model Parameters and Weights

Risk Factor	Weighting Percent	Score
Drinking Water Zone B	14	0, 100
Stream Buffer	11	0, 100
Flood Risk Zones	11	0, 40, 100
Shoreline 200 ft setback	9	0, 100
Depth to Water	8	0, 100
Insufficient Filtration	8	0, 100
OSDS Density	8	1, 10, 60, 100
Groundwater Impact	8	0, 25, 50, 75, 100
Depth to Rock	5	0, 25, 50, 75, 100
Drinking Water Zone C	8	0, 100
Soil Septic Unsuitability	5	0, 25, 50, 75, 100
Shoreline 2 year Setback	5	0, 100

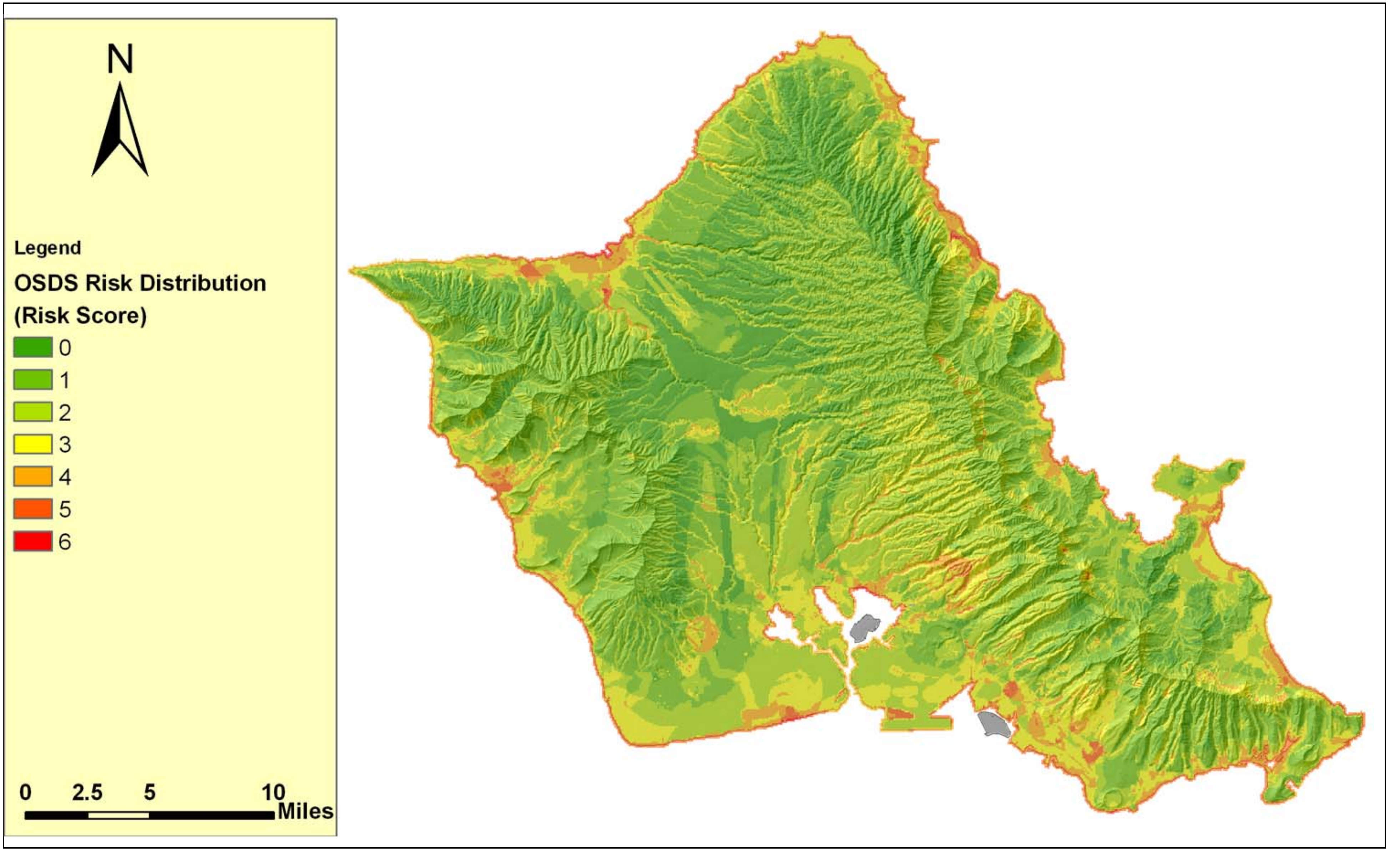

Figure ES-4. Spatial Distribution of OSDS Siting Risk Scores

RISK RANKING FOR OSDS ON OAHU

The risk score was mapped to the each OSDS unit or groups of units if a TMK had more than one OSDS. Figure ES-5 shows a histogram of the quantity of OSDS within each score class.

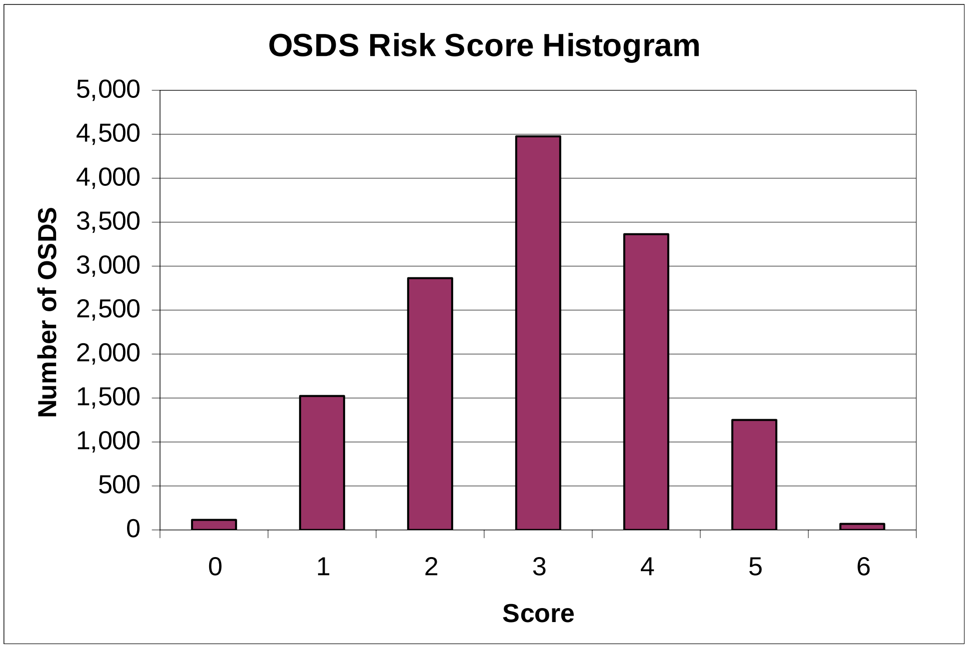

Figure ES- 5. OSDS Risk Score Histogram

The histogram shows a near normal distribution of risk scores among the OSDS. It is desirable that number of OSDS that fall within the higher risk categories be small compared to the total number of OSDS. There were 77 OSDS with a risk score of 6, and 1,321 with a risk score of 5. These two risk score classes identify the OSDS units that have the highest potential to adversely affect human health and the environment and thus should be given top priority for engineering inspections. Table ES-6 is a summary of the OSDS and scores assigned breaking the scoring down by the type of unit.

Table ES- 6. OSDS Risk Score by Type

	SCORE						
OSDS Type	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Class I	27	261	555	762	740	260	15
Class II	9	58	173	192	75	26	1
Class III	4	30	40	64	32	27	2
Class IV	77	1,288	2,373	3,745	2,703	1,008	59
Total OSDS	**117**	**1,637**	**3,141**	**4,763**	**3,550**	**1,321**	**77**

Figure ES-6 shows the locations of the OSDS units with the highest risk score. Of concern is the prevalence of high risk OSDS in some north shore and leeward communities. For example, Waialua, a growing north shore community, has a high density of OSDS, many of them in the high risk category. There are multiple streams that discharge into Kaiaka Bay. The nutrient flux from the OSDS will impact the streams in the lower reaches where they gain water from groundwater. The increase above current nutrient load in the stream can cause alien algae invasions that have occurred elsewhere.

Limitations of this study are related to the absence of site specific data, especially regarding heterogeneities of hydrogeological parameters, resolution of spatial data, inaccuracies in OSDS records, and uncertainties in modeling results. However, models were carefully run with input data to the best of their availability. Uncertainties are also related to risk factors which were not based on formal risk procedures. A similar approach is adopted in the widely used DRASTIC model. However, we have introduced an improvement by including OSDS's specific elements in the analysis. The results are expected to be acceptable considering that the study was aimed at estimating relative scores for OSDS and not absolute values.

The results of this study will allow the Department of Health planners prioritize OSDS inspections and focus water impact investigations on areas where negative impact on water resource is greatest. The risk model is flexible in that weighting can be easily changed to better reflect the actual risk posed by OSDS.

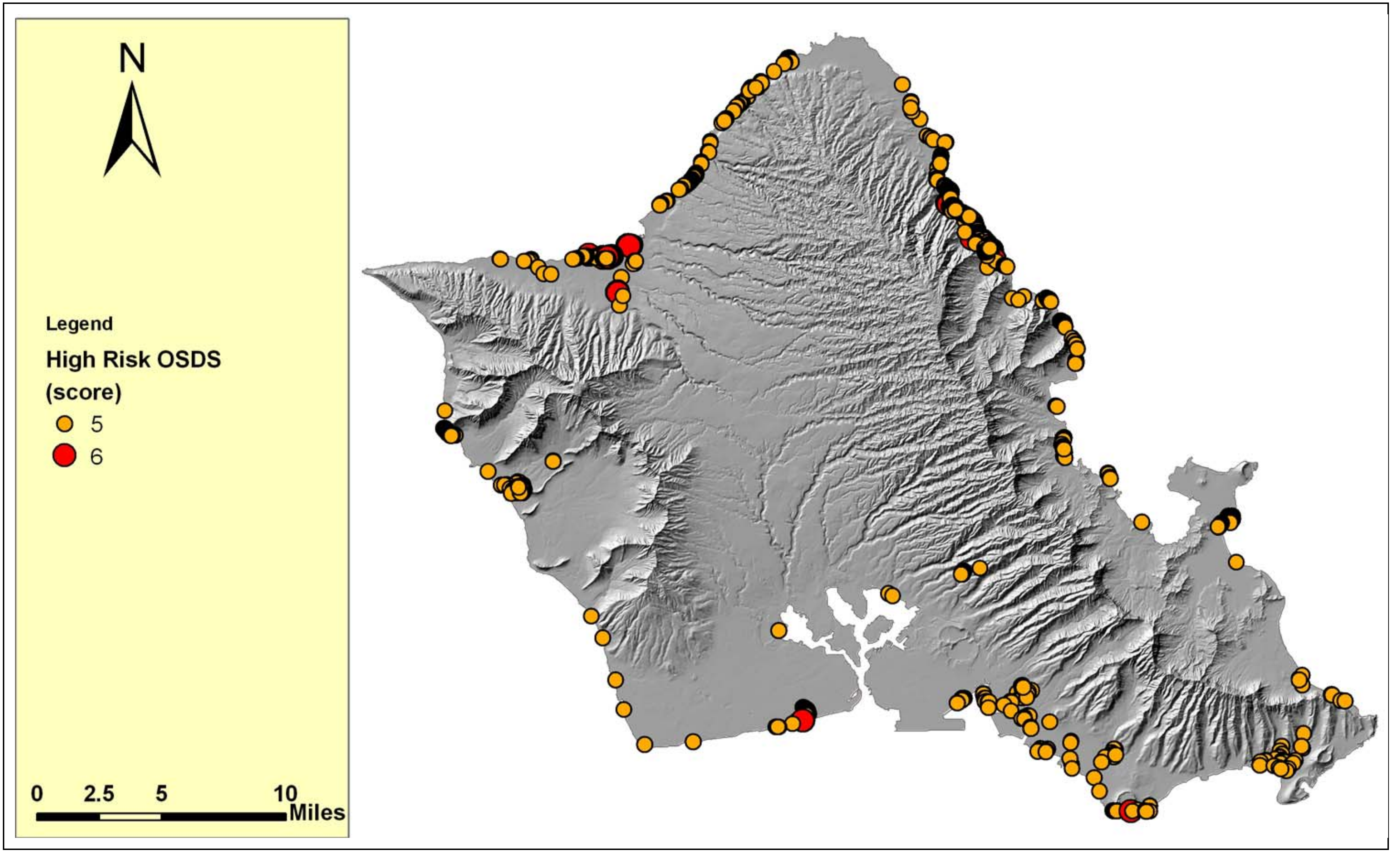

Figure ES-6. Location of High Risk OSDS on Oahu

SECTION ONE: INTRODUCTION

The risk that on-site sewage disposal systems (OSDS) pose to human health and the environment are well documented. This study used geographic information system (GIS) analysis and groundwater modeling to estimate the severity and spatial distribution of this risk. The results are presented on a map of the Island of Oahu ranking risk posed by each OSDS on a scale from 0 to 6, with the higher score indicating higher risk. 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.

Oahu was selected as a pilot study area for OSDS due to availability of more accurate data sets. The procedures developed by this study will be applied to the other islands in the near future.

1.1 HUMAN HEALTH RISKS FROM OSDS

Studies assessing human health risks from OSDS include Hrudey and Hrudey (2007) who reviewed cases of waterborne disease outbreaks in developed countries tabulating 75 cases. 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) resulting in two deaths. The suspected source of the pathogens was a septic tank seepage pit located 38 feet (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 and a follow-up survey indicated that at least 2,800 people were infected. 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 U.S. Environmental Protection Agency (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*) that causes gastroenteritis, and others that cause serious illnesses such as leptospirosis, salmonellosis, and cholera. Bacteria are effectively removed by soil treatment units so that 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 ^{o}C increase in the range from 5 to 30 degrees Celsius (^{o}C). Other hostile conditions are acidic pH, lack of organic nutrients, high ionic strength, and presence of oxygen. However, 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 rather than health risk problem since these strains have not been shown to be pathogenic. 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 that causes infectious hepatitis and adenoviruses that 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 resulting in their accumulation and later mobilization under saturated conditions. However, soil is still an effective retardation and inactivation matrix, resulting in a 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 Helminths, 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 since they 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).

Chemical constituents of raw wastewater that affect human health include nitrogen (normally in the oxidized form 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. This constituent in a sufficiently high concentration can interfere with the transport of oxygen in the blood stream of young children. This condition, known as methemoglobinemia, results in blue color to the skin and has been nick-named “blue baby” syndrome. Water used to make baby formulas with as little as 12 milligrams per liter (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 (MCL) of 10 mg/L for the 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.

1.2 ENVIRONMENTAL RISKS FROM OSDS

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, causing incidence of toxic algal blooms (Rabalais, 2002). Sewage effluent has been linked to excessive algal growth. Excessive growths of macroalgae that covered the reef slopes and the outer reef flats in Kaneohe Bay decreased substantially 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 have concluded that sewage related sources are a significant factor in algae blooms off Kihei and Lahaina, Maui (Honolulu Advertiser, 2009). Although the Kihei and Kaneohe Bay examples involve municipal waste water, 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.

1.3 OSDS REGULATIONS

Most OSDS fall under a variety of labels and include onsite wastewater treatment systems (USEPA), or individual wastewater systems (State of Hawaii). The USEPA defines onsite wastewater treatments systems (OWTS) as those systems serving fewer than 20 people and disposing of the effluent onsite. Regulation of these units is left to the state and local governments. Federal regulations control decentralized systems serving 20 or more people. These systems, if disposing of effluent underground, are regulated by Underground Injection Control (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 EPA banned new large capacity cesspools (LCC) and effective April 5, 2005 a ban on existing LCCs went into effect. A LCC is a disposal system with an open bottom that receives effluent from a multi-dwelling community (e.g. townhouse complex or apartment building) or a non-residential facility that serves 20 or more person per day (e.g. churches, schools, etc.)

In the state of Hawaii individual wastewater systems (IWS) are regulated by Hawaii Administrative Rules (HAR), Chapter 62, Title 11. Subchapter 3 specifically addresses IWS and defines them as “a facility which is used and designed to receive and dispose of no more than one thousand gpd of domestic wastewater.” This regulation establishes the minimum lot size for an IWS at 10,000 ft^2, with a maximum effluent rate of 1,000 gpd, and a maximum number of dwellings units of 50 residential lots or dwelling units. Also included in this statute are engineering standards such as percolation test rates and 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) and inspected and approved by a PE after construction. The actual permit for an IWS is part of the City and County of Honolulu 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 must get a UIC permit. Treatment prior to disposal is required since large capacity cesspools are no longer allowed.

The Safe Drinking Water Branch of HDOH regulates the underground injection of wastewater under HAR Title 11, Chapter 23. This regulates OSDS that utilize a seepage pit or similar disposal method serving more than one residence and has a daily load greater than 1,000 gpd. The majority of OSDS are exempted since they are for a single residence. No sewage injection well is currently allowed to discharge to an underground source of drinking water if above the exempted injection quantity. Also, such a 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 only allow 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 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 33 streams and 61 coastal water bodies listed under the State of Hawaii CWA, Section 303 List. Excessive nutrient levels were a factor in a majority of these listings. OSDS impacted groundwater discharging to these surface water bodies will increase the TMDL and need to be considered in any management plan.

1.4 STUDY AREA SETTING

1.4.1 Physical Setting

Located between 157^{o} 39’ and 158^{o} 17’ west longitude, and 21^{o} 15’ and 21^{o} 45’ north latitude, Oahu lies near the middle of the Pacific Ocean far from any continental land mass, and is part of an island chain that formed as the Pacific Tectonic Plate passes over a mid-ocean hotspot. Volcanoes forming this island chain generally occur in parallel trending pairs. Oahu is no exception to this trend, consisting of the Koolau Volcano and the Waianae Volcano. The lavas of these volcanoes coalesced forming the Central Oahu corridor.

Oahu is the State of Hawaii’s major urban center, having a population of nearly 900,000 out of a state wide population of approximately 1,200,000 (Department of Business and Economic Development and Tourism [DBEDT], 2004). The majority of Oahu’s population is concentrated along southern coastal plain from east end of the island to the Ewa Plain on the southwest portion of Oahu. There are smaller urban centers elsewhere on the island with such as Mililani and Waipio areas where former sugar cane and pineapple lands were converted to residential development. Sugar, once the dominant agriculture crop on Oahu, occupied most of the Ewa Plain, and Central Oahu north and south of the Schofield Plateau. All sugar agriculture ceased in the late 1990s and has been replaced by residential development, coffee, corn, and diversified agriculture. However, residual agriculture chemicals from sugar agriculture are still detected in the wells of Central Oahu. Pineapple cultivation on Oahu has also deceased significantly with the 2,700 acre Dole plantation as the only producer on Oahu. Smaller plantations of coffee are in north Central Oahu and corn in southwest Central Oahu.

Military bases are also prominent on Oahu. Schofield Barracks, Wheeler Army Airfield, and their associated training areas occupy much of the Schofield Plateau. The Pearl Harbor Naval Base, Hickam Air Force Base, and the former Barbers Point Naval Air Station are located in southern Oahu, while Kaneohe Marine Corp Base and Bellows Air Force Base are located in northeastern Oahu. Agriculture and military activities account for most of the contamination detected in Oahu drinking water sources and are thus important when conducting contamination susceptibility assessments.

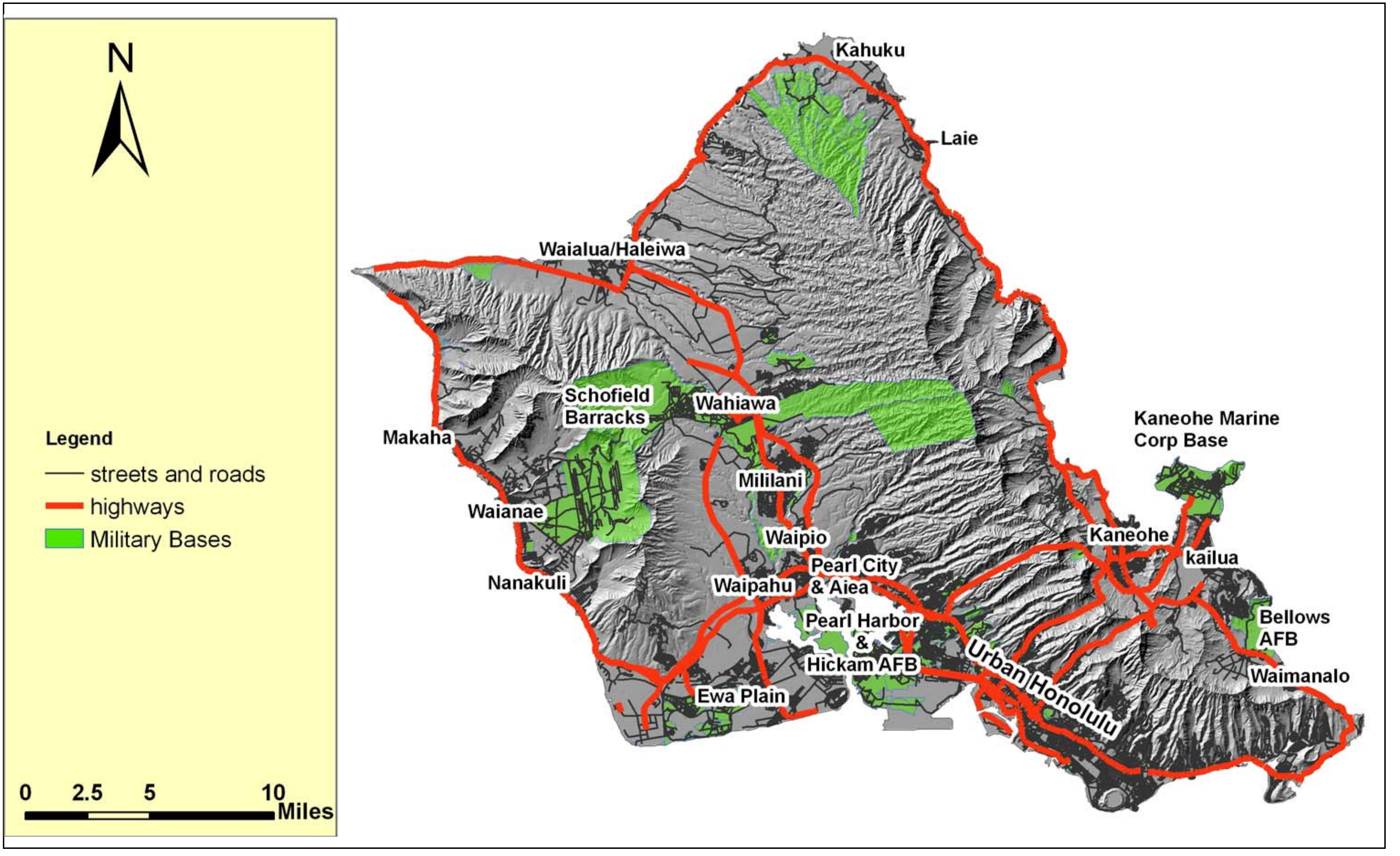

Figure 1. Map of the Study Area Showing Major Features

1.4.2 Geology and Hydrogeology of Oahu

Igneous Geology

Figure 2 is a generalized geologic map of Oahu. The primary features of Oahu are the remnants of the Waianae and Koolau Volcanoes. Of the two, the Waianae Volcano is the oldest, although these volcanoes had overlapping periods of activity. The lavas of these volcanoes coalesced forming the Central Oahu corridor. Both volcanoes also suffered catastrophic slumps where major portions of each slump into the ocean, placing the central calderas near the present shorelines (Moore et al., 1989).

The Waianae Volcano occupies the western third of Oahu. It is older, but rises to a higher elevation than the Koolau Volcano. At 4,025 feet above mean sea level (ft msl), Mount Kaala is the highest point on Oahu. The Waianae Volcano has three well developed rift zones that account for the majority of the exposed area of this volcano. One rift zone extends to the northwest, one to the south, and a minor rift zone extends from the caldera area to the northeast (Takasaki and Mink, 1984). The oldest portions of the exposed Waianae Volcano lavas are thin-bedded pahoehoe lavas with a cumulative thickness of about 2000 ft. Separated by an erosional unconformity is a second unit also about 2000 ft thick. Like the lower lavas, some are thin bedded but the aa type lavas are more prevalent (Stearns, 1985). Lastly, late eruptions of massive aa lavas were extruded near the site of the ancient caldera. Where present, these are thick-bedded massive lavas, know as the Kolekole Volcanics, having a cumulative thickness of up to 2,300 ft (Stearns, 1985). Most of the flank lavas west of the rift zones have been lost due to catastrophic slumps of the western third of the volcano. Thus the majority of the remaining portion of the Waianae Volcano has a very low hydraulic conductivity due to the dikes that permeate the rift and caldera areas of this volcano. On the east slopes of the Waianae volcano true flank lavas exist with hydraulic characteristics consistent with the highly permeable flank lavas that dominate the Hawaiian Islands.

Dominating eastern Oahu is the Koolau Volcano. A long ridgeline running from southeast Oahu north-northwest to Kahuku Point is formed by the two dominant rift zones of the Koolau Volcano. A catastrophic landslide has removed much of the eastern portion of this volcano, placing the central caldera near the shoreline where the present day communities of Kaneohe and Kailua. In the northwest rift zone from the Nuuanu Pali to Waialee the orientation of the dikes generally parallels the axis of the rift zone. Southeast of the Nuuanu Pali, the dike trend becomes more dispersed such that in the Waimanalo area there seems to be no dominant dike orientation (Takasaki and Mink, 1985). A third Koolau rift zone occurs on the leeward (southwest) side of the Koolau topographic divide. This rift zone, named the Kaau Rift Zone, trends southwest in the Palolo Valley and Kaimuki areas of Honolulu. The preferred orientation of the dikes is also southwest paralleling the natural groundwater flow direction. For this reason the Kaau Rift Zone does not support the highly elevated water table elevations common in other rift zones.

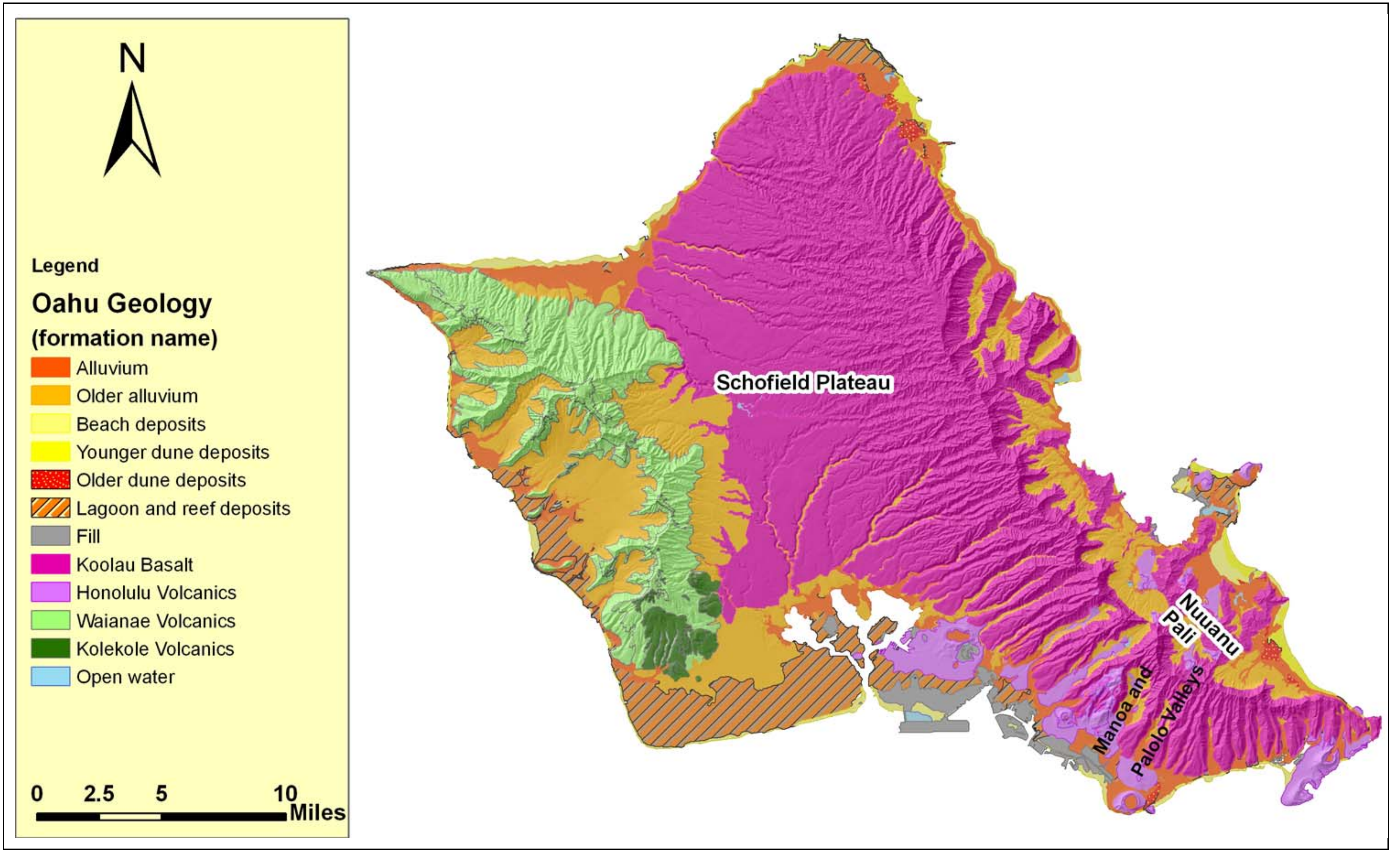

Figure 2. Geologic Ma of the Island of Oahu

After a period of volcanic quiescence, the Koolau Volcano entered a period of rejuvenated activity known as the Honolulu Volcanic Series. During this phase, explosive eruptions formed a series of craters that extend from Salt Lake area to the east coast of Oahu. No late stage eruptions are found west of line drawn from Aiea to Kaneohe. The lavas produced by these eruptions include thick massive lavas from the Tantalus vent that flowed down the Manoa Valley. This renewed activity also laid down thick ash deposits along the eastern shoreline of Oahu.

By volume the majority of any Hawaii volcano is made up of flank lavas. For the Koolau Volcano, these flank lavas extend westward and southward from just leeward of the crest. In the west the flank lavas buttress up against the eroded surface of the Waianae Volcano in the Kunia/Ewa regions and the Mokuleia area. In the south and north the flank lavas extend past the coastline and out to sea. The most important drinking water aquifers lay in the Koolau flank lavas. Being thin-bedded lavas the ability of these flank lavas to transmit water is very high.

Sedimentary Geology of Oahu

From a hydrogeology perspective the most important sedimentary deposits in Oahu are the marine sediments of the coastal plains. Coastal sediments are also found in the Waialua/Haleiwa areas of North-Central Oahu, on the coastal plain of leeward Oahu, along the northeast coast from Kahuku to Kahana Bay, and to lesser extents in the Kailua and Waimanalo areas of the windward side of Oahu.

These deposits are most prevalent in the southern coastal areas forming a thick wedge, commonly referred to as caprock, over the lavas in this area. The hydraulic conductivity of the caprock spans many orders of magnitude due to diversity of materials making up this structure. On the low end of the scale are the fine grained muds with hydraulic conductivities that range from 0.01 to 1.0 feet per day (ft/d) (Oki et al., 1996). On the high end are the coral gravels and reef limestones. These coral reef remnants have the highest hydraulic conductivities of any formation in Hawaii with estimated values as high as 30,000 ft/d based on tidal response analysis (Oki et., 1996). In between these extremes are weathered volcanic or saprolite with hydraulic conductivities that are estimated to range from 0.0028 ft/d to 283 ft/d (Oki et al., 1996; and Miller, 1987), and sands with an estimated hydraulic conductivity ranging from 1 to 1,000 ft/d (Nichols et al., 1996). Taken as single unit, the hydraulic conductivity of the caprock tends toward the lower values, retarding the discharge of groundwater to ocean. The caprock acts as a confining wedge producing artesian groundwater in the Pearl Harbor area of southern Oahu. An effective vertical hydraulic conductivity for the Pearl Harbor Caprock of 0.02 ft/d was estimated by Oki (1998); and an effective hydraulic conductivity of 0.15 ft/d was estimated by Souza and Voss (1987).

A second class of sediments that influence groundwater flow in the basal aquifers is the alluvium the fills the deep cut streams valleys. Due to subsidence of Oahu, estimated to be between 6,500 to 13,000 ft since the island reached the ocean surface (Oki, 1998; and Moore, 1987), the bottom of the sediments in many stream valleys extend significantly below the water table. Wells drilled in the Honolulu area indicate that near the coast the Nuuanu Stream sediments extends to a depth of more than 800 ft (Oki, 1998). The fine grained nature of these sediments reduces their hydraulic conductivity, with estimates of the hydraulic conductivity of alluvium ranging from 1 to 500 ft/d (Nichols et al., 1996). In most cases the lower range of this estimate more closely reflects the effective hydraulic conductivity contrasting with that of the surrounding flank lavas, making these valley fill deposits a barrier to groundwater flow. However, since the dominant driven direction of groundwater flow is usually parallel to the trend of the stream cut valleys they do not greatly alter the groundwater flow direction.

Geohydrologic Barriers

Geohydrologic barriers are low permeability features that retard the flow of groundwater. These include the dikes of the rift zones previously described, the Waianae Confining Unit, valley fill, and the North and South Schofield Groundwater Barriers (Nichols et al., 1996).

The direction of groundwater flow is greatly influenced by the dike orientation because of the very low hydraulic conductivity of dikes. The hydraulic conductivity of the intrusive dike material has been estimated by Meyer and Souza (1995) to range between 10^{-5} and 10^{-2} ft/d. Interspersed between the dikes are flow lavas of much higher hydraulic conductivity. A dike complex, where between 100 and 1,000 dikes can be crossed in a linear mile, has and estimated effective hydraulic conductivity of 0.01 to 0.1 ft/d (Oki, 1998; and Meyer and Souza, 1995). However, the effective hydraulic conductivity of the dike complex parallel to the preferred orientation of the dikes is expected to be much greater than the hydraulic conductivity perpendicular to the preferred orientation of the dikes. Dikes impede the lateral movement of groundwater resulting in a highly elevated water table. The groundwater in the Koolau dike complex Volcano reaches elevations of over 1,000 ft msl, while the groundwater elevation in the Waianae dike complex reaches an estimated 1,600 ft msl.

Commonly a marginal dike zone occurs between a dike complex and the flank lava zones. In the marginal dike zones the frequency of dikes decreases from 100 dikes per linear mile, in a dike complex, to a few dikes per linear mile. This greatly increases the effective hydraulic conductivity of these areas and results in a water table only slightly higher than that in the down gradient flank lava aquifers.

As previously stated, exposures of the Waianae Volcanics are restricted to the western third of Oahu. At some point east of where the Waianae Volcanics dip below the sediments of the Central Oahu Plain, the lavas of the Koolau Volcano buttress up against the eroded surface of the Waianae Volcano. This is known as the Waianae Confining Unit and forms a low hydraulic conductivity barrier between the groundwater of the Waianae areas and the groundwater of the Central Oahu Plain. In northern Oahu, the Kaukonahua Valley fill combines with the Waianae Confining Unit to further separate the Mokuleia groundwater from that of the neighboring Waialua groundwater (Nichols et al., 1996).

Groundwater in the Schofield Plateau is elevated about 250 ft higher than that in the basal aquifers north and south of the Schofield Plateau. Based on water table elevations, the barriers responsible for this high-level confinement of groundwater occur as a northeast trending narrow structure at the northern margin of the Schofield Plateau and an east-northeast trending narrow structure at the southern margin of the Schofield Plateau. The origin of these two barriers is unknown, but is postulated to be the remains of dike intruded rock, a buried erosional surface, or a massive lava formation (Nichols et al., 1996).

Deep cut valleys in southeast Oahu filled with alluvium extend well below the water table. The low hydraulic conductivity of this alluvium confines the majority of groundwater movement to a direction roughly parallel to the stream-cut valleys. The major valley fill barriers in southeast Oahu are, the North Halawa Valley fill, the Kalihi Valley fill, the Nuuanu Valley fill, and Manoa Valley fill. In northern Oahu the Anahulu Valley along with the previously described Kaukonahua Valley fill separate the aquifer sectors of the North Aquifer.

1.4.3 Hydrology

Oahu is located in a sub-tropical setting where moderate temperatures prevail year around. The rainfall on this island varies from 280 inches at the crest of the Koolau Range to less than 20 inches on dry leeward side of the island (Giambelluca et al., 1986 as describe in Anthony et al., 2004). The rain that reaches the ground surface is divided between that fraction which recharges the groundwater, the fraction that is transpired by plants or directly evaporates to the atmosphere as evapotranspiration, and that faction that flows overland and is captured by streams.

Water percolates downward from the ground surface due to precipitation and irrigation water recharge to the island aquifers. Streams, well pumpage, and discharge to the ocean remove water from the aquifers. Recharge is greatest in the upper elevation of the Koolau Mountains with annual recharge rates exceeding 150 inches per year (in/yr) (Shade and Nichols, 1996). Although higher in elevation, the Waianae Mountains are in the rain shadow of the Koolau Mountains. The maximum recharge rate in the upper elevations of the Waianae Mountains is less than 50 in/yr (Shade and Nichols, 1996). Based on a mid-1980's land use scenario, the total recharge to non-caprock areas of Oahu is approximately 880 million gallons per day (mgd) with about 50 mgd being from irrigation water return.

Stream flow is supported by that fraction of precipitation the flows overland as direct runoff. More importantly from a groundwater flow analysis perspective is the groundwater that returns to the ground surface in the form of springs and seeps, providing base flow for streams. The combination of the high precipitation rates in the upper elevations of the Koolau Mountains, a well developed dike complex in Windward Oahu, and the vertical truncation of a major portion of the dike complex by a catastrophic landslide produce many streams that intercept the elevated water table on the windward side of the Koolau Mountains. Nearly all of the streams that have flow supported by groundwater discharge are on the windward side of the Koolau crest. The exceptions are streams in the Manoa and Palolo Valleys (Takasaki and Mink, 1985). Elsewhere on the leeward side of the Koolaus, the stream valleys are not cut deep enough to intercept the drinking water aquifers. The DBEDT GIS database lists 91 watersheds on Oahu. Of these 19 are listed as having intermittent flow and 49 have perennial flow. Seventeen are listed as streams systems, several of which have perennial flow.

Watersheds tend to be small. The largest watershed is the Waikele Watershed at 48.5 square miles (mi^2). This stream and the Kaukonahua Stream drain both the Koolau and Waianae

Ranges. Waikele Stream has an average daily flow of about 40 cfs and maximum peak flow of 13,600 cfs. Watersheds on Oahu are typically small (average of 6.2 mi^2) with short distances from the headwaters to the coastal discharge points. Also there is high relief over this short span resulting in “flashy” streams were stream discharge can increase very rapidly in response to storm events. The most productive streams have head waters in the Koolau Range and are perennial in mountains, but become intermittent when the coastal plains or central plateau is reached due to channel losses and diversions. Streams also become perennial as the channel approach the coast and streambed elevation is less than the groundwater elevation. These low elevation gaining reaches of stream are particularly important for this study since this a potential pathway for OSDS effluent products to discharge into surface waters. This condition is most prevalent for windward and north shore streams. Figure 3 shows the major watersheds and perennial streams on Oahu.

1.5 STUDY OBJECTIVES

The objectives of this study were to:

- Estimate the quantity and types of OSDS on Oahu;
- Estimate the effluent load added to the environment by these systems;
- Identify which critical receptors such as drinking water sources or streams most impacted by OSDS;
- Identify other factors contributing to potential risk of OSDS;
- Develop a risk scoring scheme based on these various factors to assist regulatory managers in prioritizing inspection efforts for OSDS; and
- Assign a risk score to each OSDS.

Prior to this study there was no central database that detailed the number, types, and locations of OSDS. This study linked an existing OSDS database, sewer infrastructure GIS files, and a structure information database to create a detail listing and associated GIS shape file of OSDS on Oahu. The potential environmental and health impact of each OSDS is dependent in large part on the amount of treatment the effluent receives. The volume of effluent was estimated using building structure criteria. The concentration of nitrogen, phosphorus, and fecal coliform were estimated based on OSDS type and disposal method. For a health or environmental risk to occur, there must be exposure by humans or surface waters to OSDS effluent. Areas where this would occur were identified (such as drinking water sources or recreational waters) and setback buffers were delineated. A GIS query was done to identify those OSDS in the buffers that could contribute to risk at the exposure points. Proximity of an OSDS to an exposure point or the severity of contamination in the effluent does not adequately define the risk the OSDS poses. Many processes occur between the point of discharge and the point of exposure that can mitigate the risk. Literature was reviewed to identify those environmental factors that can mitigate the impact of OSDS effluent. Maps were created of these factors and scores assigned that increased with a decreasing ability of a factor to remediate the wastewater. The scores where spatially combined to create a map showing the degree of risk associated with OSDS. Finally this risk scoring map was spatially linked to the OSDS database to assign a risk score to each system.

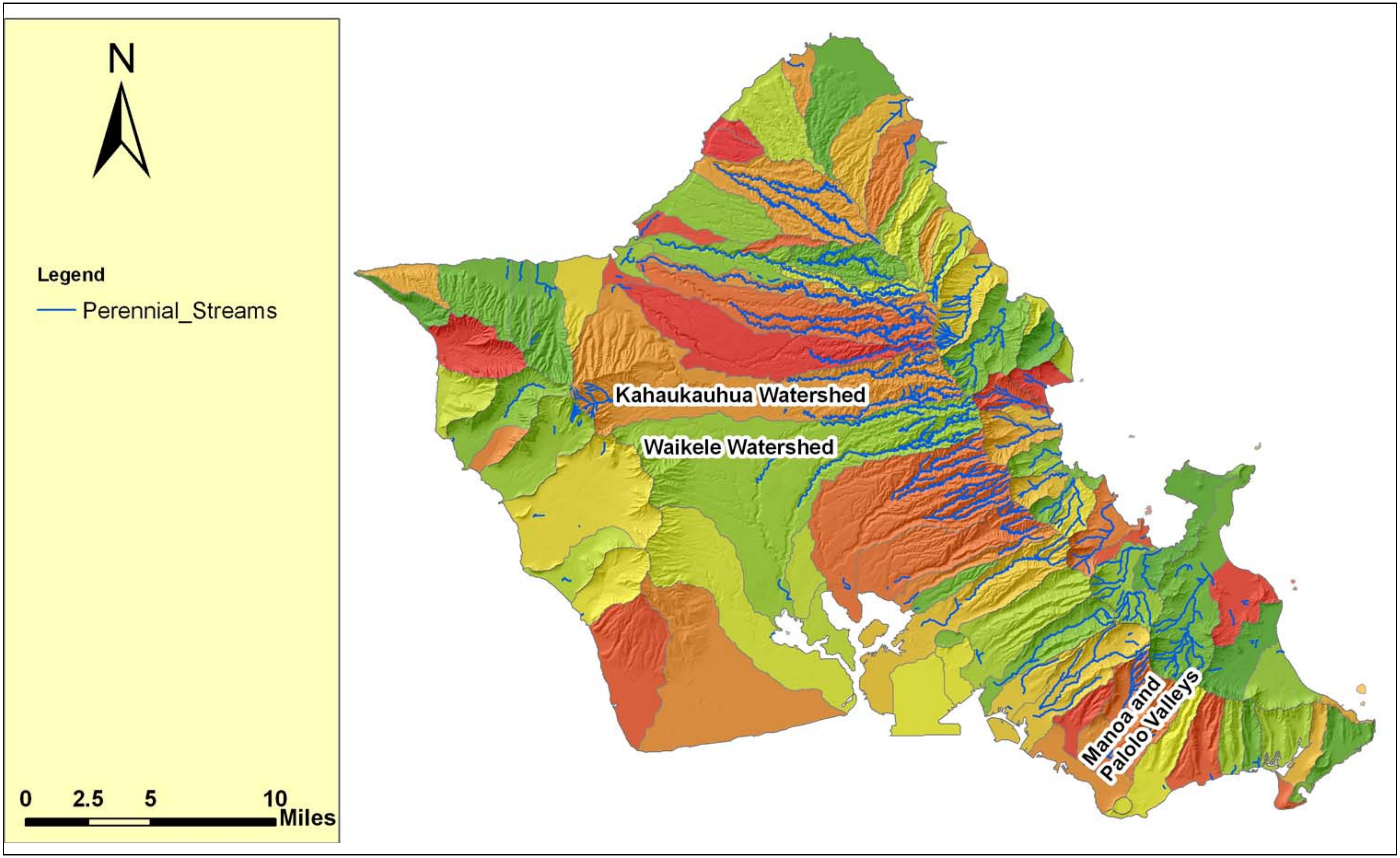

Figure 3. Watersheds and Perennial Streams on Oahu

SECTION TWO: OSDS INVENTORY METHODOLOGY

2.1 OAHU WASTEWATER INVENTORY INFORMATION

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 and the overwhelming majority have not been transferred to an electronic database. The sheer numbers of cards and obsolete records make using this data set impractical for accurately estimating the numbers identifying types of systems. The number and spatial distribution of OSDS were estimated by utilizing data directly from available electronic sewage disposal databases and indirectly from Tax Map Key (TMK) information, sewer, Honolulu Board of Water Supply billing, and parcel/structure databases. The TMK number was the common field in each data set and was used as the key field for this study.

2.1.1 TMK Shape File and Database

TMK shape file and associated data table provided the key data set to which all other data was referenced. This data assigns a unique TMK number to each parcel in a polygon shape file. The polygon shape file then provides the spatial data needed to link to other data by geographic locations.

2.1.2 Off-Site Wastewater Treatment Collection System Information

Parcels that are served by an off-site wastewater treatment and collection system (OWTCS) were excluded from the list of TMKs that potentially utilize an OSDS. The initial exclusion was done by intersecting TMK parcels with GIS shape files of sewer laterals and sewer mains obtained from the City and County of Honolulu (Oahu) and Hawaii GIS database. TMK parcels that had a sewer main or sewer lateral within its boundaries were flagged as being served by a OWTCS and excluded from further consideration by this study.

Not all OWTCS are owned by the City and County of Honolulu. The largest private system is located in east Honolulu and is operated by the American Water Works. This utility provided a map of their coverage area. Parcels that fell within their service area were also removed from the list of parcels that may have an OSDS. Other large sewer systems are operated by the military and the assumption was made that all major military bases were connected to a sewer. Figure 4 shows those areas served by an OWTCS in green while those areas with no off-site wastewater collection service are shown in red.

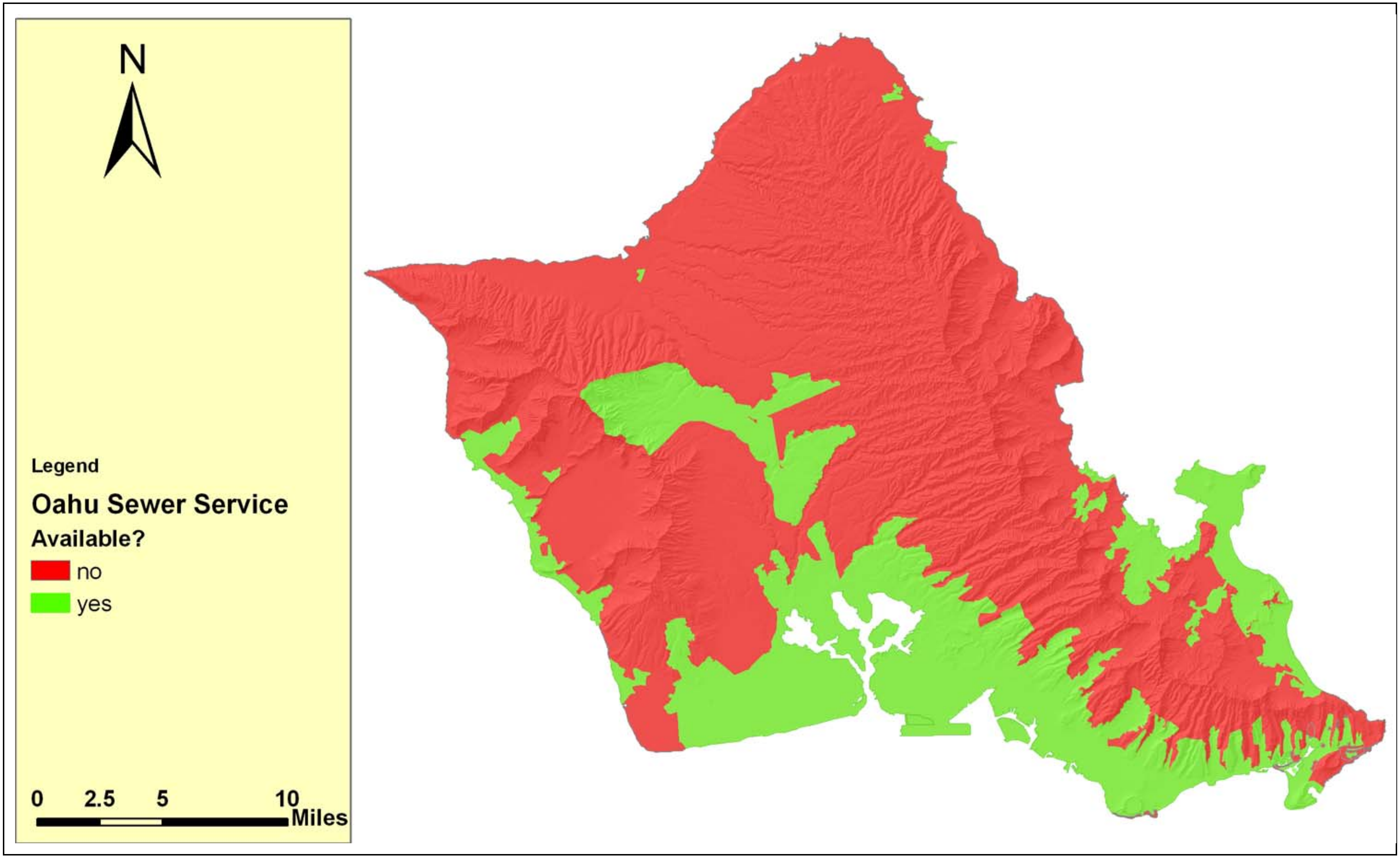

Figure 4. Map of Sewer Status on Oahu

2.1.3 Permitted Individual Wastewater Systems

The next major data source was the electronic records of approved Individual Wastewater System (IWS) permits. IWS permit information was obtained from the Department of Health Wastewater Branch's database. 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, and TMK where OSDS is to be constructed or upgraded. The IWS data was 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 confirms that the system has actually been constructed and approved by HDOH. This information was joined to the TMK parcel information using the 8-digit TMK as the common field. Table 1 below correlates the OSDS class used by this study to the IWS classifications in the database. 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.

Table 1. OSDS Class 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.
Class III	Aerobic units discharging to a seepage pit.
Class IV	All cesspools

2.1.4 Dwellings Database

Because records of OSDS are not complete, a real estate database was used to identify those parcels on Oahu that, according to building value and structure information, would have some form of sewage disposal system. The dwelling database contained specific structure information and monetary value, and a TMK number. Parcels with structures valued at more than $25,000 and having a fixed bathroom were assumed to need some sort of sewage disposal system. This database also listed the number of bedrooms for each structure. This information was used to estimate the daily volume of OSDS effluent for use in loading estimates.

2.1.5 Honolulu Board of Water Supply Billing Data

Honolulu City and County OSWTC service is included in the monthly water billing from the Honolulu Board of Water Supply (HBWS). The database used to generate the monthly bills lists a parcel's TMK of the parcel served and the status of the sewer connection. Table 2 below lists the sewer status codes. Those TMKs with a sewer connection code of 1 or 4 were removed from the OSDS database.

Table 2. HBWS Sewer Connection Codes

Code	Description
1	Public Sewer
2	Public Sewer Available But Not Connected
3	Cesspool
4	Private Sewer Systems
5	Doubtful, Recheck Required
6	Vacant Lot or Under Construction

2.1.6 Identifying Cesspools - Assumptions

A large number of TMK parcels remained in the candidate OSDS database that were indicated by DEWALT data to have a fixed bathroom, but had no indication of a sewer connection or approved IWS permit. If the parcel was not sewered, did not have an IWS permit and there was a building (with a toilet per DEWALT data) on the parcel then the parcel was considered to be on cesspool.

2.2 METHODOLOGY USED TO ESTIMATE OSDS EFFLUENT CHARACTERISTICS

The risk that OSDS pose to the human health and the environment is strongly influenced by the volume and the constituents in the effluent. The number of persons served by and the use of the parcel (residential, public, or commercial) were used to estimate the effluent quantity. The treatment that the effluent receives can significantly reduce the amount of nutrients and pathogens that are transported beyond the disposal site.

For residential units, guidance was provided by HAR Title 11, Chapter 62 that estimates an effluent rate of 200 gpd for each bedroom served by the OSDS. The IWS database gave the number of bedrooms for condominiums and that value was multiplied by 200 to get a daily effluent rate. There were 248 records in the IWS database listing units as having treatment systems that disposed of the effluent on-site. These included businesses, churches, schools, parks, and condominiums. The effluent rate for schools was taken from Metcalf and Eddy, Inc. (1991) that estimates 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 for each school was downloaded from the State of Hawaii Department of Education website (2009). Effluent rate estimates for the remaining large capacity units are very difficult, but representative values were assigned based on best estimates of 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 for an assembly hall is 3 gpd per person. Based on this estimate the average attendance would be about 1,260 persons. Table 3 lists the respective activities with large disposal units and estimated effluent for each, as well as the number of units on Oahu.

Table 3. Large Volume OSDS Summary

Operations With Large Disposal Units	**Estimated Effluent Rate (gpd)**	**Number of Parcels**
Baseyards	195 -390	20
Businesses	130 – 4,590	116
Cemeteries	1,200 – 2,400	7
Churches	540 – 2,600	23
Golf courses	540 – 1,080	7
Non-profit organizations	240 – 2,200	24
Non-profit organizations with showers	1,825 – 2,500	8
Parks	200 – 800	22
Schools without gyms	600 – 5,640	15
Schools with gyms	12,625 – 42,425	12

The contaminant flux to the environment was based on concentration estimates given by Water Resources Research Center (WRRC) and Engineering Solutions, Inc (2008). The concentration was then multiplied by the estimated effluent rate. Table 4 lists the effluent chrematistics by OSDS type.

Table 4. Effluent Characteristics of OSDS Classes

OSDS Class	Typical Nitrogen Concentration	Typical Phosphate Concentration	Typical Fecal Chloroform Concentration	SOURCE
	(mg/L as nitrogen)	(mg/L as phosphorus)	(colony forming units [CFU]/100 mL)	(WRRC and Engineering Solutions, 2008)
AU to Seepage Pit	24	8	1.00E+06	Aerobic unit, seepage pit disp., Page 5-15
All Cesspools	60.5	16.5	1.00E+06	Cesspool, Table 4-1, page 4-6
Septic tank to Seepage Pit	36	13	1.00E+06	Septic Tank to seepage pit, Page 5-9
Soil Treatment	1	2	13	Soil treatment, Table 4-1, page 4-6

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SECTION THREE: RISK ANALYSIS METHODOLGY

3.1 INTRODUCTION

This section is a summary of widely used groundwater contamination risk models including those that are specific to Hawaii. These models have a common basis in that they evaluate the hydrogeologic parameters that influence contaminant transport. The probability that groundwater contamination will occur is assessed based on these and other parameters such as persistence of a species in the environment.

3.1.1 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 is a summary of information contained in Aller et al. (1985). The acronym DRASTIC is made up of the primary risk factors for groundwater contamination that are:

- D – depth to water,
- R – (net) recharge,
- A – aquifer media,
- S – soil media,
- T – topography (slope),
- I – impact of the vadose zone, and
- 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:

- 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.

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.

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.

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 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 Oahu. This study also took a more deterministic approach by using numerical modeling to simulate the impact of existing OSDS on the groundwater and group many of the many of the hydrogeologic factors into a single risk parameter for scoring. The risk scores computed using the model developed by this study is compared to that computed by DRASTIC in Section 4.

3.1.2 Pesticide Leaching to Groundwater Tool for the Island of Hawaii

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". The 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 travel time required to reach 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.

3.1.3 GIS and Numerical Based Model

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 yes and no represented by 0 and 1. This logic tool was used to assign weights and rating 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.

3.1.4 Source Water Assessment Program Modeling

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 was used to inventory potentially contaminating activities inside of the delineated drinking source zones. A susceptibility score to contamination was estimated for each source based on the quantity and risk associated with activities inside of the delineated source zones.

3.2 OSDS RISK RANKING STUDY

The method used here is generally similar to those previously described. However, there are considerations that unique to OSDS, such as the method of disposal and the treatment the effluent receives at the point of discharge. In this study, the risk was assessed using GIS analysis and groundwater modeling. The risk score incorporated OSDS specific factors, namely, the ability of the environment to mitigate pathogens and contamination, and transport distance between points of disposal and where humans or the environmental are impacted. These risk categories were sub-divided into twelve factors with a score assigned that correlated with an increasing degree of risk to create a GIS layer for each. Using these tools a spatial distribution of various contributing factors was created and then linked to the OSDS locations to estimate a risk score. The results are presented as maps of the Island of Oahu with rankings based on the relative risk posed by each unit.

The approach we adopted was similar to the DRASTIC model in assigning a risk score to the hydrogeologic factors. However, numerical modeling was used to better quantify the actual severity of contamination resulting from OSDS discharge. Also, the delineations created for the SWAP study were used here to identify the units that pose a risk to public drinking water systems. In calculating a risk score, we followed a methodology similar to that by Norbe et al. (2008) who used GIS and a sliding scale for individual factors to create a spatial distribution of risk.

Many risk models, such as DRASTIC, are “overlay and index”, where a weight and rating are assigned to a parameter. Although this technique was used by this study, the inclusion of groundwater models provided a process-based analysis. This study used three groundwater models in the risk analysis, namely, the U.S. Geologic Survey (USGS) groundwater flow model MODFLOW, the USGS particle tracking model MODPATH, and the contaminant transport model MT3D-MS. MODFLOW was used to numerically simulate groundwater flow processes that transport OSDS contamination to ROCs. MT3D used the groundwater flow solution from MODFLOW to account for dilution of the contamination by recharge and by hydrodynamic dispersion, calculating flux to and concentration at ROCs. MODPATH was used to calculate TOT for a conservative contaminant plume to delineate protective setback distances from the ROCs. The models are briefly described below.

MODFLOW

MODFLOW, the USGS modular groundwater flow model (Harbaugh et al., 2000), is a finite difference model that simulates the flow of groundwater through porous media. This model uses a finite difference solution of the groundwater flow equation for steady state and transient groundwater flow problems. Complex hydrogeology can be incorporated into the models such as confined or unconfined aquifers, stream and groundwater interaction, heterogeneous geology, and discrete hydrogeologic features such as drains and flow barriers. The flow solution from MODFLOW can be used by contaminant transport models to simulate the transport of dissolved constituents in groundwater.

MODPATH

MODPATH, the USGS particle tacking model (Pollock, 1994), uses the MODFLOW groundwater flow solution to simulate the non-dispersive transports of discrete particles in groundwater. Simulated particles are inserted into model grid cells and are transport through the cells at a velocity determined by the groundwater flow solution. The model continues to move the particle until it comes to a termination point such as a model boundary or well, or has traveled the amount time specified by the modeler. MODPATH can also be used in the reverse tracking mode where the particle is moved in the exact opposite direction and velocity as the groundwater flow. This option is commonly used in delineating capture zones for wells and time of travel setbacks.

MT3DMS

The contaminant transport model Modular Three-Dimensional Multispecies Transport Model (MT3DMS; Zheng and Wang, 1999)), uses the groundwater flow solution from MODFLOW or any similar model to simulate the transport of dissolved constituents in groundwater. This modeling code includes all of the major transport mechanisms including advection, dispersion, sorption, and first order decay. The output of the model is the dissolved concentration of the constituent in each cell during each time step rather than just the path line and the ending position of discrete particles MODPATH produced.

3.3 FACTORS AFFECTING OSDS IMPACT TO HUMAN HEALTH AND THE ENVIRONMENT

The five steps used to evaluate OSDS risk included:

1. quantifying the effluent characteristics of each major category of OSDS (described in the previous section);
2. identifying areas where risk to human health or degradation of the environment would occur if OSDS effluent constituents were present;
3. delineating buffers around potential risk areas;
4. tabulating the number and types of OSDS in the buffers; and
5. evaluating the ability of the environment to mitigate the risk posed by OSDS effluent.

The second item in the list includes public drinking water sources that can capture OSDS effluent products and thereby provide a pathway for ingestion of pathogens and contaminants. It also includes surface and near shore waters impacted by OSDS effluent resulting in a direct contact between humans and pathogens. The contamination can also cause environmental problems by damaging plant or coral growth due to an excessive nutrient load. Collectively these potential risk areas will be referred to as receptors of concern (ROC). Buffer zones were delineated around the ROCs using a fixed setback or time travel criteria. The ability of the environment to mitigate the negative impacts of OSDS effluent was evaluated by considering soil characteristics, and the amount of dilution and dispersion provided by groundwater transport.

3.3.1 Receptors of Concern and Their Buffers

For this study, ROCs are represented by drinking water sources, streams, and the Oahu shoreline. Risks to these receptors are due to the pathogens and contaminants in OSDS effluent that pose a risk to human health and the environment by the enrichment of nutrients in the receiving waters. A combination of the time of travel (TOT) and fixed set-back methods was used in identify those areas where OSDS if present could adversely affect these ROCs.

Time of Travel Setbacks

Drinking water sources and the near shore environment were evaluated by using the time of travel (TOT) approach. This method has been identified as one of the five major strategies for wellhead protection from contamination (Oki et al., 1992). TOT is most applicable to the transport of pathogens. This approach is less suitable for nitrate, the primary OSDS effluent contaminant. This constituent will undergo very little attenuation once it leaves the biologically active zone of the soil making it a nearly conservative constituent of water (Gold et al., 1990). The primary mitigation process for nitrate will be by dilution with clean water. This process was evaluated using contaminant transport modeling via MT3D.

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 5 shows the time required for 90 percent (10^1) reduction emerging pathogens of concern. A computed die-off rate and the time require 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 with that had been subject to this magnitude of pathogen reduction.

Table 5. Pathogen Kinetics and Time Required for a 10^5 Reduction in Population (Crockett, 2007)

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 histolyt*ica	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

The SWAP study (Whittier, et al., 2004) utilized the TOT approach in assessing the risk to contamination of Hawaii's public drinking water systems. A two-year TOT was used to delineate areas around groundwater sources that may contribute bacteria and viruses to the well intake (HDOH, 1999). This 2-year TOT only considers travel in the saturated zone and ignores vadose zone transport where pathogen die-off and retardation will also occur. Vadose zone transport is complex and difficult to model with confidence on the scale needed for this study.

The purpose of the TOT buffer is to prevent waterborne disease outbreaks due to consumption of drinking water. Hence, with a two year travel time, 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 5, which shows a maximum of 92 days. Using a conservative TOT is necessary since 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. They recommended that any TOT buffer be much greater than the expected viable lifespan of pathogens. The state of scientific knowledge of 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. The longer setback time was necessary to account for factors such fast flow paths that can result in pathogen transport velocities greater than that of the bulk groundwater. 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). Figure 5 shows the Zone B CZDs for drinking water wells on the island of Oahu. For the SWAP, the two-year TOT was modeled by using MODPATH based on the flow field created by MODFLOW. For this simulation, the MODPATH particles were inserted in the cell representing the well. The backwards tracking option was used to delineate the two-year TOT represented by a polygon that enveloped all the termination points for particles originated from the well.

For drinking water sources the Zone B identifies those OSDS that can potentially introduce pathogens into a public drinking water supply. Contaminants from OSDS, particularly nitrate, can also pose health risk to consumers of contaminated water. Since 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. A delineation of a 10-year TOT was used to assess if the number of OSDS in a capture zone to 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. Figure 5 show the Zone C CZDs in red.

A TOT buffer was also used for the near shore waters. OSDS effluent will migrate vertically to the water table, then be carried with the groundwater flow to submarine 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 or the environment. OSDS derived pathogens in the near shore recreational waters can result in direct contact between these disease causing organisms and humans. Current research in the coastal waters off of Kahekili, Maui has confirmed the presence of pathogens in that area consistent with sewage and elevated levels of sewage derived nitrate that is likely responsible for an increase in invasive algae populations (Smith et al., 2009; and Toonen et al., 2009). OSDS effluent also contains high levels of nutrients that have been identified as a factor in the accelerated growth and spread of invasive algae in this same area. While the sewage impact in southern Maui is primarily associated with municipal injection of treated wastewater this does not preclude an OSDS impact and does demonstrate that the submarine groundwater discharge of sewage effluent to near shore waters has a negative impact on the environment.

The two-year TOT buffer was delineated using methodology similar that used for drinking water wells. The MODFLOW model of Oahu was again used for the groundwater flow field. Using MODPATH, a two year TOT assessment was done by distributing virtual particles at the coastal boundary of the model. As with the drinking water simulations, these particles were programmed to go the opposite direction of groundwater flow for a period of two years. Figure 6 shows the results of the shoreline TOT setback model.

Fixed Distance Setbacks

Fixed distance setbacks were used where the uncertainties made TOT setback modeling impractical. The SWAP used fixed distance setbacks public drinking water systems that were supplied by water development tunnels or springs. This study also used the fixed distance method to define buffers around stream channels and to reflect the increased risk posed by OSDS in very close proximity to the shoreline.

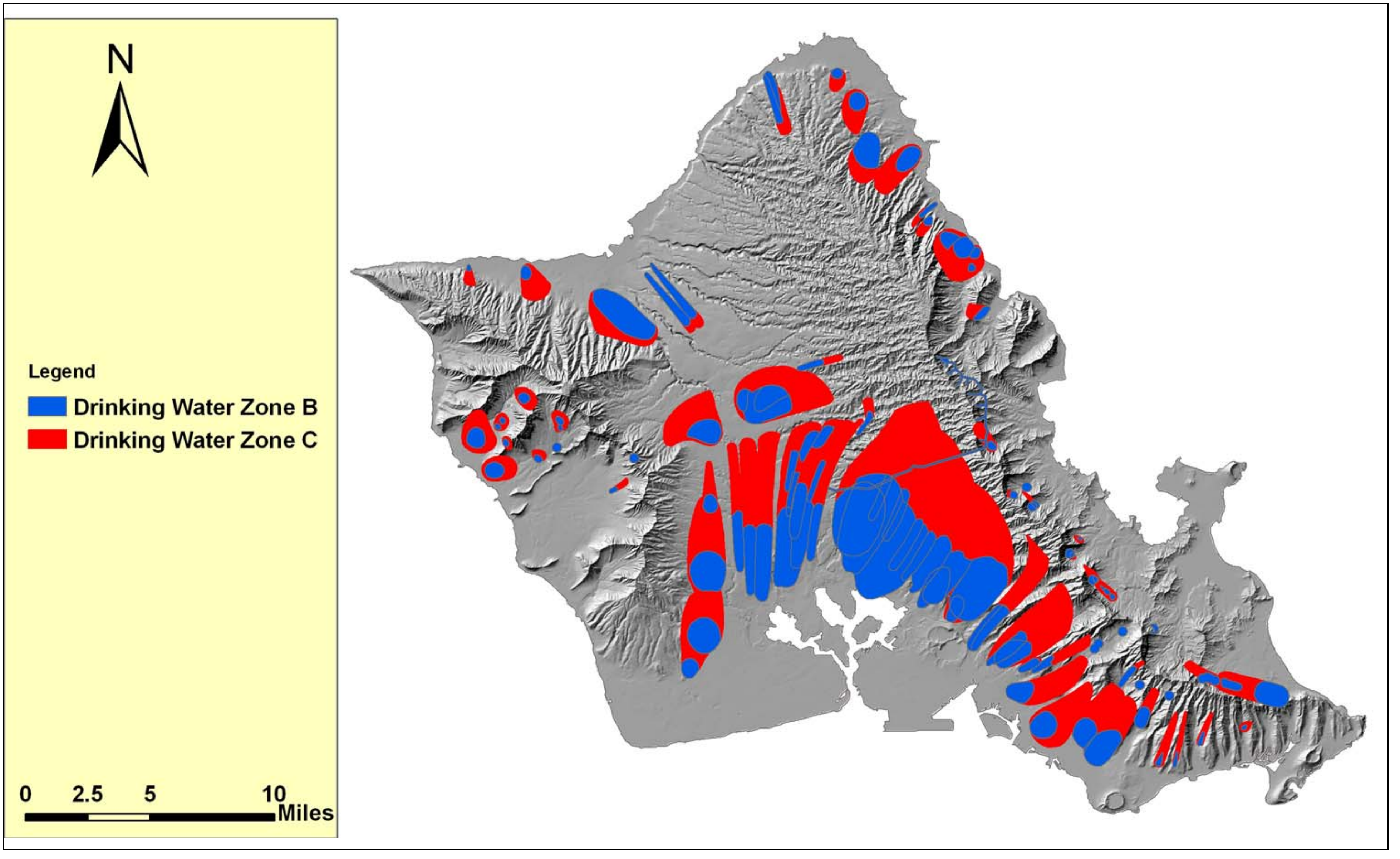

Figure 5. Zone B and Zone C Source Areas Delineations for Drinking Water Wells

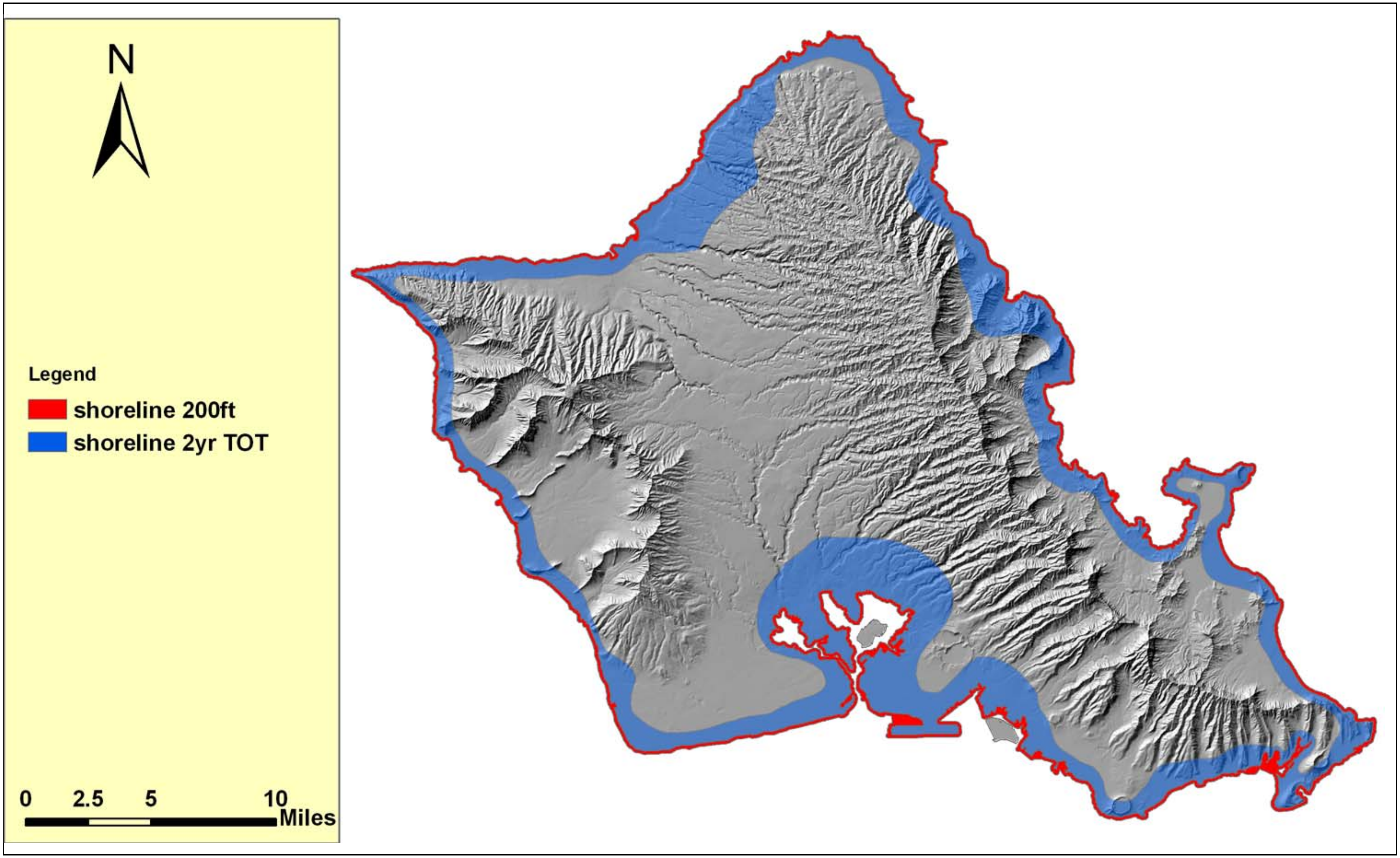

Figure 6. Tow-Year TOT Shoreline Setback

Setbacks Used for Drinking Water Sources Supplied By Groundwater Under the Direct Influence of Surface Water

Springs and water development tunnels commonly occur in hydrogeologically complex areas such as volcanic rifts zones, or where subsurface ash or soil layers produce perched water conditions. Many times these types of water sources receive percolating water from surface water and are designated groundwater under the direct influence of surface water (GWUDISW). The SWAP used the fixed-setback method to delineate the Zone B for GWUDISW sources. This approach was also taken because the hydrogeologic conditions surrounding these ROCs are too variable and complex to model with certainty. For example, groundwater development tunnels commonly occur in dike intruded lavas. Dikes are commonly near vertical-tabular structures of very low permeability. The presence of a dike poses a barrier to groundwater resulting in either a change in groundwater flow direction or impounding groundwater to high elevations. Uncertainty regarding the occurrence and orientation of the dikes hampers efforts towards reliable groundwater modeling. For these systems, a fixed 1,000 ft radius was delineated around the source intake or spring. Physically based modeling for drinking surface water sources is also difficult mainly due to complications in overland flow assessment. For surface water sources, the Zone B buffer was created by setting a 200 ft setback from stream and ditch banks and 400 ft setback from lakes and reservoirs (HDOH, 2004). Figure 7 shows the buffer zones for GWUDISW and surface water drinking water sources. The zone C delineation, protecting against the introduction of chemical contamination, was the entire watershed up gradient from the stream intake or tunnel entrance for GWUDISW systems. There were no OSDS in any GWUDISW Zone C area so those are not show in Figure 7.

Fixed-Setback Delineation For Surface Water ROCs

The potential effect of OSDS on streams was assessed by modifying the methods used for surface water drinking water sources. A 200 ft setback from the streams consistent with the Zone B for surface water sources was used as a base buffer. This setback was merged with Federal Emergency Management Agency (FEMA) 100 year flood risk zones to account for the introduction of sewage contaminated water due to flooding the could enter the steam. This stream bank setback was also extended to include the adjacent flood plains that were not designated as flood risk zones by FEMA. The alluvial flood plains commonly have perched aquifers that are hydraulically connected to the stream. OSDS effluent that leaches to this aquifer can potentially migrate to the stream. To identify the fluvial flood plains not included in the FEMA flood risk coverage, a 1000 ft stream buffer was mapped to a digital elevation coverage. A slope analysis was performed on the extracted elevation data and clipped to include only those areas with 1000 ft of a stream channel and with a slope of 6.5 percent or less. Such a slope was estimated based on comparing the resulting zone with topographic maps which showed that the identified flood plains were within 1000 ft from a stream channel.

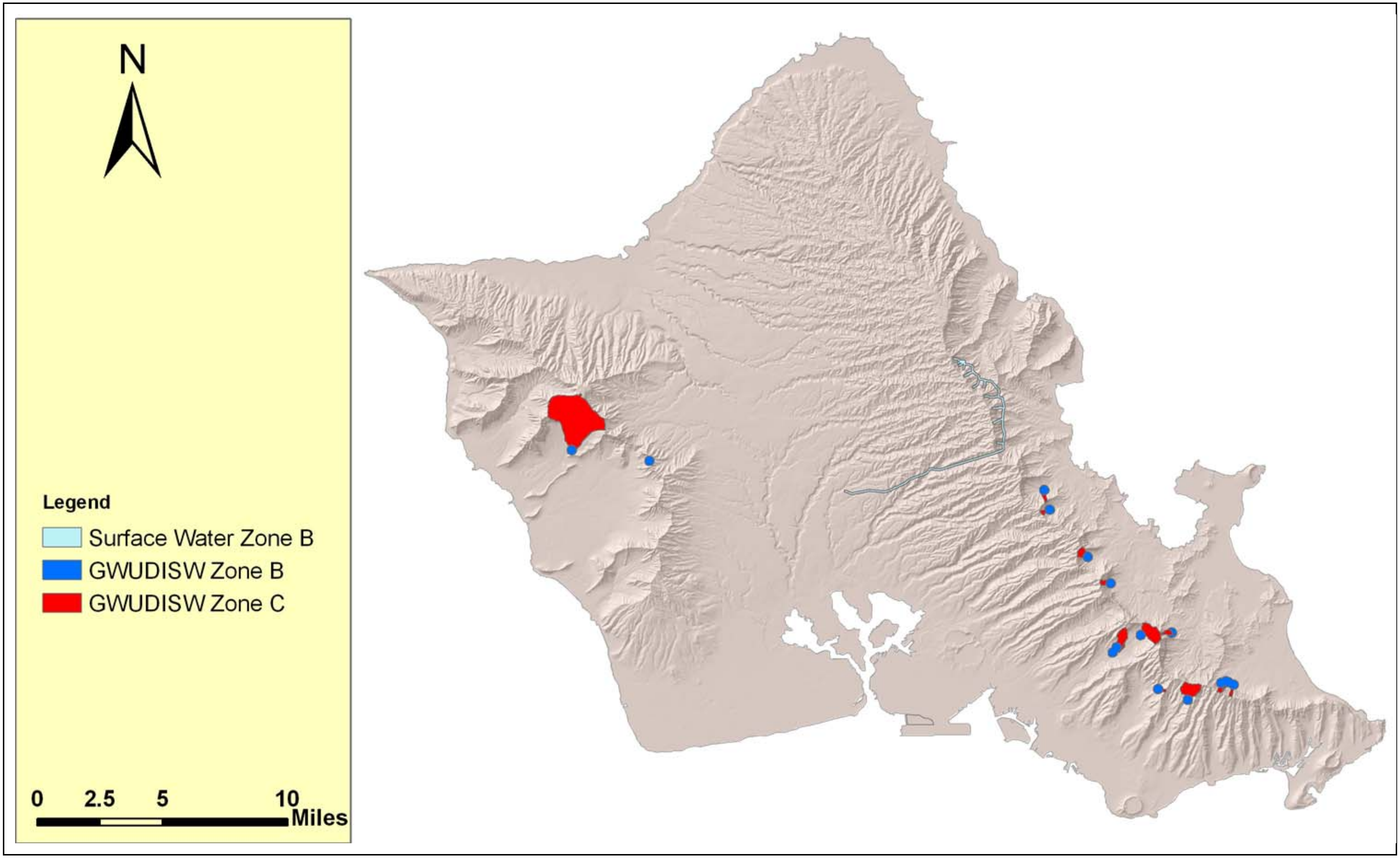

Figure 7. GWUDISW Zone B and Zone C, and Surface Water Zone B Source Area Delineations

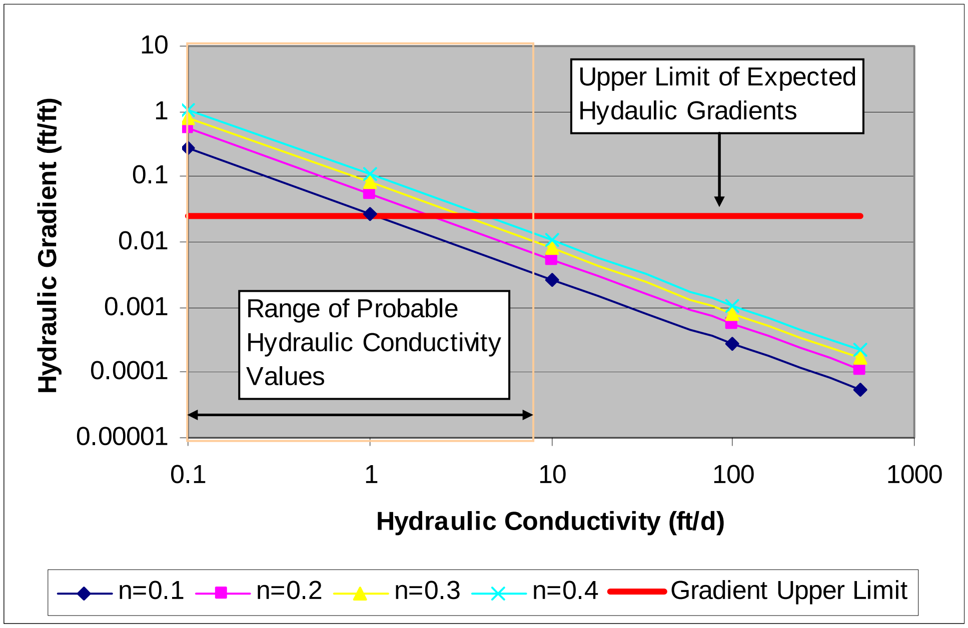

Figure 8. Range of Hydraulic Conductivities, Porosities, and Hydraulic Gradients Where Transport Distance is Less than 200 ft in Two Years

The 200 ft setback should equal or exceed the same level of protection as a two-year TOT to ensure pathogens are not introduced into the surface waters. To test the suitability of the 200 ft stream setback buffer, a family of curves were developed that considered possible values of hydraulic conductivity, hydraulic gradient, and saturated zone porosity. In Figure 8, the lines on the graph represent value of these parameters that would result in groundwater traveling 200 ft in two years. Areas to the lower left of the lines indicate conditions where a 200 ft setback would be equal to or greater than a two-year TOT buffer. Areas to the upper right of the lines indicate combinations where the predicted TOT would be less than two years.

One key parameter is the hydraulic conductivity of alluvium surrounding the stream channel. Nichols et al. (1996) list the hydraulic conductivities of alluvial material as ranging from 1 to 500 ft/d. Other sources indicate that the probable value is on the lower portion of this range. Based on Wentworth, 1938, Oki (2005) modeled the affect of valley fill (this is alluvial material) on groundwater flow in the Pearl Harbor Aquifer using alluvial hydraulic conductivity values ranging from 0.019 to 0.37 ft/d. His model produced good correlation between simulated and modeled responses to pumping stresses when he used a value of 0.058 ft/d for the stream valley alluvium. TEC, Inc. (2001) estimated hydraulic conductivity values that range from 0.5 to 8 ft/d for the alluvium along Kipapa Stream based on slug tests and groundwater modeling. The probably hydraulic conductivity of stream valley alluvium is less than or equal to 8 ft/d. This is shown as a yellow vertical line in Figure 8.

Very little data was found to establish an upper probable limit for the hydraulic gradient, but gradients measured by TEC, Inc. along Kipapa Stream varied from 0.01 to 0.02 ft/ft. A probable upper limit of groundwater gradient for alluvium along stream channels of 0.025 ft/ft was used in this study since such a value closely follows the stream bed gradient. An upper limit to the hydraulic gradient was set at 0.025 ft/ft and is shown as a red horizontal line in Figure 8.

Based on these limits, the 200 ft fixed setback from the stream channel may not be adequate in cases to ensure that the TOT from the OSDS to the stream is at least two years. OSDS effluent may also be introduced into streams by overland flow. Flooding may cause structurally damaged septic tanks to release large quantities of effluent to the environment that can be carried to streams by the floodwaters. For this reason the flood plain of streams was also incorporated into the buffer. The setback distance was increased to a maximum of 1000 ft from the stream bank where the flood plain was extended further than 200 ft from the stream bank. Flood plains are where alluvial aquifers are expected to occur. This buffer area was further increased to include the FEMA's 100 year flood risk zones where it was part of a stream's flood plain.

3.3.2 Soil Risk Factors

Soil plays an important role in mitigating the adverse environmental impact of OSDS effluent. Small pore sizes in many soils filter out pathogens; clay particles act as sorption sites for nitrate and other nutrients; and 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 were 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, to retard and reduce contaminants, and to 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 the 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 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; USGS, 1988, 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 3 ft of the infiltrating surface (Field et al., 2007 and 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 in effluent quality 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. 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). However, 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 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).

The soil information source for this study was the online soils database of the National Resources Conservation Service (NRCS) (NRCS, 2008). The soils database for Oahu (SDBO) includes a polygon shape file of the soil taxonomy and tables of the soil characteristics. The Access database in the SDBO was setup 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 evaluates the soil suitability for septic tank absorption fields and the second evaluation is for siting sewage lagoons. This study used to septic tank absorption field suitability to evaluate the soil factors that influence the environmental and human health risk posed by OSDS. A printout of the NRCS Sewage Disposal Report is available in Appendix A of this report. The SDBO 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).

Table 6 in this report lists the Interpretive Soil Properties from Table 6-1 in Soil Survey Manual and lists the corresponding field and scores listed in the SDBO. These scores vary between 0 and 1.0, with 1.0 indicating a severe limitation for that parameter. For example a depth to bedrock was assigned a score of zero for values greater than 5.90 ft (slight limitation) and assigned a score of 1.0 for a value less than 3.28 ft (severe limitation). The SDBO scores were multiplied by 100 to allow sufficient scaling in the risk model. The last column in this table correlates the Soil Survey Manual soil property limitation with factors incorporated into the risk model and shows the score values assigned.

Critical soil parameters were mapped to a raster shape file for inclusion in the risk scoring model. Each parameter assessed was assigned a suitability score that varied from 0 (no limitation) to 100 where the limitation is severe. For example, soils underlain by loose sand or fractured rock would not adequately filter the effluent and would be assigned a limitation score of 100, which is equivalent to a severe limitation.

Table 6. Interpretive Soil Properties and Limitation Classes for Septic Tank Soil Absorption Suitability (NRCS, 1993).

Interpretive Soil Property	**Limitation Class**			**Corresponding Field in the SDBO Report and Scores Assigned**
	Slight	***Moderate***	***Severe***	
Bedrock Depth or Cemented Pan (ft)	>5.90	3.28-5.90	<3.28	Depth to Bedrock, 0 and 100
Free Water Occurrence				**Flooding and Ponding; 0, 40, and 100**
Flooding	None	Rare	Common	
Ponding (ft)	>5.90	3.28-5.90	<3.28	
Saturated Hydraulic Conductivity ft/d)				
Minimum 1.97 to 4.92 ft[b]	0.26-1.05	0.11-0.26	<0.11	Percolation rate, factored with soil suitability
Maximum 1.97 to 3.28[c]			>1.05	Filtration Capacity, 0 and 100
Soil Suitability Factors				**0, 25, 50, 75, 100**
Total Subsidence (ft)	--	--	>1.97	
Slope (Pct)	<8	8-15	>15	
Fragments > 3.95 inches[a,d]	<25	25-50	>50	
Down slope Movement[e]				Not Listed

[a] Used to evaluate limitations on septic tank and absorption field installation

[b] 1.97 to 4.92 ft pertains to percolation rate

[c] 1.97 to 3.28 ft pertains to filtration capacity, soils with hydraulic conductivities greater than 1.05 ft/d will not properly filter pathogens from the effluent

[d] Weighted average to 3.28 ft

[e] Severe if occurs, this parameter is not listed as a sewage disposal limitation in the SDBO

3.3.4 OSDS Density

A single OSDS that is operating properly is expected to only pose a small risk to the environment. However, a dense cluster of OSDS will have a cumulative effect since little dilution and attenuation 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 the 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.

Yates 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 on Oahu, 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.

3.3.5 Hydrogeologic Risk Factors

Many hydrogeologic factors influence the risk posed by OSDS to the environment, including depth to the water table, groundwater recharge, and the volume of groundwater flow. To assess the influence these factors have on OSDS risk, the hydrogeologic setting was characterized using GIS and groundwater modeling. The hydrogeologic risk factors considered by this study were the vertical distance between the OSDS point of discharge and the water table, and the severity of contamination in the groundwater water from OSDS effluent.

In this study, the minimum depth to groundwater needed to allow sufficient time for pathogen removal was established using OSDS design regulations for cesspools. An insufficient vertical distance between the point of discharge and the water table creates a potential for adding pathogens to the groundwater and decreases the nutrient load reduction occurring by natural processes in the soil. The Hawaii Administrative Rules (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,
- 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.

Areas where the depth to water is less than 25 ft were delineated by using digital elevation data, a modeled groundwater elevation, and historical well records. USGS groundwater level records with data in the current decade and a history longer than 10 years were downloaded (USGS, 2009b). A review of this data showed a ten year annual average fluctuation of +/- 2.5 ft and seasonal fluctuation of one to six feet with an average of 2.7 ft (+/- 1.4 ft). Since the water table elevation was estimated by modeling the accuracy of the model results were considered. Model calibration results showed that the absolute mean difference between the simulated and measured water table elevations varied from 1.27 ft for the Honolulu Aquifer to 3.97 for the Windward Aquifer. Finally, the vertical resolution of the digital data, which was 1 m or 3.05 ft, was accounted for. The sum of the uncertainties was approximately 8 ft; which was rounded up to 10 ft for this study. A maximum depth of 25 ft (that is 15 ft plus 10 ft) can be taken thus as the upper limit. No risk was assigned to areas where the distances from the ground surface to the water table were less than 25 ft. To map the areas where the depth to groundwater was less than 25 ft, two raster grids were used. The first was 1/3 arc second ground surface elevation downloaded from the USGS Seamless Dataset Server (USGS, 2009a). The modeled water table elevation from Oahu SWAP model was mapped to a second raster grid (Whittier, 2004; and Rotzoll and El-Kadi, 2006). The difference between the two rasters was calculated and those cells where the difference was less than 25 ft were assigned a value of 100. A zero value was assigned to the remaining cells.

As discussed earlier, OSDS effluent adds undesired and potentially harmful contaminants to the groundwater. However, OSDS effluent impact on the water table is reduced by dilution due to recharge and mixing with un-impacted groundwater. In this study, OSDS impact was assessed by groundwater modeling using nitrate concentrations as a risk indicator. This approach incorporated the contributions of the following factors:

- OSDS treatment efficiency,
- OSDS effluent discharge rate,
- Groundwater recharge,
- Dilution by groundwater flow,
- Groundwater flow direction, and

- The cumulative impact of multiple OSDS**.**

The SWAP Oahu groundwater model was modified by merging the OSDS density polygon shape file with an Oahu groundwater recharge shape file. The merging of the two shape files provided the spatial resolution needed to adequately model the effect of the increase in groundwater nitrate concentration from OSDS effluent. The nitrogen loading for each polygon was calculated by multiplying the OSDS effluent rate by the nitrate concentration in the effluent based on the OSDS category and disposal type. The nitrogen load for each OSDS type was based on data in WRRC and Engineering Solutions, Inc. (2009) and is presented in Table 7.

Table 7. OSDS Nitrogen Concentrations

OSDS Type	**Total Nitrogen**	
	Maximum	Typical
	(mg/L)	(mg/L)
All Soil Treatment Systems	1	1
Septic tank discharging to a seepage pit	82	36
Aerobic unit discharging to a seepage pit	30	24
Cesspools	90	60.5

Nitrogen was treated as a conservative species with no degradation/transformation simulated. Since Hawaii aquifers are well oxygenated, it is further assumed that all of the dissolved nitrogen species are oxidized to nitrate. This is consistent with stability of nitrate in an oxidizing environment below the biological active zone, and is considered a worst case scenario. A reduction in nitrate concentration will occur by the mixing of nitrate due to groundwater movement, hydrodynamic dispersion, and the addition of nitrate free recharge. These processes were modeled using the Oahu 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 Swartz (1990) (TEC, Inc, 2001 and 2004). The nitrate transport simulation was run for 50 years to ensure that the simulated nitrate concentrations would reach a steady state distribution. The results of the nitrate transport model were then mapped to a shape file with polygons delineated using the nitrate concentration contours. The polygons were given a risk score that varies from zero (no OSDS nitrate) to 100 (the maximum simulated nitrate concentration) for use in the risk model.

3.4 THE CUMULATIVE RISK MODEL

The spatial distribution of OSDS risk was assessed using a weighted overlay. This was done by "stacking" each of the individual risk rasters, assigning a weight to each factor, then summing the risks in each vertical column of cells. For the resulting grid, the sum was scaled to the span of values of zero to ten, with the higher scaled sum indicating a greater degree of OSDS risk to human health or the environment. There were 12 risk raster data sets created for this model. The factors that assess the risk to human health were given the highest weight. These included drinking water source buffers and stream and shoreline setbacks. Table 8 gives the weighting values for each scenario. Many of the risk factors were 'yes-no' type evaluations represented by a zero for no risk and 100 if a mitigation threshold was not attained. For example as areas where the depth to water was greater than 25 ft were assigned a risk score of zero, while areas where the depth to water was less than 25 ft were assigned a risk score of 100. Others were divided into sub-classes of risk such as groundwater impact where the risk score was proportional to the modeled OSDS nitrate concentration.

Table 8. Risk Scoring Model Parameters and Weights

Risk Factor	Weighting Percent	Score
Drinking Water Zone B	14	0, 100
Stream Buffer	11	0, 100
Flood Risk Zones	11	0, 40, 100
Shoreline 200 ft setback	9	0, 100
Depth to Water	8	0, 100
Insufficient Filtration	8	0, 100
OSDS Density	8	1, 10, 60, 100
Groundwater Impact	8	0, 25, 50, 75, 100
Depth to Rock	5	0, 25, 50, 75, 100
Drinking Water Zone C	8	0, 100
Soil Septic Unsuitability	5	0, 25, 50, 75, 100
Shoreline 2 year Setback	5	0, 100

The risk model is flexible in that weighting can be easily changed to better reflect the actual risk posed by OSDS. Section Four describes the results of the individual risk mapping and the final risk score distribution for OSDS on Oahu.

SECTION FOUR: RESULTS

This study estimated, to the extent of data availability, the total number of OSDS on Oahu and listed them by type and location. Using this information and the risk scoring model described in Section Three, the spatial distribution of risk posed by these systems was mapped. Finally a risk score was assigned to each parcel containing an OSDS. The results of this study will allow Department of Health planners to prioritize OSDS inspections and focus water impact investigations where the potential of negative impact to this resource is greatest.

4.1 OSDS INVENTORY AND ROC DELINEATIONS

4.1.1 Oahu OSDS Inventory

This study estimates that there are 14,606 OSDS on Oahu. This number was reduced from nearly 25,000 during a comprehensive review of available records. The process of records screening and the resulting numbers are described below.

The IWS database contained 5,127 records for Oahu. Of these records only 1,160 had inspection or a final approval date. Those without a final approval or inspection were assumed to have not been completed and the structure was served by a cesspool. The DEWALT database identified 22,167 parcels as not being intersected by a sewer lateral, not having completed the OSDS permitting process and needing some type of OSDS based on having a fixed bath. These parcels were assumed to be served by a cesspool. Merging the assumed cesspool records with IWS records with a completed permitting process gave a potential total of 23,327 OSDS. The records were further filtered using the sewer connection data from the HBWS, which reduced the potential number of parcels using and OSDS to 19,658. A review of the remaining parcels using ArcGIS showed that many were actually utility easements, streets, or lots that should not include wastewater disposal systems. Trial and error showed that the parcel polygons with an area less than 600 ft^2 or an area to perimeter ratio of less than 3.5 would not have a wastewater system. A final visual review was done to ensure that the remaining parcel would be expected to host a wastewater disposal system. The final screening step reduced the number of records to 13,684. However, many parcels host more than one OSDS which increased the number to an estimated total OSDS on Oahu of 14,606.

The inventory of OSDS was broken down into four categories as listed in Table 9. This study estimates that nearly 10 mgd of sewage is released to the environment, the majority reaching the groundwater (a small amount would be lost to the atmosphere as ET). Of the estimated quantity of OSDS, cesspools accounted for 77 percent of the total with an estimated release of nearly 7.2 mgd of untreated sewage effluent. Since the cesspool effluent receives no treatment this results in nearly 96 percent of the OSDS nitrogen released coming from these systems (1,660 kg/d out 1,732 kg/d). Table 9 summarizes the estimated quantities of OSDS and the effluent produced by each.

Table 9. Estimated Quantities of OSDS on Oahu and the Daily Effluent Output

OSDS Type	Quantity	Daily Effluent (mgd)	Daily N Flux (Kg/d)	Daily P Flux (Kg/d)
Class I	2,620	1.96	7.6	14.9
Class II	534	0.38	51.4	18.5
Class III	199	0.15	13.4	4.5
Class IV	11,253	7.19	1660.0	462.6
Total	**14,606**	**9.67**	**1732.1**	**500.4**

4.1.2 ROC Buffer Zones OSDS Inventory

An inventory was done to quantify the number of OSDS in each buffer zone (Table 10). It should be noted that many of the OSDS fall in multiple buffer zones making the sum of the numbers listed in the table is greater than the total number of OSDS. For example, many OSDS occur near the coast, placing these units in the both shoreline setbacks and in broader flood plains of the streams.

Based on this assessment, over 7,000 OSDS are in locations where the effluent could cause human exposure to pathogens. This includes 839 OSDS in the drinking water Zone B, (the two-year TOT buffer), 5,211 OSDS in the stream buffers, and 1,469 OSDS in the shoreline 200 ft setback buffer. In addition, those were 1,016 OSDS located in the drinking water Zone C buffer (the ten-year TOT) and 6,967 OSDS located within a two-year TOT from the shoreline (including those already accounted for in the 200 ft setback) increase the contaminant and nutrient load to the environment and increase human exposure to water borne contamination such as nitrates, pharmaceuticals, and other chemicals with proven or suspected adverse health impacts. Although this assessment identifies those OSDS with the potential to cause the aforementioned problems, no assessment has been made as to whether these impacts area actually occurring, which should be the subject of a future study. Table 10 below details the OSDS that are inside of the ROC buffer zones.

Table 10. Summary of OSDS Located in ROCs

	Drinking Water CZD		Stream Buffer	Shoreline	
	Zone b	Zone c		200 ft setback	Two Yr TOT
Soil Treatment	80	113	1,058	291	1,908
Septic System with Seepage Pit	15	52	157	39	319
Aerobic Treatment with Seepage Pit	14	6	64	29	132
Cesspool	730	845	3,932	1,110	6,967
Total OSDS	**839**	**1,016**	**5,211**	**1,469**	**9,326**
Total Effluent (mgd)	0.54	0.65	3.48	0.95	6.17
Total Nitrogen (kg/d)	109	128	607	166	1,062
Total Phosphorous (kg/d)	30.8	36.6	176	48.0	308.5

The distribution of OSDS by community is, as expected, uneven. The OSDS are much more prevalent in rural communities, although urbanization is progressing faster than the sewer infrastructure is expanding. For the purposes of this study, Oahu was divided into communities based on the town designation of the Neighborhood Board districts. The large town districts of North Shore (Mokuleia, Waialua, Haleiwa, and Pupukea/Sunset Beach) and Waianae (Nanakuli, Maili, Waianae, and Makaha) were divided along Neighborhood Board districts. Table 11 lists the communities with the highest number of OSDS. These ten communities out of 39 account for 71 percent of the OSDS. Half of these districts have OSDS densities greater than 40 units/mi^2, the value the USEPA has evaluated as posing a high risk to the environment. An OSDS listing by community and a map this same data is provided in Appendix B.

Table 11. The Ten Communities With the Highest Number of OSDS

TOWN	Total OSDS	Total Effluent (mgd)	Total Nitrogen (kg/d)	Total Phosphorus (kg/d)	OSDS Density (units/mi^2)
Koolauloa	1,913	1.251	182.5	54.2	32.9
Ewa	1,373	0.870	181.5	51.4	18.8
Pupukea, Sunset Beach	1,306	0.896	132.6	39.7	123.3
Kahaluu	1,275	0.859	140.8	41.2	63.4
Waianae	1,085	0.745	132.0	38.1	32.0
Waialua	1,006	0.732	136.0	39.1	39.1
Waimanalo	759	0.512	85.0	24.7	70.1
Haleiwa	592	0.408	67.8	19.8	15.3
Makakilo, Kapolei, Honokai Hale	551	0.310	62.7	17.8	15.6
Makiki, Lower Punchbowl, Tantalus	533	0.331	67.7	19.3	155.7

4.2 RISK MODEL

The risk model created by this study mapped the spatial distribution of risk factors assessing the impact these systems pose to human health and the environment. Such a relative risk can be used as a criterion for OSDS inspection prioritization. The results can be also used by planners and regulators to assess the suitability of OSDS types for a certain location during reviewing permit applications and to target OSDS inspections toward areas where the most positive benefit could be realized from identifying and upgrading malfunctioning OSDS. The following sections will cover results for various risk factors.

4.2.1 Groundwater Contamination

The groundwater model shows the impact of existing OSDS on the groundwater system using nitrate concentration as a risk indicator. Figure 9 shows the simulated OSDS derived nitrate concentration distribution on Oahu. The model results shows a maximum additional OSDS derived nitrate concentration of about 11 mg/L. This simulated concentration does not include nitrate already in the groundwater from other sources such as agriculture. This models shows that OSDS effluent alone can produce groundwater concentration of NO_3-N that exceeds the USEPA MCL of 10 mg/L for drinking water. It should be alarming that the OSDS-derived nitrate concentration was close to or exceeded the MCL in the areas of Waianae, Waialua, Diamond Head, and the Mokapuu Peninsula.

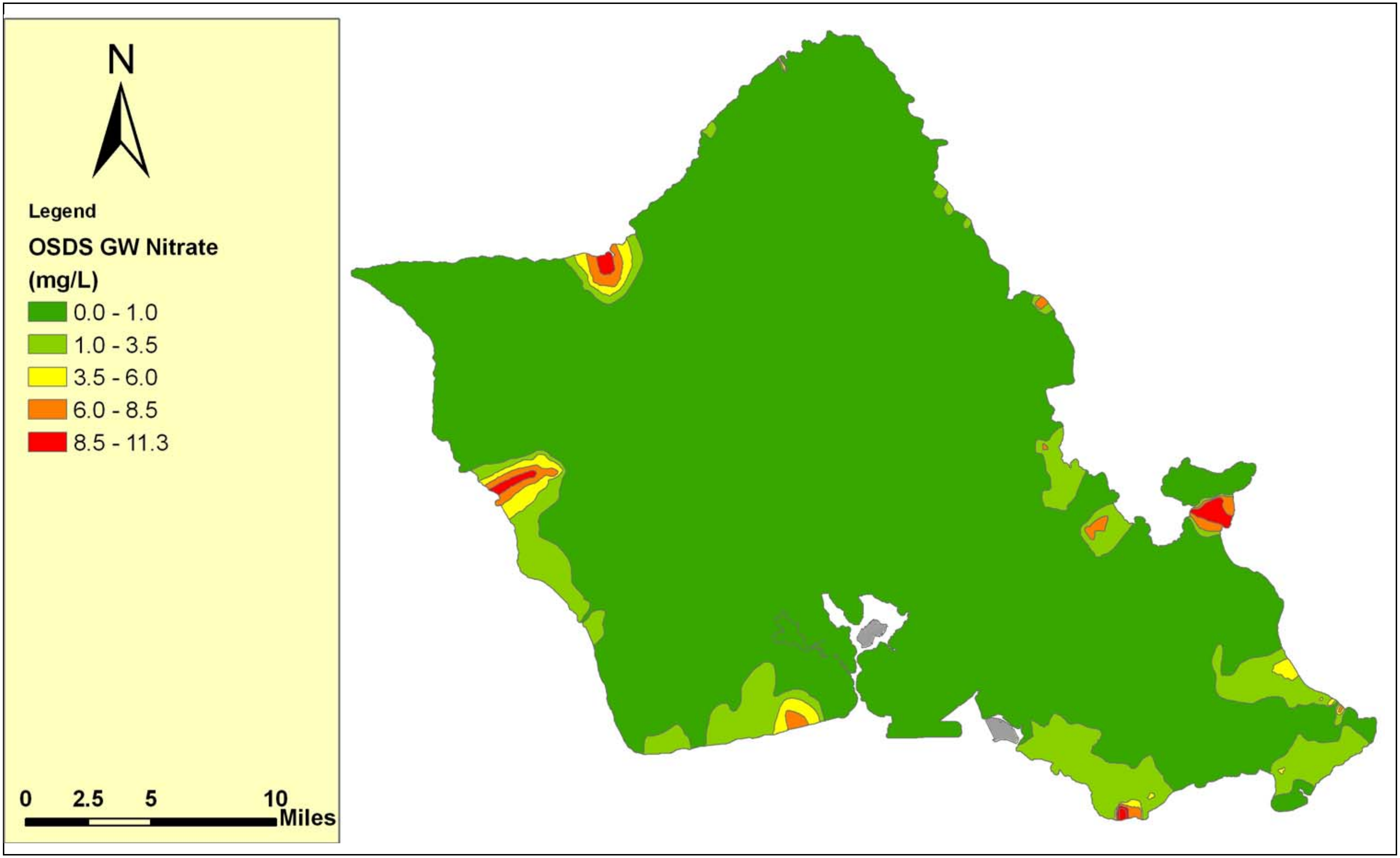

Figure 9. Simulated Concentration of OSDS Derived Nitrate in Groundwater

To adequately assess if OSDS derived nitrate poses a health risk other sources of this contaminant must also be considered. Past and current land use add nitrate to the groundwater. Higher concentrations of this species closely correlate with land where sugar cane was once grown. Figure 10 shows the distribution of nitrate in groundwater wells superimposed on a map of past sugar cane and pineapple fields. There still is a significant amount of leachable nitrate in the vadose zone to maintain the elevated nitrate concentrations in groundwater. Wells up gradient of agricultural areas show the natural background concentration varies from about 0.5 to 1.5 mg/L. Wells in or down gradient from agricultural areas have nitrate concentrations ranging from 3 to greater than 5 mg/L. The nitrate model showed that OSDS effluent in the Waialua area would increase the groundwater concentration by about 3.5 to 11 mg/L. The contribution of OSDS concentrations will certainly cause values to exceed the MCL. Waimanalo is similar to Waialua in that both areas are dominated by agriculture and there is a heavy dependence on OSDS for wastewater disposal. Both the Waialua and Waimanalo areas have perennial stream reaches where the nitrate laden groundwater will contribute to the nutrient load. However, based on CRWM (2008) data no public drinking water systems or domestic wells are in the areas of high OSDS nitrate so consumption of nitrate contaminated water is not a risk factor in these high nitrate areas.

4.2.2 Soil

Soil provides the primary media for mitigating the undesired impacts of OSDS influence. Using methods described in Section 3, the spatial distribution of various risk factors are outlined below.

4.2.2.1 Soil Filtration Ability

Figure 11 shows that most of the soils on Oahu provide adequate filtration of OSDS effluent, with the exception of areas shown in red in the figure. Coastal and stream valleys are areas where the soil media have a high probability of providing insufficient filtration. Inland, areas of the Tantalus, Mokuleia, and the Mokapuu Peninsula have insufficient filtration ability. This should be alarming considering that such areas include a significant number of OSDS.

4.2.2.2 Soil Thickness

The probability that pathogens will be released to environment increases in areas where the soil thickness is less than 5.9 ft. Figure 12 shows the spatial distribution of soil thickness limitations on OSDS effluent treatment based on the SBDO assessment. A score of zero indicates no limitation and a score of 100 indicates a severe limitation. The figure illustrates that the soil thickness is not a limiting factor for most of the island. Severe limitations occur in most of the mountain ridge areas where there are few OSDS except in eastern Oahu. Areas where soil thickness is insufficient are also located in the Ewa plain, some leeward valleys, and the Kaiwi area of eastern Oahu. There are numerous OSDS in such areas placing severe limitations on the treatment of OSDS effluent.

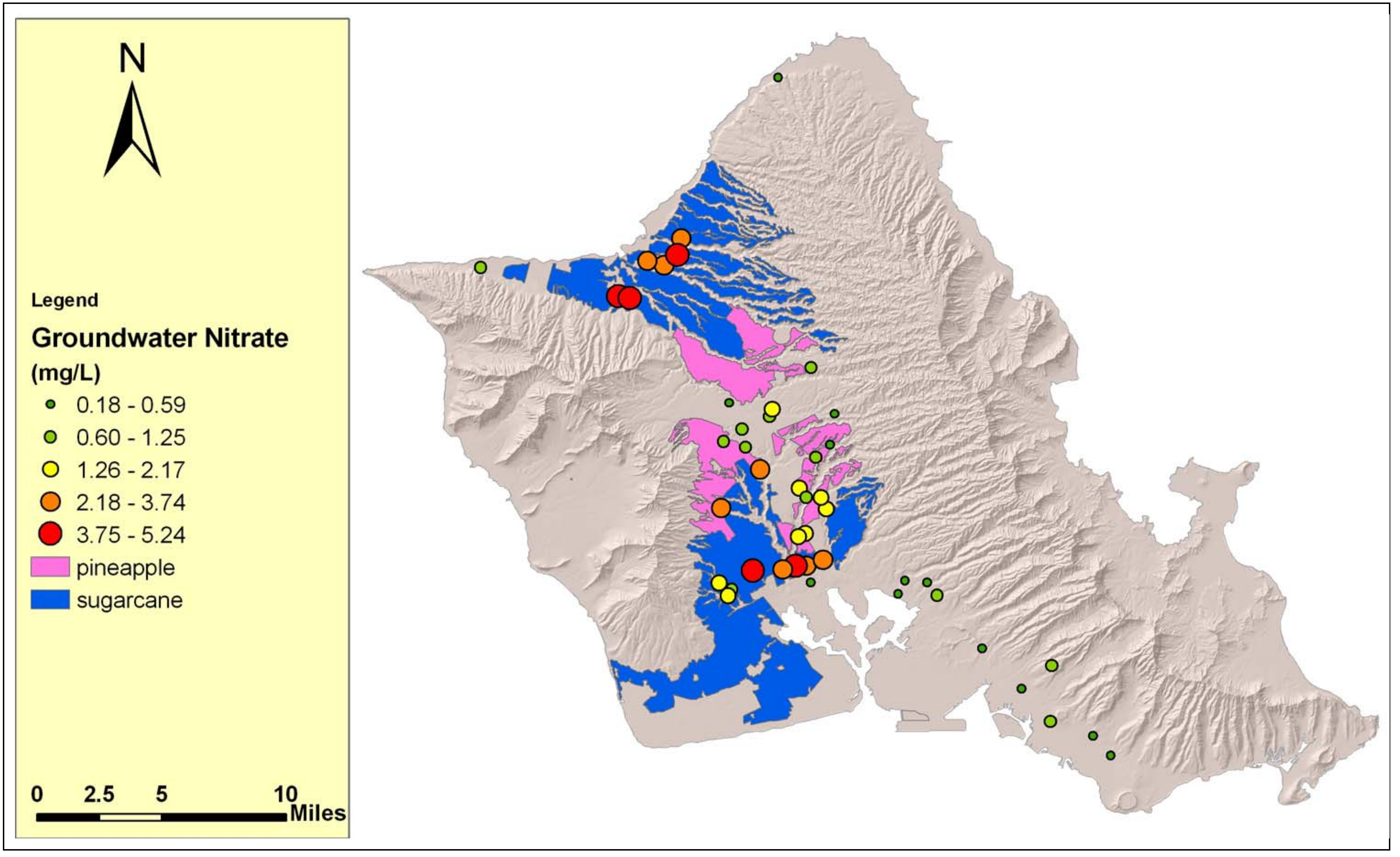

Figure 10. Past Sugar Cane and Pineapple Agriculture and the Distibution of Nitrate in Groundwater

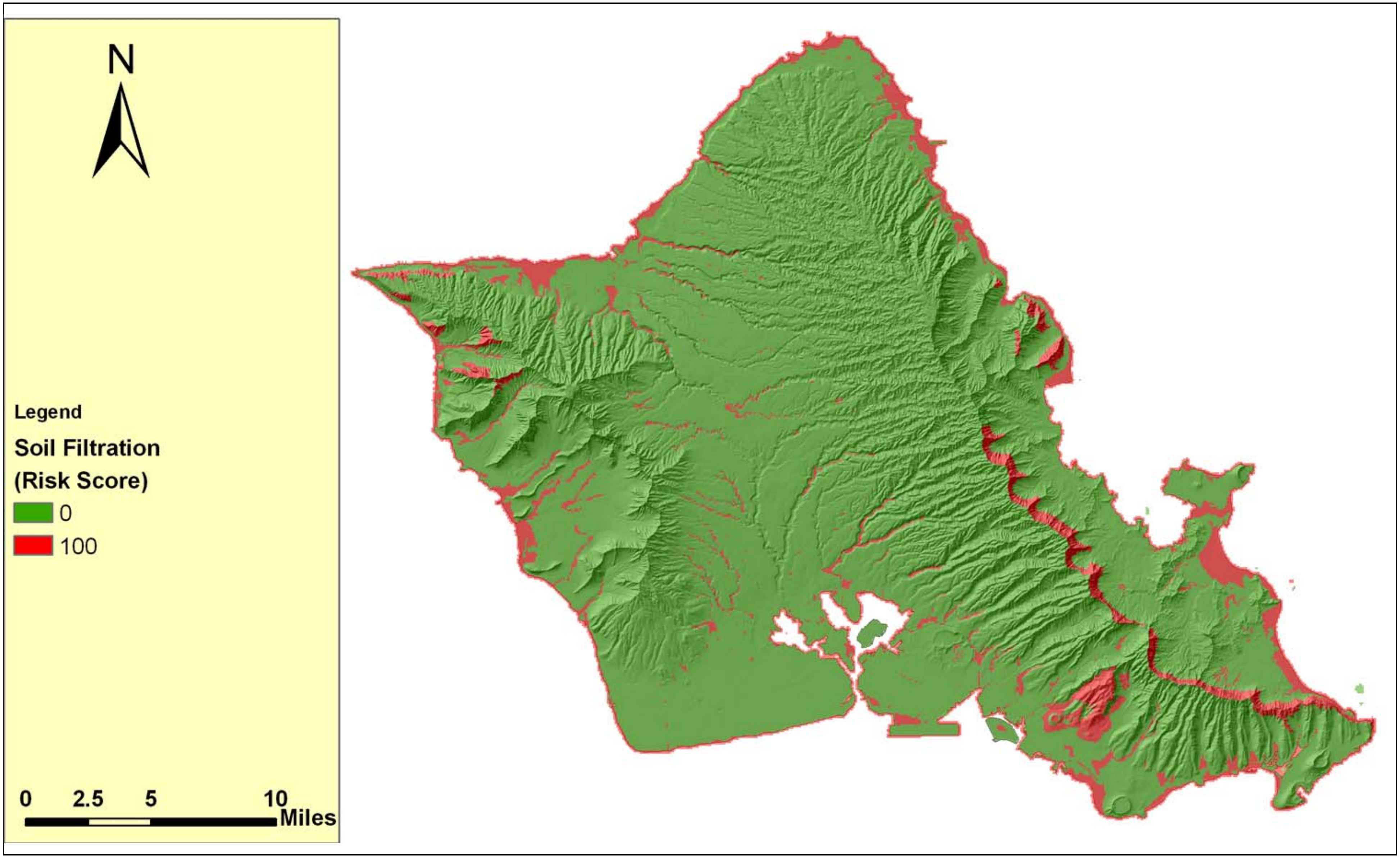

Figure 11. Areas on Oahu Where Soil Filtration Capacity is a Limitation

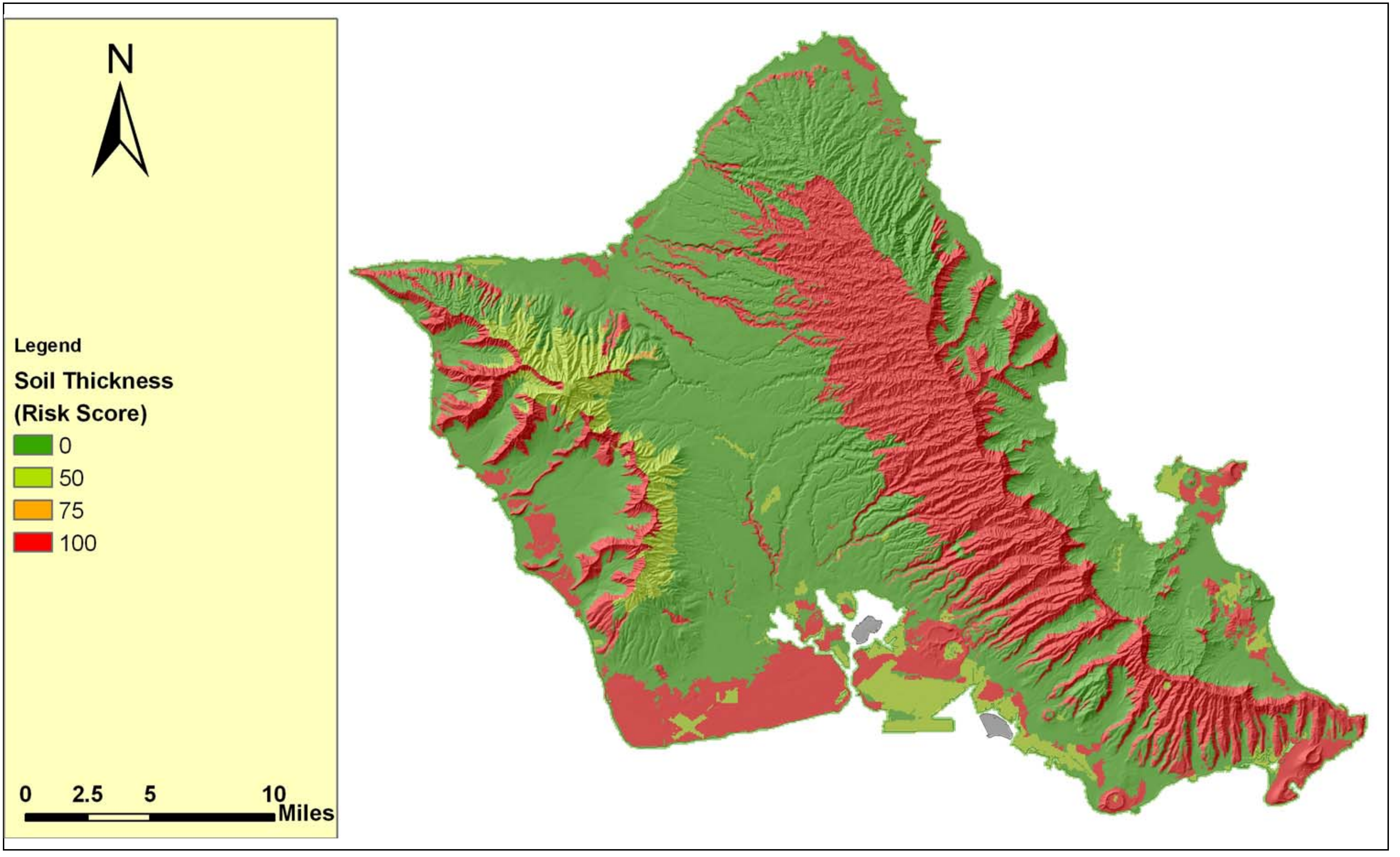

Figure 12. Areas Where Soil Thickness is a Limitation

4.2.2.3 Other Soil Factors

The remaining NRCS septic soil suitability factors were evaluated together. These factors include:

- Slow water movement,
- Excessive slope,
- Large stone content, and
- Seepage out of the bottom layer.

Nearly all of Oahu shows limitation in one or more of these areas. Figure 13 shows the spatial distribution of relative limitations placed on OSDS effluent treatment by these factors combined. The score varies from zero (no limitation) to 100 (severe limitations). The areas of least suitability, as with the other soil factors, are the mountain slopes. The areas of greatest suitability are the Honolulu and Ewa coastal plains. However, as described earlier, the suitability of these areas for OSDS effluent disposal is limited by the soil thickness and depth to water.

4.2.3 Flooding

Flooding can cause damage to septic tanks by buoying tanks and causing structural damage as they are dislodged. The more serious and immediate risk is related to the mixing of OSDS effluent with flood waters, resulting in potential direct human contact. Areas having a risk of flooding or ponding include:

- Areas and soils evaluated as susceptible to flooding or ponding in the SDBO; and
- The FEMA 100 year flood zones excluding those already in a stream buffer area.

The NRCS flood and ponding score was normalized to 100 resulting in three score values for this parameter of 0, 40, and 100. The 100 year flood plain areas not already covered by the SBDO flood prone areas were assigned the maximum risk score value of 100.

The areas where the OSDS are most at risk from flooding include much of the southern coastal plain area (Honolulu and Ewa), Waianae Valley, Waialua, the coastal plain in the Kahuku area, and low lying areas in the Kaneohe, Kailua, and Waimanalo districts (Figure 14).

4.2.4 Depth to Water

As discussed in Section 3, a vertical distance between the ground surface and groundwater (or the thickness of the unsaturated zone) of 25 ft or less was evaluated as insufficient for proper treatment of the OSDS effluent, particularly the die-off or inactivation of pathogens. Those areas were assigned a risk score of 100 while the areas where the depth to groundwater was greater than 25 ft were assigned zero risk. Figure 15 shows that the thickness of the unsaturated zone is less than 25 ft nearly all of the coastal plains. These coastal plains are unfortunately areas of high OSDS density.

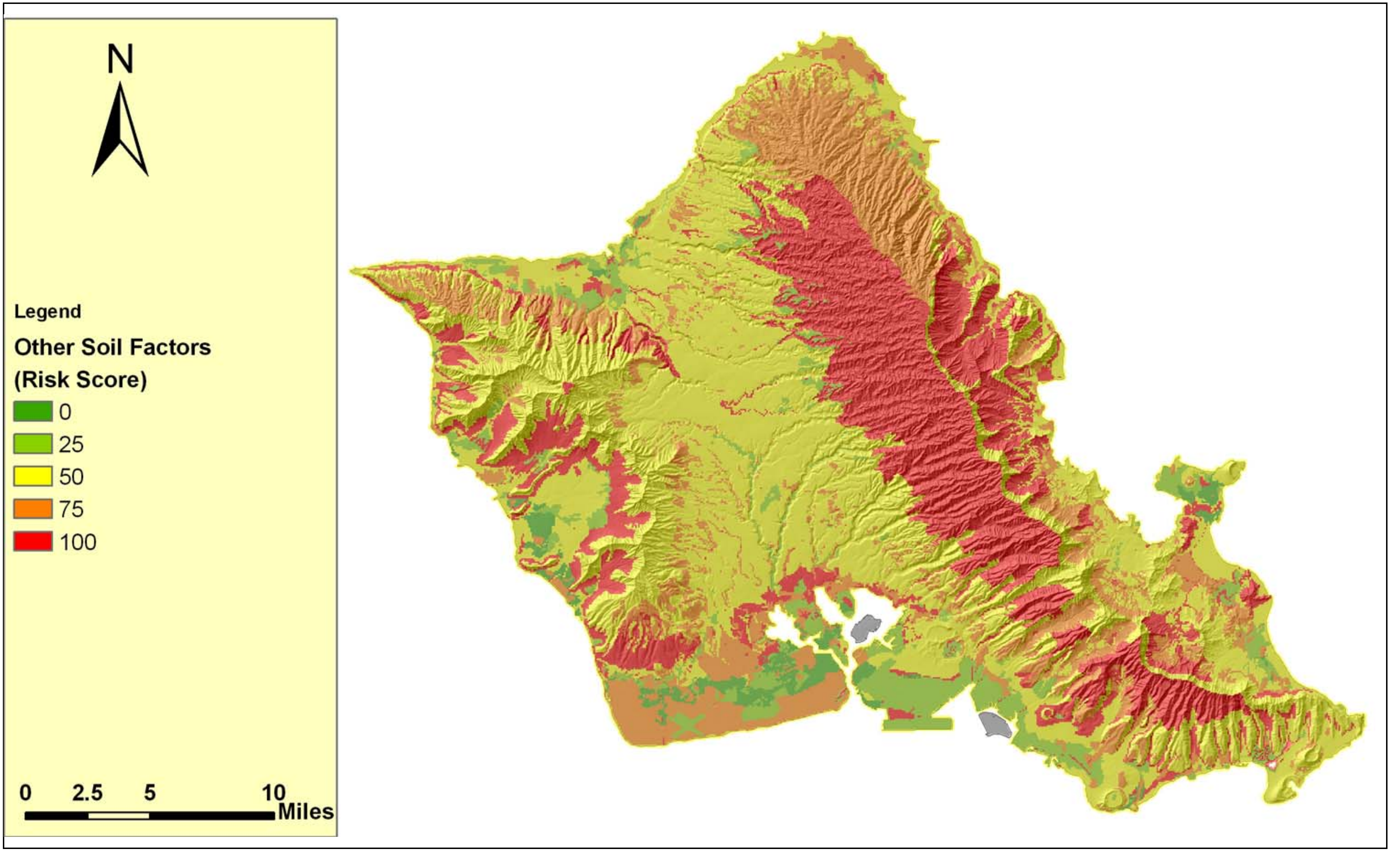

Figure 13. Map of the Severity of Other Soil Limitations

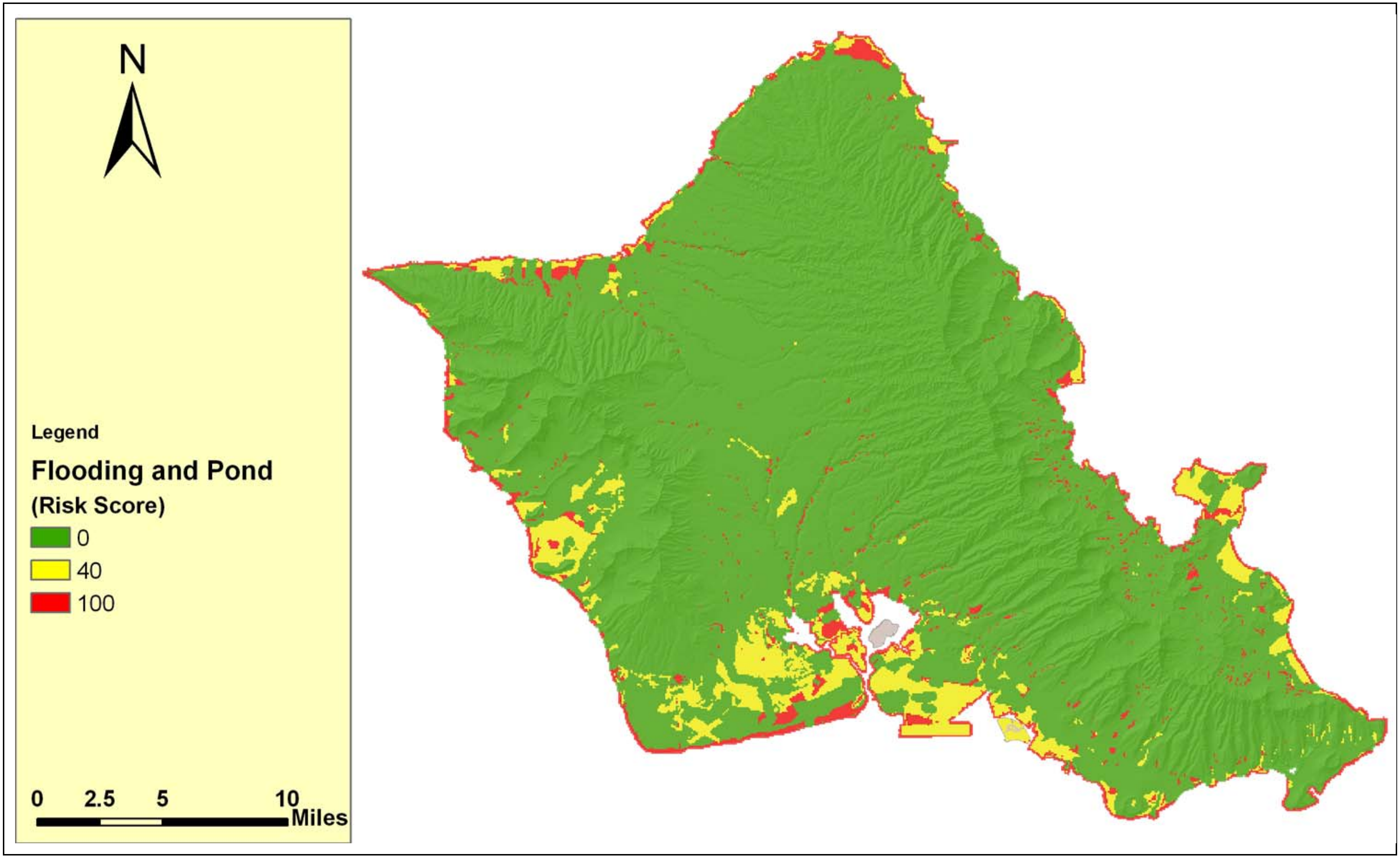

Figure 14. Areas Susceptible to Flooding or Ponding

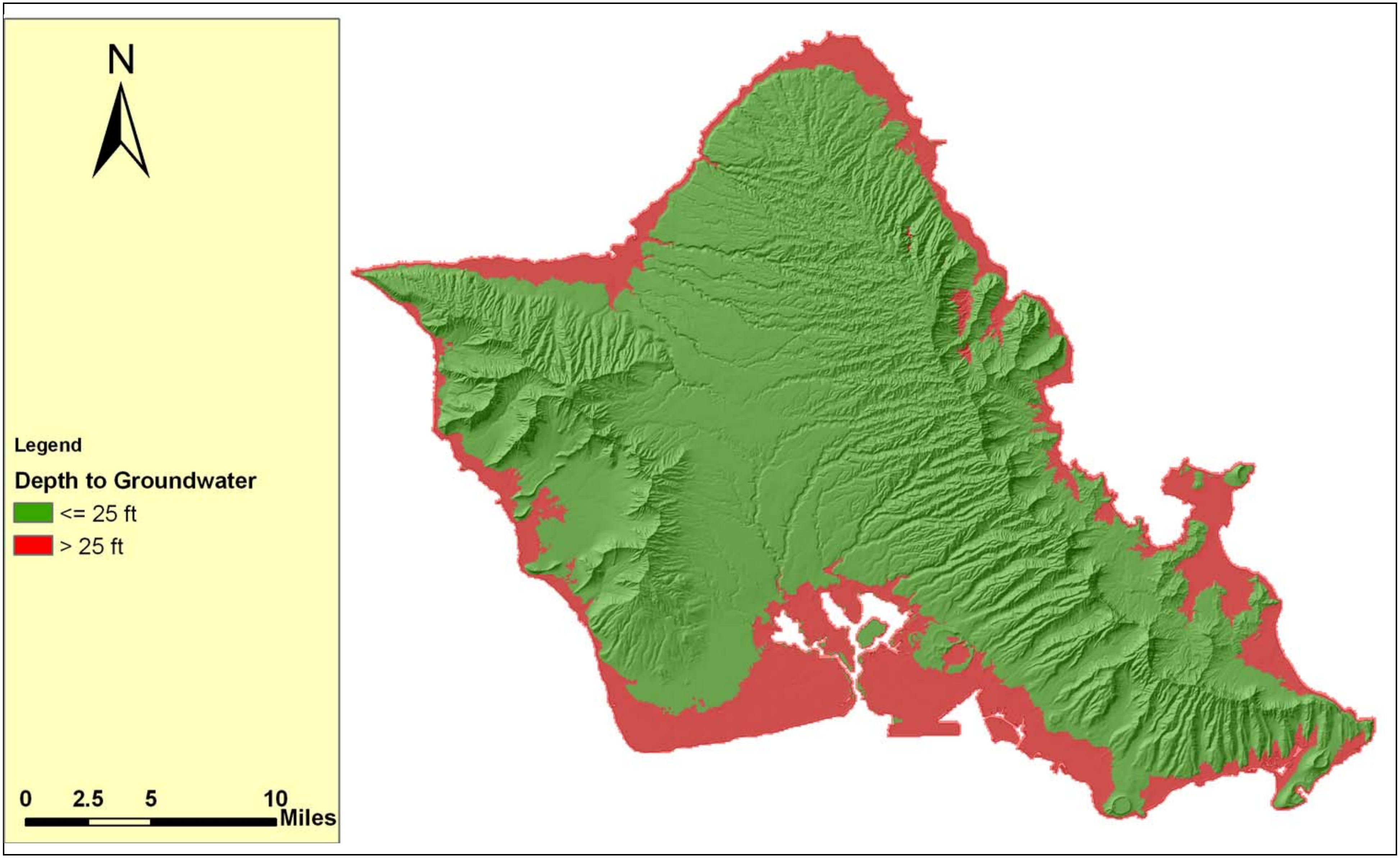

Figure 15. Areas Where the Depth to Groundwater is Less Than 25 ft

4.2.5 OSDS Density

Proximity to the ocean and flat topography make the coastal plains attractive for development. Unfortunately, dwellings in these prized areas must rely on OSDS for sewage disposal if the area is not served by a sewer. Figure 16 shows the density of OSDS on Oahu. The areas with the highest density (and thus highest risk) were Waianae, Waialua, Hauula/Punaluu, Kahaluu, Waimanalo, Honolulu, and Ewa Beach. These areas have an estimated OSDS density that exceeds 40 units/mi^2. The USEPA has designated areas with an OSDS density of greater than 40 units per mi^2 as regions where there is a significant potential for causing unacceptable groundwater contamination. Honolulu and Ewa Beach are served by sewers, but during the inventory process it could not be confirmed that numerous parcels in these areas were actually connected to the sewer system.

The scoring scheme follows the conclusions of Yates (1985):

- densities of 0 – 1 units/mi^2 were assigned a score of 0;
- densities of 1 to 10 units/mi^2 were assigned a score of 25 (low risk);
- densities of 10 to 40 units/mi^2 were assigned a score of 50 (moderate risk);
- densities of 40 – 100 units/mi^2 were assigned a score of 75 (high risk); and
- densities greater than 100 units/mi^2 were assigned a score of 100 (maximum OSDS density was 370 units/mi^2).

Areas where the risk using the USEPA value of greater than 40 units/mi^2 area shown in orange or red on the map (Figure 16). A 1977 study done for the USEPA recommended that septic systems be restricted to lot sizes of 2 to 10 acres (Yates, 1985). This would correlate to an OSDS density of 64 to 320 units/mi^2. A review of the OSDS and TMK data showed that over 80 percent of the parcels with OSDS had an area of less than 2 acres. These numbers are particularly troublesome in the high OSDS density areas such as Waialua and the windward coast that are also in close proximity to the ocean. Further analysis showed that there were 10,086 OSDS in high density areas (greater than 40 units/mi^2) that are also located on a lot size of less than two acres.

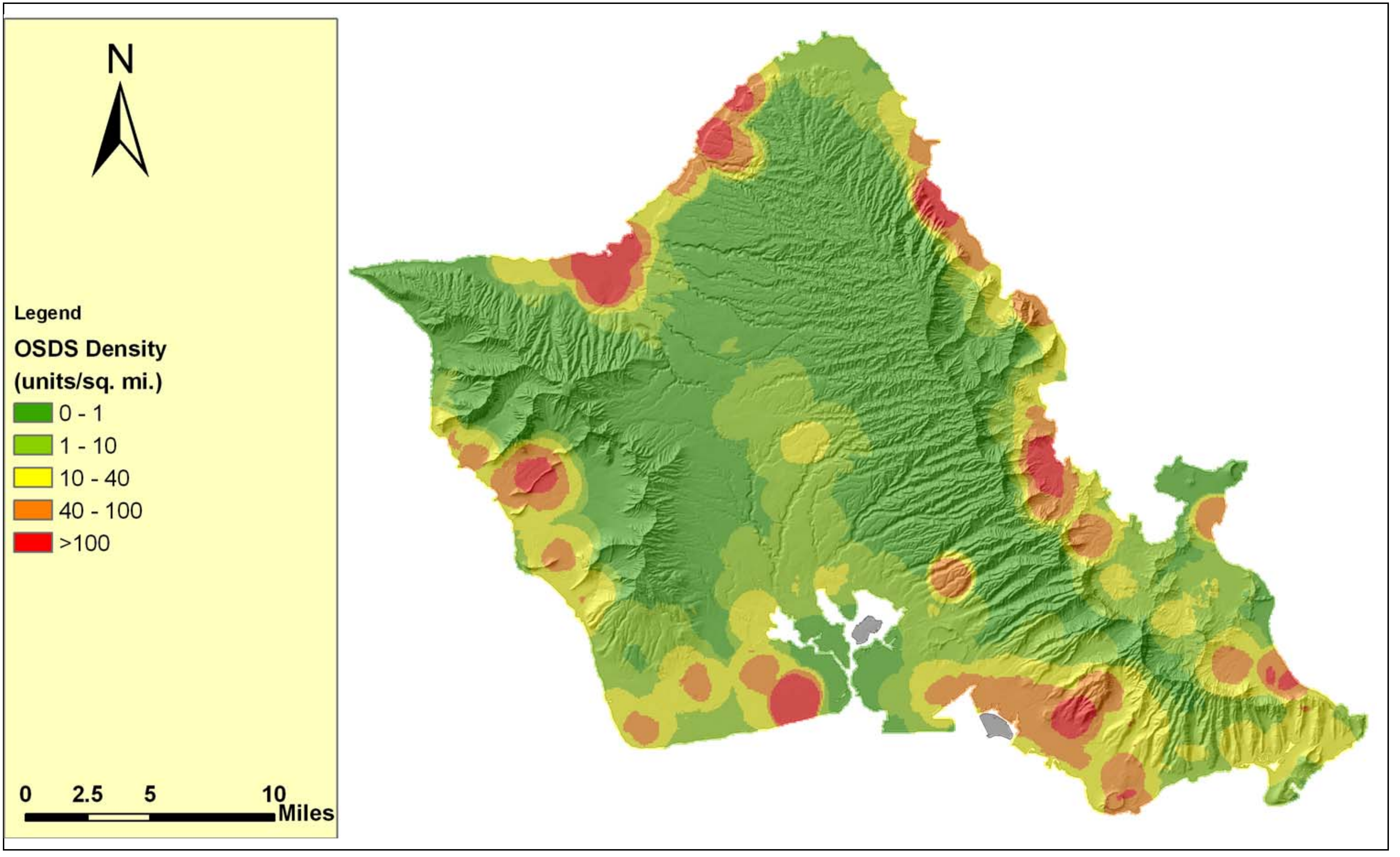

Figure 16. The Spatial Distribution of OSDS Density on Oahu

4.2.6 Cumulative Risk Factors

Each of the foregoing OSDS risk factors were placed in an overlay model to weight and sum the risk into a single spatially distributed score. The weighting and scoring table described in Section 3 is also shown in Table 12 below for convenience.

Table 12. Risk Scoring Model Parameters and Weights

Risk Factor	Weight Percent	Score Values
Drinking Water Zone B	14	0, 100
Stream Buffer	11	0, 100
Flood Risk Zones	11	0, 40, 100
Shoreline 200 ft setback	9	0, 100
Depth to Water	8	0, 100
Insufficient Filtration	8	0, 100
OSDS Density	8	1, 10, 60, 100
Groundwater Impact	8	0, 25, 50, 75, 100
Depth to Rock	5	0, 25, 50, 75, 100
Drinking Water Zone C	8	0, 100
Soil Septic Unsuitability	5	0, 25, 50, 75, 100
Shoreline 2 year Setback	5	0, 100

A cumulative risk score for each vertical set of raster cells was summed using the weighted score. This score was then normalized to 10 (the output of the GIS Weighted Overlay Tool). This produced an OSDS risk score map For Oahu. Figure 17 is the map of the risk distribution computed by this model. The highest score calculated was 6, because there were no areas where the each of the individual parameters we evaluated as having the highest risk. For example, a coastal area a high risk score for being in a shoreline buffer zone and having insufficient filtration, but would not be in drinking water buffer zone. There areas having the highest risk were within 200 ft of the shoreline, and small areas in Waialua, Punaluu, Honolulu, Ewa Beach, and Waianae. Larger areas in the coastal plains in the Waialua, northeast Oahu, Honolulu, Ewa Beach, and Waianae were given the second highest score of 5. The areas with the lowest risk and thus most suitable for OSDS use include the upland areas of the central Oahu corridor and northern Oahu that fall outside of ROC buffer zones. The next lowest risk areas are uplands in general that fall outside of ROC buffer zones and have sufficient soil cover to remediate OSDS effluent.

The risk score computed by this study was compared by that computed by DRASTIC for a high risk OSDS and a low risk OSDS. The locations of these systems are shown in Figure 17. An OSDS in Waialua was selected for the high risk system. This study assigned a score of 6 compared to a maximum score of 10. The score using the DRASTIC model was taken from coastal setting table in Section 12 – Hawaii Islands of the DRASTIC documentation (Aller et al., 1985). Based on the hydrogeologic setting, DRASTIC assigned a score of 201 out of a maximum possible score of 226. The low-risk OSDS selected was in a small community near Waipio. This study assigned a score of 2 out of a maximum possible score of 10. Using the table for a volcanic upland setting, DRASTIC assigned a score of 160 out of a possible maximum score of 226.

This comparison shows that a risk model must account for those characteristics and processes specific to the potential threat. Both the OSDS risk model and DRASTIC indicated a lower potential risk for an OSDS located in the volcanic uplands. However, the DRASTIC risk score was still 71 percent of the possible maximum implying significant risk, while the OSDS risk model showed the risk for the volcanic uplands OSDS location was low when compared to the coastal location. The DRASTIC risk score value remained high due to the permeability of the soils and the basalt, and the significant amount of recharge that occurs in this area. These are significant factors in determining contaminant risk potential, but other critical factors are not considered by DRASTIC, where only seven factors, all hydrologic/hydrogeologic are considered. The OSDS risk model considers 12 factors, three of them specific to OSDS (OSDS density, soil septic suitability, and insufficient soil filtration), and six specific to locations of potential human contact (the ROC buffers). The remaining three factors were hydrologic/hydrogeologic. However, included in those remaining factors was the result of process based modeling that incorporated many of the hydrogeologic factors considered separately by DRASTIC. This modeling used estimated OSDS effluent quantity and nitrate concentration to identify those areas of significant OSDS impact on the groundwater. Models such as DRASTIC provide a firm basis for risk modeling, but must be expanded to include source and receptor specific factors, and should include process based modeling.

The OSDS risk model also adds flexibility to risk evaluation. Using the ArcGIS Weighted Overlay Tool (WOT) with a GIS model allows for easy revisions to the relative weighting of the risk factors. New values can be entered into the WOT table and model ran. Each model run will produce a risk distribution map based on the relative weights assigned to each risk factor. As current and future research quantifies the actual impact of OSDS effluent on the environment it would be reasonable to reevaluate the current weighting and adjust the values so the modeled risk is in closer agreement with the study results.

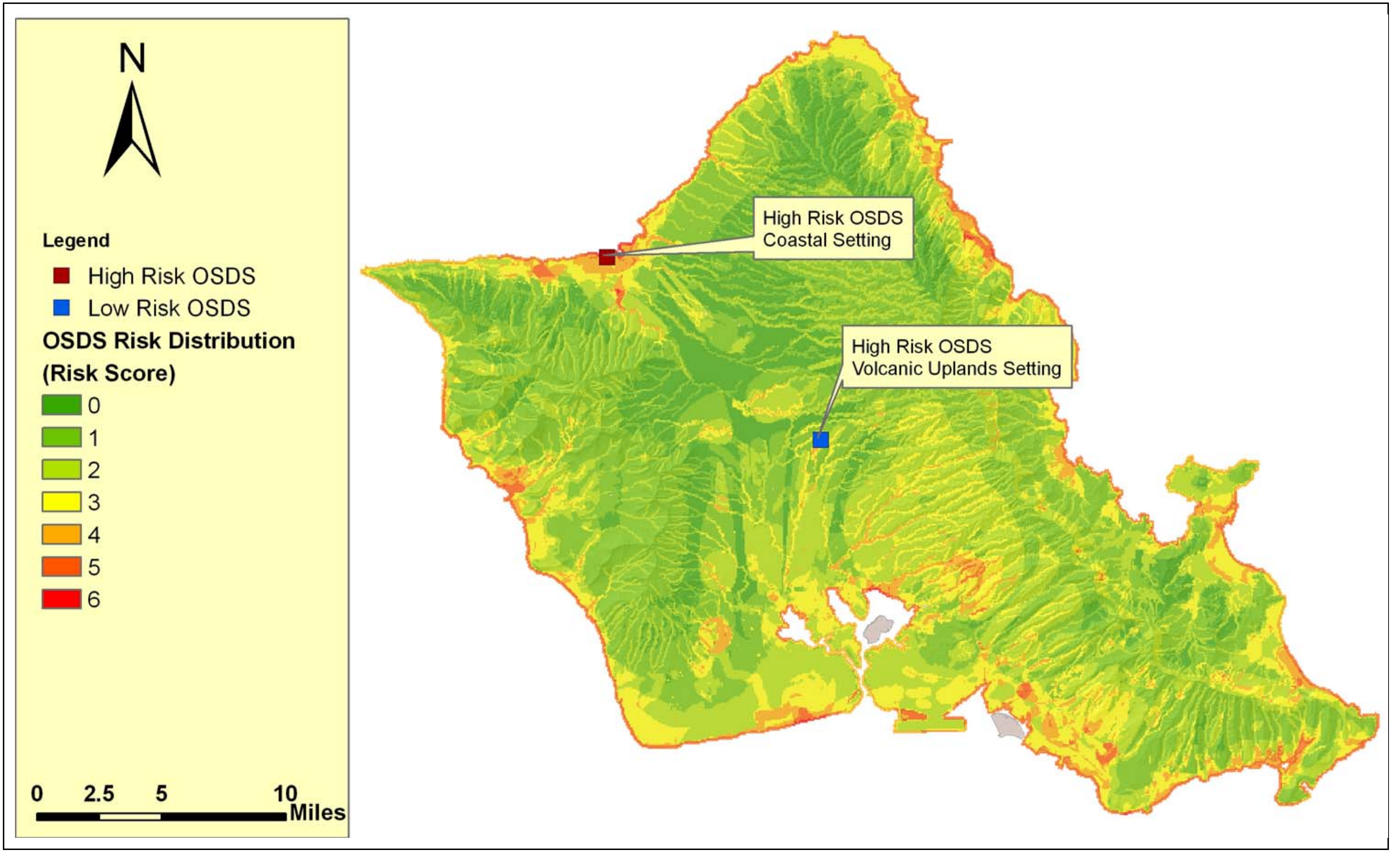

Figure 17. Spatial Distribution of OSDS Siting Risk Scores and OSDS Locations Used in Model Comparisons

4.3 RISK RANKING FOR OSDS ON OAHU

The risk score was mapped to the each OSDS unit or groups of units if a TMK had more than one OSDS. Figure 18 shows a histogram of the quantity of OSDS within each score class.

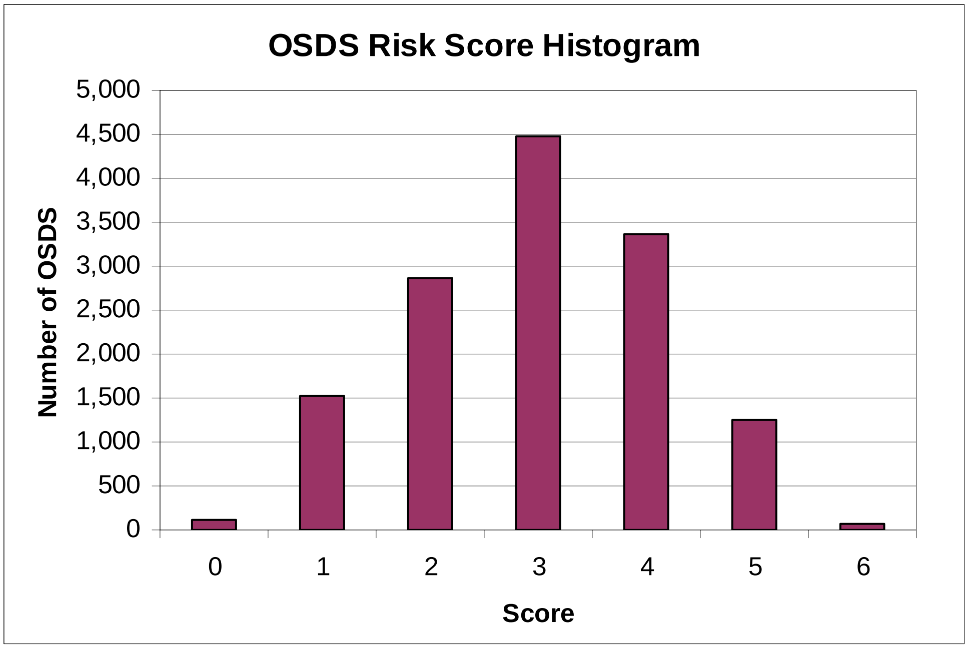

Figure 18. OSDS Risk Score Histogram

The histogram shows a near normal distribution of risk scores among the OSDS. For a risk ranking assessment to be useful it is important that the number of OSDS that fall within the higher risk categories be small compared to the total number of OSDS. There were 77 OSDS with a risk score of 6, and 1,321 with a risk score of 5. These two risk score classes identify the OSDS units that have the highest potential to adversely affect human health and the environment and thus should be given top priority for engineering inspections. Table 13 is a summary of the OSDS and scores assigned breaking the scoring down by the type of unit.

Table 13. OSDS Risk Score by Type

	SCORE						
OSDS Type	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Class I	27	261	555	762	740	260	15
Class II	9	58	173	192	75	26	1
Class III	4	30	40	64	32	27	2
Class IV	77	1,288	2,373	3,745	2,703	1,008	59
Total OSDS	**117**	**1,637**	**3,141**	**4,763**	**3,550**	**1,321**	**77**

Figure 19 shows the locations of the OSDS units with the highest risk score. Of concern is the prevalence of high risk OSDS in some north shore and leeward communities. For example, Waialua, a growing north shore community, has a high density of OSDS, many of them in the high risk category. There are multiple streams that discharge into Kaiaka Bay. The nutrient flux from the OSDS will impact the streams in the lower reaches where they gain water from groundwater. This combined with the nutrient load already in the stream will be discharge into the near shore waters increasing the possibility of alien algae invasions that have occurred elsewhere.

An analysis was done of the quantity of OSDS in each community on Oahu. The communities were based on the neighborhood board town listings. Geographically large towns such as the north shore and leeward Oahu were subdivided based on neighborhood board district. The communities with the greatest number of OSDS are (in decreasing order); Koolauloa, Ewa, Pupukea-Sunset Beach, Kahaluu, and Waialua. Appendix B shows the distribution of OSDS in each community and tabulates the quantity and the estimated effluent produced.

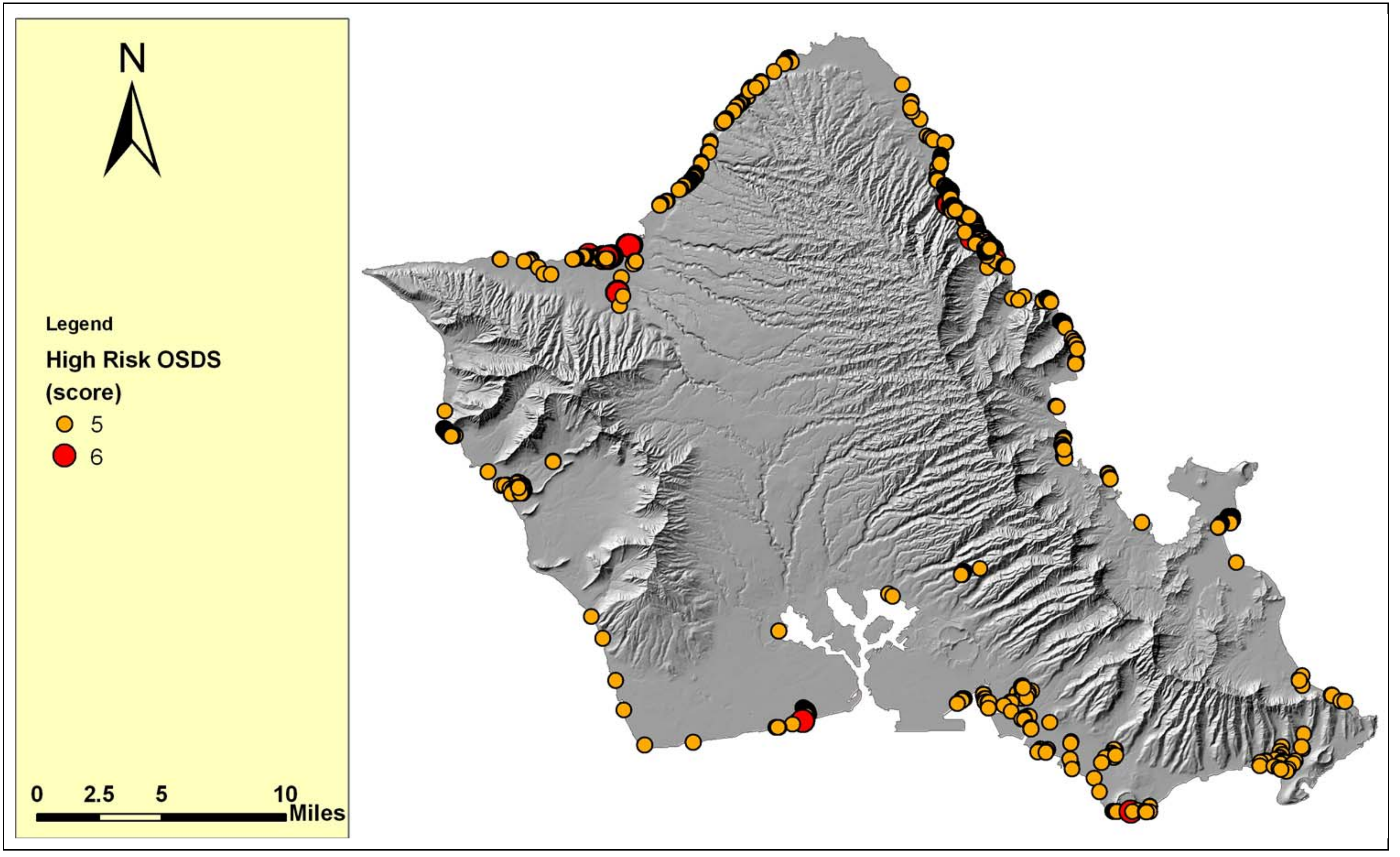

Figure 19. Location of High Risk OSDS on Oahu

SECTION FIVE: STUDY LIMITATIONS AND FINAL CONCLUSIONS

This study estimated the number and spatial distribution of OSDS on Oahu to evaluate the potential risk these systems pose to human health and the environment.

This study concludes that areas with the highest probability that OSDS effluent will cause adverse impact to the environment are Waialua, Waianae, the windward coast between Kahuku and Kahana Bay, and Waimanalo. The proximity of these areas to the shoreline, the high OSDS density, and streams (except for Waianae) puts these systems in close proximity to ROCs. In the north shore and windward area, this is further aggravated by higher background concentration of nutrients in the groundwater due to agricultural leachate. Of the estimated 14,606 OSDS, 77 OSDS were evaluated as posing a high degree of risk to health (score of 6) or to the environment. Another 1,321 were evaluated as posing a moderately high risk (score of 5) to health and the environment.

5.1 LIMITATIONS

The purpose of this study was to provide information regarding the potential impact to the environment and human health posed by on-site sewage disposal systems. Additionally it provides a geographic distribution of areas where the impact of these systems would be greatest. Information provided in this report was primarily from maps and geographic information system shape files. The scale of these resources is more general in nature and does not constitute site specific information. For example digital elevation data has a vertical resolution of 1 m. The NRCS soil data is the best of this type available. However, the NRCS soils data are mapped to a scale of 1:24,000. With this scale, 1 inch on a map is equal to 2000 ft on the ground. This is coarser than the size of a leach field, and may not reflect important heterogeneities.

OSDS have been a primary method of sewage disposal since well before records were being kept. HDOH or its territorial counterpart began keeping hard copy records since the 1940s. This has resulted in a very large and unwieldy complication of data. The record keeping for IWS permits was shifted to an electronic database in the early 1990s. However, there are uncertainties in this database since the final resolution of the majority of the permits has not been determined. Only 65 percent of the applications submitted for IWS permits on Oahu have a final inspection or final approval date leaving uncertainties about whether the IWS was installed for the remaining 35%. Of the estimated 14,606 estimated OSDS on Oahu, 4,535 fall within areas that are served by sewer systems. The fact that a parcel is in area served by a sewer does not guarantee that there is a connection; however, the probability is high that some those parcels identified as having an OSDS are in fact served by a sewer.

The potential OSDS's impact on the environment was estimated using a combination of models and relative risk factors for various elements affecting such a risk. In some cases, inaccuracies were introduced by using a fixed setback rather than that based on the time of travel criterion. Such an approach is acceptable, to some extent, by reflecting potential pathogens die off or contaminant degradation. Models were carefully run with input data to the best of their availability. However, uncertainties are mostly related to risk factors which were not based on formal risk procedures. A similar approach is adopted in the widely used DRASTIC model. However, we have introduced an improvement by including OSDS's specific elements in the analysis. The results are expected to be acceptable considering that the study was aimed at estimating relative scores for OSDS and not absolute values.

5.2 SUMMARY AND CONCLUSIONS

Based on available data, this study estimated the total number of OSDS on Oahu and listed them by type and location. The number of potential OSDS sites was estimated at 13,684. However, many parcels host more than one OSDS which increased the number to an estimated total of 14,606 units. This study estimates that nearly 10 mgd of sewage is released to the environment, the majority of which reaching the groundwater. Of the estimated quantity of OSDS, cesspools accounted for 77 percent of the total with an estimated release of nearly 7.2 mgd of untreated sewage effluent. Nearly 96 percent of potential nitrogen release from OSDS comes from cesspools (1,660 kg/d out of 1,732 kg/d).

Risk factors include OSDS position relative to receptors of concern (ROC), groundwater contaminated with OSDS effluent, soil characteristics, including filtration ability and thickness, flooding, depth to the water table, and OSDS density. ROCs include public drinking water sources and surface and near shore waters. Such receptors can provide a pathway for ingestion of pathogens and contaminants to humans or damage plant and harm coral growth due to an excessive nutrient load. Buffer zones were delineated around the various receptors using a fixed setback or time travel criteria. Risk was estimated in this study based the distance of the OSDS relative to the buffer zone.

Groundwater models were used to assess the risk for contamination, using nitrate concentration as a risk indicator. The study estimated a maximum potential increase in nitrate concentration due to OSDS of about 11 mg/L above existing or background values. More importantly, this indicates that OSDS effluent can produce groundwater concentration of nitrate that exceeds the EPA MCL of 10 mg/L for drinking water. Areas of concern on Oahu are Waianae, Waialua, Diamond Head, and the Mokapuu Peninsula where the concentration can exceed the MCL.

Soil provides the primary media for mitigating the undesired impacts of OSDS. Main factors include soil filtration ability and soil thickness. Most of the soils on Oahu provide adequate filtration of OSDS effluent, with the exception of coastal areas, stream valleys, and some inland areas, including Tantalus, Mokuleia, and the Mokapuu Peninsula. This should be alarming considering that these areas include a significant number of OSDS. On the other hand, soil thickness is not a limiting factor regarding the OSDS effluent treatment n most of Oahu. Severe limitations occur in most of the mountain ridge areas, where there are few OSDS, with the exception of eastern Oahu. Areas where the soil layer is not thick enough are also located in the Ewa plane and some leeward valleys, and the Kaiwi area of eastern Oahu, where numerous OSDS exist. In addition to soil filtration ability and thickness, other soil risks are related to the ease of water movement, a slope greater than 6.5 percent, large stone content, and seepage out of the bottom of the soil layer. Nearly all of Oahu shows a limitation due to one or more of these factors. The areas on Oahu of least suitability, as with the other soil factors, are the mountain slopes. The areas of greatest suitability are the Honolulu and Ewa coastal plains. However, as described earlier, the suitability of these areas for OSDS effluent disposal is limited by soil thickness and depth to water considerations.

Flooding can damage septic tanks by buoying tanks, causing structural damage, and more seriously, leading to a mixing of OSDS effluent with flood waters that may results in direct human contact. The areas where the OSDS are most at risk from flooding include much of the southern coastal plain area (Honolulu and Ewa), Waianae Valley, Waialua, the coastal plain in the Kahuku area, and low lying areas in the Kaneohe, Kailua, and Waimanalo districts.

A vertical distance between the ground surface and groundwater (or the thickness of the unsaturated zone) larger than 25 ft is needed for proper treatment of the OSDS effluent. Nearly all of the coastal plains, areas of high OSDS density, fail to meet this condition.

The areas with the highest OSDS density on Oahu are Waianae, Waialua, Hauula/Punaluu, Kahaluu, Waimanalo, Honolulu, and Ewa Beach. These areas were identified based on an estimated OSDS density that exceeds 40 units/mi^2, which was set by the EPA for OSDS having a significant negative environmental impact. Honolulu and Ewa Beach are served by sewers, but during the inventory process it could not be confirmed that numerous parcels in these areas were actually connected to the sewer system. Additional investigative effort is needed to clarify this uncertainty.

The spatial distribution of risk posed by OSDS was mapped through available information based on a risk scoring model. A cumulative spatially-distributed risk score was estimated by overlaying geographical information system's coverages of various risk maps. A risk score was assigned to each parcel containing an OSDS. The results of this study will allow the Department of Health planners prioritize OSDS inspections and focus water impact investigations on areas where negative impact on water resource is greatest. The results can be also used by planners and regulators to assess the suitability of OSDS types for a certain location during reviewing permit applications.

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APPENDIX A. NRCS SOILS SEWAGE DISPOSAL PREPORT AND SOILS MAP OF OAHU

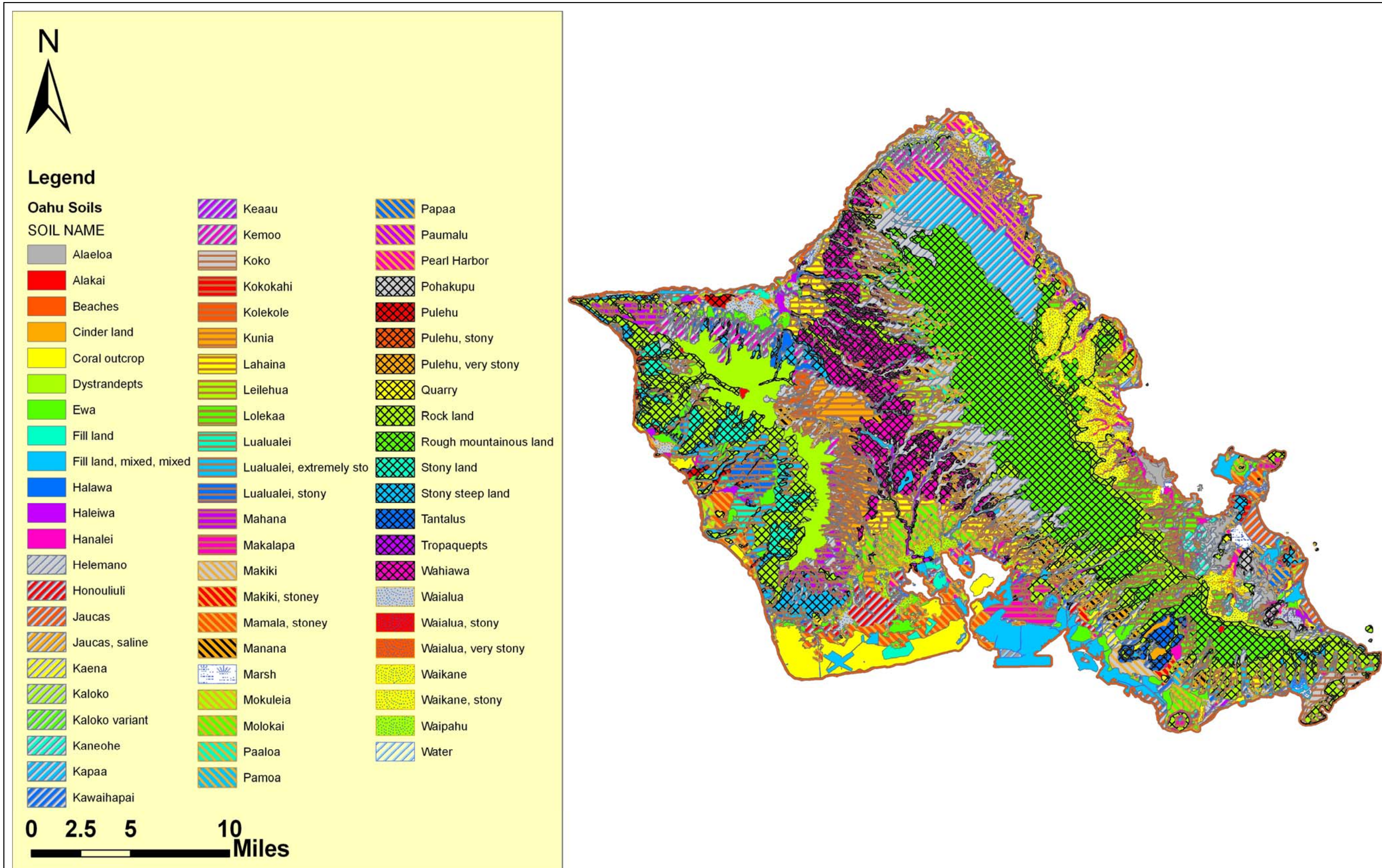

Figure A-1. Soils Map of Oahu

Sewage Disposal

Island of Oahu, Hawaii

[The information in this table indicates the dominant soil condition but does not eliminate the need for onsite investigation. The numbers in the value columns range from 0.01 to 1.00. The larger the value, the greater the potential limitation. The columns that identify the rating class and limiting features show no more than five limitations for any given soil. The soil may have additional limitations. This report shows only the major soils in each map unit]

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
AeE:					
Alaeloa	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00		
ALF:					
Alaeloa	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00		
BS:					
Beaches	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Seepage	1.00
		Filtering capacity	1.00	Depth to saturated zone	1.00
		Seepage, bottom layer	1.00	Slope	0.08
CR:					
Coral outcrop	85	Not rated		Not rated	

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
EaB:					
Ewa	100	Somewhat limited		Somewhat limited	
		Slow water movement	0.50	Slope	0.68
				Seepage	0.50
EaC:					
Ewa	100	Somewhat limited		Very limited	
		Slow water movement	0.50	Slope	1.00
		Slope	0.04	Seepage	0.50
EmA:					
Ewa	100	Very limited		Very limited	
		Depth to bedrock	1.00	Depth to soft bedrock	1.00
		Slow water movement	0.50	Seepage	0.50
EmB:					
Ewa	100	Very limited		Very limited	
		Depth to bedrock	1.00	Depth to soft bedrock	1.00
		Slow water movement	0.50	Seepage	0.50
				Slope	0.32

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
EwA:					
Ewa	100	Somewhat limited		Somewhat limited	
		Slow water movement	0.50	Large stones content	0.83
				Seepage	0.50
EwB:					
Ewa	100	Somewhat limited		Somewhat limited	
		Slow water movement	0.50	Large stones content	0.83
				Seepage	0.50
				Slope	0.32
EwC:					
Ewa	100	Somewhat limited		Very limited	
		Slow water movement	0.50	Slope	1.00
		Slope	0.04	Large stones content	0.83
				Seepage	0.50
Fd:					
Fill land	100	Very limited		Very limited	
		Flooding	1.00	Depth to hard bedrock	1.00
		Depth to bedrock	1.00	Flooding	1.00
		Slow water movement	0.50	Organic matter content	1.00
				Seepage	0.50

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
FL:					
Fill land, mixed, mixed	100	Somewhat limited		Somewhat limited	
		Slow water movement	0.68	Flooding	0.40
		Flooding	0.40	Seepage	0.32
		Depth to bedrock	0.27		
HeA:					
Haleiwa	85	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Slow water movement	0.50	Seepage	0.50
HeB:					
Haleiwa	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Slow water movement	0.50	Seepage	0.50
				Slope	0.32
HJE:					
Halawa	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Depth to bedrock	0.63	Seepage	1.00
		Slow water movement	0.50	Depth to soft bedrock	0.18

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
HJF2:					
Halawa	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Depth to bedrock	0.94	Seepage	1.00
		Slow water movement	0.50	Depth to soft bedrock	0.84
HLMG:					
Helemano	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	0.50	Seepage	1.00
HnA:					
Hanalei	85	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Organic matter content	1.00
		Slow water movement	0.50	Depth to saturated zone	0.99
				Seepage	0.50

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
HnB:					
Hanalei	85	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Organic matter content	1.00
		Slow water movement	0.50	Depth to saturated zone	0.99
				Seepage	0.50
HoB:					
Hanalei	85	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Organic matter content	1.00
		Slow water movement	0.50	Depth to saturated zone	0.99
				Seepage	0.50
HxA:					
Honouliuli	100	Very limited		Very limited	
		Slow water movement	1.00	Ponding	1.00
		Ponding	1.00	Flooding	0.40
		Flooding	0.40		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
HxB:					
Honouliuli	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Flooding	0.40
		Flooding	0.40	Slope	0.32
JaC:					
Jaucas	100	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Seepage, bottom layer	1.00	Slope	1.00
		Flooding	0.40	Flooding	0.40
		Slope	0.01		
JcC:					
Jaucas, saline	100	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Filtering capacity	1.00	Depth to saturated zone	0.99
		Seepage, bottom layer	1.00	Slope	0.92
		Flooding	0.40	Flooding	0.40
KaB:					
Kaena	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Depth to saturated zone	0.99
		Depth to saturated zone	1.00	Slope	0.32

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KaC:					
Kaena	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	0.99
		Slope	0.04		
KaeB:					
Kaena	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Depth to saturated zone	0.99
		Depth to saturated zone	1.00	Large stones content	0.86
		Large stones content	0.12	Slope	0.32
KaeC:					
Kaena	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	0.99
		Large stones content	0.12	Large stones content	0.86
		Slope	0.04		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KaeD:					
Kaena	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	0.99
		Slope	1.00	Large stones content	0.86
		Large stones content	0.12		
KanE:					
Kaena	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Depth to saturated zone	1.00	Large stones content	1.00
		Slope	1.00	Depth to saturated zone	0.99
		Large stones content	0.58		
Kfa:					
Kaloko, drained	60	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Slow water movement	1.00	Flooding	1.00
		Ponding	1.00		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Kfa:					
Kaloko	40	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Slow water movement	1.00	Flooding	1.00
		Ponding	1.00	Depth to saturated zone	1.00
		Depth to saturated zone	1.00		
Kfb:					
Kaloko variant	85	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Slow water movement	1.00	Flooding	1.00
		Ponding	1.00		
KgB:					
Kaneohe	100	Somewhat limited		Very limited	
		Slow water movement	0.82	Seepage	1.00
				Slope	0.92
KgC:					
Kaneohe	100	Somewhat limited		Very limited	
		Slow water movement	0.82	Slope	1.00
		Slope	0.63	Seepage	1.00

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KHMC:					
Kaneohe	100	Somewhat limited		Very limited	
		Slow water movement	0.82	Slope	1.00
		Slope	0.16	Seepage	1.00
KHME:					
Kaneohe	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	0.82	Seepage	1.00
KHMF:					
Kaneohe	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	0.82	Seepage	0.18
KHOF:					
Kaneohe	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	0.82	Seepage	0.18
KIG:					
Kapaa	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	0.82	Seepage	1.00

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KlA:					
Kawaihapai	100	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00		
KlaA:					
Kawaihapai	100	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00	Large stones content	0.22
KlaB:					
Kawaihapai	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00	Slope	0.32
				Large stones content	0.22

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KlB:					
Kawaihapai	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00	Slope	0.32
KlbC:					
Kawaihapai	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00	Slope	1.00
		Slope	0.01	Large stones content	0.99
KlC:					
Kawaihapai	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00	Slope	1.00
		Slope	0.37		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KmA:					
Keaau	85	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Seepage	1.00
		Seepage, bottom layer	1.00	Depth to saturated zone	1.00
		Slow water movement	1.00		
KmaB:					
Keaau	85	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Seepage	1.00
		Seepage, bottom layer	1.00	Depth to saturated zone	1.00
		Slow water movement	1.00	Slope	0.32

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KmbA:					
Keaau	85	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Seepage	1.00
		Seepage, bottom layer	1.00	Depth to saturated zone	1.00
		Slow water movement	1.00		
KpB:					
Kemoo	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.32
KpC:					
Kemoo	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.04		
KpD:					
Kemoo	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KpE:					
Kemoo	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		
KpF:					
Kemoo	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		
KPZ:					
Kemoo	60	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00		
Badland	40	Not rated		Not rated	
KsB:					
Koko	100	Very limited		Very limited	
		Slow water movement	1.00	Seepage	1.00
		Depth to bedrock	0.86	Depth to soft bedrock	0.61
				Slope	0.32

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KsC:					
Koko	100	Very limited		Very limited	
		Slow water movement	1.00	Seepage	1.00
		Depth to bedrock	0.86	Slope	1.00
		Slope	0.04	Depth to soft bedrock	0.61
KsD:					
Koko	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Seepage	1.00
		Depth to bedrock	0.86	Depth to soft bedrock	0.61
KtC:					
Kokokahi	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.04		
KTKE:					
Kokokahi	100	Very limited		Very limited	
		Slow water movement	1.00	Large stones content	1.00
		Slope	1.00	Slope	1.00
		Large stones content	0.99		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KuB:					
Kolekole	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.32
KuC:					
Kolekole	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.04		
KuD:					
Kolekole	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00		
KyA:					
Kunia	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Seepage	0.18
KyB:					
Kunia	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.92
				Seepage	0.18

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
KyC:					
Kunia	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.63	Seepage	0.18
LaA:					
Lahaina	100	Somewhat limited		Very limited	
		Slow water movement	0.82	Seepage	1.00
LaB:					
Lahaina	100	Somewhat limited		Very limited	
		Slow water movement	0.82	Seepage	1.00
				Slope	0.68
LaC:					
Lahaina	100	Somewhat limited		Very limited	
		Slow water movement	0.82	Slope	1.00
		Slope	0.37	Seepage	1.00
LaC3:					
Lahaina	100	Somewhat limited		Very limited	
		Slow water movement	0.82	Slope	1.00
		Slope	0.37	Seepage	0.18

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
LeB:					
Leilehua	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.32
LeC:					
Leilehua	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.04		
LoB:					
Lolekaa	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.92
LoC:					
Lolekaa	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.63		
LoD:					
Lolekaa	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
LoE:					
Lolekaa	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		
LoF:					
Lolekaa	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		
LPE:					
Lualualei, extremely stony	100	Very limited		Very limited	
		Slow water movement	1.00	Large stones content	1.00
		Large stones content	1.00	Slope	1.00
		Slope	1.00		
LuA:					
Lualualei	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Flooding	0.40
		Flooding	0.40		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
LuB:					
Lualualei	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Flooding	0.40
		Flooding	0.40	Slope	0.32
LvA:					
Lualualei, stony	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Flooding	0.40
		Flooding	0.40		
LvB:					
Lualualei, stony	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Flooding	0.40
		Flooding	0.40	Slope	0.32
MBL:					
Mahana	55	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00	Seepage	0.18
Badland	45	Not rated		Not rated	

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
McC2:					
Mahana	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.04	Seepage	0.18
McD2:					
Mahana	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Seepage	0.18
McE2:					
Mahana	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00	Seepage	0.18
MdB:					
Makalapa	100	Very limited		Very limited	
		Slow water movement	1.00	Depth to soft bedrock	1.00
		Depth to bedrock	1.00	Slope	0.32

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
MdC:					
Makalapa	100	Very limited		Very limited	
		Slow water movement	1.00	Depth to soft bedrock	1.00
		Depth to bedrock	1.00	Slope	1.00
		Slope	0.04		
MdD:					
Makalapa	100	Very limited		Very limited	
		Slow water movement	1.00	Depth to soft bedrock	1.00
		Depth to bedrock	1.00	Slope	1.00
		Slope	1.00		
MkA:					
Makiki	100	Very limited		Very limited	
		Seepage, bottom layer	1.00	Seepage	1.00
		Slow water movement	0.50		
MlA:					
Makiki, stony	100	Very limited		Very limited	
		Seepage, bottom layer	1.00	Seepage	1.00
		Slow water movement	0.50	Large stones content	0.22

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
MnC:					
Mamala, stony	100	Very limited		Very limited	
		Depth to bedrock	1.00	Depth to hard bedrock	1.00
		Flooding	0.40	Seepage	1.00
				Slope	0.92
				Flooding	0.40
MoB:					
Manana	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.32
				Seepage	0.18
MoC:					
Manana	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.04	Seepage	0.18
MoD2:					
Manana	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
MpB:					
Manana	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.92
				Seepage	0.18
MpC:					
Manana	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.63	Seepage	0.18
MpD:					
Manana	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Seepage	0.18
MpD2:					
Manana	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00		
MpE:					
Manana	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Seepage	0.18

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Ms:					
Mokuleia	100	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Seepage, bottom layer	1.00	Flooding	0.40
		Flooding	0.40		
Mt:					
Mokuleia	100	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Seepage, bottom layer	1.00	Flooding	0.40
		Flooding	0.40		
Mtb:					
Mokuleia	100	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Seepage, bottom layer	1.00	Flooding	0.40
		Flooding	0.40		
MuA:					
Molokai	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Seepage	0.50

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
MuB:					
Molokai	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.68
				Seepage	0.50
MuC:					
Molokai	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.37	Seepage	0.50
MuD:					
Molokai	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00	Seepage	0.50
MZ:					
Marsh	100	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Organic matter content	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
				Depth to saturated zone	1.00

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
PaC:					
Paaloa	100	Somewhat limited		Very limited	
		Slow water movement	0.72	Slope	1.00
		Slope	0.01	Seepage	1.00
PbC:					
Paaloa	100	Somewhat limited		Very limited	
		Slow water movement	0.72	Seepage	1.00
				Slope	1.00
PeB:					
Paumalu	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.92
				Seepage	0.18
PeC:					
Paumalu	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.63	Seepage	0.18
PeD:					
Paumalu	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00	Seepage	0.18

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
PeE:					
Paumalu	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00	Seepage	0.18
PeF:					
Paumalu	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00	Seepage	0.18
Ph:					
Pearl Harbor	80	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Slow water movement	1.00	Flooding	1.00
		Ponding	1.00	Depth to saturated zone	1.00
		Depth to saturated zone	1.00	Organic matter content	1.00
PID:					
Pamoa	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.84		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
PkB:					
Pohakupu	100	Very limited		Very limited	
		Slow water movement	1.00	Seepage	1.00
				Organic matter content	1.00
				Slope	0.32
PkC:					
Pohakupu	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.63	Seepage	1.00
				Organic matter content	1.00
PsA:					
Pulehu	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00		
PuB:					
Pulehu, stony	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00	Slope	0.32

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
PvC:					
Pulehu, very stony	100	Very limited		Very limited	
		Flooding	1.00	Flooding	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00	Large stones content	0.99
				Slope	0.92
PYD:					
Papaa	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Depth to soft bedrock	0.99
		Depth to bedrock	0.99	Seepage	0.50
PYE:					
Papaa	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Depth to soft bedrock	0.99
		Depth to bedrock	0.99	Seepage	0.50
PYF:					
Papaa	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Depth to soft bedrock	0.99
		Depth to bedrock	0.99	Seepage	0.50

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
PZ:					
Paumalu	50	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Seepage	0.18
Badland	30	Not rated		Not rated	
QU:					
Quarry	100	Not rated		Not rated	
rAAE:					
Alakai	100	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
				Slope	1.00
		Slow water movement	1.00	Organic matter content	1.00
		Slope	1.00		
		Subsidence	1.00	Depth to saturated zone	0.44
		Depth to bedrock	0.27		
rCI:					
Cinder land	100	Very limited		Very limited	
		Filtering capacity	1.00	Slope	1.00
		Slope	1.00	Seepage	1.00
		Seepage, bottom layer	1.00		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
rRK:					
Rock land	55	Very limited		Very limited	
		Depth to bedrock	1.00	Depth to hard bedrock	1.00
		Slope	1.00	Slope	1.00
rRO:					
Rock outcrop	100	Not rated		Not rated	
rRT:					
Rough mountainous land	100	Very limited		Very limited	
		Slope	1.00	Depth to soft bedrock	1.00
		Seepage, bottom layer	1.00	Slope	1.00
		Depth to bedrock	1.00	Seepage	1.00
		Large stones content	0.64	Large stones content	1.00
rST:					
Stony land	100	Very limited		Very limited	
		Large stones content	1.00	Large stones content	1.00
		Slope	1.00	Slope	1.00
		Slow water movement	0.50	Seepage	0.50

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
rSY:					
Stony steep land	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Large stones content	1.00	Large stones content	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
rTP:					
Tropohumults	50	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Depth to bedrock	0.36	Seepage	1.00
				Depth to soft bedrock	0.01
Dystrandepts	30	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Depth to bedrock	0.78	Depth to soft bedrock	0.42
TAE:					
Tantalus	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
TAF:					
Tantalus	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00		
TCC:					
Tantalus	100	Very limited		Very limited	
		Seepage, bottom layer	1.00	Slope	1.00
		Filtering capacity	1.00	Seepage	1.00
		Slope	0.63		
TCE:					
Tantalus	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Seepage, bottom layer	1.00	Seepage	1.00
		Filtering capacity	1.00		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
TR:					
Tropaquepts	90	Very limited		Very limited	
		Flooding	1.00	Ponding	1.00
		Ponding	1.00	Flooding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Slow water movement	0.50	Organic matter content	1.00
				Seepage	0.50
W:					
Water > 40 acres	100	Not rated		Not rated	
WaA:					
Wahiawa	100	Somewhat limited		Somewhat limited	
		Slow water movement	0.82	Seepage	0.18
WaB:					
Wahiawa	100	Somewhat limited		Somewhat limited	
		Slow water movement	0.82	Slope	0.92
				Seepage	0.18

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
WaC:					
Wahiawa	100	Somewhat limited		Very limited	
		Slow water movement	0.82	Slope	1.00
		Slope	0.63	Seepage	0.18
WaD2:					
Wahiawa	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	0.82	Seepage	0.18
WkA:					
Waialua	100	Very limited		Not limited	
		Slow water movement	1.00		
WkB:					
Waialua	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.92
WlB:					
Waialua	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.92

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
WlE:					
Waialua, stony	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00		
WmD:					
Waialua, very stony	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	1.00	Large stones content	0.93
WnB:					
Waialua	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.32
WpaE:					
Waikane, stony	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		
WpB:					
Waikane	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Slope	0.92

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
WpC:					
Waikane	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.63		
WpE:					
Waikane	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		
WpF:					
Waikane	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		
WpF2:					
Waikane	100	Very limited		Very limited	
		Slope	1.00	Slope	1.00
		Slow water movement	1.00		
WzA:					
Waipahu	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Flooding	0.40
		Flooding	0.40		

Sewage Disposal

Island of Oahu, Hawaii

Map symbol and soil name	Pct. of map unit	Septic tank absorption fields		Sewage lagoons	
		Rating class and limiting features	Value	Rating class and limiting features	Value
WzB:					
Waipahu	100	Very limited		Somewhat limited	
		Slow water movement	1.00	Flooding	0.40
		Flooding	0.40	Slope	0.32
WzC:					
Waipahu	100	Very limited		Very limited	
		Slow water movement	1.00	Slope	1.00
		Slope	0.04		

APPENDIX B. OSDS AND ESTIMATED EFFLUENT BY COMMUNITY

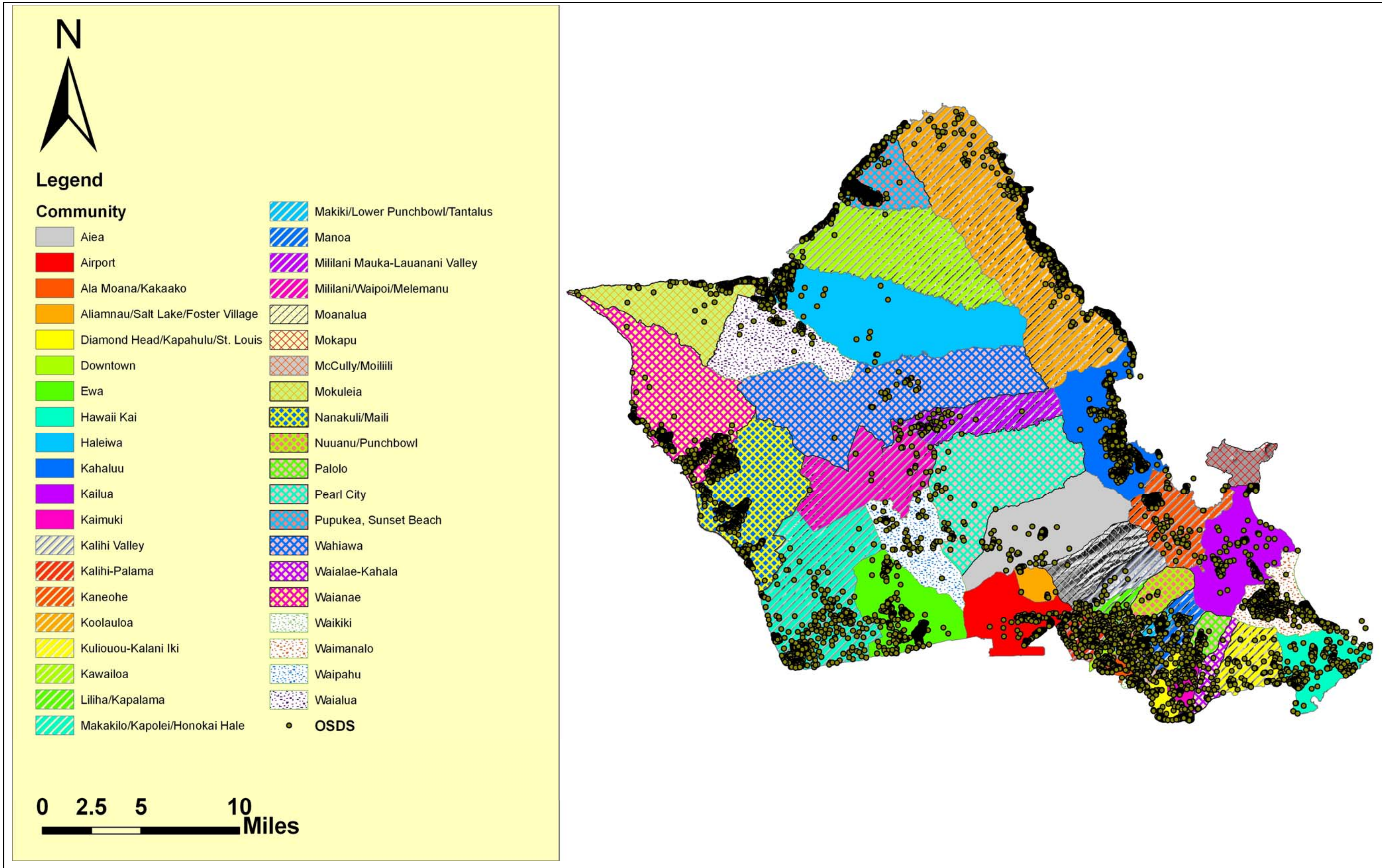

Figure B-1. OSDS Locations and the Communities on Oahu

Table B-1. OSDS Type and Effluent Characteristics Listed by Community

Community	Soil Treatment	Septic	Aerobic	Cesspool	Total OSDS
Aiea	14	8	1	158	181
Airport	1	1	0	201	203
Ala Moana, Kakaako	0	0	0	80	80
Aliamanu, Salt Lake, Foster Village	0	0	0	19	19
Diamond Head, Kapahulu, Saint Louis	4	0	1	97	102
Downtown	0	0	0	38	38
Ewa	72	34	21	1246	1373
Haleiwa	142	29	11	410	592
Hawaii Kai	2	0	0	205	207
Kahaluu	309	44	23	899	1275
Kailua	80	15	4	235	334
Kaimuki	5	6	0	118	129
Kalihi Valley	0	0	0	22	22
Kalihi-Palama	0	0	1	276	277
Kaneohe	45	20	3	273	341
Kawailoa	63	11	9	166	249
Koolauloa	587	55	31	1240	1913
Kuliouou-Kalani Iki	1	1	1	96	99
Liliha, Kapalama	0	2	0	72	74
Makakilo, Kapolei, Honokai Hale	78	32	0	441	551
Makiki, Lower Punchbowl, Tantulas	35	35	6	457	533
Manoa	0	3	0	121	124
McCully, Moilili	0	0	0	40	40
Mililani Mauka-Launani Valley	0	0	0	57	57
Mililani, Waipio, Melemanu	8	1	0	26	35
Moanalua	0	0	0	3	3
Mokapu	0	0	0	0	0
Mokuleia	140	11	8	234	393
Nanakuli, Maili	80	22	2	323	427
Nuuanu, Punchbowl	4	5	0	142	151
Palolo	12	1	0	95	108
Pearl City	3	1	0	29	33
Pupukea, Sunset Beach	363	90	23	830	1306
Wahiawa	2	3	0	44	49
Waialae, Kahala	14	28	1	220	263
Waialua	161	43	19	783	1006
Waianae	205	24	28	828	1085
Waikiki	0	0	0	81	81
Waimanalo	190	9	2	558	759
Waipahu	0	0	4	90	94

Table B-1. OSDS Type and Effluent Characteristics Listed by Community

Community	Total Effluent (mgd)	Total Nitrogen (kg/d)	Total Phosph. (kg/d)	Area (mi^2)	OSDS Density ($units/mi^2$)
Aiea	0.123	25.1	7.1	24.2	7.5
Airport	0.122	27.9	7.8	14.3	14.2
Ala Moana, Kakaako	0.048	11.1	3.1	1.5	52.4
Aliamanu, Salt Lake, Foster Village	0.009	2.0	0.6	2.9	6.5
Diamond Head, Kapahulu, Saint Louis	0.063	14.0	3.9	3.3	31.2
Downtown	0.023	5.3	1.5	1.1	33.7
Ewa	0.870	181.5	51.4	18.8	73.2
Haleiwa	0.408	67.8	19.8	38.7	15.3
Hawaii Kai	0.124	28.4	7.9	11.7	17.7
Kahaluu	0.859	140.8	41.2	20.1	63.4
Kailua	0.250	42.6	12.4	18.6	18.0
Kaimuki	0.082	17.4	4.9	2.0	65.0
Kalihi Valley	0.020	4.6	1.3	5.2	4.2
Kalihi-Palama	0.168	38.8	10.8	4.5	61.8
Kaneohe	0.261	50.5	14.5	13.7	24.8
Kawailoa	0.174	27.4	8.1	32.9	7.6
Koolauloa	1.251	182.5	54.2	58.1	32.9
Kuliouou-Kalani Iki	0.060	13.5	3.8	9.4	10.5
Liliha, Kapalama	0.046	10.5	2.9	3.1	24.1
Makakilo, Kapolei, Honokai Hale	0.310	62.7	17.8	35.2	15.6
Makiki, Lower Punchbowl, Tantulas	0.331	67.7	19.3	3.4	155.7
Manoa	0.074	17.0	4.8	5.3	23.5
McCully, Moilili	0.024	5.5	1.5	1.0	41.2
Mililani Mauka-Launani Valley	0.032	7.3	2.0	12.2	4.7
Mililani, Waipio, Melemanu	0.023	4.3	1.2	22.0	1.6
Moanalua	0.002	0.4	0.1	10.5	0.3
Mokapu	0.000	0.0	0.0	4.7	0.0
Mokuleia	0.262	35.7	10.7	17.6	22.3
Nanakuli, Maili	0.282	50.9	14.7	27.5	15.5
Nuuanu, Punchbowl	0.096	21.1	5.9	6.7	22.4
Palolo	0.067	13.5	3.8	4.1	26.5
Pearl City	0.022	4.2	1.2	32.8	1.0
Pupukea, Sunset Beach	0.896	132.6	39.7	10.6	123.3
Wahiawa	0.032	6.9	2.0	46.6	1.1
Waialae, Kahala	0.170	34.5	9.9	4.0	66.5
Waialua	0.732	136.0	39.1	19.9	50.6
Waianae	0.745	132.0	38.1	34.0	32.0
Waikiki	0.049	11.2	3.1	1.0	84.2
Waimanalo	0.512	85.0	24.7	10.8	70.1
Waipahu	0.057	12.9	3.6	14.3	6.6