UPCOUNTRY MAUI GROUNDWATER NITRATE INVESTIGATION REPORT MAUI, HAWAII

Draft

Prepared by:
Hawaii Department of Health
Safe Drinking Water Branch
2385 Waimano Home Road
Uluakupu Building 4
Pearl City, Hawaii 96782

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The following people should receive a copy of this document. This document and any amendments will be distributed once all approval signatures have been received:

Name	Project Role	Address
Joanna L. Seto, P.E.	Branch Chief Safe Drinking Water Branch	Safe Drinking Water Branch Department of Health 2385 Waimano Home Rd, Uluakupu Building 4 Pearl City, Hawaii 96782-1400 Email: joanna.seto@doh.hawaii.gov
Sina Pruder, P.E.	Branch Chief, Wastewater Branch	Wastewater Branch Department of Health 2827 Waimano Home Rd, Hale Ola Pearl City, Hawaii 96782-1400 Email: sina.pruder@doh.hawaii.gov
Norris Uehara	Supervisor, Groundwater Pollution Control Section	Safe Drinking Water Branch Department of Health 2385 Waimano Home Rd, Uluakupu Building 4 Pearl City, Hawaii 96782-1400 Email: norris.uehara@doh.hawaii.gov
Robert B. Whittier, P.G.	Source Water Protection Geologist	Safe Drinking Water Branch Department of Health 2385 Waimano Home Rd, Uluakupu Building 4 Pearl City, Hawaii 96782-1400 Email: robert.whittier@doh.hawaii.gov
Alan S. Dillon	Quality Assurance Officer, Safe Drinking Water Branch	Safe Drinking Water Branch Department of Health 2385 Waimano Home Rd, Uluakupu Building 4 Pearl City, Hawaii 96782-1400 Email: alan.dillon@doh.hawaii.gov
Danilo Licudine	Supervisor, Water Pollution Section, Environmental Health Analytical Services Branch, State Laboratory Division.	State Laboratories Division Environmental Health Analytical Services Branch 2725 Waimano Home Road, Kamauleele Building Pearl City, Hawaii 96782 Email: danilo.licudine@doh.hawaii.gov
Ephraim Leon-Guerrero	EPA Region 9, Project Officer	U.S. Environmental Protection Agency, Region 9 Drinking Water Management Section (WTR-3-1) 75 Hawthorne Street San Francisco, California 94105-3901 Phone: 415-972-3444 Email: leon-guerrero.ephraim@epa.gov
Kate Rao	EPA Region 9, Project Officer	U.S. Environmental Protection Agency, Region 9 Large-Capacity Cesspool Coordinator (WTR-3-2) 75 Hawthorne Street San Francisco, California 94105-3901 Phone: 415-972-3533 Email: rao.kate@epa.gov

Name	Project Role	Address
Eugenia McNaughton Ph.D.	EPA Region 9 Quality Assurance Manager	U.S. Environmental Protection Agency, Region 9 Environmental Management Division (EMD-3) Quality Assurance Office 75 Hawthorne Street San Francisco, California 94105-3901 Phone: 415-972-3411 Email: mcnaughton.eugenia@epa.gov

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Acronyms and Abbreviations

BRE-1	Well for the Baldwin Ranch Estates development
BSIF	Biogeochemical Stable Isotope Facility
COC	Chain of Custody
DIN	Dissolved inorganic nitrogen
CWRM	Commission on Water Resources Management, Department of Land and Natural Resources
CZD	Capture Zone Delineation
DOH	Department of Health
DON	Dissolved organic nitrogen
EHASB	Environmental Health Analytical Services Branch
ft	feet
ft msl	feet above mean sea level
ft/d	feet per day
HDPE	High density polyethylene
in/yr	inches per year
L	liter
m	meters
MCL	Maximum Contaminant Level (U.S. Environmental Protection Agency)
mg/L	Milligram per liter = part per million
MHI	Main Hawaii Islands
N	nitrogen
NA	Not Analyzed
ND	Not detected
ng/L	Nanogram per liter = part per trillion
NH_4	ammonium
NO_2	nitrite
NO_3	nitrate
$^{o}/_{oo}$	Parts per thousand, a measure of stable isotopes abundances at or near natural levels
OSDS	Onsite Sewage Disposal Systems
P	phosphorus
PCA	potentially contaminating activities
PDWW	Public drinking water wells
ppb	Part per billion = microgram per liter
PPCPs	Pharmaceuticals and Personal Care Products
ppm	Part per million = milligram per liter
PWS	Public Water System
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
SDWB	Safe Drinking Water Branch, Department of Health
SDWIS-CDb	Safe Drinking Water Information System Contaminant Database
SOEST	School of Ocean and Earth Science and Technology, University of Hawaii at Manoa
STL	Soil treatment leachfield
SWAP	Source Water Assessment Program
SWPP	Source Water Protection Program
TN	Total nitrogen
U.S. EPA	U.S. Environmental Protection Agency

USGS	U.S. Geological Survey
WP-SAP	Work Plan and Sampling and Analysis Plan
WERF	Water Environmental Research Foundation
WWRF	Wastewater Reclamation Facility
$\delta^{15}N$	Delta-^{15}N value (a measure of enrichment of the heavy isotope of nitrogen with an atomic weight of 15)
$\delta^{18}O$	Delta-^{18}O value (a measure of enrichment of the heavy isotope of oxygen with an atomic weight of 18)
$\delta^{2}H$	Delta-^{2}H value (a measure of enrichment of the heavy isotope of hydrogen with an atomic weight of 2)

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SECTION 1 INTRODUCTION

This report was prepared by the Department of Health (DOH), Safe Drinking Water Branch (SDWB) to document the sampling of wells in east Maui and evaluate the results to determine the source of the elevated nitrate concentrations in the groundwater. The area of elevated groundwater nitrate is on the west slope of the Haleakala Volcano of east Maui where the upslope area will be referred to as Upcountry Maui. This report describes the DOH efforts to characterize the chemical and physical parameters of the groundwater in Upcountry Maui. The primary purpose of this report is to document the source of the elevated nitrates and evaluate their impact on current and future public drinking water sources.

1.1 BACKGROUND

Elevated nitrate concentrations have been found in Upcountry Maui. A sample collected from the Pukalani Golf Course Well in 2010 had a nitrate concentration of 6.8 milligrams per liter (mg/L). Further investigation found the nitrate concentration at the Baldwin Ranch Estates 1 (BRE-1) well drilled in 2015 was 8.7 mg/L. This concentration is near the State and Federal Maximum Contaminant Level (MCL) for nitrate in drinking water of 10 mg/L. The BRE-1 well is in the process of becoming a public drinking water source, and due to the elevated nitrate concentration that is approaching the MCL, is installing an ion exchange system for nitrate removal. A review of other wells in the area also showed that many had elevated nitrate concentrations. This investigation defines the extent and probable source(s) of the contamination to inform future water development and contaminant reduction efforts.

1.2 DESCRIPTION OF CURRENT STUDY

1.2.1 Project Objectives and Scope

The primary purpose of this investigation is to provide critical data about the source of nitrate in Upcountry Maui including the distribution of nitrate contamination in the aquifer and identify the most likely source(s) of contamination. The secondary purpose of this investigation is to gather data on groundwater chemistry to better define the groundwater flow paths from the areas of recharge to drinking water wells. Geographically, the study area includes the drinking water wells on the west slope of Haleakala, the potential groundwater recharge areas upgradient of the drinking water wells, and the potential sources of nitrate contamination within this area. Figure 1-1 shows the island of Maui and the revised study area that includes the model domain described in Section 3.3.3.

1.2.2 Project Tasks

The following tasks were performed during this study.

1. Developed a Work Plan and Sampling and Analysis Plan (WP-SAP) to identify wells and the groundwater parameters needed to assess the source of groundwater nitrates and to characterize groundwater flow paths from the contaminant sources to public drinking water wells (PDWW);

2. Reviewed the available nitrate and other groundwater chemistry of the Upcountry Maui wells (completed as part of preparing the WP-SAP);

3. Conducted an inventory of the potential sources of nitrate contamination;

4. Executed the WP-SAP, collecting samples from 12 wells and analyzing for 27 parameters;

5. Interpreted the data collected to identify the nitrate contamination source(s);

6. Developed a groundwater flow and transport model to further evaluate the relative contributions from the various nitrate sources; and

7. Produced a comprehensive report documenting the activities, data collection, and the conclusions of this study.

1.3 PROJECT ORGANIZATION

The key personnel and their role in this investigation are listed below:

Mr. Robert Whittier, P.G. is the DOH SDWB Source Water Protection Program (SWPP) geologist that planned and executed the project including collecting the samples, measuring the field parameters, interfaced with the laboratories, and interpreted the data.

Mr. Norris Uehara is the DOH SDWB Groundwater Pollution Control Section Supervisor and supervised the SWPP geologist in the execution of this project. Mr. Uehara reviewed the Quality Assurance Project Plan (QAPP), sampling and analytical results, and the data interpretation.

Ms. Joanna L. Seto, P.E. is the DOH SDWB Chief and was responsible for the overall management and oversight of this project.

Mr. Alan S. Dillon is the DOH SDWB General Professional IV**,** and provided DOH Quality Assurance (QA) oversight of this project ensuring all QA objectives were met.

Mr. Daniel Chang is the DOH SDWB Monitoring and Analysis Section Supervisor and Groundwater Protection Program leader who provided monitoring assistance on this investigation. Mr. Chang also planned and supervised the Pharmaceutical and Personal Care Product sampling.

Ms. Natalie Walsgrove is the School of Ocean and Earth Science and Technology (SOEST) Biogeochemistry Laboratory Supervisor and ensured proper that analytical techniques and laboratory protocols and quality assurance were employed during nitrogen and water isotope analysis.

Ms. Catherine Rong is the laboratory supervisor for the University of Hawaii Water Resources Research Center (WRRC), Water Quality Laboratory. Ms. Rong ensured proper analysis of the major ion Chemistry.

Mr. Danilo Licudine is the laboratory supervisor for the DOH State Laboratory Division Environmental Health Analytical Services Branch (EHASB), Water Pollution Chemistry Section. Mr. Licudine ensured proper analysis of the groundwater nutrient concentrations.

1.4 DESCRIPTION OF THE STUDY AREA

1.4.1 Physical Setting

Maui is the second largest island of the Main Hawaii Islands (MHI) and lies near the southeast extent of the State of Hawaii. The Hawaiian island chain is formed as the Pacific Tectonic Plate passes over a mid-ocean hotspot. Maui, like most of the MHI, is made up of two volcanoes (Langenheim and Clague, 1987). Haleakala forms the eastern part of Maui that is separated from the West Maui Volcano by a central isthmus that provides a natural division between eastern and western Maui. Figure 1-2 is a map of east Maui showing the major geologic formations and features. The Haleakala Volcano, rises to 10,023 ft (3055 m) above sea level. Haleakala is much younger than the West Maui Volcano, with the shield building stage of this volcano ending between 0.93 and 0.97 million years ago (Gingerich, 1999a and b). Haleakala has three well defined rift zones, one radiating from the summit to the north-

northwest, one to the east, and the third rift zone extends to west-southwest. In East Maui irrigated agriculture exists on the central isthmus between the urban centers of Kahului and Kihei. Further upslope diversified agriculture and Haleakala Ranch dominate. Smaller residential communities exist on the western and windward slopes of Haleakala at the low to mid-level elevations. The middle to upper elevations of Haleakala are agricultural lands, and conservation land that is dominated by the Haleakala National Park. The study area is the west facing slope of Haleakala. This includes the west slope of Haleakala between northwest and southwest rift zones, and east to middle of the isthmus between east and west Maui (Figure 1-1).

1.4.2 Regional Groundwater Hydrology

The precipitation that falls on Upcountry Maui is partitioned between surface runoff, evapotranspiration, soil moisture storage, and groundwater recharge. Recharge, (the fraction of groundwater that reaches the water table) ranges from over 500 inches per year (in/yr) at the higher elevations up to about 8,000 feet above mean sea level (ft msl) to less than 10 in/yr along the coast (Johnson et al., 2014). When the recharge reaches the aquifer, it flows radially out from the central highlands to discharge areas along the coast. Figure 1-3 shows the boundaries of the study area, the recharge rate (Johnson et al., 2014), and water table elevation for east-central Maui. The water table elevations are those modeled by Gingerich (2008) in his groundwater flow model of central and west Maui.

In the subsurface, the groundwater becomes a lens of freshwater floating on the underlying saltwater with a water table elevation of less than a few tens of ft msl. This Ghyben-Herzberg principal states that the thickness of the freshwater lens is 41 times the elevation of the water table above sea level. This is only an estimation, however, and the actual thickness of the freshwater lens can deviate from this value due to factors such as non-horizontal flow and heterogeneous geology (Izuka and Gingerich, 1998). The mixing of the two waters at the bottom of the basal lens results in a sloping transition rather than a sharp interface between fresh and saltwater.

As the groundwater approaches the shoreline, it may encounter sedimentary deposits and formations that retard its flow. These formations, referred to collectively as caprock, have an effective hydraulic conductivity that is significantly lower than that of the thin bedded lavas forming volcanic formations of the study area. This results in a thicker freshwater lens due to the flow impedance of the caprock that retards saltwater intrusion into the aquifer. The sediments in the central isthmus area between east and west Maui extend beneath the surface of the water table about 1 to 2 miles inland from the coast (Gingerich, 2008) and are deeper than 80 ft msl at the coast. The slopes of Upcountry Maui consist of a thick veneer of more recent Kula Volcanics overlying the shield building stage Honomanu Basalts (Izuka et al., 2016). Gingerich (2008) modeled the Kula Volcanics and the Honomanu Basalt as a single hydrogeologic unit. However, the Kula Volcanics are generally viewed as having lower permeability than the Honomanu Basalts (Stearns and Macdonald, 1942; Izuka et al., 2016). For groundwater transport that has little bearing in the study area since the contact between the Kula Volcanics and the Honomanu Basalt is above the saturated zone (Gingerich, 2008). However, recharge infiltrating into the unsaturated zone may be influenced by the structure and lower permeability of the Kula Volcanics resulting in perched water.

The water transport characteristics of the various aquifer materials vary greatly along the flow path. In a groundwater model that included central Maui, Gingerich (2008) assigned horizontal longitudinal and transverse hydraulic conductivities of 11,083 and 3,694 feet per day (ft/d) respectively and a vertical hydraulic conductivity of 13.85 ft/d for the Kula/Honomanu Basalts in the Upcountry Maui area. For the sedimentary deposits, he used values of 17 and 0.38 ft/d for the horizontal and vertical hydraulic conductivity, respectively.

1.4.3 Land Use

In Upcountry Maui, the land utilization is predominantly agriculture with small urban centers and rural zones at the mid-elevations. Pineapple and sugar cultivation once dominated most of the study area, but have now ceased. However, residual fertilizer from past agriculture still likely add to the groundwater nitrate load. Portions of this land remain fallow or have been converted to low density housing and diversified agriculture. The upper elevations are zoned as conservation land. Figure 1-4 shows the current land use zoning for East Maui (Hawaii Office of Planning, 2015).

1.5 UPCOUNTRY MAUI NITRATE CONTAMINATION

Nitrate in drinking water can interfere with the transport of oxygen in the bloodstream of young children. This condition, known as methemoglobinemia (or blue baby syndrome), results in blue color to the skin. Water used to make baby formula with as little as 12 mg/L of nitrate can result in this condition (Knobeloch et al., 2000). For this reason, the U.S. Environmental Protection Agency (U.S. EPA) has established a Maximum Contaminant Level (MCL) of 10 mg/L for nitrate (as nitrogen) in groundwater. Nitrate in groundwater can naturally be reduced by denitrification (the biological conversion of nitrate to gaseous nitrogen), but this only occurs under anoxic conditions with dissolved organic carbon present. Most Hawaii drinking water aquifers are well oxygenated and denitrification is not expected to occur (Hunt, 2004).

1.5.1 Historical Distribution of Nitrate in Upcountry Maui

The concentration of groundwater nitrate in Upcountry Maui varies from less than 0.5 mg/L to concentrations approaching the MCL of 10 mg/L. The nitrate in groundwater from natural sources is very low. A review of the DOH Safe Drinking Water Information System Contaminant Database (SDWIS-CDb) shows the vast majority of wells located in areas with little or no human impact within the source of contribution have nitrate concentrations less than 0.5 mg/L. However, there are exceptions to this general trend. In the Kaupulehu area of West Hawaii Island there are groundwater nitrate concentrations of greater than 2 mg/L (Fackrell et al. 2016) and as high as 4.3 mg/L (SDWIS-CDb, data extracted 1/26/2017). These nitrate concentrations are unexpectedly high since there are no identified anthropogenic source for the elevated nitrate in the Kaupulehu area. Predominantly, throughout the State, groundwater nitrate concentrations approaching the MCL of 10 mg/L are only associated with sugar cane cultivation and seed corn agriculture (Ling, 1996). While agriculture is viewed as the primary source of groundwater nitrate contamination, other sources including onsite sewage disposal systems (OSDS) do contribute nitrate to the groundwater. Prior to this investigation, a connection between OSDS leachate and significantly elevated groundwater nitrate concentrations had not been established. Whittier and El-Kadi (2014) compared the nitrate concentrations in drinking water wells with concentrations predicted by OSDS leachate transport model and found no convincing evidence that OSDS were responsible for any significant elevation of groundwater nitrate. This new data emerging from Upcountry Maui is the first to make a connection between significantly elevated concentrations of groundwater nitrate and OSDS.

In the area of Pukalani, Makawao, and Hailemaile the groundwater nitrate concentrations range from less than 0.5 mg/L to more than 8 mg/L. Table 1-1 lists the wells in the area and summarizes the nitrate concentration. Figure 1-5 is a map showing the most recent nitrate concentrations in the area wells measured prior to this investigation. The Pulehu Farms Well had the highest nitrate concentration at 16 mg/L in a sample collected on 8/27/2007, significantly greater than the MCL. However, prior and subsequent samples collected from this well had nitrate concentrations less than 3 mg/L. The high result from the Pulehu Farms Wells is evaluated as an outlier and possible analytical error. The BRE-1 well had the next highest concentration of 8.8 mg/L in a sample collected on 9/24/2015. Three samples collected using a pump from this well had nitrate concentrations greater 8 mg/L indicating that the groundwater around this well has significantly elevated nitrate concentrations. The third highest nitrate concentration was in the Pukalani Golf Course Well. The sample collected from this well on 9/1/2010 had a concentration of 6.7 mg/L. By contrast the Pookela Well had a nitrate concentration of 0.1 mg/L in a sample collected on 1/2/2016.

Table 1-1. Historic nitrate concentrations in the Upcountry Maui wells

Well Name	Well ID	Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Date of Maximum	Most Recent (mg/L)	Date
BRE-1	6-5220-002	NA	8.7	NA	NA	8.8	9/24/2015
Haiku Well	6-5419-001	1.9	2.0	2.3	11/21/2016	2.3	11/21/2016
Kaupakulua Well	6-5317-001	0.1	0.7	0.8	8/14/2001	0.8	3/31/2016
Maui Highlands Wells 1, 2	6-4425-001,2	0.5	0.6	0.9	8/5/2009	0.6	9/7/2016
Maunaolu-Smith Well	6-5320-002	0.3	4.7	6.3	2/10/2009	4.6	7/25/2016
Pookela Well	6-5118-002	0.5	0.5	0.5	2/24/2009	0.1	1/28/2016
Pukalani Golf Course	6-5021-001	NA	6.7	NA	NA	6.7	9/1/2010
West Kuiaha Meadows Well	6-5418-002	0.7	0.8	0.8	3/28/2005	0.8	3/19/2007
Hamakaupoko Wells	6-5320-001,2	3.3	4.8	6.8	2/1/2000	4.7	3/30/2017
Omaopio-Esty	6-4821-001	3.6	4.3	4.8	8/23/2006	4.8	8/23/2006
Pulehu Farms	6-4719-001	3.0	8.0	16.2	8/27/2007	2.9	4/12/2017

1.6 Potential Sources of Nitrate Contamination in Upcountry Maui

The purpose of this investigation is to determine the source of the elevated nitrate measured in current and future PDWWs. A review of land use and the list of potentially contaminating activities (PCAs) from Table 5-2 in SWAP indicate that the most likely sources of the nitrate contamination are:

- Confined animal feed operations, which may occur at the Haleakala Ranch lands,
- Former sugar cane agriculture,
- Former pineapple agriculture,
- Golf courses, and
- Onsite Sewage Disposal Systems (OSDS).

Figure 1-6 maps the locations of the potential sources of nitrate contamination relative to the location of current PDWWs. The Haleakala Ranch, the most likely source of livestock contamination is located upslope of two wells with elevated nitrate concentrations. Sugar cane agriculture, a known source of elevated nitrate in the groundwater water (Ling 1996; and Hunt, 2004), occurs predominantly downgradient of the PDWWs. Former pineapple cultivation does occur upgradient of many PWS wells. However, the nitrate concentrations in areas of pineapple cultivation are generally much lower than in areas where sugar cane is grown due to the lower groundwater recharge from pineapple cultivation (Soicher and Peterson, 1996; Hunt, 2004; and Glenn et al., 2012). Other agriculture and golf courses, while sources of nitrate contamination, are only present over a small area. OSDS and confined animal feed operations are the most likely sources of elevated nitrate in the Upcountry Maui groundwater. As the table in Figure 1-6 shows there are approximately 10,000 OSDS within the Upcountry Maui Cesspool Priority Area 1. Of the OSDS, the majority are cesspools. Since the discharge from cesspools receive no engineered treatment, cesspools by number and by effluent quality will be the largest source of groundwater nitrate from OSDS. Section 3.3.3 lists the estimated nitrate load from the different OSDS types.

1.7 THE ISOTOPIC COMPOSITION OF NITRATE AS A SOURCE TRACKER

This investigation evaluated the possible connection between impacted groundwater and potential contamination sources using groundwater chemistry and the isotopic composition of the groundwater nitrate. The purpose of this investigation was to identify to the extent practical the source of the elevated nitrates at the Upcountry Maui. The potential sources include: 1) leaching of fertilizers; 2) contamination of groundwater by wastewater; and 3) leaching of livestock and other animal waste products. Discriminating between the sources cannot be done by measuring the nitrate concentration alone. However, nitrate sources differ in the isotopic composition of nitrogen and oxygen. Fertilizer and animal wastes have differing nitrogen isotopic compositions. Commonly, the isotopic composition of nitrogen is expressed as the ratio the nitrogen-15 isotope to the nitrogen-14 isotope in the water sample compared to the same ratio in atmospheric nitrogen. This is expressed as a delta-^{15}N value (δ^{15}N) (Kendall, 1998). Since nitrate contains atoms of oxygen, the isotopic composition of this element is also of interest. For oxygen the ratio is that of the heavy and rarer isotope, oxygen 18, to that the common isotope, oxygen 16. Similar to nitrogen, the ratio is symbolized by a δ^{18}O value.

Figure 1-7 graphs the representative δ^{15}N and δ^{18}O values for likely sources for nitrate including:

- Naturally occurring nitrate in rain and soil,
- Fertilizers,
- Animal waste, and
- Wastewater.

A process called "denitrification" can also influence the isotopic composition of nitrate, by bacteria using nitrate as a nutrient source while decomposing organic carbon. Denitrification bacteria preferentially utilize the lighter isotopes of nitrogen and oxygen resulting with the remaining nitrate being isotopically heavier than the starting composition. This process is shown as the denitrification line on Figure 1-7. While the isotopic composition of the remaining nitrate would get heavier, the nitrate concentration would decrease since the process converts nitrate to nitrogen gas. The expected results of denitrification of fertilizer nitrate would be a low concentration of isotopically heavy nitrate. Denitrification, if it does occur would most likely happen in the soil zone rather than in the aquifer. Since denitrification results in nitrate be converted to gaseous nitrogen, the process would be manifest by elevated δ^{15}N values, but lower nitrate concentrations.

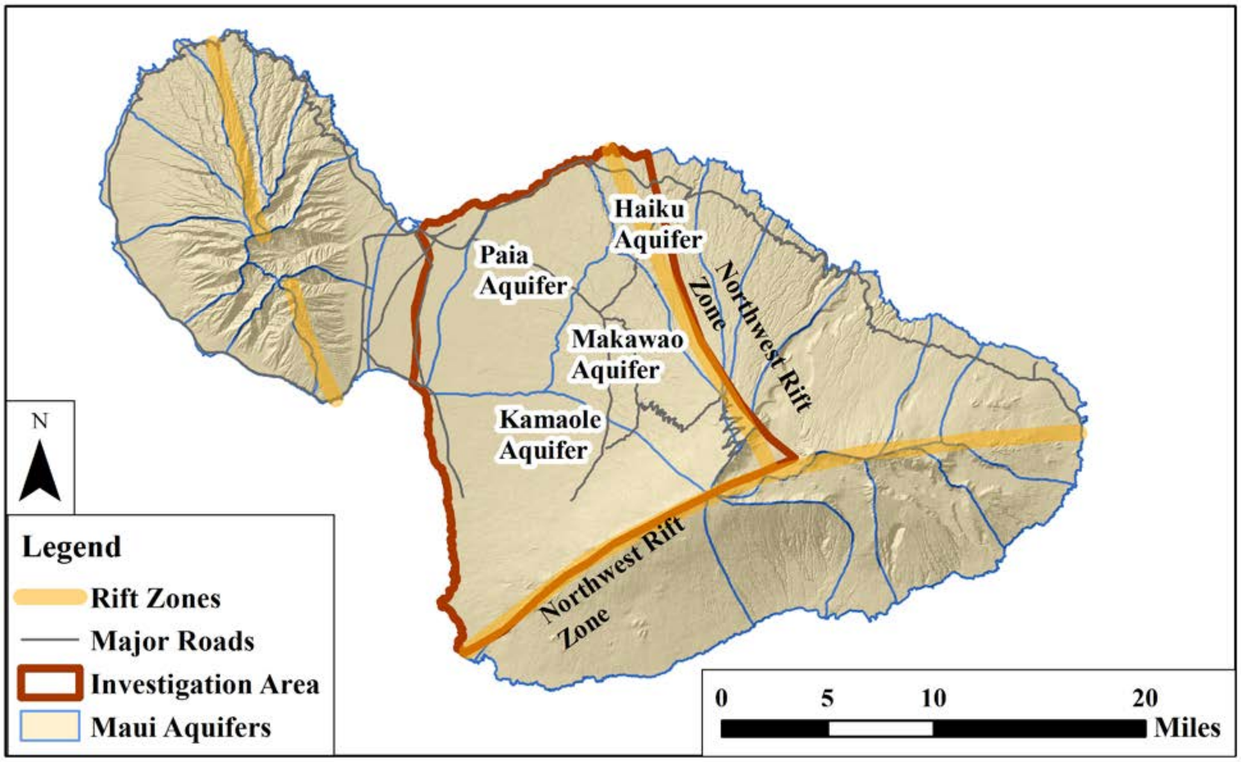


Figure 1-1. Map showing Maui and the location of the investigation area

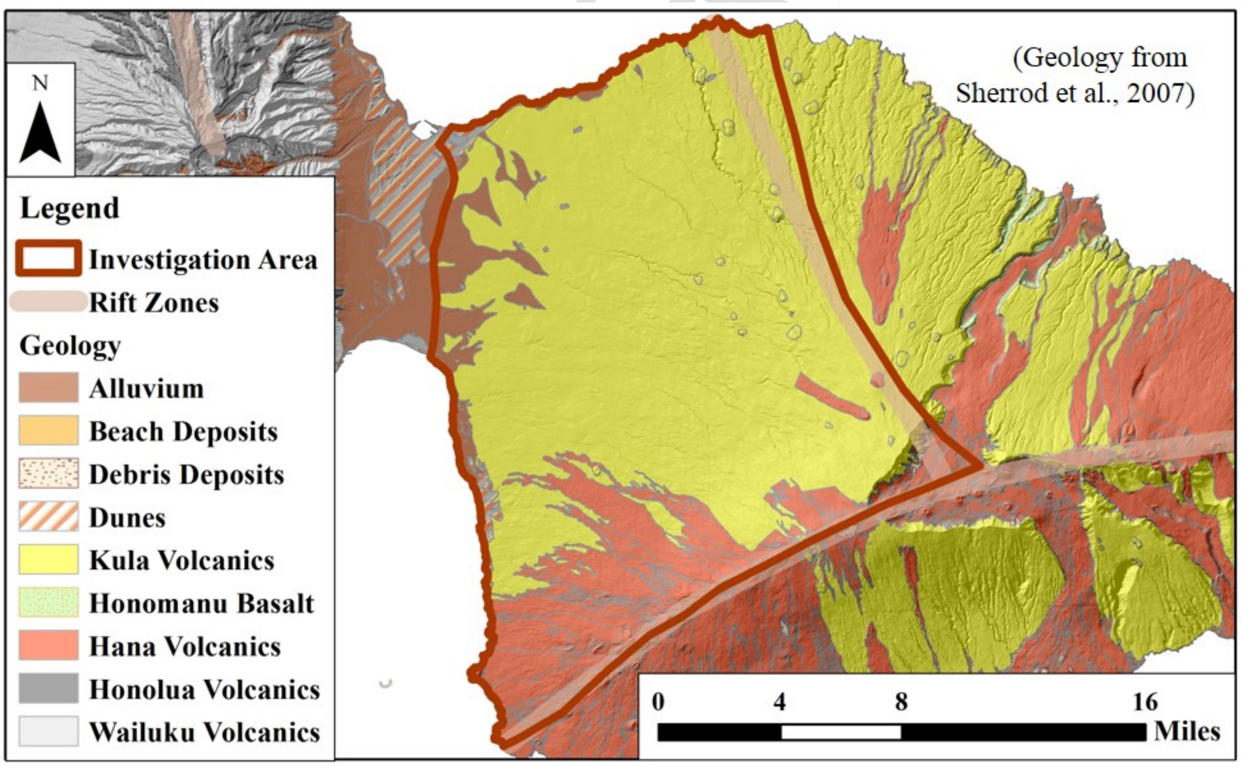


Figure 1-2. Geologic map of east-central Maui

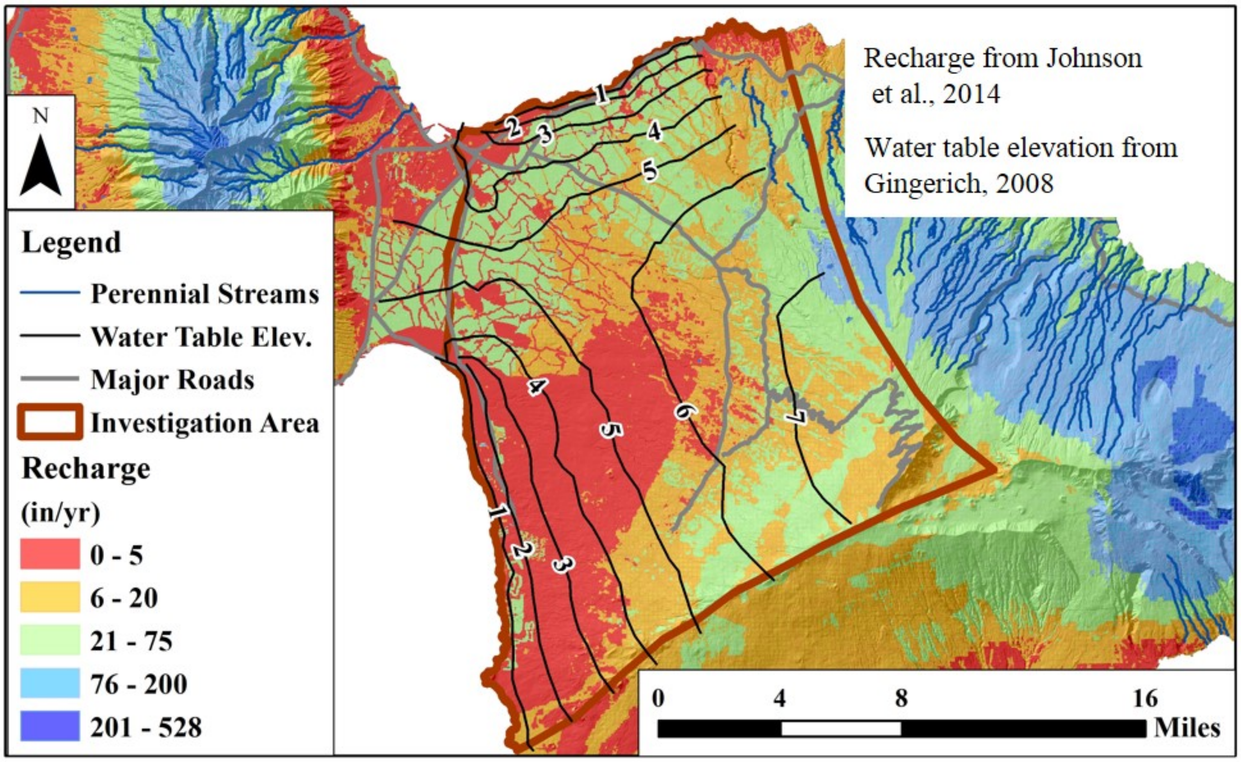


Figure 1-3. Groundwater recharge rates and the groundwater surface elevation for east-central Maui

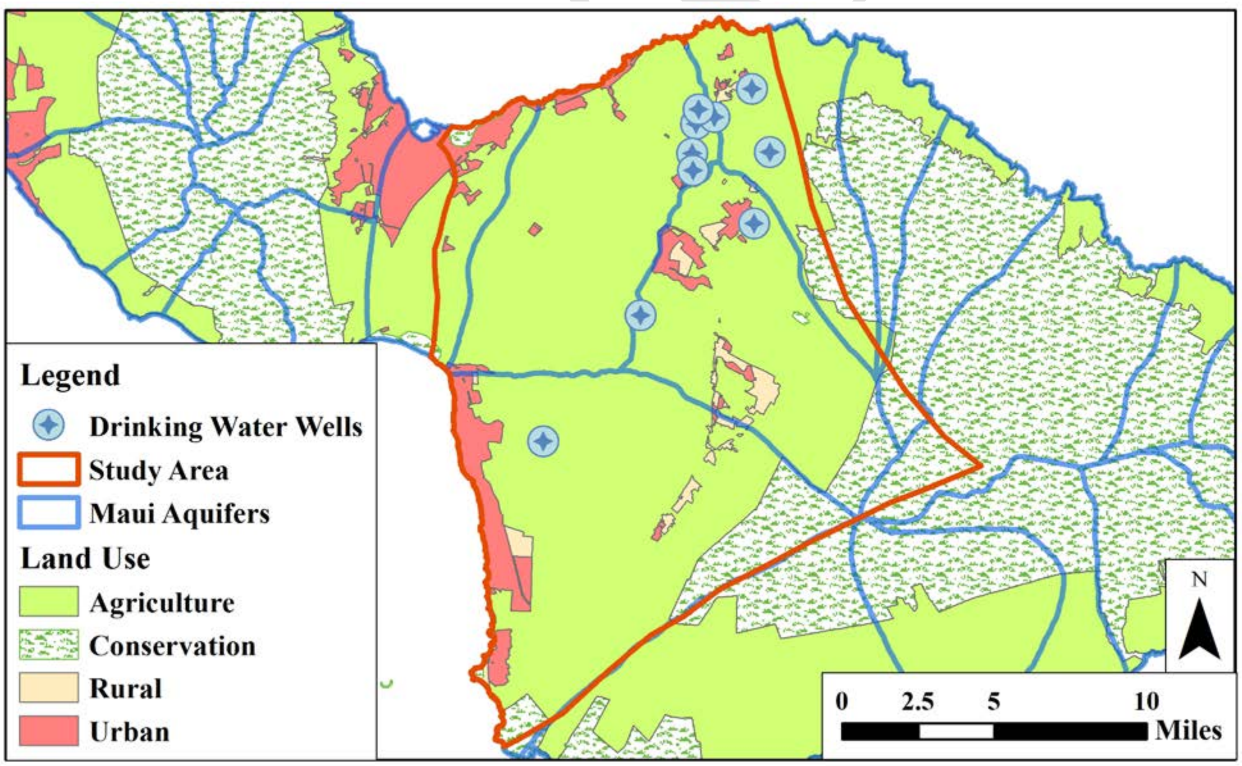


Figure 1-4. The aquifer boundaries and land use designations for Maui

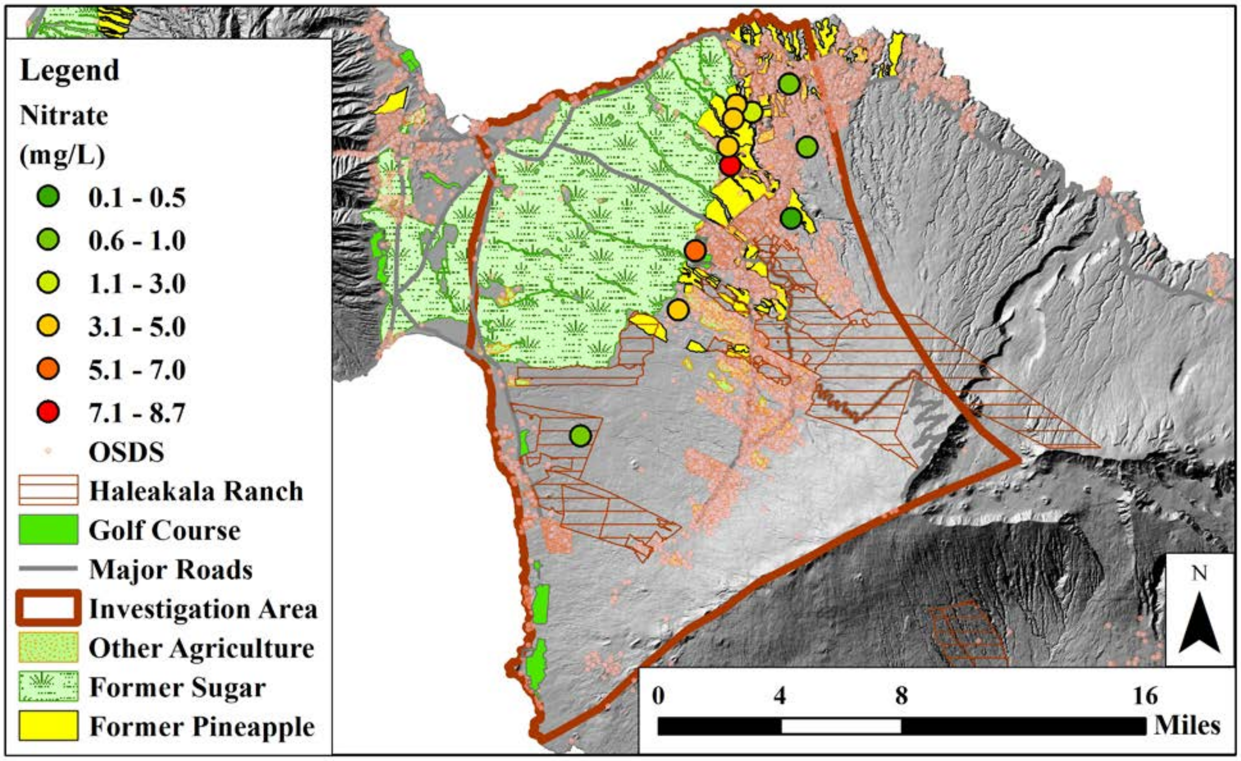
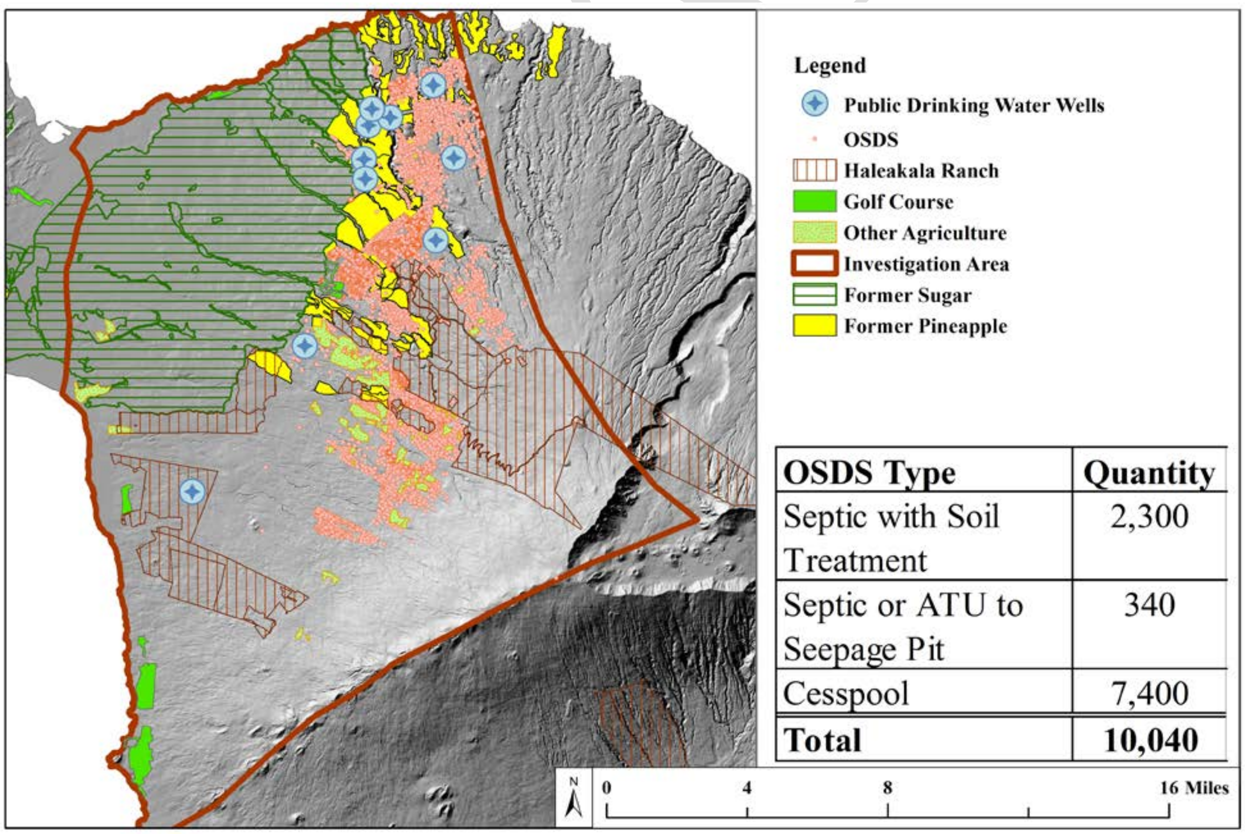


Figure 1-5. The distribution of historical groundwater nitrate concentrations



OSDS Type	Quantity
Septic with Soil Treatment	2,300
Septic or ATU to Seepage Pit	340
Cesspool	7,400
Total	**10,040**

Figure 1-6. The location of Public Drinking Water wells in east-central Maui relative to potential sources of nitrate contamination.

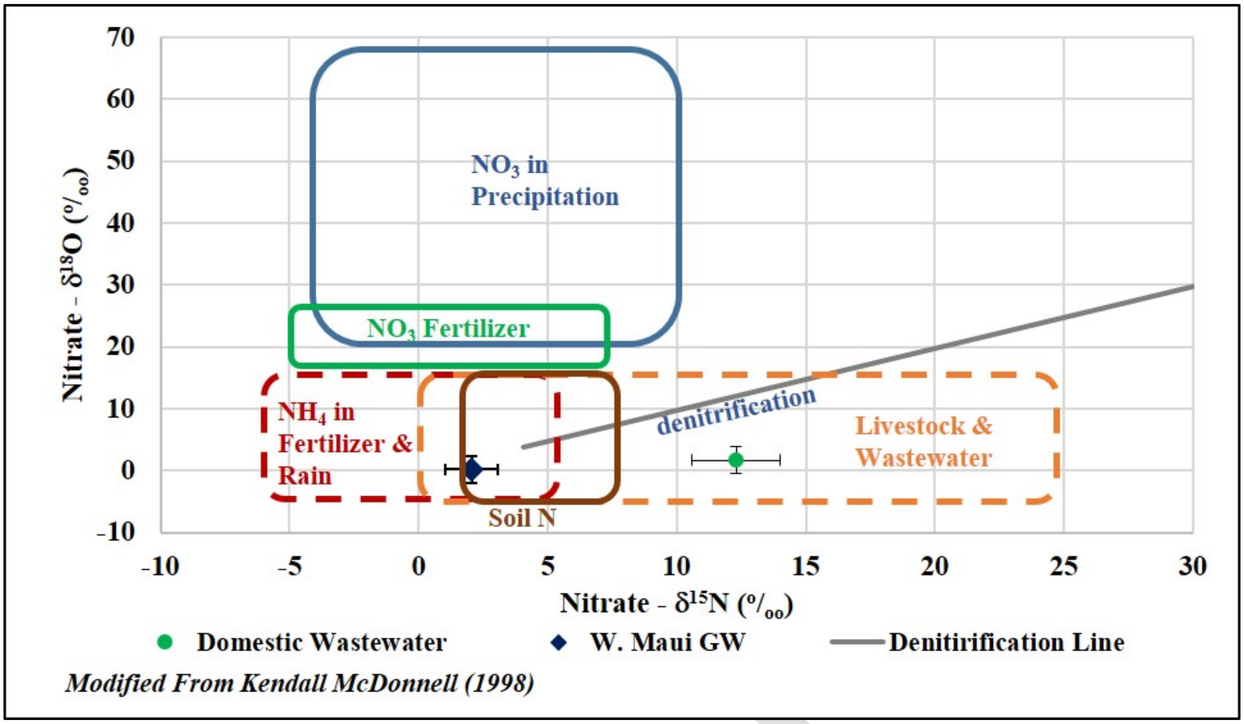


Figure 1-7. The isotopic composition of various nitrate sources

SECTION 2 UPCOUNTRY MAUI GROUNDWATER FIELD INVESTIGATION

2.1 INTRODUCTION

To investigate the source(s) of elevated groundwater nitrate in Upcountry Maui, DOH conducted a single round of groundwater sample collection from the study area wells and did a field survey of potentially contaminating activities (PCA). Twelve wells were sampled for 27 physical, chemical, and isotopic parameters. This was done to identify those activities that could result in elevated groundwater nitrate concentrations.

2.2 NON-SAMPLING ACTIVITIES

2.2.1 Planning and Site Reconnaissance

Prior to initiating field activities, the sampling points were identified and permission for access obtained. Since OSDS are a likely source of the elevated nitrate, the distribution of OSDS in Upcountry Maui was overlain on wells in this region. Twenty wells were identified as being good candidates for sampling. Of the wells identified, permission had been obtained to access 12 wells. Table 2-1 and Figure 2-1 list the wells and their owners for which access was granted. Two wells, the Pulehu Farms Well and the Hailimaile Well were considered candidates for sampling but were out of service due to having no electrical power. Installed well infrastructure prevented collecting grab samples.

Site reconnaissance included a roadway survey of potential sources of nitrate contamination. The nitrate PCAs identified in Figure 2-1 were visited to the extent practical to evaluate the degree to which they may be contributing nitrate to the groundwater. For example, 12 animal feedlots are suspected to be in the investigation area. However, during the site reconnaissance no livestock concentrations great enough to pose a groundwater contamination risk were observed. The Haleakala Ranch operations are upgradient of the wells with elevated nitrate. Most of this operation consists of pasture grazing that does not pose a risk to groundwater. However, confined animal feeding operations, if present, pose a groundwater contamination risk and have isotopic compositions similar to that of OSDS effluent. Pharmaceutical sampling (Section 3.3.2) and groundwater flow and transport modeling (Section 3.3.3) were done to further evaluate whether the Haleakala Ranch operations were a significant contribution to the elevated groundwater nitrate.

Table 2-1. List of sampling locations

Well No.	Well Name	Owner/Operator	Use	Date Sampled
6-5320-002	Maunaolu-Smith	David Woodham/Pural	Drinking Water	7/18/2017
6-4821-001	Omaopio-Esty	Edward Esty/Pural	Drinking Water	7/18/2017
6-5418-002	West Kuiaha Meadows	Smith Development/Pural	Drinking Water	7/18/2017
6-4424-001	Maui Highlands 2	Maui Highlands Properties/Pural	Drinking Water	7/18/2017
6-5118-002	Pookela	Maui Department of Water Supply	Drinking Water	7/17/2017
6-5317-001	Kaupakulua	Maui Department of Water Supply	Drinking Water	7/17/2017
6-5320-001	Hamakuapoko 2	Maui Department of Water Supply	Drinking Water	7/17/2017
6-5419-001	Haiku	Maui Department of Water Supply	Drinking Water	7/17/2017
6-5420-002	Hamakuapoko I	Maui Department of Water Supply	Drinking Water	7/17/2017
6-5021-001	Pukalani Golf Course	Pukalani Golf Club, LLC	Irrigation	7/19/2017
6-5220-002	BRE-1	Baldwin Ranch Estates	Drinking Water	7/19/2017
6-4422-001	Waiohuli Observation Well	Pacific Islands Water Science Center, USGS	Observation	8/9/2017

2.3 GROUNDWATER SAMPLING

2.3.1 Sampling Rationale

Sampling activities included a single round of groundwater sampling in the Upcountry Maui wells. This section presents the rationale for identifying potential chemicals of concern, screening criteria, evaluating the groundwater chemistry and determining the probable source of the elevated nitrates. The logic used in this investigation was to sample the groundwater in Upcountry Maui for nitrate and other nitrogen species to characterize the magnitude and extent of the nitrate contamination. The stable isotope analysis was done to determine the source of the nitrate contamination. Wastewater and animal wastes are enriched in the heavy nitrogen-15 isotope relative the nitrate in fertilizer and soil making the isotopic composition of nitrate a good indicator of the source of the nitrate contamination. Major ions, silica, and water quality parameters were analyzed to characterize the general groundwater chemistry to better understand flow paths and origin.

2.3.2 Groundwater Sampling Procedures

2.3.2.1 Groundwater Sampling Equipment

Table 2-2 lists the groundwater sampling equipment that was used during this investigation, the purpose, and preventive maintenance requirements.

Table 2-2. Groundwater sample collection equipment summary

Equipment	Purpose	Preventive Maintenance Requirements
YSI ProPlus Water Quality Analyzer	Document the water quality parameters of the samples collected including temperature, pH, specific conductivity, dissolve oxygen concentration, and oxidation reduction potential.	Remove batteries for long term storage. See Appendix I for specific preventive maintenance requirements.
Hach DR-820/90 Colorimeter and reagents	Screen samples for nitrate and nitrite concentration prior to delivery to the stable isotope laboratory.	Remove batteries for long term storage and cleaning sample cells. See Appendix I for sample cell cleaning procedures.
Alkalinity Test Kit	Measure the acid buffering capacity of the groundwater.	Clean glassware and titrator after use.
HydraSleeves®	Used to collect samples from wells without pumps.	None, single use only.
HydraSleeves® Retrieval Mechanism	Deploy and retrieve HydraSleeves® samplers.	Decontaminate between samples.
Digital Camera	Provide photo documentation of field activities.	Remove batteries for long term storage. Clean lenses daily when in use.
Nitrile gloves	Used to protect the integrity of the samples from contamination.	None, single use only.
Spray bottle, laboratory detergent, and scrub brush	Decontaminate equipment that will be re-used. Primarily weight and hangers for HydraSleeves®.	None.
Coolers and chemical ice	Sample storage and preservation.	

2.3.2.2 Groundwater Sampling – Pumped Wells

2.3.2.2.1 Well Purging and Water Quality Parameter Measurement

The sampling team coordinated with well operators to collect samples. The well operator started the pump and it was run for a sufficient amount of time to clear the well and discharge line of stagnant water. With production wells, the clearing of stagnant water occurred shortly after starting the pump due to the large volume pumping rates. Regardless, the well was purged for at least five (5) minutes. At that point water quality measurements were taken with the water quality analyzer (WQA). Usually this was done using the flow cell and tubing that are part of the WQA instrument package and described in Appendix I. The tubing was connected to the sampling port of the pump but left disconnected from the flow cell. The valve for the sampling port was be opened slightly until the discharge rate of one (1) to two (2) liters per minute was established. Flow rates greater than this risked pressuring the flow, biasing the dissolved oxygen measurements, and damaging the dissolved oxygen probe. Once the flow was established the discharge tubing was connected to the flow cell with the WQA sonde inserted. Readings of temperature, pH, and specific conductivity were taken and recorded in the field notebook and data transferred to an electronic version of Field Sampling Form (Form E-1, Appendix I) in the evening after sampling. The sampling port valve was then shut and the flow cell was then disconnected from the sampling port.

This procedure was deviated from when the Pukalani Golf Course Well was sampled. As per an agreement between the Pukalani Golf Course and Maui Electric Company, the pump could not be run after 6:00 a.m. This requirement was not known by the sampling team who arrived at the well at 7:45 am. The sample was collected from the water in the discharge line. The only parameter this deviation from the standard sampling procedures should bias is the temperature.

2.3.2.2.2 Sample Collection

When the purge was completed and the water quality field measurements had been taken, the groundwater samples were collected from the wells. The fitting and tubing used during well purging and water quality parameter measurements were removed and a new-decontaminated fitting and length of tubing were connected to the sampling port. The sampling port valve was cracked and water was allowed to flow through the fitting and tubing for about 0.5 minutes. A 0.45 micron filter was then connected to the tubing and purged for about another 0.5 minutes. The sample containers were then filled. All sample containers except those for alkalinity, oxygen and hydrogen isotope analysis were filled to the shoulder of the bottle. The containers for alkalinity, and oxygen and hydrogen isotope analysis were filled to overflowing. The cap for these containers was rinsed and filled with sample water then placed on the sample container. After being capped the alkalinity, and oxygen and hydrogen isotope containers were checked for head space bubbles. If a bubble was present, the containers were uncapped and water added then recapped. This process was continued until there was no headspace bubble in the alkalinity, and oxygen and hydrogen isotope bottles. When the sample containers were filled, the sample valve was shut off and the fitting and tubing disconnected. Section 2.3.5 describes the sample containers and preservation need for the samples.

2.3.2.3 Groundwater Sampling – Wells without Pumps

The BRE-1 Well and the Waiohuli Observation Well had no downhole pumps so sampling was done with HydraSleeves. A HydraSleeve is a no-purge, depth specific sampling method that consists of a plastic sleeve suspended from a line with weight at the bottom (Appendix I). As the sleeve is lowered down through the water column, the orifice at the top remains closed due to hydrostatic pressure. When the sleeve is at the desired sampling depth the sleeve is raised about 3 ft at a rate of 1 ft per second or more, then slowly lowered to starting depth. This process is repeated about 2-3 times to fill the sleeve. Details of HydraSleeve sampling procedures can be found in Appendix I. Table 2-3 lists the well construction details for these wells, providing the distance from ground surface to the screened interval of the well, identify the depth where the sample was collected.

For the BRE-1 Well the HydraSleeve was deployed using thin nylon cord on an extension cord reel. A sufficient length on nylon line was placed on a retrieval reel and the depth to water marked on the line. To prevent cross contamination, a dedicated length of line was added so the line that would be reused never reached the groundwater. The dedicated line was then connected to the retrieval reel line and the sleeve and weight was connected to HydraSleeve in accordance with procedures in Appendix I. The HydraSleeve was then lowered to the desired sampling depth and jigged as described in Appendix I to open and fill the sleeve. The sleeve was then retrieved and the sample bottles filled using procedures described in Appendix I.

The extension cord reel was not robust enough for the nearly 1,900 ft deployment depth needed for the Waiohuli Observation Well. Geologist from the Hawaii Department of Land and Natural Resources, Commission on Water Resources Management (CWRM) provided assistance with the sampling of this well when they did their quarterly depth to water measurements. After the CWRM geologists completed their depth to water measurement, the probe and wireline were retrieved. The HydraSleeve was attached to the WLI cable and probe assembly, and lowered to sampling depth. The sample was collected as before.

2.3.2.4 Nitrate Stable Isotope Sample Collection

The sample aliquots for nitrate stable isotope analysis were filtered by passing the water through a 0.45 micron filter to remove suspended solids. The sample bottles were immediately placed in a cooler with ice. At the end of the sampling day, the field colorimetric nitrite and nitrate analysis was done to document the concentrations of these two (2) nitrogen species. The nitrate stable isotope sample aliquots were then frozen and remained frozen until analysis. The analysis was performed by the Biogeochemical Stable Isotope Facility (BSIF) at the University of Hawaii, Department of Geology and Geophysics.

Table 2-3. Well construction data for wells sampled with HydraSleeves®

Well No.	Well Name	Well Elevation (ft msl)	Length of Solid Casing (ft)	Approximate Water Level (ft msl)	Sample Depth (ft below ground surface)
6-5220-002	BRE-1	1047.9	1073	5.5	1075
6-4422-001	Waiohuli Obs.	1864	1834	5.6	1870

2.3.2.5 Field Analysis

The field analysis was done to document the water quality parameters at the time of sampling. The field chemistry served two (2) purposes; 1) to characterize the basic water quality physical and chemical parameters, and 2) screen the nitrate/nitrite concentration in the sample water as a reference for the nitrate isotope analysis.

2.3.2.5.1 Water Quality Parameter Measurement

The water quality parameters were measured using a YSI ProPlus Water Quality Analyzer and included:

- Temperature,
- pH,
- Specific Conductivity,
- Dissolved oxygen concentration, and
- Oxidation/reduction potential (ORP).

2.3.2.5.2 Field Nitrite and Nitrate Analysis

The BSIF at the University of Hawaii needed the nitrite and nitrate concentrations in the sample aliquot to determine specifics of the isotopic analytical process. This analysis was done as soon after sample collection as feasible and just prior to freezing using a Hach DR890 Colorimeter. Nitrite was analyzed for using Hach Method 8507, while nitrate was analyzed using Hach Method 8309. The details for these procedures can be found in Appendix I.

2.3.3 Sample Identification

When the samples were collected, a label was placed on the bottle containing the following information:

- Date of collection,
- Time of collection,
- Site name where the sample was collected,
- Whether or not sample was filtered,
- Analysis to be performed, and
- The name(s) of the sampler(s).

This information was also recorded in the field notebook, then transferred to an electronic copy of the daily field sampling form, Form E-1 in Appendix I.

2.3.4 Sample Handling

Upon collection, samples were labeled and stored in coolers with wet or chemical ice for transport from the field to the field office. At the field office, the samples were placed in a refrigerator. This was done to ensure that the samples were cooled and maintained at a temperature of between 0 and 6 °C. Any wet ice was changed out with chemical ice prior to transport of the samples by air. The nitrate isotope samples were frozen at the field office. The samples analyzed by the DOH EHASB were shipped via overnight air freight. Samples analyzed by the other laboratories were delivered the day after completion of the sampling. All samples were placed in shipping containers with chemical ice and shipped to Honolulu via overnight air freight or checked as luggage. The samples shipped via air freight were picked up the following day and delivered to the laboratory for analysis.

Standard Chain of Custody (COC) protocol was adhered to throughout the sample handling process, from collection to interisland transport, and delivery to the laboratory. Completed COC forms can be found in Appendix II.

2.3.5 Sample Containers, Preservation Techniques, and Holding Times

Table 2-4 lists the containers, sample quantity, preservation method, and holding times for groundwater samples. The holding times were taken from current DOH guidelines.

Table 2-4. Sample containers, preservation, and holding times for groundwater samples

Constituents	Container	Volume	Field Preservation	Lab Preservation	Holding Time
Nitrate-Nitrite Nitrogen (NO_2+NO_3)	Brown HDPE	1 L	Cool below 6 ºC	Freeze at <-20 ºC (filtered)	28 days if frozen within 48 hours of sample collection
Ammonia Nitrogen (NH_4)	Brown HDPE	1 L	Cool below 6 ºC	Freeze at <-20 ºC (filtered)	28 days if frozen within 48 hours of sample collection
Total Nitrogen	Brown HDPE	1 L	Cool below 6 ºC	Freeze at <-20 ºC (unfiltered)	28 days if frozen within 48 hours of sample collection
Total Phosphorus	Brown HDPE	1 L	Cool below 6 ºC	Freeze at <-20 ºC (unfiltered)	28 days
Dissolved Silica	Brown HDPE	1 L	Cool below 6 ºC	Cool below 6 ºC	28 days
Nitrate Isotopes ($\delta^{15}N$ & $\delta^{18}O$)	White HDPE	500 ml	Cool below 6 ºC	Freeze at <-20 ºC	None when frozen
Water Isotopes ($\delta^{2}H$ & $\delta^{18}O$)	glass with septum	40 ml	None	None	None
Major Ion	Amber HDPE	125 ml	None	None	28 days
Alkalinity	Amber glass with septum	250 ml	Cool below 4 ºC	Cool below 4 ºC	As soon as practical, 14 days maximum
NO2/NO3 Screening Analysis	White HDPE	125 ml	Cool below 4 ºC	Cool below 4 ºC	48 hours
Note: Sample volume for Ammonia Nitrogen, NO_3+NO_2, Total Nitrogen, Total Phosphorus, and Dissolved Silica were in the same 1 Liter (L) brown High Density Polyethylene (HDPE) container. The contents of this container were frozen by the laboratory after an aliquot was extracted for dissolved silica analysis.					

2.3.6 Sample Analysis

Groundwater samples were analyzed for the constituents listed in Table 2-5 below. This table also lists the analyzing laboratories. The major dissolved inorganic nitrogen species were analyzed for using EPA Method 353.2 (Nitrate + Nitrite) and EPA Method 350.1 (Ammonia Nitrogen). The presence of organic nitrogen was screened for by analyzing the samples for the total dissolved nitrogen concentration. The digestion of samples with potassium persulfate under UV photo-oxidation oxidizes all forms of inorganic and organic nitrogen to nitrate (NO_3) which is then quantitatively reduced to nitrite (NO_2) by passing the digested sample through a cadmium reduction. Thus, there are two (2) steps in the analysis; the digestion process and the actual analysis using an automated nutrient analyzer. The result is the total organic plus inorganic content of the samples. A significant difference between the Nitrate + Nitrite concentration and the Total Nitrogen concentration indicated the presence of organic nitrogen. See Appendix III for details of the Total Nitrogen analysis.

Table 2-5. Groundwater analysis summary

Water Quality Parameter	Method Number or Description	Analyzing Laboratory
Nitrate + Nitrite Nitrogen (NO_3+NO_2)	EPA Method 353.2	EHASB
Ammonia Nitrogen (NH_4)	EPA Method 350.1	EHASB
Total Nitrogen	Photo-oxidation of organic nitrogen with ultraviolet light then nitrate analysis using EPA 353.1	EHASB
Total Phosphorus	EPA Method 365.1	EHASB
Dissolved Silica	EPA Method 370.1	EHASB
Nitrate Isotope Analysis	Isotopic ratio mass spectrometry	BSIF
Water Isotope Analysis	Cavity Ring-Down Spectrometry	BSIF
Alkalinity Analysis	Hach Method 8203	SDWB Personnel
Screening Nitrite Analysis	Hach Method 8507	SDWB Personnel
Screening Nitrate Analysis	Hach Method 8039	SDWB Personnel

2.3.6.1 Nitrate Stable Isotope Sample Analysis

The isotopic composition of aqueous nitrate is measured after bacterial conversion to nitrous oxide using isotope ratio mass spectrometry at the University of Hawaii, BSIF in Honolulu, Hawaii. Accuracy is verified using solutions of international isotopic reference materials (USGS 32, USGS 34, NIST 3, and USGS 35 when measuring the $\delta^{18}O$) and an in-house standard that has been characterized against these reference materials and verified via inter-laboratory comparison. The references are analyzed in duplicate alongside samples using the exact same treatment principle. The measured values of those reference materials are then used to determine the isotopic composition of the unknown samples (i.e. isotope ratio mass spectrometry). Details of this analytical method are outlined in McIlvin and Casciotti (2011), Appendix I.

2.4 ANALYZING LABORATORIES

2.4.1 Environmental Health Analytical Services Branch (EHASB)

The EHASB provides chemical and microbiological analytical services to DOH programs and to various federal, state and county agencies concerned with air pollution, drinking water, recreational waters, water pollution, and foods. EHASB evaluates and certifies laboratories involved in regulatory monitoring for contaminants in drinking water and dairy products. The EHASB laboratories are certified by the U.S. EPA for the analysis of drinking water and by the Food and Drug Administration for the analysis of dairy products and shellfish. Below is the contact information for the EHASB:

Wanda Chang
EHASB Branch Chief
2725 Waimano Home Road
Pearl City, Hawaii 96782
Phone: (808) 453-6671
Fax: (808) 453-6685
Email: wanda.chang@doh.hawaii.gov

2.4.2 University of Hawaii – Biogeochemical Stable Isotope Facility (BSIF)

The University of Hawaii, BSIF is a research facility that measures stable isotopes of carbon, nitrogen, hydrogen, and oxygen in a variety of solid, liquid, and gas samples. This analysis includes the stable isotopes making up nitrate ($\delta^{15}N$ and $\delta^{18}O$) and water ($\delta^{2}H$ and $\delta^{18}O$) that are critical to this investigation.

The BSIF is part of the School of Ocean and Earth Science and Technology (SOEST) on the Manoa campus of the University of Hawaii. Below is the contact information for the BSIF.

Biogeochemical Stable Isotope Facility
School of Ocean and Earth Science and Technology
University of Hawaii at Manoa
1680 East-West Road. POST 726
Honolulu, Hi 96822
Lab Phone: 808-956-5362
Lab Fax: 808-956-5512
Lab email: isobiogeo@soest.hawaii.edu

2.4.3 University of Hawaii – Water Resources Research Center, Water Quality Laboratory

The WRRC Analytical Laboratory is housed in 700 square feet of space in the University of Hawaii - Manoa engineering building, Holmes Hall, room 181. WRRC works closely with the department of Civil and Environmental Engineering, and, together, they have furnished the laboratory with up-to-date, and state-of-the-art, equipment for the analysis of environmental pollutants at trace levels of parts per million (ppm), parts per billion (ppb), and even parts per trillion. This includes Volatile and Semi Volatile Organic compounds like Petroleum Hydrocarbons, Industrial Solvents, Explosives, Pharmaceuticals and Personal Care Products (PPCPs), and Endocrine Disruptors like Organochlorine Pesticides, Polychlorinated Biphenyls, Polynuclear Aromatic Hydrocarbons and dissolved inorganic solids.

Water Resources Research Center
Holmes Hall 283, 2540 Dole St.
Honolulu, HI 96822
Phone: 808-956-7847
Fax: 808-956-5044
Email: wrrc@hawaii.edu

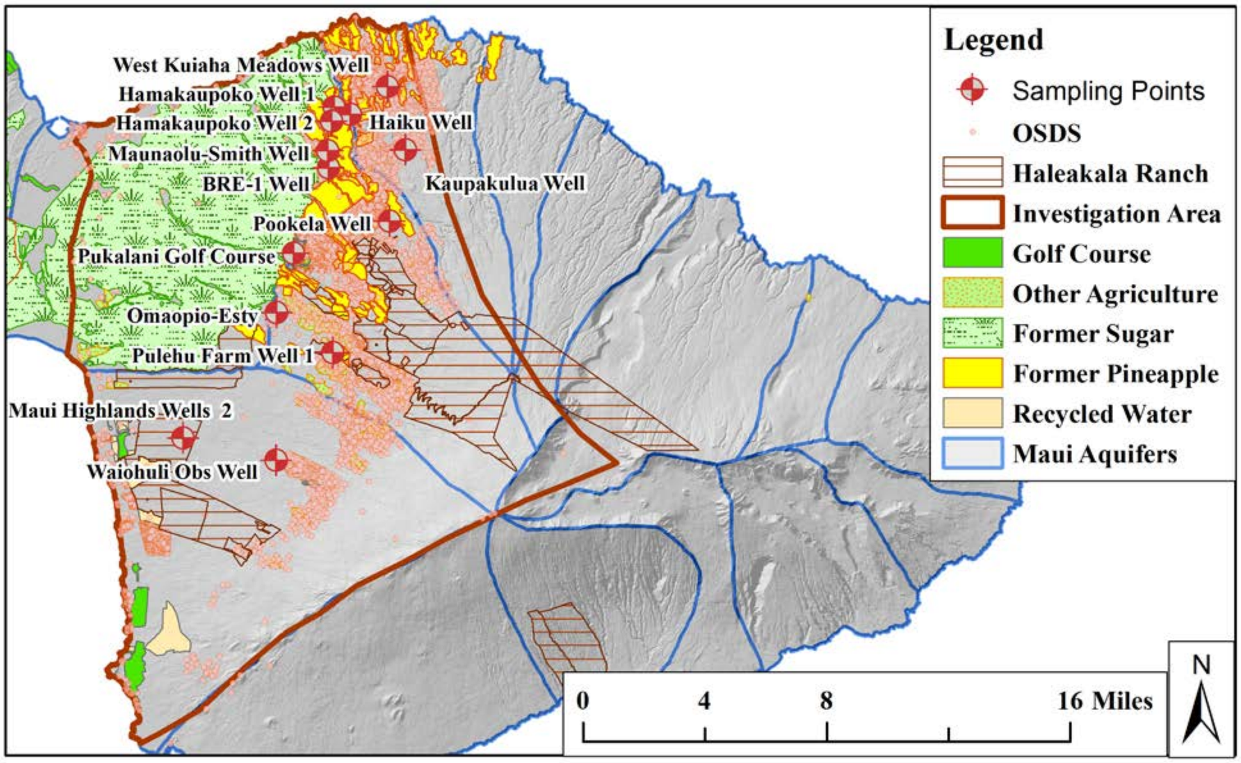


Figure 2-1. Upcountry Maui Sampling locations relative to the PCA locations

SECTION 3 UPCOUNTRY MAUI NITRATE INVESTIGATION RESULTS

3.1 INTRODUCTION

The primary purpose of this investigation was to characterize the magnitude and distribution of nitrate in the drinking water aquifers of Upcountry Maui and to determine the source of the elevated nitrate. As described in Section 2, 12 wells were sampled for 27 different, chemical, water quality, and isotopic constituents. A complete listing of the analytical results can be found in Appendix IV. This section describes the results of the results most relevant to the purposes of this study.

3.2 NUTRIENT CHEMICAL RESULTS

The focus of this project is to characterize the magnitude and distribution of nitrate in the Upcountry Maui groundwater since nitrate is a primary drinking water contaminant. However, nitrate is only one of a suite of nutrients that leach to the groundwater from anthropogenic activities.

3.2.1 Nitrate and Other Groundwater Nutrients

The groundwater samples were analyzed for the following nutrients:

- Ammonium,
- nitrite, nitrate plus nitrite,
- total nitrogen,
- phosphate,
- total phosphorus, and
- dissolved silica.

Table 3-1 lists the nutrient concentrations for each well and that of the duplicate samples collected for Quality Assurance purposes.

Table 3-1. Nutrient concentrations in Upcountry Maui groundwater

Well Name	Well Number	Nitrite (mg/L as N)	Ammonium (mg/L as N)	Nitrate+ Nitrite (mg/L as N)	Total Nitrogen (mg/L as N)	*DON (mg/L as N)*	Ortho - phosphate (mg/L as P)	Total Phosphorus (mg/L as P)
Pukalani Golf Course	6-5021-001	0.003	0.005	5.78	12.9	*7.1*	0.050	0.025
Omaopio-Esty	6-4821-001	0.001	0.002	5.03	10.9	*5.9*	0.041	0.018
Waiohuli Obs. Well	6-4422-001	0.001	0.014	2.46	27*	*24.5**	0.005	0.005
West Kuiaha Meadows Well	6-5418-002	0.001	0.002	0.67	0.7	*0.1*	0.068	0.053
BRE-1	6-5220-002	0.004	0.145	3.99	9.1	*4.9*	0.177	0.168
Kaupakulua Well	6-5317-001	0.001	0.003	0.69	0.8	*0.1*	0.081	0.061
Haiku Well	6-5419-001	0.001	0.002	1.91	4.7	*2.8*	0.074	0.061
Maui Highlands Wells 2	6-4425-001	0.001	0.002	0.90	1.2	*0.3*	0.051	0.035
Maunaolu-Smith Well	6-5320-002	0.001	0.003	5.26	8.5	*3.3*	0.083	0.066
Hamakaupoko Well 1	6-5420-002	0.001	0.003	2.38	5.4	*3.0*	0.089	0.074
Hamakaupoko Well 2	6-5320-001	0.001	0.002	4.14	7.9	*3.7*	0.094	0.077
Pookela Well	6-5118-002	0.002	0.003	0.41	0.9	*0.5*	0.057	0.041
Haiku Well	Duplicate	0.001	0.002	1.91	3.7	*1.8*	0.076	0.060
Pukalani Golf Course Well	Duplicate	0.003	0.002	6.10	13.7	*7.6*	0.050	0.025
Minimum		0.001	0.002	0.41	0.74	*0.07*	0.005	0.005
Average		0.001	0.015	2.78	6.07	*3.22*	0.067	0.053
Maximum		0.004	0.145	5.78	12.9	*7.11*	0.177	0.168
Standard Deviation		0.001	0.039	1.88	4.38	*2.62*	0.044	0.042

* The initial TN result for the Waiohuli Obs. Well was 27 mg/L, resulting in a DON conc. of 24.5 mg/L. The TN concentration is unusually high so the sample was re-analyzed with a resulting TN conc. of 9.5 mg/L. However, because the re-analysis was done outside of the holding time the higher value is reported. The summary statistics for TN and DON disregarded the anomalously high TN concentration of 27 mg/L.

The nitrate concentrations in the wells sampled ranged from 0.4 mg/L to 5.8 mg/L. Figure 3-1 and 3-2 show the distribution of nitrate relative to potential sources of nitrate contamination. These sources of nitrate contamination include:

- OSDS,
- Former sugar cane cultivation,
- Former pineapple cultivation,
- Cemeteries, and
- Major livestock operations (Haleakala Ranch).

3.2.1.1 Nitrate Distribution in Upcountry Maui

The most upslope wells in the northern part of the study area and the Maui Highlands Well 2 to the southwest of the study area have the lowest nitrate concentration, less than 1 mg/L. This concentration is only slightly greater than what would be expected from natural sources of nitrate (Hunt, 2004). All of the other wells show moderate to significantly elevated nitrate concentrations. The wells with the highest nitrate concentrations are located downgradient of communities served by OSDS. Other wells are in areas where agriculture and OSDS are the likely sources of nitrate. For example, the Hamakaupoko Wells 1 and 2, Maunaolu-Smith Well and the BRE-1 Well are also downgradient of areas of former pineapple cultivation. Additionally, the Hamakaupoko Wells 1 and 2 are located in an area that is likely affected by former sugar cane fields.

The wells with the highest nitrate concentrations were the Maunaolu-Smith Well, Pukalani Golf Course Well, and Omaopio-Esty Wells. The Pukalani Golf Course and the Omaopio-Esty Wells are located in areas of little agriculture activity, but downgradient from areas of dense concentrations of OSDS. These two wells could also be affected by operations at the Haleakala Ranch lands. The Maunaolu-Smith Well is located downgradient of former pineapple fields and a large number of OSDS. Figure 3-2 is a more detailed map of the wells and PCAs in the Makawao and Pukalani area. The Pookela Well had the lowest nitrate concentration at 0.4 mg/L. It is located close to a small plot were pineapple was formerly grown and downgradient from scattered OSDS. The Kaupakulua Well is located adjacent to communities served by OSDS but not downgradient from any significant agricultural activity. The nitrate concentration in this well is slightly higher at 0.7 mg/L. The Haiku, Hamakaupoko 1 and 2, Maunaolu-Smith, and BRE-1 wells are located downgradient from areas of former pineapple cultivation and significant densities of OSDS. The Pukalani Golf Course Well is located on the upper edge of a former sugar cane field and in close proximity to where recycled water is applied to a golf course. Nitrate concentrations alone cannot specifically link the nitrate in a well to a particular source. This study also analyzed the water samples for the isotopic composition of nitrate. Section 3.3.1 discusses the nitrate isotope results and inferences as to the sources of groundwater nitrate. Table 3-2 lists the groundwater nitrate results and the nitrate source setting upgradient of each well.

Table 3-2. The groundwater nitrate concentrations relative to the potential nitrate sources

Well	Nitrate Concentration (mg/L)	Setting Relative to Potential Nitrate Sources
West Kuiaha Meadows Well	0.7	Near small plots were pineapple was formerly grown and down gradient from scattered OSDS
Kaupakulua Well	0.7	Adjacent to a limited number of OSDS
Haiku Well	1.9	In an area of former pineapple cultivation and down gradient from some scattered OSDS
Hamakaupoko Wells	2.4 and 4.1	Near areas of former sugar cane cultivation and down gradient of scattered OSDS
Maunaolu-Smith Well	5.3	Down gradient of large fields where pineapple was formerly grown and down gradient from where the density of OSDS starts increasing
BRE-1 Well	4.0	Down gradient of large fields where pineapple was formerly grown and from a high density of OSDS
Pookela Well	0.4	Adjacent to a former pineapple field and down gradient from very few OSDS

Well	Nitrate Concentration (mg/L)	Setting Relative to Potential Nitrate Sources
Pukalani Golf Course Well	5.8	Located within a golf course where recycled water is applied; and down gradient from a where pineapple was formerly grown, Haleakala Ranch Lands, and a large density of OSDS
Omaopio-Esty Well	5.0	Down gradient of some agriculture, a high density of OSDS, and Haleakala Ranch Lands
Maui Highlands Wells	0.9	Significantly down gradient from a community served by OSDS
Waiohuli Observation Well	2.5	Located down gradient from a community served by OSDS

3.2.1.2 Other Nutrients in Upcountry Maui

This study analyzed for a broad spectrum of nutrient species including Ammonium (the ionic form of ammonia), nitrite, nitrate, and total nitrogen. Ammonium, nitrite, and nitrate are the inorganic forms of nitrogen referred to as dissolved inorganic nitrogen (DIN). By far the dominant form of DIN was nitrate. Nitrite was only present in very trace concentration near the limit of detectability. This is expected since nitrite gets oxidized to nitrate. Ammonium, a major constituent in wastewater and fertilizers was also only present in trace concentrations except for a concentration of 0.14 mg/L as nitrogen in the BRE-1 well. The dissolved organic nitrogen (DON) can be estimated by subtracting DIN from total nitrogen (TN). In the high nitrate wells, the DON concentration was equal to or greater the DIN (sum of ammonium, nitrite and nitrate) concentration. This was an unexpected result since the distance from the ground surface to the water table in the zone of contribution to the wells is 1000 ft or more. It was expected that the majority of the nitrogen in infiltrating down from the ground surface would be converted to nitrate or nitrogen gas.

Phosphorus is an agricultural and wastewater contaminant. This study analyzed for orthophosphate and total phosphorus. The concentrations of both were less than 0.1 mg/L except for the BRE-1 Well that had an orthophosphate concentration of 0.18 mg/L and a total phosphorus concentration of 0.17 mg/L. In many cases the total phosphorus concentration was less than the orthophosphate concentration, making the results counter intuitive. However, this is an artifact of the very low concentrations detected and the difference in methods for analyzing the two species. The low phosphorus concentrations reflect the strong tendency for phosphorus and orthophosphate to bind to soil immobilizing these species near the ground surface (Manahan, 2005).

Dissolved silica, while considered a nutrient, is not the focus of this investigation. This species was analyzed to better characterize the groundwater chemistry of the study area relative to the other groundwater in Hawaii. The silica concentrations are reported in Appendix IV and will be merged with other Hawaii groundwater chemistry data sets to help define the normal groundwater chemistry for the State of Hawaii is. This knowledge can be important in developing accurate Capture Zone Delineations (CZDs) for PDWWs.

3.3 NITRATE SOURCE INDICATORS

Three (3) approaches were taken to determine the source of the nitrate contamination:

1. Finger printing the nitrate source using stable isotopes of nitrogen and oxygen that make up nitrate;
2. Analyzing samples from the high nitrate wells for the presences of pharmaceuticals associated with wastewater; and
3. Using a groundwater flow and transport model to test the preliminary conclusions of the study.

3.3.1 Stable Isotopes of Nitrate

The purpose of this investigation was to identify to the extent practical the source of the elevated nitrates in Upcountry Maui groundwater. The potential sources include: 1) natural nitrate from precipitation and decay of naturally occurring organic matter; 2) leaching of fertilizers; 3) contamination of groundwater by wastewater; and 4) leaching of livestock and other animal waste products. Discriminating between the sources cannot be done by measuring the nitrate concentration alone. However, nitrate sources differ in the isotopic composition of nitrogen and oxygen. Wastewater and animal wastes are isotopically heavier than fertilizer and natural nitrogen sources (Kendall, 1998). Commonly, the isotopic composition of nitrogen is expressed as the ratio the nitrogen-15 isotope to the nitrogen-14 isotope in the water sample compared to the same ratio in atmospheric nitrogen. This is expressed as a delta-15N value ($\delta^{15}N$) (Kendall, 1998). Since nitrate contains atoms of oxygen, the isotopic composition of this element is also of interest. For oxygen the ratio is that of the heavy and rarer isotope, oxygen 18, to that the common isotope, oxygen 16. Similar to nitrogen, the ratio is symbolized by a $\delta^{18}O$ value.

Figure 3-3 graphs the representative $\delta^{15}N$ and $\delta^{18}O$ values for likely sources for nitrate including (From Kendall, 1998):

- Naturally occurring nitrate in rain and soil,
- Fertilizers,
- Animal waste, and
- Wastewater.

Nitrate is made up of nitrogen and oxygen so the isotopic composition of both elements are graphed. Since ranges overlap and nitrate in groundwater is usually a combination of different sources, the Oxygen-18 isotopic fraction ($\delta^{18}O$) in combination with the $\delta^{15}N$ help distinguish between nitrate sources. Fertilizer nitrate has a higher $\delta^{18}O$ value and ammonium fertilizer has a lower $\delta^{15}N$ value than wastewater. There is a significant overlap of the soil nitrate with the livestock/wastewater nitrate ranges. However, as shown by low background nitrate concentrations, soil nitrate can only account for low concentrations of nitrate in groundwater.

A process called "denitrification" can also influence the isotopic composition of nitrate, by bacteria using nitrate as a nutrient source while decomposing organic carbon. Denitrification bacteria preferentially utilize the lighter isotopes of nitrogen and oxygen resulting in the remaining nitrate being isotopically heavier than the starting composition. This process is shown as the denitrification line on Figure 3-3. While the isotopic composition of the remaining nitrate would get heavier, the nitrate concentration would decrease since the process converts nitrate to nitrogen gas. The expected results of denitrification of fertilizer nitrate would be a low concentration of isotopically heavy nitrate.

Another approach for using the nitrate isotopic composition to evaluate the source of the nitrate is to define end members. End members would be the extreme or "book-end" values of the $\delta^{15}N$ values. For the purposes of this study, since wastewater is a suspected nitrate source, domestic wastewater would be a high-end member. Wiegner et al. (2016) analyzed eight (8) domestic wastewater samples for their nitrate isotopic composition. The average $\delta^{15}N$ value was 12.30 $^{o}/_{oo}$. The green symbol in Figure 3-3 shows the average eight (8) domestic wastewater samples taken in the Kapoho area of Hawaii Island. The low end-member or "book-end" is the average isotopic composition from west Maui where natural and fertilizer are the only nitrate sources. The whiskers on the symbol show the range values of $\delta^{15}N$ and $\delta^{18}O$ for domestic wastewater and west Maui groundwater.

The low-end member would be groundwater containing natural and fertilizer nitrate. West Maui is an area with very few OSDS compared to Upcountry Maui and provides a good basis for interpreting the isotopic composition of groundwater nitrate with no wastewater contamination. Glenn et al., (2012) conducted two (2) sampling rounds of eight (8) wells in west Maui. The $\delta^{15}N$ values ranged from 0.65 to 4.2 ‰, with an average value of 2.1 ‰ and a standard deviation of 1.0 ‰. The Hahakea 2 Well that is located significantly downslope from the upland edge of the former sugar cane had $\delta^{15}N$ values of 0.65 and 0.91 ‰. The USGS analyzed a sample from the Puukolii Well in west Maui for the nitrate isotopic composition. This well, like the Hahakea 2 Well, is located within the footprint of former sugar cane fields and like the Hahakea 2 Well had an elevated nitrate concentration compared to the other wells sampled in west Maui. The resulting $\delta^{15}N$ for the Puukolii Well was 1.17 ‰. Hunt (2014) in his baseline sampling study of the nutrient sources to the Kaloko-Honokohau National Historical Park, used the upslope Honokohau Well to represent the non-wastewater impacted groundwater. This well had a $\delta^{15}N$ value of 1.99 ‰. Based on the data from west Maui and Hawaii Island, natural sources of nitrate in the groundwater water would have a $\delta^{15}N$ composition of about 2.5 ‰. As fertilizer leachate is added to the groundwater that value will tend to decrease to about 1 ‰. For the purposes of this study the average $\delta^{15}N$ value measured in west Maui represents groundwater with only natural and fertilizer sources of nitrate. Groundwater with $\delta^{15}N$ isotopic compositions greater the average west Maui value plus one standard deviation (3.1 ‰) indicate a likely wastewater contribution. The magnitude of the wastewater contributions increases proportionally with $\delta^{15}N$ isotopic composition. Table 3-3 lists representative values of $\delta^{15}N$ in soil, fertilizer, and groundwater from various Hawaii studies.

Table 3-3. Representative ranges of $\delta^{15}N$ in Hawaii soil, fertilizer, and groundwater

Nitrate Source	Range of $\delta^{15}N$ Values (‰)	Average $\delta^{15}N$ Value (‰)	Source
Soil nitrate (an estimate of natural nitrate)	+0.75 to +4.21	+2.3	Derse et al., 2007
Soil nitrate (an estimate of natural nitrate)	-4.68 to +9.3	+1.33	Wiegner et al., 2016
Fertilizer nitrate	-1.4 to -0.3	-0.85	Wiegner et al., 2016
Fertilizer nitrate	Not given	-2.1	Derse et al. 2007
Fertilizer plus natural nitrate in groundwater	+0.65 to +4.2	+2.1	Glenn et al., 2012
Domestic Wastewater	11.5 to 17.0	+12.3	Wiegner et al., 2016

3.3.1.1 Results of the Nitrate Stable Isotope Sampling

The nitrate isotopic composition of the Upcountry Maui groundwater varied from 2.9 to 8.1 ‰. Figure 3-3 graphs the isotopic composition relative to the accepted ranges of nitrate sources. Figure 3-4 shows nitrate isotopic distribution of the Upcountry Maui wells relative to the wastewater and west Maui nitrate isotopic compositions. The isotopic composition of nitrate in the west Maui wells (Glenn et al., 2012) are evaluated as being the most reliable end-member for Maui groundwater not impacted by OSDS leachate. The average west Maui $\delta^{15}N$ value is shown as the dark blue symbol in Figure 3-3 with the whiskers showing one (1) standard deviation from the average. Table 3-4 tabulates the analytical results.

Figure 3-5 shows the location and isotopic composition of the wells sampled by the west Maui studies. The color coding used for the west Maui nitrate isotope values is the same as that used for Upcountry Maui in Figure 3-4, except the range of 0.8 to 2.0 was added to reflect the lower values in west Maui. The difference is the lower (blue) range is extended for the west Maui to more concisely capture the much lower nitrate isotope composition in west Maui. As described above the green symbol represents the average of eight (8) domestic wastewater samples and the whiskers represent the range. The purple symbols in Figure 3-3 graphs the isotopic composition of Upcountry Maui nitrate samples. The important concept is that as the wastewater or livestock nitrate fraction in a sample increases, the $\delta^{15}N$ isotopic value moves farther from the dark blue symbol toward to the green symbol.

The function of the nitrate isotope analysis is to evaluate the source of the nitrate. The inset in Figure 3-3 displays the sample results in more detail. Only one sample result (the Pukalani Golf Course Well) falls exclusively in the livestock/wastewater range and outside of the soil nitrate range. The Omaopio-Esty Well results fall on heavy end of the soil nitrate border, but well into the livestock/wastewater nitrate range. However, the contribution of soil nitrate would only account for less than 1 mg/L of the total nitrate 5.0 mg/L concentration. So the isotopic composition of nitrate from this well strongly implicates that livestock/wastewater are the dominant source of nitrate. All of the rest of the sample results fall within the range overlapped by soil nitrate, ammonium fertilizer, and livestock/wastewater nitrate range. This will be discussed in more detail in the modeling section of this report (Section 3.3.3).

The location of the wells relative to OSDS and other nitrate sources must be taken into account when estimating the degree of wastewater contamination in these wells. Figure 3-5 shows the distribution of the nitrogen isotopes results for Upcountry Maui. As expected based on the low nitrate value and sparse population of OSDS upgradient, the Pookela Well had the lowest $\delta^{15}N$ value at 2.9 $^{o}/_{oo}$. The highest $\delta^{15}N$ values were in the Omaopio-Esty and the Pukalani Golf Couse Wells with values 6.5 and 8.1 $^{o}/_{oo,}$ respectively. Both of these wells are downgradient of areas with high OSDS density, but little agricultural activity with the exception of Haleakala Ranch. The remaining wells are downgradient of OSDS and former pineapple and sugar cane agriculture. The water captured by these wells will have a mixture of wastewater and agricultural nitrate.

For Upcountry Maui, the $\delta^{15}N$ value of 2.9 $^{o}/_{oo}$ in the Pookela Well sample is the most consistent with what is to be expected in Upcountry Maui for groundwater with little OSDS impact. This value is also consistent with the average $\delta^{15}N$ plus one standard deviation value measured in west Maui. However, as shown in Figure 3-5 there are OSDS upgradient of this well and due to the low nitrate concentrations even a small amount of wastewater can shift isotopic composition to heavier values. For this study a $\delta^{15}N$ greater than 3.1 $^{o}/_{oo}$ (the average west Maui isotopic composition plus one standard deviation) is considered the value where wastewater or livestock leachate contributes to nitrate load.

Table 3-4. Nitrate stable isotopes results

Well Name	Well Number	Figure 3-3 Abbreviations	$\delta^{15}N$ (‰)	$\delta^{18}O$ (‰)	Nitrate + Nitrite (mg/L as N)	Total Nitrogen (mg/L as N)
Pookela Well	6-5118-002	POK	2.9	1.8	0.41	0.9
Maui Highlands Wells 2	6-4425-001	MHW	4.0	1.2	0.9	1.2
Kaupakulua Well	6-5317-001	KW	4.1	5.6	0.69	0.8
West Kuiaha Meadows Well	6-5418-002	WKM	4.5	6.1	0.67	0.7
Haiku Well	6-5419-001	HW	4.0	5.5	1.91	4.7
Hamakaupoko Well 1	6-5420-002	HPW1	3.4	5.2	2.38	5.4
Hamakaupoko Well 2	6-5320-001	HPW 2	3.3	4.8	4.14	7.9
Maunaolu-Smith Well	6-5320-002	MSW	4.0	4.6	5.26	8.5
Waiohuli Obs. Well	6-4422-001	WOW	4.8	1.5	2.46	9.5
BRE-1	6-5220-002	BRE	4.1	4.5	3.99	9.1
Pukalani Golf Course	6-5021-001	PGC	8.1	3.6	5.78	12.9
Omaopio-Esty	6-4821-001	OEW	6.5	3.3	5.03	10.9
Haiku Well		Duplicate	4.3	6.6	1.91	3.7
Pukalani Golf Course Well		Duplicate	8.2	3.3	6.1	13.7

3.3.2 Pharmaceutical and Personnel Care Product Sampling

In collaboration with the DOH Groundwater Protection Program, wastewater and well water samples were collected from Upcountry Maui and analyzed for the presence of Pharmaceutical and Personnel Care Products (PPCPs). In 2017, Monitoring Section personnel as part of the Groundwater Protection Program embarked on a project to sample groundwater, raw wastewater, and wastewater treated to R-1 and R-2 recycled water standards for PPCPs (DOH, 2017). This PPCP project sampled raw wastewater at four (4) wastewater treatment plants, R-1 and, R-2 recycled water at 11 wastewater reclamation facilities, and three (3) wells. Two (2) of the wells sampled were the Omaopio-Esty and Pukalani Golf Course Wells. These wells were chosen because of their high nitrate concentrations and the possibility that wastewater from OSDS could be a major nitrate source. Raw wastewater and R-1 water were also sampled at the Pukalani Wastewater Reclamation Facility (WWRF) in Upcountry Maui. Table 3-5 lists the PPCPs detected in the Upcountry Maui wells. There were seven (7) PPCPs detected, but two (2) were herbicides and not indicative of wastewater. The other five (5) are indicators of wastewater contamination. The Pukalani WWRF influent was sampled twice. A total of 29 different compounds were detected in the Pukalani WWRF influent. Many of these compounds degrade quickly and will not migrate to the groundwater. The seven (7) PPCP compounds detected in the two Upcountry Maui groundwater samples account for a quarter of the number of PPCP detections in raw wastewater. It is important to understand that although pharmaceuticals were detected in the groundwater, the concentrations were extremely low and thus the health risk is extremely low. It would be physically impossible to consume enough water during the course of a day to get anywhere near the therapeutic dose for these compounds.

Pharmaceuticals and similar compounds are not unique to wastewater. Livestock operations are also a source of these contaminants due to the use of veterinary medicines. In 2013, the U.S. EPA published a study of the relationship between groundwater nitrate and potential sources in the Lower Yakima Valley, Washington (U.S. EPA, 2013). The focus of their study was to evaluate what impact dairy operations in Lower Yakima Valley was having on the groundwater. Their approach was similar to ours in that the U.S. EPA sampled groundwater for nutrients, stable isotopes of nitrate, and pharmaceutical and hormones. The focus of the pharmaceutical and hormone analysis was directed to those compounds associated with livestock. However, there were 20 compounds out of the 96 that we analyzed for that were also analyzed for by the U.S. EPA study. Only two of the PPCPs detected in the Upcountry Maui groundwater were analyzed for by the U.S. EPA (2013) study. Both were detected in the groundwater in community served by OSDS and in the dairy wastewater lagoon. However, neither were detected in the groundwater down gradient from the dairy farms.

The presence of compounds such as Sulfamethoxazole, a PPCP that does not readily degrade, is a strong indicator of wastewater contribution to groundwater captured by these wells. However, the detection by the U.S. EPA (2013) in dairy wastewater lagoons means the detection of this PPCP in the groundwater from the Pukalani Golf Course Well and the Omaopio Esty Well can't be exclusively linked to OSDS. However, the detection of Acesulfame-K, a non-calorie sugar substitute, does provide a much stronger link between the groundwater sampled from these two wells to OSDS. All of the non-pesticide PPCPs, except Amoxicillin, were detected in at least one (1) of the two (2) R-1 water samples collected from the Pukalani WWRF. If funding is made available, a second round of PPCP sampling will be done to include livestock pharmaceuticals, such as Tetracycline that was detected by the U.S. EPA in two (2) of the three (3) wells downgradient of the Yakima Valley dairy farms (U.S. EPA, 2013). The laboratory analysis reports for the Upcountry Maui PPCP sampling can be found in Appendix V. In summary the detection of Acesulfame-K provides a non-livestock between the PPCPs detected in the Upcountry Maui groundwater and human wastewater.

Table 3-5. PPCPs detected in the Upcountry Maui wells

PPCP	Reporting Limit (ng/L)	Pukalani Golf Course Well (ng/L)	Omaopio-Esty Well (ng/L)	Description	Comments
4-nonylphenol	100	460	460	Component of non-ionic surfactants used in detergents	Not analyzed for U.S. by EPA (2013), detected in R-1 Water
Acesulfame-K	20	30	<20	Non-calorie sugar substitute	Not analyzed for U.S. by EPA (2013), detected in R-1 Water
Amoxicillin	20	300	72	Common anti-biotic to treat infections	Not analyzed for U.S. by EPA (2013), ND in R-1 Water
Bromacil	5	<5	13	Herbicide commonly used to control perennial grasses	Not analyzed for U.S. by EPA (2013), ND in R-1 Water
Chloridazon	5	13	11	widely used organochlorine herbicide	Not analyzed for U.S. by EPA (2013), ND in R-1 Water
Sulfameth - oxazole	5	11	<5	Antibiotic for treating infections	Analyzed for by U.S. EPA (2013) , detected in R-1 Water (1 of 2)
Sulfathiazole	5	30	6.2	Organosulfur compound used as a short acting sulfa-drug	Analyzed for by U.S. EPA (2013) , detected in R-1 Water (1 of 2)
ND – Not detected					

3.3.3 The Groundwater Total Nitrogen Model

The nitrate isotopic analysis indicates that much of the elevated nitrate in the groundwater is from wastewater/animal wastes. While the 7,000 plus cesspools in Upcountry Maui are suspected to be the primary cause, leaching of animal wastes from Haleakala Ranch operations could also account for the elevated $\delta^{15}N$ values. For example, the Pukalani Golf Course and Omaopio-Esty Wells, the high nitrate and $\delta^{15}N$ wells, are downgradient of the Haleakala Ranch properties. During the field portions of this study, no large concentrations of animals were observed, but the investigation was limited to what could be observed from the road.

A groundwater flow transport model was developed to test if the amount of leachate from the OSDS is consistent both in concentration and spatial distribution of the dissolved TN in the Upcountry Maui groundwater. To test this assumption, the model assumed that the Haleakala Ranch was not a significant source of groundwater nitrogen and was modeled as a low concentration nitrogen source.

Total nitrogen rather than nitrate was modeled since nitrogen in wastewater is predominantly ammonium and DON and the sampling results show the DON concentration was equal to or greater than the nitrate concentration. This imparts a great uncertainty in what fraction wastewater nitrogen is converted to nitrate between time of discharge and capture by Upcountry Maui wells. The model nitrogen sources included OSDS, and leaching from previous sugar cane and pineapple cultivation. A reasonable agreement between the simulated and measured groundwater nitrogen would indicate that the assumption that operations at Haleakala Ranch are not be a significant source of groundwater nitrogen is valid.

Recharge into the model was that estimated by the USGS (Johnson et al., 2016). Table 3-6 lists the OSDS loading rates and the simulated recharge concentration of nitrogen for each of nitrogen sources. The simulation was run for 50 years to allow the simulated groundwater nitrogen to reach steady state. Appendix VI gives more detail on the model construction and the boundary conditions. Table 3-6 list the different nitrogen sources and simulated nitrogen load for each. The OSDS TN load was incorporated into the model recharge by summing the nitrogen mass from OSDS in each recharge polygon. In the areas of high OSDS density, the size of the individual recharge polygons was limited to a rectangle that was approximately 500 meters on a side. This provided the spatial resolution needed to simulate the distribution of TN in the Upcountry Maui groundwater.

3.3.3.1 Upcountry Maui Groundwater Nitrogen Model Results

Figure 3-6 maps the simulated groundwater nitrogen relative to the location of the Haleakala Ranch lands and areas where the OSDS density is greater than 100 systems per square mile. The highest TN concentrations were located adjacent to and down slope of areas where the OSDS density is 100 systems per square mile or greater. Much of the elevated TN lower on the west flank of Haleakala and in the eastern part of the isthmus is from former sugar cane cultivation. It will take years to decades for the residual agricultural nitrogen to flush out of the unsaturated zone and aquifer. The low TN near the western boundary of the model is an artifact of the specified concentration boundary condition that imposed a low nitrogen concentration at the western edge of the model. This likely is not true, but has low relevance to the model since the western boundary is significantly removed from the Upcountry Maui area of interest.

The groundwater flow and transport model tested the assumptions about the source of the TN in the Upcountry Maui groundwater. The color shading for the simulated and measured TN concentrations are the same. So in essence, if the model assumptions are correct, the groundwater nitrogen background color (modeled concentration) and the color of symbols (measured concentration) should be similar or the same. This does seem to be the case indicating good spatial correlation between the modeled and the measured total nitrogen. More to the purpose of this report, where the measured and modeled TN are elevated show good spatial correlation with areas where the OSDS density is greater than 100 systems per square mile and poorer correlation with the areas downgradient from the Haleakala Ranch lands. The graph in Figure 3-6 plots the measured TN concentration versus that simulated by model. Most of the data points fell close the 1:1 that represents perfect agreement between the measured modeled concentrations. Two (2) wells, the Omaopio-Esty and BRE-1 Wells had measured groundwater nitrogen concentrations significantly greater than those simulated (as indicated by the points falling below the 1:1 line). These wells are on the lower edge of the TN plume where there is a sharp gradient. One assumption of the model is that the infiltration path from the ground surface to the water table is strictly vertical. In reality, in 1,000 or more feet the slope of the lava bedding will tend to offset the infiltrating water down slope. The net effect would be to move the plume downslope in a manner that can’t be predicted. This offset downslope would increase the simulated TN concentration in the Omaopio-Esty and BRE-1 wells.

As stated above, the primary purpose of the Upcountry Maui groundwater flow and transport model was to test the hypothesis that OSDS rather than Haleakala Ranch operations were the source of the elevated groundwater TN concentrations. The good agreement between the measured and modeled groundwater TN concentrations do support this hypothesis. The good agreement also indicates that there is little natural attenuation of the TN during the more than 1,000 ft vertical travel distance from the point of OSDS discharge wastewater to the environment and where the impacted groundwater is captured by the wells.

Table 3-6. Nitrogen concentrations used to model the Upcountry Maui study area

Nitrogen Source	Quantity	Nitrogen Conc. (mg/L)	Comments
OSDS within the model domain	Effluent rate assumed 70 gal/day/person and 1.5 persons per bedroom		U.S. EPA, 2002
Cesspools	9,150	87	Septic influent concentration from WERF, 2007
Septic to Seepage Pit	450	58	Assumed 33 percent nitrogen removal rate in septic tank (WERF, 2009a)
Septic to Soil Treatment	2,700	34	Assumed 41 percent nitrogen removal rate in soil (Tasato and Dugan, 1980)
Former Pineapple	2,800 hectares	1.5	Adjusted recharge concentration so nitrogen concentration beneath pineapple fields was about 1 – 2 mg/L
Former Sugar Cane	14,700 hectares	5	Adjusted recharge concentration so nitrogen concentration beneath sugar cane field was about 2 – 4 mg/L
Recycled Water Application	370 hectares	7	Accounts for golf course fertilizer and the additional nitrogen in the recycled water
Soil Nitrogen	70,000 hectares	0.3	Applied to entire model domain to simulate the assumed background TN concentration of 0.3 mg/L

3.4 SUMMARY OF GROUNDWATER NITRATE IN UPCOUNTRY MAUI

Preliminary testing done for new PDWWs in Upcountry Maui have encountered groundwater with significantly elevated nitrate concentrations. To investigate this problem this study sampled 12 wells for 27 water quality, chemical, and isotopic constituents. In addition, this study collaborated with the Groundwater Protection Program and sampled two (2) wells for more than 90 PPCP compounds. The primary analyses used to evaluate the magnitude, distribution, and source of the nitrate contamination were nitrate, TN, the stable isotopes of nitrate, and PPCP compounds. The distribution of each of these analytical suites showed a strong correlation between the elevated groundwater nitrate concentrations, and OSDS and past industrial agriculture.

The Haleakala Ranch operations were considered a potential source of the elevated groundwater nitrate. There have been insufficient studies to concisely ascertain the impact of large livestock operations to our drinking water aquifers. The Big Island Dairy in the Hamakua region of Hawaii Island has recently become focus of concern regarding the risk this operation poses to surface water and groundwater. A groundwater risk assessment currently underway for the Hawaii Department of Water Supply is evaluating the risk that this livestock operation poses to groundwater and the Ookala PDWW. Cropped fields where treated livestock waste and wastewater are applied covers a large fraction of the two-year time of travel CZD. The milking parlors and the cropped fields are located within the 10-year time of travel CZD (DOH, in preparation). As part of this study, the nitrate and agricultural contaminant history was reviewed for the Ookala Well. Sugar cane was cultivated in this area until the mid-1990s (AgriPro, 2017). Dairy operations started at the site in 1998 and have been continuous since then (Agripro, 2017). Figure 3-7 shows the nitrate and atrazine concentrations from 1997 through 2016. The potential for agricultural activities to affect groundwater is evident from the atrazine detection history. The cessation of sugar cane cultivation is also evident in the Ookala Well contaminant history as shown by the decreasing concentrations of both atrazine and nitrate since 1997. The continued decline in the nitrate concentration strongly implies that at least through 2016, livestock operations at the Big Island Dairy are not a source of groundwater nitrate. However, DOH plans to work with the Hawaii Department of Water

Supply and the Big Island Dairy to do baseline sampling to ensure that the livestock operations are not degrading the groundwater and drinking quality.

The conclusion of this study is that while large livestock operations have the potential to increase the groundwater nitrate concentration, the elevated groundwater nitrate in Upcountry Maui is a combination of agricultural fertilizer, particularly in the north-central part of the study area, and OSDS leachate, particularly in central part of the study area. This conclusion is based on the nitrate and nitrate isotope sampling results, the PPCP sampling results, and groundwater flow and transport modeling. The groundwater flow and transport modeling was done assuming that past agriculture and OSDS were the primary source of nitrate. This assumption produced a reasonable agreement between the simulated results and groundwater nitrate measured in the Upcountry Maui wells. Table 3-7 tabulates the results of the nitrate sampling and the interpreted source of the nitrate to each well. The nitrate source interpretations are based primarily on the nitrate isotopic analysis described in Section 3.3.1.1.

Table 3-7. Current nitrate concentrations and an evaluation of the nitrate source

Well	Nitrate (mg/L)	Remarks
BRE-1	4.0	Sample was a grab sample since no pump is installed. Nitrate is mixture of fertilizer and OSDS leachate.
Omaopio-Esty Well	5.0	OSDS leachate is a significant fraction of the nitrate.
Pulehu Farms Well 1	3.0	This well was not sampled by this investigation. The nitrate value is from a sample collected by the water system operator on 9/24/2017. Based on location it is expected that the nitrate captured by this well has a significant OSDS leachate fraction.
Haiku Well	1.9	Nitrate is a mixture of fertilizer and OSDS leachate.
Hamakaupoko 1	2.4	Nitrate is predominantly fertilizer leachate.
Hamakaupoko 2	4.1	Nitrate is predominantly fertilizer leachate.
Kaupakulua Well	0.7	Nitrate is a mixture of fertilizer and OSDS leachate.
Maunaolu-Smith Well	5.3	Nitrate is a mixture of fertilizer and OSDS leachate.
West Kuiaha Meadows Well	0.7	Nitrate is a mixture of fertilizer and OSDS leachate.
Maui Highlands Well 2	0.9	Nitrate is a mixture of fertilizer and OSDS leachate.
Pukalani Golf Course Well	5.8	A sample collected from a previous sampling event had a nitrate concentration of 6. 4 mg/L. Nitrate in this well has a significant OSDS leachate fraction.

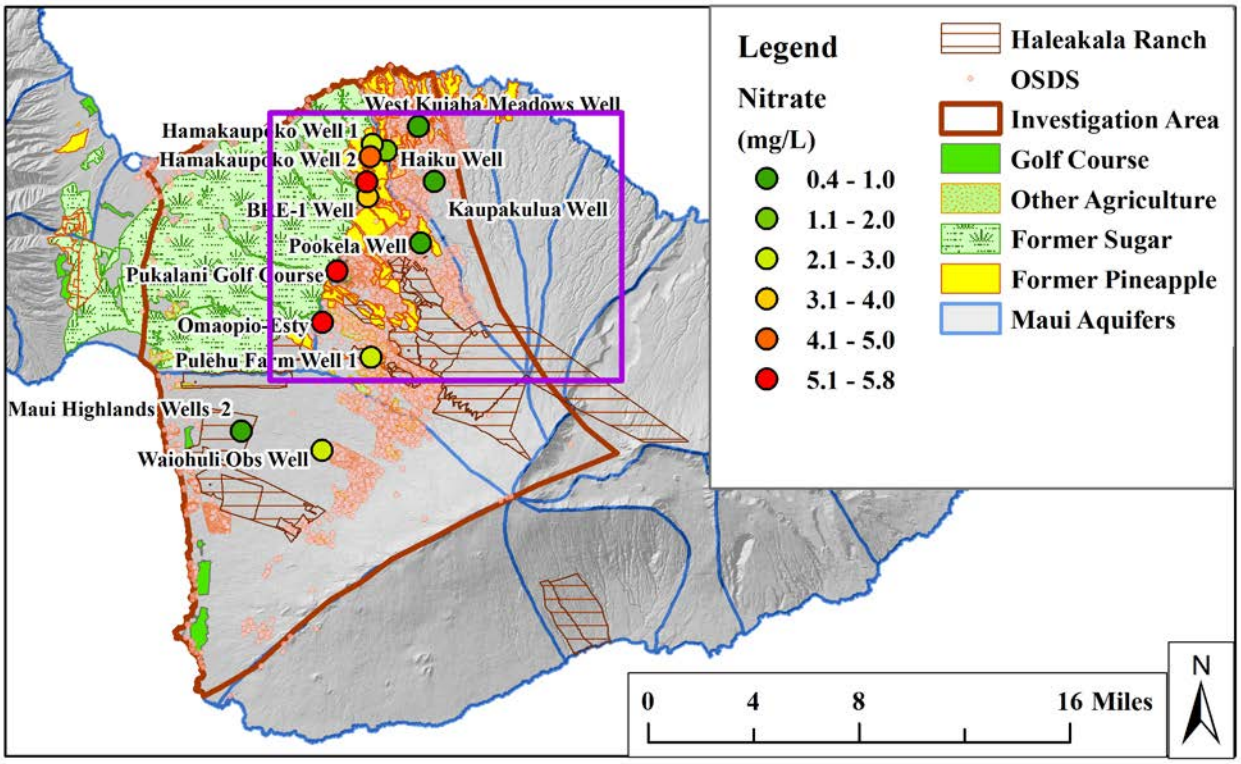


Figure 3-1. Location of the measured groundwater nitrate concentrations relative to nitrate producing PCAs

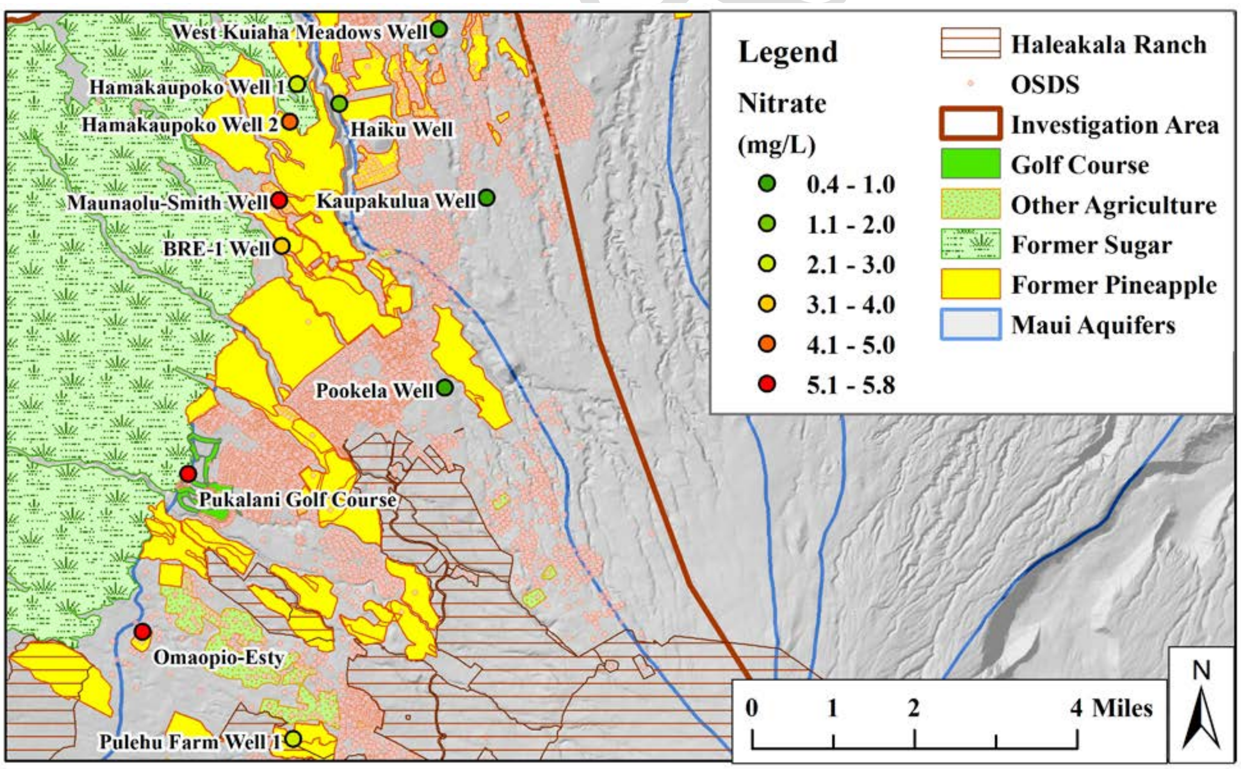


Figure 3-2. Detail map of the measured groundwater nitrate concentrations relative to PCAs

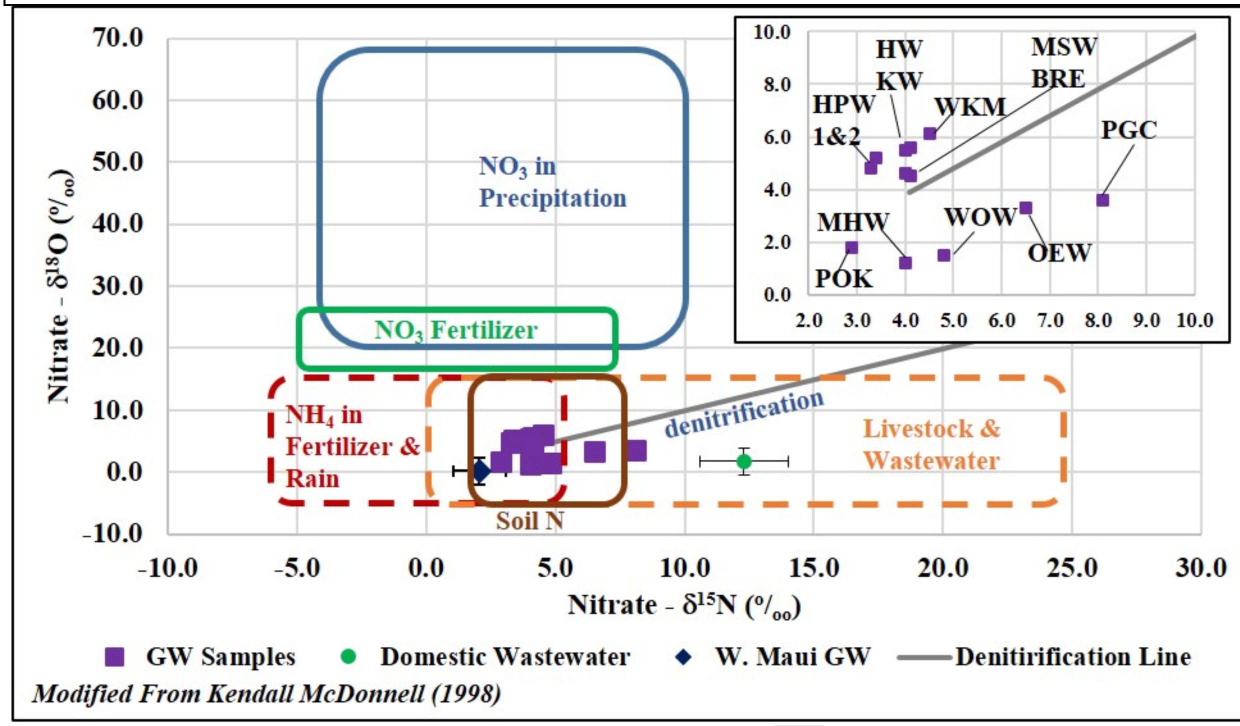


Figure 3-3. A Graph of $\delta^{15}N$ versus $\delta^{18}O$ composition of different nitrate sources compared to the sample results

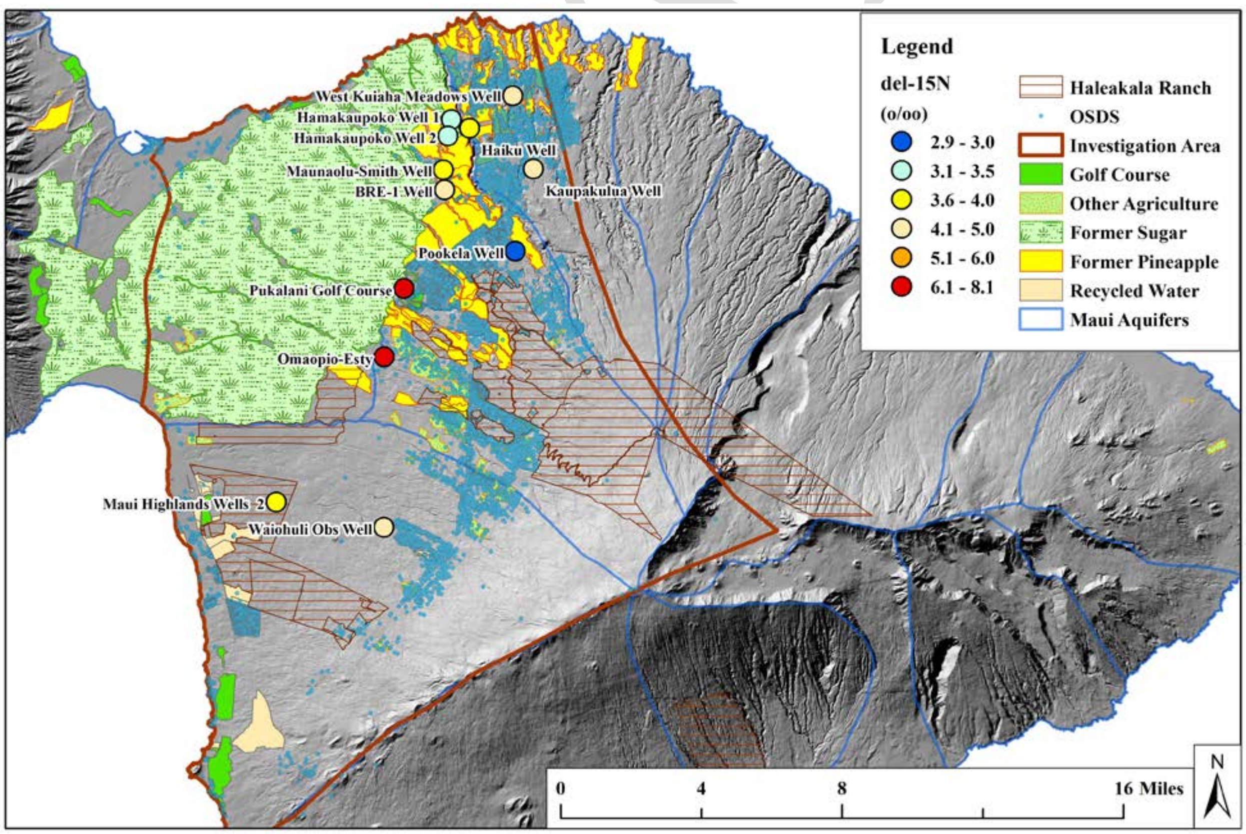


Figure 3-4. The $\delta^{15}N$ results relative to nitrate producing PCAs

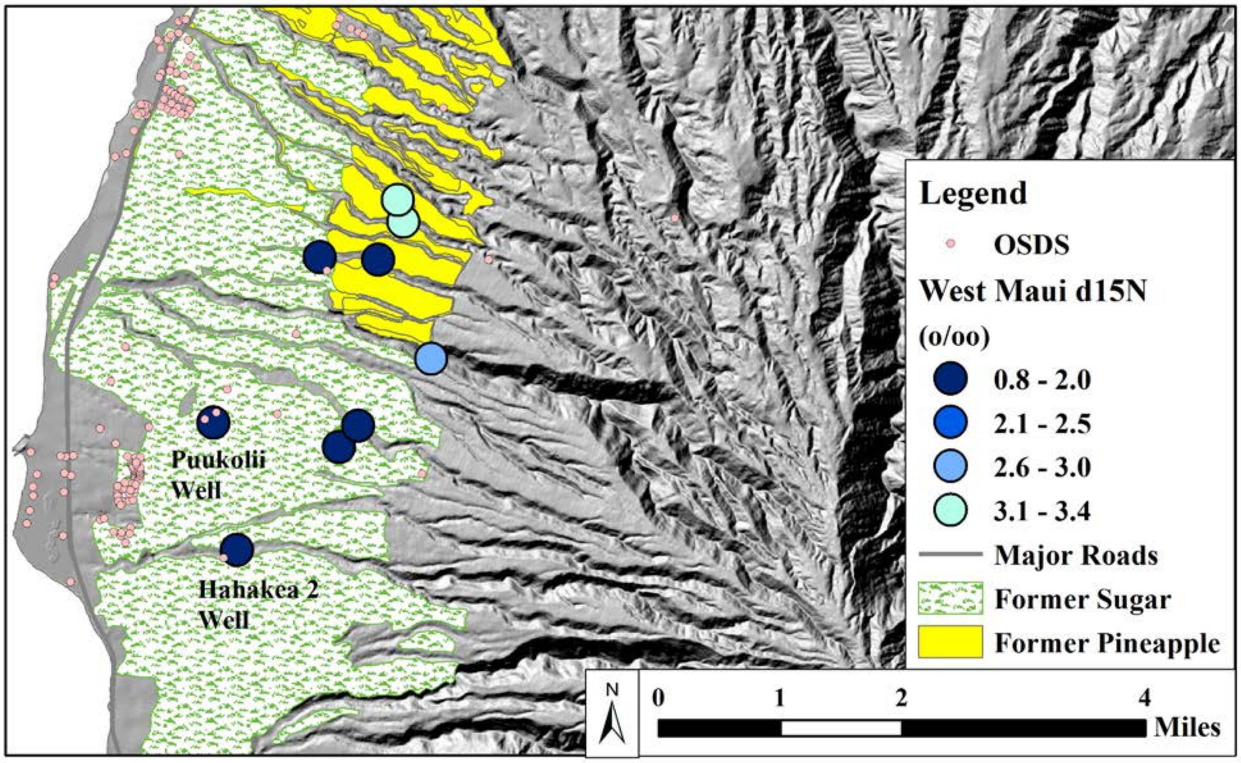


Figure 3-5. The isotopic composition of nitrate in the groundwater in west Maui

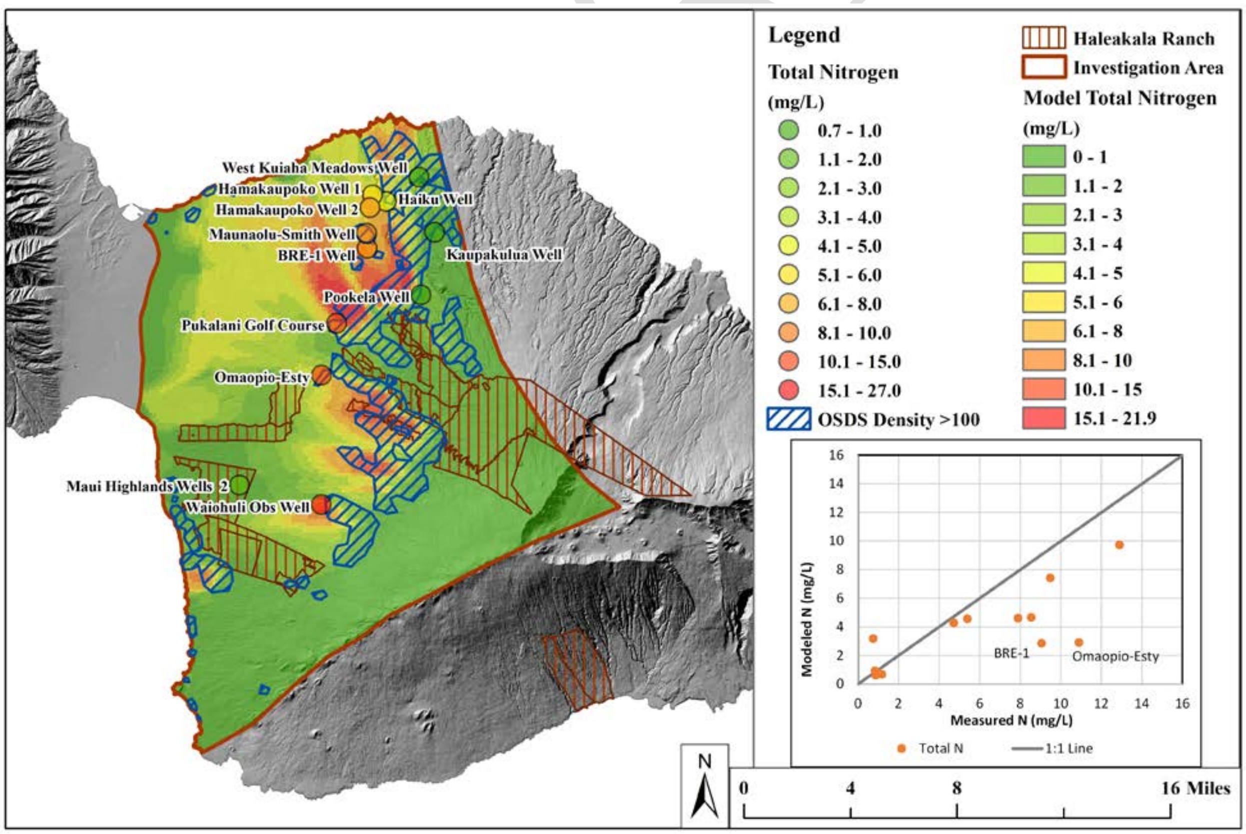


Figure 3-6. The simulated and measured distribution of total nitrogen in the groundwater

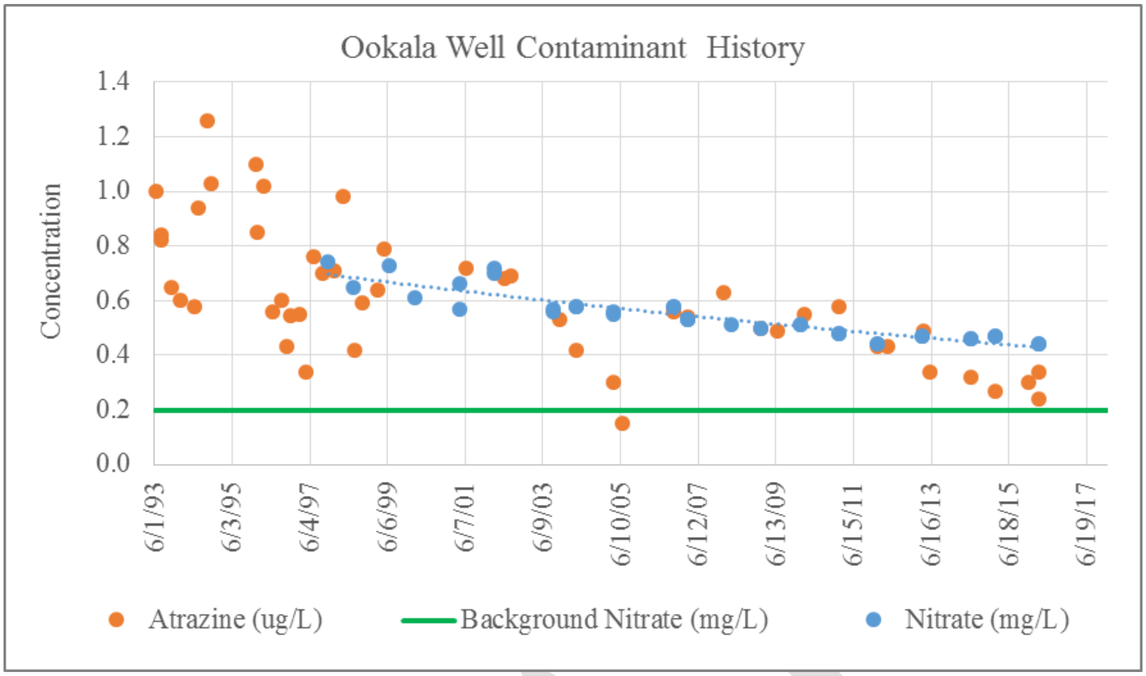


Figure 3-7. The Nitrate and Atrazine contaminant history for the Ookala Well on Hawaii Island

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SECTION 4 IMPLICATIONS FOR PUBLIC DRINKING WATER SOURCES

4.1 INTRODUCTION

There are four (4) currently approved public drinking water systems and four (4) water systems that are in process of getting approval to become a public drinking water system that are impacted to varying degrees by OSDS in Upcountry Maui. Additionally, there is a plan for a development that will require the installation of the PDWW in the Pukalani area. Table 4-1 lists these systems, the wells affected, the population served, and the most recent nitrate concentrations. This section discusses the degree to which each Public Water System (PWS) is impacted by OSDS, and considerations for future PWSs in Upcountry Maui.

4.2 IMPLICATIONS FOR PUBLIC DRINKING WATER SOURCES

First it is important to state that both the groundwater sampling and the modeling indicate that no current public drinking water source appears to be at risk of exceeding the nitrate MCL. However, several current or planned drinking water wells are capturing groundwater which has been degraded to varying degrees by OSDS leachate contamination. The most severely impacted wells are for water systems that are currently in the PWS approval process. These are the Baldwin Ranch Estates and the Omaopio-Esty water systems. The planned Baldwin Ranch Estates development is installing nitrate removal infrastructure due to the high nitrate concentrations measured during initial well testing. The nitrate removal system will ensure the safety of the water customers, but will increase the cost of the water delivered to the residents of this development. The Omaopio-Esty Well had the highest nitrate concentration and the highest $\delta^{15}N$ value of the wells sampled. The high $\delta^{15}N$ value indicates that a significant fraction of the nitrate is from OSDS leachate. This well also tested positive for PPCPs indicating a wastewater component to the well water. When approved as a PWS, the Omaopio-Esty Water System will likely be required to sample for nitrate quarterly. It is not expected that this water system will have to install nitrate removal infrastructure in the foreseeable future.

4.2.1 Trends and Outlook for Current Drinking Water Wells

Figure 4-1 and Table 4-2 summarize the nitrate trends in the drinking water wells for which sufficient data exists. The Hamakaupoko Wells show decreasing nitrate concentrations. This is expected since sugar cultivation, likely a significant source of nitrate to the wells, has ceased. The Pookela, Kaupakulua, Maui Highlands Wells 1 and 2, and West Kuiaha Meadows Wells have low nitrate concentrations that are stable. The Haiku Well, although the nitrate concentration is relatively low, shows a distinct increasing trend. The $\delta^{15}N$ value of 4.0 indicates a combined wastewater/agriculture source of nitrates. This is consistent with its setting surrounded by former pineapple cultivation and a moderate population of cesspools. The nitrate concentrations at the Maunaolu-Smith Well appear to be cyclic and is now in an ascending phase of the cycle. Like the Haiku Well, the $\delta^{15}N$ value of 4.0 indicates combined agriculture and wastewater source of nitrate. The current nitrate concentration is 5.3 mg/L and the historic high concentration was 6.3 mg/L. The increasing trend and a historical high that is about two-thirds of the MCL gives reason to be concerned that at some point in the future this well may require nitrate removal infrastructure to meet drinking water standards. While not currently a public drinking water source, the Omaopio-Esty Well is in the process of becoming a PWS. The available data show a slowly increasing trend in the nitrate concentration and increased monitoring will likely be required when this well is approved as a PWS. The $\delta^{15}N$ value of 6.3 $^{o}/_{oo}$ indicate that wastewater is a significant fraction of the current 5.0 mg/L nitrate concentration. While at the current rate of increase it will be some time before nitrate removal treatment would be required, the groundwater captured by this well appears to be significantly impacted by untreated wastewater. The BRE-1 well is also in the process of becoming a PWS. The nitrate concentration of 4.0 mg/L measured by this investigation may be deceptively low.

This sample was a grab sample representing a composite of the water in the well bore. Two (2) previous samples collected using a pump had nitrate concentrations greater than 8 mg/L. This suggests that when pumping commences the nitrate concentration will likely be near the MCL. The $\delta^{15}N$ value 4.1 $^{o}/_{oo}$ indicates that the nitrate is a mixture of agricultural and wastewater nitrate. At the recommendation of DOH, the Baldwin Ranch Estates Water System will have the capability to do nitrate removal with an ion exchange system. The customers of this water will be protected from adverse health impacts from nitrate contamination. However, the additional treatment will increase the cost of the water delivered to the residents.

Table 4-1. A summary of the Public Water Systems affected by nitrate contamination

Water System	Population Served	Wells affected	Nitrate (mg/L)	Remarks
Baldwin Ranch Estates	NA	BRE-1	4.0	In the approval process to become a PWS. Previous sampling measured nitrate concentrations greater than 8 mg/L. Nitrate is a mixture of fertilizer and OSDS leachate
Omaopio Ridge	NA	Omaopio-Esty Well	5.0	In the approval process to become a PWS. OSDS leachate is a significant fraction of the nitrate.
Kula I`o	NA	Pulehu Farms Well 1	3.0	In the approval process to become a PWS. The nitrate value is from a sample collected by the water system operator on 9/24/2017.
Makawao (Maui Department of Water Supply) PWS 213	29,868	The Makawao PWS gets 80 percent of its water from surface sources that are not affected by OSDS. Groundwater only provides 20 percent of the water to this water system.		
		Haiku Well	1.9	Nitrate is a mixture of fertilizer and OSDS leachate.
		Hamakaupoko 1	2.4	Nitrate is predominantly fertilizer leachate.
		Hamakaupoko 2	4.1	Nitrate is predominantly fertilizer leachate.
		Kaupakulua Well	0.7	Nitrate is a mixture of fertilizer and OSDS leachate.
Kula Meadows To be PWS 253	9	Kula Meadows Well	NA	In the approval process to become a PWS. This well was not sampled but is near the Omaopio-Esty Well and will likely have nitrate with a significant OSDS leachate fraction.
Maunaolu Plantation, PWS 254	100	Maunaolu-Smith Well	5.3	Nitrate is a mixture of fertilizer and OSDS leachate.
West Kuiaha Meadows, PWS 252	60	West Kuiaha Meadows Well	0.7	Nitrate is a mixture of fertilizer and OSDS leachate.
Maui Highlands, PWS 256	26	Maui Highlands Well 1 & 2	0.9	Well No. 1 not sampled. Well No. 2 nitrate is a mixture of fertilizer and OSDS leachate.
NA	NA	Pukalani Golf Course Well	5.8	Not a PWS, however this well was previously sampled to evaluate the groundwater for a proposed well to serve the planned Kobayashi Upcountry Affordable Housing Project. OSDS leachate is a significant fraction of the nitrate.
Total population currently served by Upcountry Maui PWSs				**30,088**

Table 4-2. Summary of nitrate concentrations in the Upcountry Maui Wells and recent trends

NAME	Well ID	Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Date of Maximum	Most Recent (mg/L)	Date	Trend	Pump Intake Elevation (ft MSL)
Hamakaupoko Well 1	6-5420-002	2.4	4.3	6.1	8/14/1997	2.4	7/17/2017	Decreasing[1]	-18
Hamakaupoko Well 2	6-5320-001	3.5	5.4	6.8	2/1/2000	4.1	7/17/2017	Decreasing[1]	-15
Pookela Well	6-5118-002	0.4	0.5	0.5	2/24/2009	0.4	7/17/2017	Steady	-34
Haiku Well	6-5419-001	1.9	2.1	2.3	6/27/2017	1.9	7/17/2017	Increasing	-24
Kaupakulua Well	6-5317-001	0.7	0.8	0.8	8/14/2001	0.7	7/17/2017	Steady	-49
Maui Highlands Wells 1, 2	6-4425-001, 6-4424-001	0.5	0.6	0.9	7/18/2017	0.9	7/18/2017	Steady	-9.5
Maunaolu-Smith Well	6-5320-002	4.1	4.9	6.3	2/10/2009	5.3	7/18/2017	Mixed[2]	-10.3
West Kuiaha Meadows Well	6-5418-002	0.7	0.7	0.8	3/28/2005	0.7	7/18/2017	Steady	-11
Omaopio-Esty	6-4821-001	3.6	4.5	5.0	7/18/2017	5.0	7/17/2017	Increasing	-6.2
BRE-1	6-5220-002	0.1	6.1	8.9	9/4/2015	4.0	7/19/2017	Insufficient Data[3]	-35[6]
Pukalani Golf Course	6-5021-001	5.8	6.2	5.8	9/1/2010	5.8	7/19/2017	Insufficient Data[4]	-38
Pulehu Farms	6-4719-001	3.0	8.0	16.2	8/27/2007	3.0	9/24/2007	Insufficient Data[5]	-33
Waiohuli Obs. Well	6-4422-001	NA	2.5	NA	NA	2.5	8/9/2017	Insufficient Data[5]	-30[6]
1	Some nitrate likely leaching of residual sugar cane fertilizer. Concentrations seem steady since 2004.								
2	Concentration increased to a peak in 2008, then decreased until 2013. Recently an increasing nitrate trend since 6/23/14								
3	Most recent sample was a grab sample and may not be representative of a pumped well								
4	Only two samples collected from this well.								
5	A highly elevated concentration was only measured in one of three samples.								
6	No pump installed, elevation is mid-point of the well screen								

4.2.2 Implications for Monitoring and Treatment Requirements

As the nitrate concentration measured at a drinking water well increases, the requirements put on the affected water system increase. Since pristine groundwater generally has a nitrate concentration 1 mg/L or less, DOH advises the water systems to start evaluating the cause of the elevated nitrate contamination when the concentration reaches about 3 mg/L. When the nitrate concentration reaches 5.5 mg/L (i.e., greater than 50 percent of the MCL) the sampling frequency for nitrate is increased from annually to quarterly. If, during initial testing to becoming a PDWW, it is found that the nitrate concentration exceeds 8 mg/L, making provisions for nitrate removal treatment is highly recommended. When the nitrate concentration exceeds 10 mg/L, nitrate removal treatment becomes a legal requirement.

Figure 4-2 shows the modeled nitrate distribution within the study area with the color coding consistent with the nitrate monitoring and treatment requirements. Also shown are the current nitrate concentrations and the aquifer systems (labeled in red) of east-central Maui. The well that currently has to meet increased nitrate monitoring/treatment requirements is the Maunaolu-Smith Well. While the nitrate concentration measured in the Maunaolu-Smith Well by this investigation was below the 5.5 mg/L increased monitoring threshold, past nitrate concentrations have resulted in a quarterly nitrate monitoring requirement. When approved as a PDWW, the BRE-1 Well will also have to be sampled quarterly for nitrate. Due to nitrate concentrations exceeding 8 mg/L during initial testing of the BRE-1 Well, the Baldwin Ranch Estates development has agreed to install nitrate removal infrastructure as part of the water treatment system.

Municipal water systems such as the Maui Department of Water Supply have flexibility in siting new wells. Private developments such as the Baldwin Ranch Estates or the Kobayashi Upcountry Affordable Housing development do not have that flexibility. The BRE-1 Well is already installed. Initial testing by the Kobayashi Upcountry Affordable Housing Project sampled the Pukalani Golf Course Well where an elevated nitrate concentration of 6.2 mg/L was found. However, the location of the Kobayashi Upcountry Affordable Housing (see the inset in Figure 4-2) falls in an area where the simulated nitrate concentration indicates that no increased monitoring or water treatment will be needed. However, future developments should consider the OSDS location and modeled groundwater nitrate concentrations when siting new wells.

4.3 RECOMMENDATIONS

First, it is the conclusion of this study that leachate from OSDS in Upcountry Maui in combination with agricultural and natural nitrate sources are adversely impacting the aquifer. Initial testing of the BRE-1 well shows nitrate concentrations very close to the MCL. The groundwater flow and transport modeling indicates that drinking water standards are very likely exceeded downgradient of the areas of highest OSDS density. The role of DOH's Groundwater and Source Water Protection Programs is to identify sources of contamination and work with the PWSs and responsible parties to remove or mitigate the contamination sources to the extent practicable. For drinking water quality in Upcountry this would entail DOH working with County, State, and Federal Agencies to find solutions to dealing with wastewater that are do not put an undue burden on the residents, but do allow the nitrate concentrations in the aquifer to be reduced to levels concentrations that are well below the MCL of 10 mg/L. This effort should be directed to those areas with the highest densities of OSDS.

4.3.1 OSDS Types and Leachate Quality

Based on data from the OSDS study for the neighbor islands (Whittier and El-Kadi, 2014) there are estimated to be 10,000 OSDS in the Upcountry Maui Category 1 area. Of these OSDS, approximately 7,400 are cesspools. Based on community input, converting a cesspool to some other form of wastewater treatment can cost up to $80,000 per unit. So the question becomes is there a demonstrable advantage to investing the required monies in cesspool replacement and will that investment allow the nitrate concentrations in the Upcountry Maui Groundwater to decline to concentrations less than 10 mg/L, the drinking water standard?

Since a septic system with a soil treatment leachfield (STL) is the logical alternative to a cesspool, the differences in leachate quality must be considered. A cesspool discharges the wastewater into a cistern where the bottom, and the primary point of discharge, is at least 15 ft below ground surface. This is only wastewater disposal since there is no engineered treatment method. However, as noted in Whittier and El-Kadi (2014) there likely is incidental treatment of the discharged wastewater. This could include filtering and microbial activity in the biologic mat that forms in the cistern. This may be the reason that the fraction of DON in the TN is significantly higher than expected. The fact that only about half of the total nitrogen in the wastewater gets converted to nitrate is advantageous from a drinking water perspective since nitrate, rather than total nitrogen is the contaminant of concern. However, the fact remains that there is a very high probability that nitrate concentrations in parts of the Upcountry Maui groundwater exceed drinking water standards.

The total fluid fraction of what is discharged into the cesspools in Upcountry Maui eventually migrates to the groundwater. The depth of wastewater discharge in a cesspool is lower than the depth at which evapotranspiration will return water to the atmosphere. In their water budget study of Maui, the USGS provides rooting depths for different land cover types (Johnson et al., 2014; Table 6). The rooting depth is that depth which plants can extract water from the subsurface and return it to the atmosphere as evapotranspiration. The deepest depth listed 60 inches, or five (5) ft, for alien forests and tree plantations. A rooting depth more representative of residential lots is 30 inches as listed for golf courses. Both of these depths are much shallower than the estimated 15 ft where a cesspool discharges effluent.

The influent into STLs receive two different forms of treatment. The first is in the septic tank where solids are allowed to settle out and the liquid fraction is then sent to a leachfield for dispersed discharge into the soil though a gravel lined trench. The total nitrogen content of the wastewater is reduced in the septic tank through such processes as volatilization of ammonia, or absorption to the solids in the tank contents. Water Environmental Research Foundation (WERF) in their literature review of waste streams from single wastewater sources found the influent into a septic tank had an average TN concentration of 87 mg/L as nitrogen. The effluent from the septic tank had an average TN concentration of 58 mg/L as nitrogen representing a 34 percent reduction in the total nitrogen load.

The second form of treatment is in the STL. The absorption trench in the STL must be at least 18 inches below the ground surface. The bottom of the trench is where the effluent enters the soil environment. This depth is also with the zone where water can move upward resulting in nitrogen capture and evapotranspiration by plants. The fraction of water and, in particular the fraction of effluent nitrogen that percolates to the water table is highly variable. However, available data indicates a significant reduction in nitrogen (and thus nitrate) by processes that occur in the soil. The WERF published a literature review on the state of the science of wastewater soil treatment performance (WERF, 2009b). When all soils were considered there was trend toward nitrogen removal as the effluent percolation depth increased. However, the results were highly variable. When clay loams soils were considered, the nitrogen reduction ranged from about 40 to 80 percent. A study done by the University of Hawaii where domestic wastewater was percolated through a soil lysimeter found nitrogen reductions ranging from 25 to 57 percent depending of the soil type (Tasato and Dugan, 1980). The lowest nitrogen reduction rates were in the silty clays of the Lahaina and Wahiawa Soil Series. The highest nitrogen reduction rate was in the silty loam of the Tantalus Soil Series. The soils in the area are generally silty clay loam (similar to the Tantalus Soil Series) which should provide good nitrogen removal and silty clays (similar to the Wahiawa or Lahaina Soil Series) that provide moderate nitrogen removal. The expected nitrogen removal rate of 25 percent or more by STLs should be sufficient for the groundwater nitrate concentrations to decrease to less than the 10 mg/L MCL. The limiting factor for STL installation is likely the land slope. The land slope at an elevation of about 2,500 ft msl and above is greater than 12 percent.

4.4 UPCOUNTRY MAUI NITRATE INVESTIGATION SUMMARY AND CONCLUSIONS

This study investigated the source of the nitrate contamination to the Upcountry Maui groundwater. Sources considered included former and present agriculture, OSDS, and livestock operations. A broad suite of methods was applied. A round of groundwater sampling was done to update and supplement existing groundwater nitrate data. The groundwater samples were also analyzed for major ions, other nutrients including the different nitrogen and phosphorus species, and the stable isotopes of nitrate. The isotopic composition of nitrate is key to differentiating the nitrate sources between natural soil nitrate, fertilizer nitrate, and OSDS (wastewater) and livestock nitrate.

This study concluded that the nitrate captured by the wells in Upcountry Maui was a combination from natural soil, fertilizer, and OSDS sources. However, naturally occurring soil nitrate only accounts for a small fraction of the total nitrate so the dominant nitrate sources were agriculture and OSDS leachate. In the northeast portion of the investigation area, fertilizer nitrate is the dominant source. Further south where there are high densities of OSDS in the Pukalani and Makawao communities, OSDS nitrate becomes the dominant source. This conclusion is supported by an increased $\delta^{15}N$ value and by groundwater flow and transport modeling. This study concluded that operations at Haleakala Ranch were not a significant source of groundwater nitrate. This conclusion is based on the detection of PPCPs in the high nitrate wells that don’t correlate well to livestock sources. Also, the groundwater flow and transport model produced reasonable agreement between the modeled and measured groundwater TN concentrations when the nitrogen contribution from the ranch lands was assumed to be consistent with natural soil concentrations.

The nitrate concentration in the water captured by the current PDWWs is significantly less than the MCL with no indication that any current drinking water well will exceed the MCL. However, the nitrate in the BRE-1 Well, that will become a PWS in the future, has nitrate concentrations approaching the MCL in three (3) out of five (5) samples collected. For future drinking water development planning, the groundwater flow and transport modeling indicates that, down gradient from the high OSDS density areas in Pukalani and Makawao, the nitrate MCL is likely exceeded. The modeled groundwater nitrate results should be considered when siting future drinking water sources.

As Hawaii is confronting the OSDS and cesspool issue there has been speculation as to the fate of wastewater nitrate that is discharged hundreds or thousands of feet above the water table. This study indicates that there is little attenuation of the total nitrogen load, but that much of the dissolved nitrogen does not get converted to nitrate. What is uncertain is whether or not the conversion to nitrate will occur later in the aquifer as the groundwater flows to the coastal and submarine discharge points. If the conversion to nitrate does occur, more of the groundwater than indicated by Figure 4-2 could have nitrate concentrations approaching or exceeding the MCL.

Finally, it is the conclusion of this study that OSDS in Upcountry Maui needs to be considered a significant groundwater contamination source. As with all sources of groundwater contamination, the contaminant source needs to be mitigated or removed, or treated prior to delivery to the customers. The priority for resolving this contamination problem should be replacement of OSDS in the high-density areas (Figure 4-3). The logical resolution in highest density areas would be installing a sewage collection system to collect the residential wastewater and deliver it to an advanced wastewater treatment facility.

In areas of lower OSDS density the cesspools should be replaced by septic or aerobic treatment systems that discharge to soil treatment leach fields. While the nitrate load is still high for soil treatment, it is much less than that of the raw wastewater that cesspools discharge.

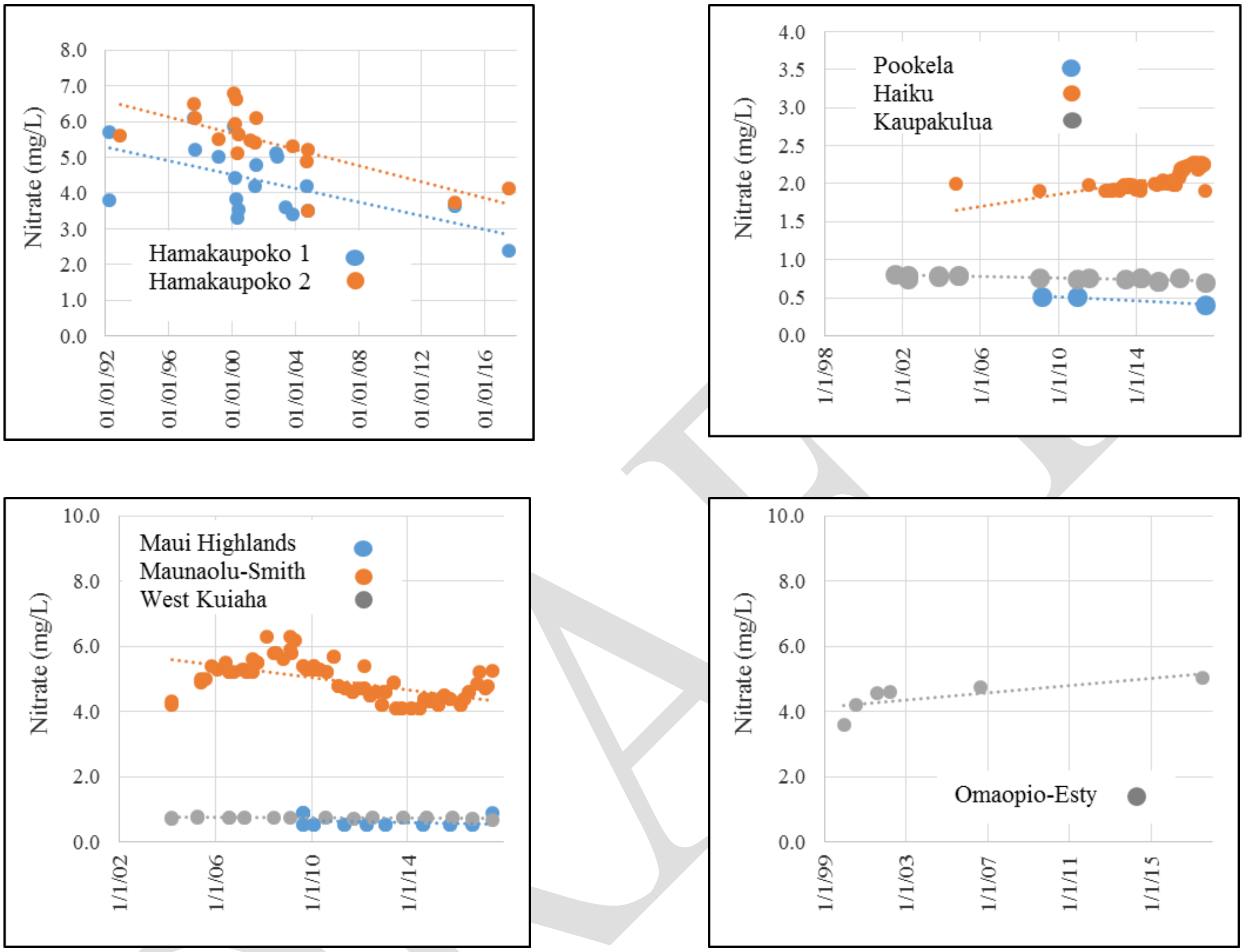

Figure 4-1. Nitrate trends in Upcountry Maui in current and future drinking water wells

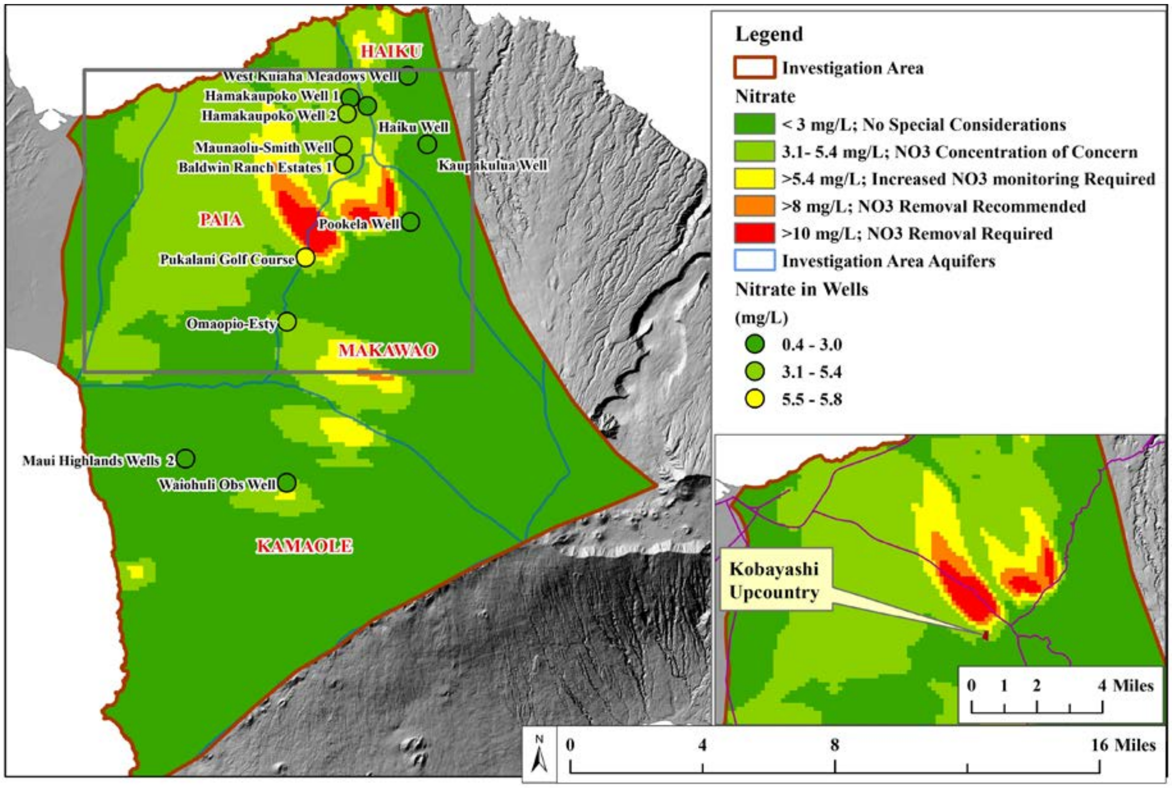

Figure 4-2. The distribution of groundwater nitrate in Upcountry Maui and the monitoring and treatment requirements

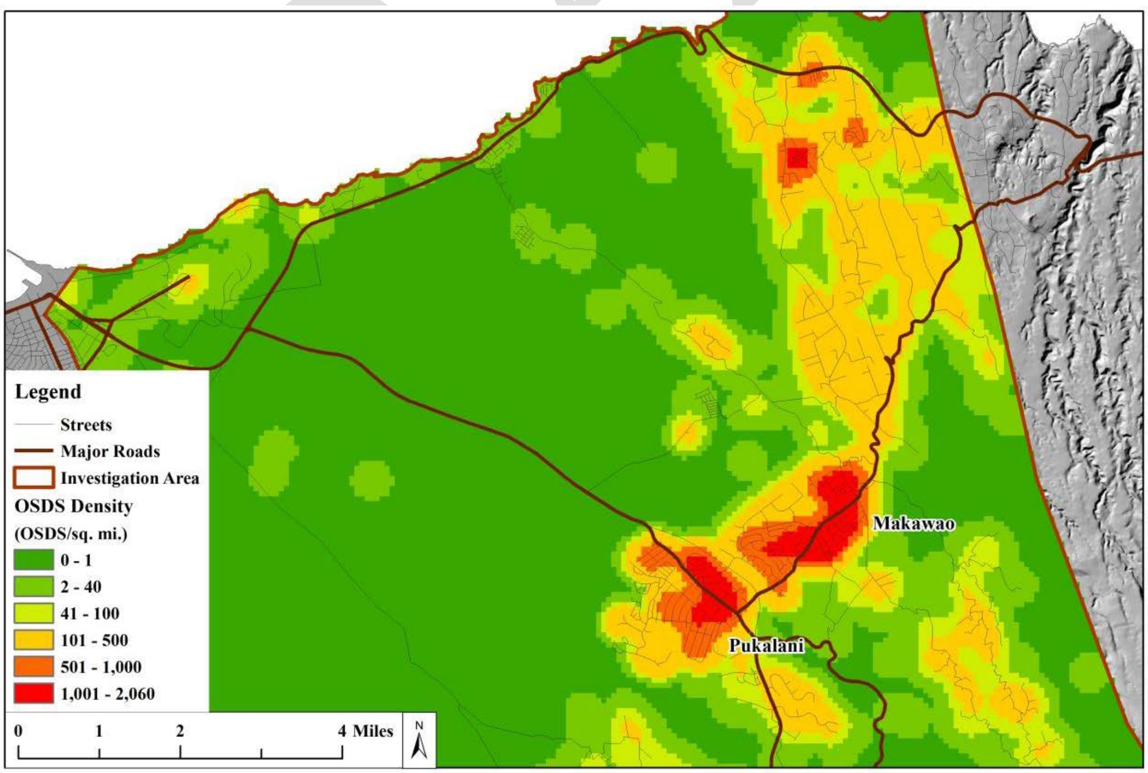

Figure 4-3. The density of OSDS in Upcountry Maui

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