U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Study Element 2:

An Appraisal of Stormwater Reclamation and Reuse Opportunities in the Ewa Plain of Oahu

FINAL REPORT SEPTEMBER 2008

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- Ms. Tina Mullis
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Hawaii Commission on Water Resource Management:

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- Ms. Lenore Ohye

An Appraisal of Stormwater Reclamation and Reuse Opportunities in the Ewa Plain of Oahu

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Acronyms

BMPs	Best Management Practices
BWS	Honolulu Board of Water Supply
CCH	City and County of Honolulu
Code	Hawaii's State Water Code
CWRM	Commission on Water Resource Management
EPA	Environmental Protection Agency
HRS	Hawaii Revised Statutes
DAR	Division of Aquatic Resources
DLNR	Department of Land and Natural Resources
DOH	Department of Health
GIS	Geographical Information System
GWUDI	Groundwater Under the Direct Influence
mgd	million gallons per day
NRCS	National Resources Conservation Services
NPDES	National Pollutant Discharge Elimination System
Plan	Hawaii Water Plan
Polychlorinated biphenyls	PCB
Reclamation	U.S. Department of the Interior Bureau of Reclamation
TMDLs	Total Maximum Daily Loads
UIC	Underground Injection Control
USDA	U.S. Department of Agriculture
WRF	Water Recycling Facility
WWTP	Wastewater Treatment Plant

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Executive Summary

Introduction

Groundwater is the principal source of potable water on Oahu. As sugar cane and pineapple production has declined over the past decade, prime agricultural land is being opened for new residential and commercial development. Over 50,000 new, single-family homes are under construction or planned for Oahu. Development has two impacts on Hawaii's groundwater supply: (1) it increases potable water demand; and (2) it decreases groundwater recharge from rainfall, which is critical for sustaining aquifer levels.

The U.S. Department of the Interior Bureau of Reclamation (Reclamation), in partnership with the Hawaii Commission on Water Resource Management (CWRM) is conducting an appraisal of stormwater reclamation and reuse in Hawaii. Unlike most stormwater management approaches, this appraisal is exploring opportunities to capture and reuse stormwater to augment potable supplies, rather than to simply improve water quality for continued discharge to our streams and near-shore coastal waters.

The appraisal consists of three study elements:

1. Study Element 1 has two components: (1) develop a state-wide framework for identifying and resolving institutional barriers to stormwater reclamation and reuse, and (2) develop a handbook for reclamation and reuse technologies and best management practices for existing and new developments.

2. Study Element 2 consists of an appraisal of opportunities for groundwater recharge of stormwater over a brackish water (caprock) aquifer in a dry, but rapidly developing area on Oahu called the Ewa Plain.

3. Study Element 3 consists of an appraisal of statewide opportunities for augmenting groundwater supplies with stormwater, including groundwater recharge.

This report presents the results of Study Element 2.

Statewide Framework

A comprehensive discussion of issues affecting stormwater reclamation and reuse is provided in a separate report, *An Appraisal of Hawaii's Framework for Stormwater Reclamation and Reuse*. A summary of some of the issues is provided in Table ES-1 as background for reclamation and reuse opportunity development and evaluation.

Table ES-1. Potential Impact of Current Regulations on Stormwater Reclamation and Reuse

Applicable Regulation	Applicable Language	Potential Impact
State Water Code	Groundwater and surface water are held as public trusts for the benefit of all people. The CWRM has considerable authority to protect surface and groundwater quantity and quality.	Issues such as stream flow standards, in-stream diversions, and Native Hawaiian Water Rights can potentially promote or detract from stormwater reclamation and reuse
State Water Code 174C-51.5	The commission can require dual water line systems in new industrial and commercial developments when located in designated water management areas. This requirement is contingent on an available source of *nonpotable water.* Though the intent of the language was to promote the use of recycled wastewater, its use of the term *nonpotable water* could apply equally to reclaimed stormwater.	Though there is no requirement for developers to develop nonpotable water sources, the language could promote the use of reclaimed stormwater if a source is made available.
HAR 11-20 *Rules Pertaining to Potable Water Systems*	Direct connections between surface and groundwater can result in a groundwater drinking water source being designated as Groundwater Under the Direct Influence (GWUDI) of surface water.	GWUDI designation would require that groundwater be treated in the same manner as surface water, which would be costly. Situations that would result potentially in a GWUDI designation would be resisted by public (and private) water supply agencies.
HAR 11-23 *Underground Injection Control*	Any new injection well cannot be sited closer than ¼-mile from any part of a drinking water source.	The location of any stormwater injection well for direct recharge would be limited by the spatial dimensions of this regulation. An entire aquifer could be considered the drinking water source, further limiting direct injection. UIC control areas are significant parts of each island.
HAR 11-54 *Water Quality Standards*	Total maximum daily loads (TMDL) will limit discharge of certain pollutants (receiving water dependent) from point sources, such as stormwater system outfalls.	TMDLs might require that stormwater be treated to meet specific waste load allocations. Such treatment would be expensive and encourage developers to seek alternatives to direct discharge of stormwater to surface waters. This could promote technologies and best management practices for stormwater reclamation and reuse.
HAR 11-62 *Wastewater Systems* *Guidelines for Treatment and Use of Recycled Water*	There are three classes of recycled water. Each class is determined by the level of treatment. The two highest levels of recycled water must meet specific microbiological quality requirements, and, in the case of the highest level of recycled water, turbidity requirements. Compliance with quality requirements for recycled water is determined at the end of the treatment process.	The DOH has verbally said that integration of recycled water and stormwater would require that stormwater meet recycled water quality.

Table ES-1. Potential Impact of Current Regulations on Stormwater Reclamation and Reuse (continued)

Applicable Regulation	Applicable Language	Potential Impact
County Stormwater Drainage Standards	Specific treatment levels (i.e., infiltration, vegetated swales, bioretention filters, and other filters) are required for stormwater flow-through treatment (little or no storage). Design standards for flood control include the following variables: ▪ Recurrence interval based on acreage ▪ Runoff quantity based on acreage The design volume for detention basins to enhance stormwater quality is based on impervious surface area, a 1-inch storm, and site acreage.	Some level of treatment is required for stormwater injection into potable and non-potable water aquifers irrespective of water quality. Design standards do not include any credit for reducing runoff quantity nor any allowance for reducing the size of detention basins if stormwater reclamation and reuse is included in designs. Consequently there are no financial incentives to developers to incorporate stormwater and reclamation reuse features.

Initial Opportunity Screening Criteria

Initial screening of stormwater reclamation and reuse opportunities was planned to be accomplished using Geographical Information System (GIS) databases from various state, federal, and municipal authorities. A matrix of information needs was developed and included the following evaluation criteria:

- Soil Permeability
- Land Zoning
- Well Locations
- UIC Line Location
- Annual Rainfall
- Proximity to Recycled Water Infrastructure
- Proximity to Contaminated Sites
- Proximity to Historic Cultural Sites
- Proximity to Critical Habitats
- Depth to Groundwater
- Stormwater Infrastructure
- Agricultural Irrigation Ditches

Agencies were contacted to determine the availability of database information, and requests were made for obtaining existing database information. As database information was obtained from various public agencies, it became apparent that geographical coverage for the selected screening criteria was not consistent. Oahu had the best geographical coverage for most of the criteria, but inconsistencies were still common.

Field visits provided the most effective means of assessing potential opportunities. These visits provided first-hand knowledge of the possible infrastructure and its relationship to areas of stormwater collection, conveyance, and use. GIS information, in conjunction with Google™ Earth, was then used to refine the opportunities.

Infrastructure Needs

Infrastructure needs for stormwater reclamation and reuse can be separated into five general categories: collection, conveyance, treatment, storage, and distribution. Each of these infrastructure categories and their role in stormwater reclamation and reuse is discussed in the report.

End Use

The end use of reclaimed stormwater could take many forms, but the most likely options are direct irrigation and non-potable groundwater recharge. Direct irrigation would likely integrate with existing irrigation systems for recreational areas, such as parks and golf courses, or agricultural areas. Reclaimed stormwater could have other end uses as well, depending on the level of treatment provided. Table ES-2 shows the level of treatment that would be required for various end uses, including groundwater recharge.

Table ES-2. Level of Treatment Required Based on End Use

End Use	Treatment						Comments
	Screening	Grit Removal	Sedimentation	Chemical Addition	Filtration	Disinfection	
Injection Well (Potable)	Y	Y	Y	Y	Y	Y	
Injection Well (Non-Potable)	Y	Y	Y	*	N	N	
Recharge Trench	Y	Y	Y	N	N	N	
Spreading Basin	Y	N	N	N	N	N	O&M required to ensure infiltration
Excavated Pond	Y	N	N	N	N	N	Series operation
Industrial Reuse	Y	Y	Y	Y	Y	N	
Direct Irrigation:							
Contact with edible portion of crop	Y	Y	Y	Y	Y	Y	Not specific to stormwater; based on Hawaii's recycled water guidelines
No contact with edible portion of crop	Y	Y	*	N	N	N	
Human contact	Y	Y	Y	Y	Y	Y	

* Depends on quality of stormwater

Opportunity Development

The preceding information was used to develop stormwater reclamation and reuse opportunities. Six opportunities were developed for the Ewa Plain of Oahu and are shown in Figure 29 (except E-7):

- E-1 – Makakilo Ridge
- E-2 – Kapolei Flood Control Channel
- E-3 – Fort Barrette Road Swale
- E-4 – Honouliuli Recharge Trench
- E-5 – Fort Weaver Road Swale
- E-7 – Waiahole Ditch Conveyance to Ewa Recharge Trench

The alphabetic character references the Ewa Plain of Oahu and the number references a specific opportunity in the Ewa Plain. Opportunity E-7 is not a stand-alone opportunity. It is an additional consideration for integration with opportunities in Central Oahu, and is discussed in a separate report *An Appraisal of Stormwater Reclamation and Reuse in Hawaii*.

Each of the opportunities was evaluated for the criteria presented in Table ES-3. These criteria are discussed further in Opportunity Ranking.

Table ES-3. Opportunity Prioritization Criteria

Criterion	Discussion
Potential Reuse Demand	Potential reuse demand is determined by the amount of land that the opportunity could serve with non-potable water irrigation. The available land could include parks, golf courses, and agriculture. Opportunities adjacent to agricultural areas are given higher priority that opportunities located in urban areas.
Cost Estimate	Cost estimates were based on bid tabulations from recent Oahu water projects were used to determine the potential cost of common elements associated with the opportunities, including unit cost of conveyance and collection pipe, reservoirs, infiltration trenches, and pumping stations. The cost estimates are not absolute planning level costs, but are relative costs to each opportunity.
Potential Stormwater Volume	The potential stormwater volume is based on the collection area of the opportunity and the annual average rainfall in the collection area.
Potential Partnerships	Potential partnerships include public agencies and private companies that would possibly support implementation of a stormwater reclamation and reuse opportunity through direct funding or indirect funding (e.g. use of land or existing infrastructure). Potential partnerships do not consider public water supply agencies that would benefit from reduced demand on potable water supplies since all opportunities would result in this benefit.
Likelihood of Implementation	Likelihood of implementation includes non-economic benefits and constraints associated with the opportunity, including, but not limited to, public acceptance and environmental impacts.
Institutional Constraints	Institutional constraints include policies, regulations, laws, and social or cultural issues that would be potential barriers to implementation of any opportunity. They also include potential barriers from agencies that are responsible for infrastructure associated with the opportunity.

Potential Integration with Recycled Water

The Honouliuli Water Recycling Facility (WRF) is owned by the Honolulu Board of Water Supply (BWS) and is operated under contract by Veolia North America. The WRF receives secondary (biologically oxidized) effluent from the Honouliuli Wastewater Treatment Plant (WWTP) that is owned and operated by the City and County of Honolulu's Department of Environmental Services.

The WRF's recycled water is used to irrigate golf courses, highway median strips, and parks in the Ewa Plain. The potential demand is greater than the current supply. Reclamation and reuse of stormwater could potentially help match supply and demand.

Six preliminary alternatives were identified for integrating stormwater with R-1 recycled water in the Ewa Plain, including:

- Introduce Stormwater into Honouliuli WWRF Influent
- Introduce Stormwater after Honouliuli WWRF Treatment (three options)
- Use Aquifer Storage and Recovery for Stormwater (two options)

Aquifer storage and recovery provides the greatest flexibility of use for stormwater integration with recycled water.

Opportunity Ranking

Once the Ewa Plain opportunities for stormwater reclamation and reuse were identified, prioritization was necessary to differentiate and rank the opportunities. The approach used for the prioritization process is known as a Pairwise Comparison.

The first step for ranking the opportunities was to identify the criteria that will be used to evaluate the opportunities. Two representatives from Reclamation and three representatives from CWRM performed the Pairwise Comparison to rank the criteria. The point totals for all five raters were averaged to determine the final ranking and value.

Table ES-4 presents the final ranking of the criteria and the average points from all raters. The average points were normalized to 1.0. The normalized value was used as a weighting factor for further evaluation of each opportunity.

Table ES-4. Evaluation Criteria Ranking

Criterion	Average Points	Weighting Factor
Potential Reuse Demand	17.0	0.19
Cost Estimate	16.6	0.18
Potential Stormwater Volume	15.2	0.17
Potential Partnerships	14.8	0.16
Likelihood of Implementation	14.4	0.16
Institutional Constraints	12.0	0.13

Final Ranking of Opportunities

Once the Pairwise Comparison for each criterion was complete, the total points each opportunity received was multiplied by the weighting factor for the respective criterion. The products of the weighted values for each criterion were totaled, and the totals were used to rank the opportunities. The results of the combined Pairwise Comparisons are provided in Appendix B. The final ranking of each of the opportunities is shown in Table ES-5.

Table ES-5. Final Ranking of Stormwater Reclamation and Reuse Opportunities

Rank	Opportunity	Summary Description
1	**E-2 Kapolei Flood Control Channel**	Collect stormwater in a flood control channel in the Kapolei commercial/institutional area and use in injection wells to improve water quality for BWS non-potable wells.
2	**E-4 Honouliuli Recharge Trench**	Collect stormwater from the area in and around the Honouliuli WWTP for recharge of the Ewa caprock unconfined aquifer through an existing recharge channel.
3	**E-1 Makakilo Ridge**	Convey stormwater from the Makakilo Ridge development to the abandoned Makakilo WWTP for treatment and use the treated stormwater for recharge of the Ewa caprock unconfined aquifer.
4	**E-5 Fort Weaver Road Swale**	Collect stormwater from residential area and surface spread on a swale for recharge of the Ewa caprock unconfined aquifer.
5	**E-3 Fort Barrette Road Swale**	Collect stormwater from a drainage gulch on the east side of Makakilo Ridge and surface spread on a grassy swale along Fort Barrette Road for recharge of the Ewa caprock unconfined aquifer.

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Introduction

Groundwater is the principal source of potable water on Oahu. As sugar cane and pineapple production has declined over the past decade, prime agricultural land is being opened for new residential and commercial development. Over 50,000 new, single-family homes are under construction or planned for Oahu. Development has two impacts on Hawaii's groundwater supply: (1) it increases potable water demand; and (2) it decreases groundwater recharge from rainfall, which is critical for sustaining aquifer levels.

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This report presents the results of Study Element 2.

Current Approach to Stormwater Management

As with many public agencies throughout the U.S. Mainland, stormwater regulations in Hawaii consist primarily of best management practices to reduce pollutants in stormwater runoff and to ensure that stormwater discharges from new developments do not exceed pre-development peak flow rates. The latter approach is effective for reducing peak pollutant loads, but not effective for reducing total pollutant loads unless the flow mitigation measures remove pollutants physically (e.g. settling in a detention basin) or biologically (e.g. wetlands treatment).

The number of green and low impact development approaches to stormwater management is increasing. Some, such as pervious paving, green roofs, and rainwater harvesting for toilet flushing have been implemented on a small scale in Hawaii. Large-scale capture and reuse of stormwater is a new concept in Hawaii, but one that can help replace some potable water being used currently for non-potable uses, such as irrigation.

Description of the Ewa Plain

The boundaries of the Ewa Plain can be generally described by the boundaries of the West Loch of Pearl Harbor on the east; the H-1 freeway on the north; Campbell Industrial Park on the west; and the Pacific Ocean on the south. Figure 1 shows the location and important landmarks of the Ewa Plain.

The Ewa Plain is experiencing significant residential, commercial, and industrial development. The City and County of Honolulu (CCH) and state agencies have expanded or relocated government services to the area to accommodate the needs of the rapidly growing population. Examples include Kapolei Hale, which houses the Department of Environmental Services and a satellite city hall, and a State judiciary complex, which is under construction currently.

Approximately one-half of the Ewa Plain is undeveloped, and approximately one-half of the undeveloped area is under active agriculture. The long-term plan, however, is quite different. Figure 2 shows the development plan from the Kapolei Area Long-Range Master Plan. Significant expansion of residential, commercial, and institutional development is planned. This includes development of the West Oahu campus of the University of Hawaii. Though the long-range plan includes recreational greenspace (e.g., parks and golf courses), the amount of agricultural land is reduced significantly to a small area adjacent to West Loch of Pearl Harbor. This set-aside for agriculture is referred to as the "blast zone", and restricted military area.

A key geological feature of the Ewa Plain is a caprock of marine and terrestrial sediments that "confines" the aquifer in the underlying basalt, and provides an "unconfined" brackish aquifer above the caprock. A 1996 report (Bauer, 1996) estimated the sustainable yield for the caprock aquifer to be less than 16 million gallons per day to maintain a chloride concentration of less than 1,000 milligrams per liter. The demand on the aquifer was relieved some in 2002, with the start-up of the Honouliuli Water Recycling Facility. It has a capacity of 10 mgd of R-1 recycled water, of which approximately 7.0 mgd is used for irrigation of golf courses, median strips, and parks. A separate section in this report discusses recycled water and its limitations for expansion.

The average annual rainfall of the Ewa Plain is approximately 20 inches per year. Despite the low rainfall, Kaloi and Honouliuli Gulches run north to south through the Ewa Plain and convey stormwater from areas that receive annual average rainfall of 40 inches or more per year. The stormwater that flows through these gulches is typically heavy with sediment and would require some form of sediment removal for most types of reclamation and reuse, except flood irrigation. The best opportunity for stormwater reclamation and reuse in the Ewa Plain is groundwater recharge through design of new residential and commercial developments, and from capture and recharge of stormwater from existing developments.

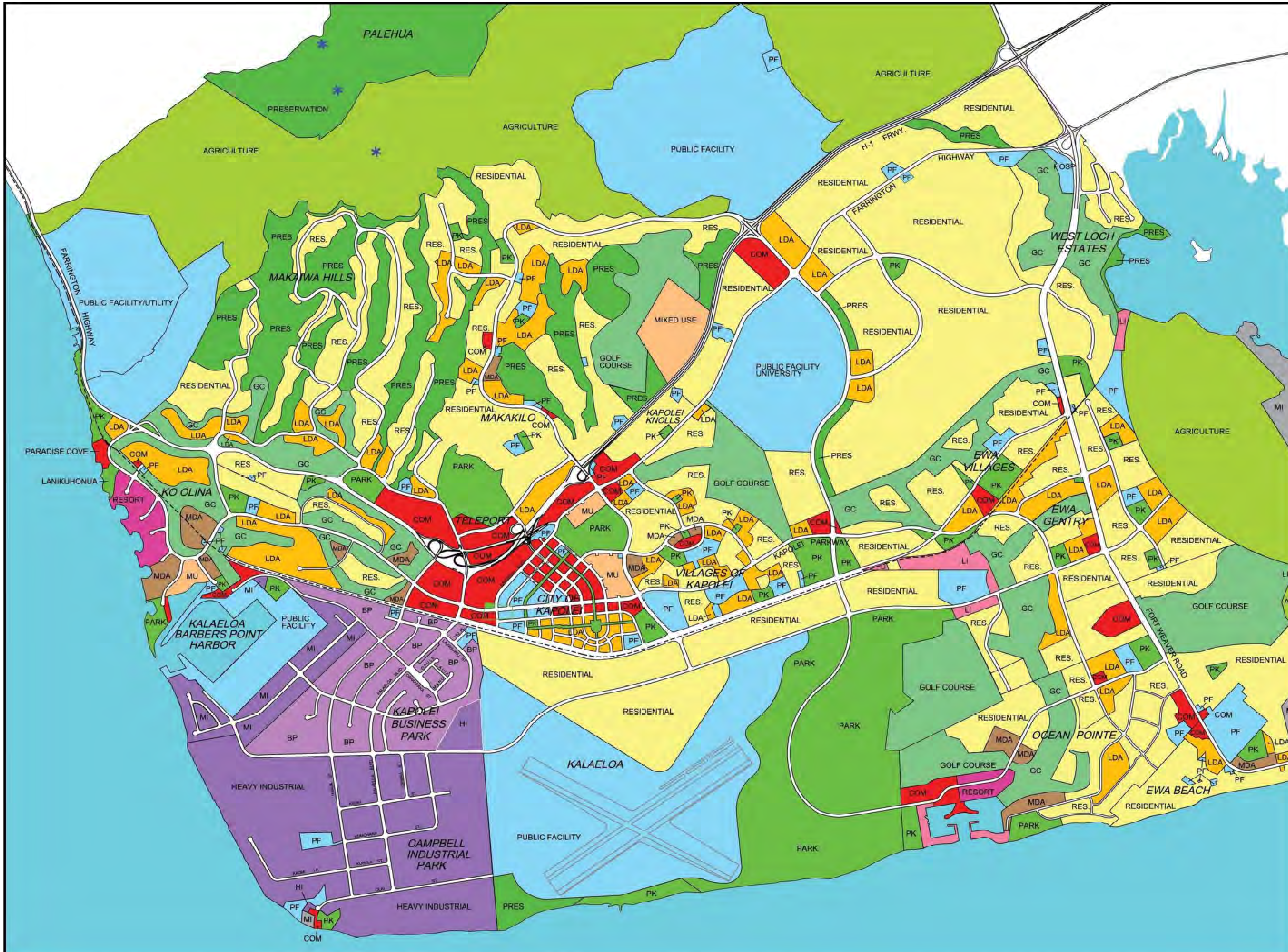
Statewide Framework

A comprehensive discussion of issues affecting stormwater reclamation and reuse is provided in a separate report, *An Appraisal of Hawaii's Framework for Stormwater Reclamation and Reuse*. A summary of some of the issues is provided in this section as background for reclamation and reuse opportunity development and evaluation.

Water Quality Regulations

Hawaii Revised Statutes (HRS) Chapter 174C establishes Hawaii's State Water Code (Code). The Code is the basis for regulating and protecting all waters of the State, except coastal waters, for the benefit of the people. The Code establishes the CWRM to oversee surface water and groundwater as public trusts.

Figure 1.
Ewa Plain



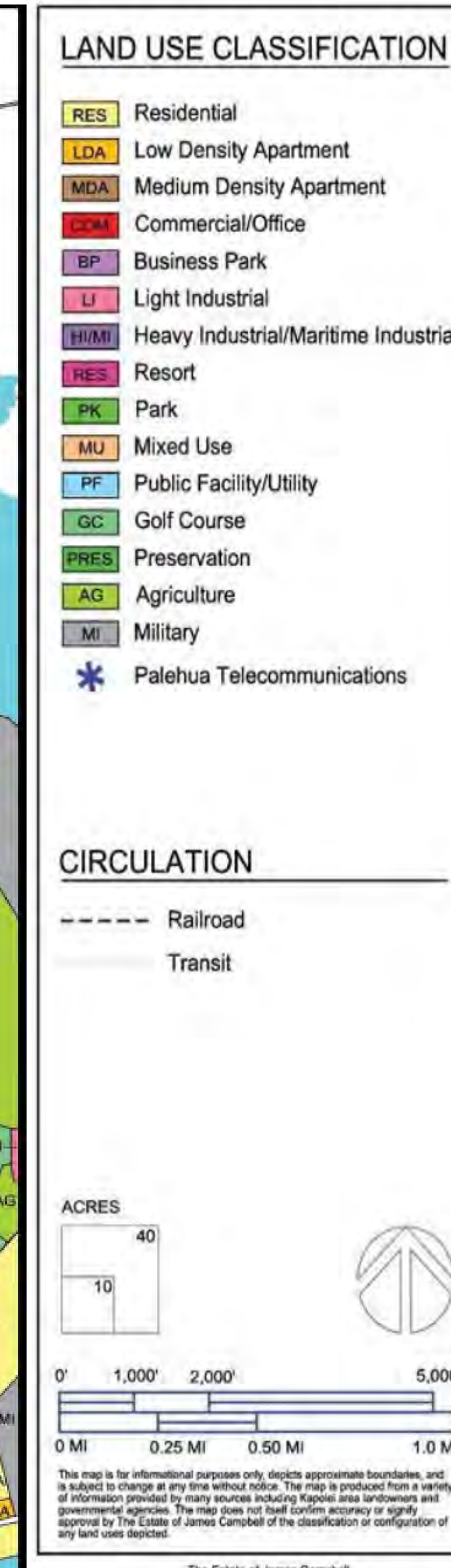


Figure 2.
Kapolei Area Long Range Master Plan

The Code establishes a requirement for a Hawaii Water Plan (Plan) that includes a water resource protection plan prepared by the CWRM, water use and development plans prepared by the Department of Agriculture and each of Hawaii's four counties, and a State water projects plan that identifies projects that potentially affect groundwater and surface water resources. The Plan also requires the Hawaii Department of Health (DOH) to develop a water quality plan.

The CWRM can designate water management areas for administrative control over withdrawals and diversions of groundwater and surface waters. The purpose is to ensure reasonable beneficial use of water resources in the public trust. The CWRM is also responsible for establishing in-stream flow standards (including minimum flow) on a stream-by-stream basis; for overseeing the registration, permit issuance, and oversight of wells for groundwater withdrawal or long-term monitoring; for registration and permitting of stream alternatives and diversion works relating to surface water; and for establishing aquifer sustainable yields.

The CWRM can require dual water supply systems for new commercial and industrial developments in designated water management areas if a non-potable source of water is available. Stormwater could serve potentially as a non-potable water source. The purpose of this requirement is to further protect the quantity and quality of potable water supplies.

The Code also includes provisions to protect Native Hawaiian Water Rights. These rights extend to ensuring adequate water reserves for current and foreseeable development and use of Hawaiian homelands, and for traditional and customary rights associated with cultural and subsistence agricultural practices.

As indicated previously, Part V of the State Water Code establishes the Hawaii DOH as the administrator of the State's water quality control program. The DOH is responsible for developing a water quality plan for all existing and potential sources of drinking water. Though the Code provides for it, the current plan does not include any water quality criteria for the designation of ground water management areas and surface water management areas.

The Hawaii DOH further regulates the quality of other water resources in the State. Though not all potential uses of reclaimed stormwater have been established, integration with recycled wastewater, recharge of drinking water aquifers, and recharge of non-potable water aquifers have been identified. Water quality-based regulations associated with these potential reuse opportunities are discussed below.

- Hawaii Administrative Rules (HAR) 11-54, *Water Quality Standards* – These standards pertain to surface discharges to inland lakes and streams, as well as coastal and ocean discharges. These rules establish narrative and numerical criteria that must be met in surface waters to prevent toxicity and water quality degradation.

- HAR 11-55, *Water Pollution Control and National Pollutant Discharge Elimination System (NPDES) General Permits, Appendices B and C* – These regulations pertain to stormwater discharges through the NPDES permit program and are intended to protect surface water quality. These discharges are considered point sources that can be readily monitored and controlled. Though stormwater discharges can have a direct impact on the water quality standards promulgated in HAR 11-54, the stormwater NPDES permits do not include numerical limits, only monitoring of pollutants. Permittees are required to implement management plans that include best management practices (BMPs) to reduce the discharge of pollutants in stormwater.

  Though stormwater discharge permits do not contain numerical limits currently, they could in the future as total maximum daily loads (TMDLs) are developed for the approximately 241 impaired waters in Hawaii. Impaired waters are those that exceed water quality standards. Stormwater reclamation and reuse could be an effective means of reducing pollutant loads as stormwater discharges to these impaired waters would be reduced. Table 1 identifies the causes of impairment and the number of water bodies with that specific impairment. The total causes of impairment exceeds the number of impaired water bodies because some water bodies exceed more than one water quality standard. Over 70 of the impaired water bodies are on Oahu, including streams and coastal waters. The State of Hawaii has only received approval for 17 TMDLs from the Environmental Protection Agency (EPA).

Table 1. Causes of Impaired Water Bodies

Water Quality Standard	Number of Water Bodies Impaired
Turbidity	197
Nutrients	177
Algal Growth	90
Pathogens	52
Floatables	17
Ammonia	13
Pesticides	6
Metals (other than mercury)	4
Polychlorinated biphenyls (PCB)	1

- HAR 11-62.26, *Wastewater Systems and Guidelines for the Treatment and Use of Recycled Water* – These establish three classifications of recycled water: R-1, R-2, and R-3. These classifications are based on the degree of treatment, which in turn governs applicable use. R-1 recycled water is the highest quality.

- HAR 11-20, *Rules Pertaining to Potable Water Systems* – The DOH has authority delegated from the EPA to enforce applicable federal rules (40 CFR Parts 141 through 143) and adopt more stringent rules if necessary. There are 88 numerical primary drinking water standards for microbiological and chemical parameters. These are enforceable as violations if they are exceeded. There are 15 secondary drinking water standards, which are not enforceable, but are intended to improve the aesthetics of drinking water.

- HAR 11-23, *Underground Injection Control (UIC)* – These regulations do not regulate water quality directly, but indirectly by determining where underground injection wells can be located in relation to potable water sources.

In addition to the DOH regulations, each of Hawaii's four counties – Kauai, Hawaii, Maui, and Honolulu – has stormwater design standards that establish requirements for mitigating peak flow stormwater discharges and poor water quality for developments.

The Honolulu Board of Water Supply's (BWS), Rules and Regulations, *Chapter III, Protection, Development and Conservation of Water Resources*, establish "No Pass Zones" on Oahu that further limit the location of waste disposal facilities that may "affect the quality and/or quantity of water resources used or expected to be used for domestic water." The "No Pass Zones" established by BWS are more restrictive than UIC lines.

The previous discussion identifies regulations that can affect stormwater reclamation and reuse in Hawaii. Table 2 summarizes potential impacts of these regulations.

Table 2. Potential Impact of Current Regulations on Stormwater Reclamation and Reuse

Applicable Regulation	Applicable Language	Potential Impact
State Water Code	Groundwater and surface water are held as public trusts for the benefit of all people. The CWRM has considerable authority to protect surface and groundwater quantity and quality.	Issues such as stream flow standards, in-stream diversions, and Native Hawaiian Water Rights can potentially promote or detract from stormwater reclamation and reuse
State Water Code 174C-51.5	The commission can require dual water line systems in new industrial and commercial developments when located in designated water management areas. This requirement is contingent on an available source of *nonpotable water.* Though the intent of the language was to promote the use of recycled wastewater, its use of the term *nonpotable water* could apply equally to reclaimed stormwater.	Though there is no requirement for developers to develop nonpotable water sources, the language could promote the use of reclaimed stormwater if a source is made available.
HAR 11-20 *Rules Pertaining to Potable Water Systems*	Direct connections between surface and groundwater can result in a groundwater drinking water source being designated as Groundwater Under the Direct Influence (GWUDI) of surface water.	GWUDI designation would require that groundwater be treated in the same manner as surface water, which would be costly. Situations that would result potentially in a GWUDI designation would be resisted by public (and private) water supply agencies.
HAR 11-23 *Underground Injection Control*	Any new injection well cannot be sited closer than ¼-mile from any part of a drinking water source.	The location of any stormwater injection well for direct recharge would be limited by the spatial dimensions of this regulation. An entire aquifer could be considered the drinking water source, further limiting direct injection. UIC control areas are significant parts of each island.
HAR 11-54 *Water Quality Standards*	Total maximum daily loads (TMDL) will limit discharge of certain pollutants (receiving water dependent) from point sources, such as stormwater system outfalls.	TMDLs might require that stormwater be treated to meet specific waste load allocations. Such treatment would be expensive and encourage developers to seek alternatives to direct discharge of stormwater to surface waters. This could promote technologies and best management practices for stormwater reclamation and reuse.

Table 2. Potential Impact of Current Regulations on Stormwater Reclamation and Reuse (continued)

Applicable Regulation	Applicable Language	Potential Impact
HAR 11-62 *Wastewater Systems* *Guidelines for Treatment and Use of Recycled Water*	There are three classes of recycled water. Each class is determined by the level of treatment. The two highest levels of recycled water must meet specific microbiological quality requirements, and, in the case of the highest level of recycled water, turbidity requirements. Compliance with quality requirements for recycled water is determined at the end of the treatment process.	The DOH has verbally said that integration of recycled water and stormwater would require that stormwater meet recycled water quality.
County Stormwater Drainage Standards	Specific treatment levels (i.e., infiltration, vegetated swales, bioretention filters, and other filters) are required for stormwater flow-through treatment (little or no storage). Design standards for flood control include the following variables: ▪ Recurrence interval based on acreage ▪ Runoff quantity based on acreage The design volume for detention basins to enhance stormwater quality is based on impervious surface area, a 1-inch storm, and site acreage.	Some level of treatment is required for stormwater injection into potable and non-potable water aquifers irrespective of water quality. Design standards do not include any credit for reducing runoff quantity nor any allowance for reducing the size of detention basins if stormwater reclamation and reuse is included in designs. Consequently there are no financial incentives to developers to incorporate stormwater and reclamation reuse features.

Public Issues

Water issues are very visible and of much importance to Hawaii residents. Voluntary water restrictions have been put in place in recent years as a result of drought. Recycled water from wastewater treatment plants has gained public acceptance in the past decade and is used for irrigating golf courses, parks, and transportation median strips. In 2006, an extended rainfall period contributed to a dam collapse on the island of Kauai, and a 50 million gallon sewer spill on Oahu. Events such as these that result in loss of life or beach closures bring stormwater issues to headline news, but for the most part, stormwater is not much of a public concern.

Water issues are extremely important to native Hawaiians and environmental groups alike. During the early 1900s, Waiahole Ditch was constructed to convey stream-diverted water from the windward side of Oahu to the pineapple and sugar cane fields on the leeward side. When the sugar industry declined and water use from Waiahole Ditch decreased, the CWRM allocated the water in a manner that resulted in a lawsuit by windward parties to protect instream flow and cultural uses of the watershed that supplied the water. The Hawaii Supreme Court ruled in the favor of the Windward parties affirming that water resources are part of the public trust. The Hawaii Supreme Court further identified three public trusts, which did not include commercial agriculture. Similar legal challenges to stream diversions have occurred on Maui and Hawaii.

Funding

Stormwater is considered an unreliable water source since supply does not match water demand. Each of the four major public water suppliers in Hawaii has implemented approximate 40-percent rate increases over the next five years to maintain their existing potable water infrastructure. Stormwater is not the responsibility of the water supply utilities and investment in an unreliable water source is not attractive to them.

Public stormwater management BMPs for compliance with NPDES permits are funded through the general fund of each county. There are no stormwater utilities to provide capital or operation and maintenance funding. Consequently, stormwater reclamation and reuse is forced to compete with more tangible public desires, such as parks and transportation.

As more TMDLs are implemented, stormwater runoff will be targeted for point source control of pollutant discharges. When this occurs, funding for reclamation and reuse, rather than treatment for continued discharge, might be more readily available.

Another funding consideration is the cost to develop potable water supplies. The BWS estimates that development of a 1.0 million gallon per day groundwater source costs between 6 and 8 million dollars. If an equivalent volume of stormwater can be reclaimed and reused (even seasonally) for a similar cost, then stormwater might be an attractive investment.

Initial Opportunity Screening Criteria

Initial screening of stormwater reclamation and reuse opportunities was planned to be accomplished using Geographical Information System (GIS) databases from various state, federal, and municipal authorities. A matrix of information needs was developed and included the following evaluation criteria:

- Soil Permeability
- Land Zoning
- Well Locations
- UIC Line Location
- Annual Rainfall
- Proximity to Recycled Water Infrastructure
- Proximity to Contaminated Sites
- Proximity to Historic Cultural Sites
- Proximity to Critical Habitats
- Depth to Groundwater
- Stormwater Infrastructure
- Agricultural Irrigation Ditches

Table 3 summarizes these criteria, their intended use, and a GIS database and figure reference.

Agencies were contacted to determine the availability of database information, and requests were made for obtaining existing database information. As database information was obtained from various public agencies, it became apparent that geographical coverage for the selected screening criteria was not consistent. Oahu had the best geographical coverage for most of the criteria, but inconsistencies were still common. Figure 3 illustrates a common discrepancy. The figure shows the stormwater collection system in the Ewa Plain. Some of the collection system lines lack continuity and are simply shown as dead-end pipes.

Another example of discrepancies is the numerous agricultural irrigation ditches that have been used historically in Hawaii. Many of the irrigation ditches are still shown in GIS coverage, but have been abandoned and/or displaced by construction. Location of agricultural irrigation ditches that are still in use was obtained from the Department of Agriculture's *Agricultural Water Use and Development Plan* (December 2003). The plan included topographical maps showing the location of the ditches in each County.

Other sources were also used to supplement information that would benefit the selection and evaluation of stormwater reclamation and reuse opportunities. The DOH 2006 State of Hawaii Water Quality Monitoring and Assessment Report (September 2007) identified a list of impaired streams and coastal waters, and the limiting pollutants for each. This information was used to assess the benefits of reduced stormwater flow on stream and coastal water quality.

The DOH's *Groundwater Contamination Maps* (July 2006), show the names and location of wells impacted by human activity, and the types and concentrations of pollutants found in the wells. This information was used to assess the benefit of groundwater recharge of stormwater for improving groundwater quality.

Field visits provided the most effective means of assessing potential opportunities. These visits provided first-hand knowledge of the possible infrastructure and its relationship to areas of stormwater collection, conveyance and use. GIS information, in conjunction with Google™ Earth, was then used to refine the opportunities. Figures 3 through 13 provide examples of the GIS database information for the Ewa Plain area.

Table 3. Initial Screening Criteria for Stormwater Reclamation and Reuse Opportunities

Criteria	Basis	Measure	Impact	Opportunity	GIS Layer and Figure Reference
Conveyance & Storage Infrastructure (Including stormwater collection systems and agricultural irrigation ditches)	Existing conveyance and storage infrastructure can be used for the purpose of groundwater recharge and can minimize the capital costs that would arise from having to build new facilities. These can be in the form of streams, ditches, stormwater facilities, lakes, ponds, etc.	Available	Provides existing infrastructure that could potentially be used for direct injection of stormwater.	Cost savings from utilizing existing infrastructure.	CCH GIS Database **Reference Figure 3**
		Not available	New infrastructure would be required for stormwater recharge programs.	No cost savings. New Infrastructure required.	USGS, Digital Line Graph, 1983. Department of Land and Natural Resources (DLNR), Division of Aquatic Resources (DAR), 2004. **Reference Figure 4**
Soil Permeability	Affects aquifer recharge using both surface application and underground injection.	Moderately Slow	May require detention structures; Recharge may be feasible if applied over larger land areas.	Incorporate into low-impact developments; BMPs such as permeable paving and subsurface infiltration chambers are possible; increase green space; may also utilize detention/infiltration ponds/trenches.	National Resources Conservation Services (NRCS), U.S. Department of Agriculture (USDA), 2007. **Reference Figure 5**
		Moderate			
		Moderately Rapid	Recharge can be accomplished easily and efficiently; Relatively large amounts of stormwater can be reclaimed.	In addition to opportunities identified for very slow to moderate permeability, injection wells may be possible.	
		Rapid			
		Very Rapid			
Depth to Groundwater	Areas with high water tables may have decreased recharge potential due to limited infiltration capacity.	< 5 feet	The subsurface soil would be saturated at a relatively shallow depth, greatly decreasing the amount of infiltration capacity.	May be limited to natural infiltration through low-impact development BMPs such as permeable paving and landscaping/vegetated areas.	DLNR, Division of Water Resource Management wells database (maintained in dBase) October, 1998 (Received from State of Hawaii - CWRM) **Reference Figure 6**
		5 - 10 feet	The subsurface soil would be saturated at a moderate depth, making stormwater infiltration feasible.	Recharge through infiltration trenches or retention ponds may be feasible.	
		> 10 feet	The subsurface soil would be saturated at a moderate depth, making stormwater infiltration feasible.	Recharge through injection wells may be feasible.	

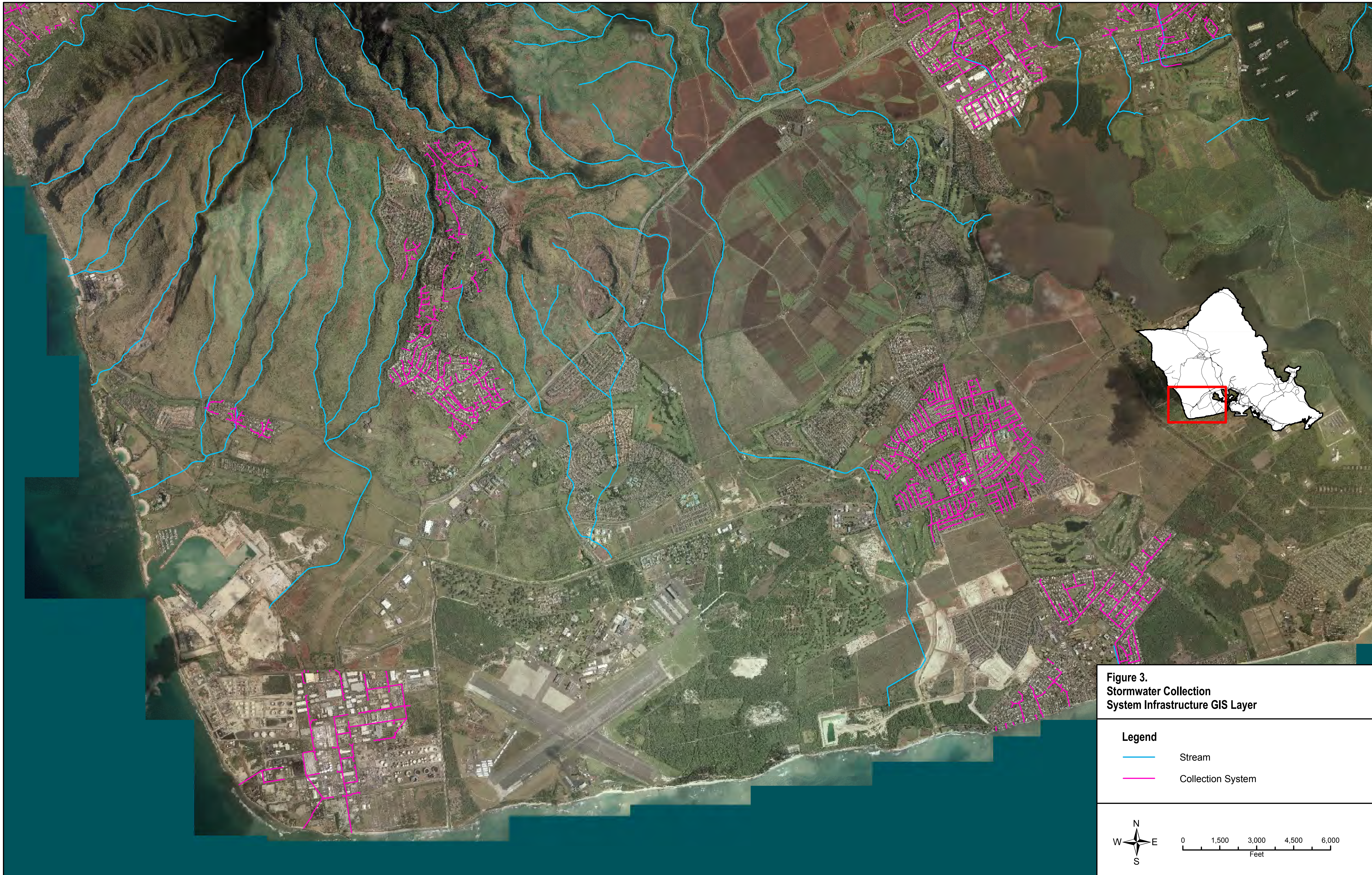


Figure 3.
Stormwater Collection
System Infrastructure GIS Layer
Legend
Stream
Collection System
N
W
E
S
0
1,500
3,000
4,500
6,000
Feet

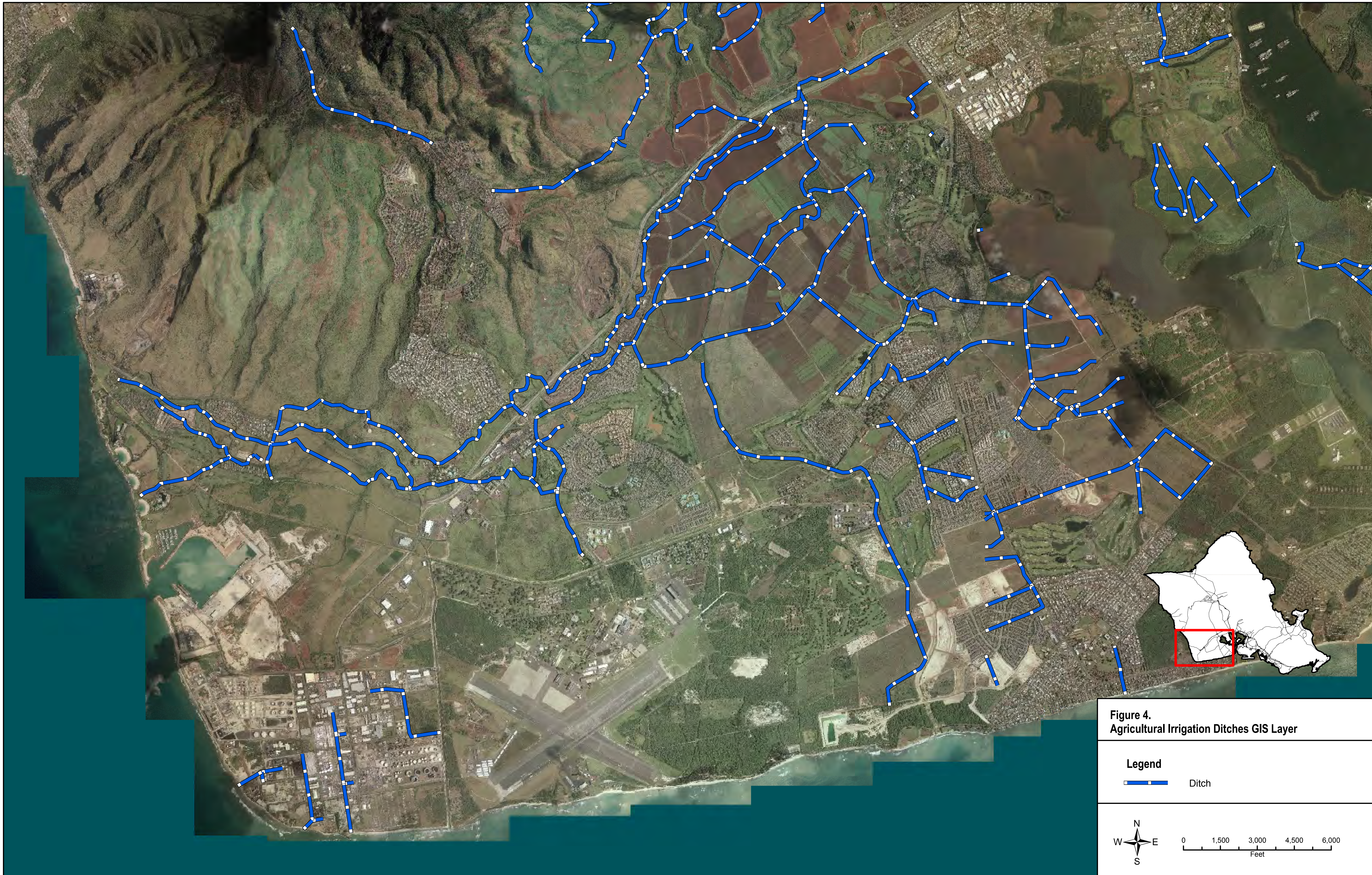


Figure 4.
Agricultural Irrigation Ditches GIS Layer

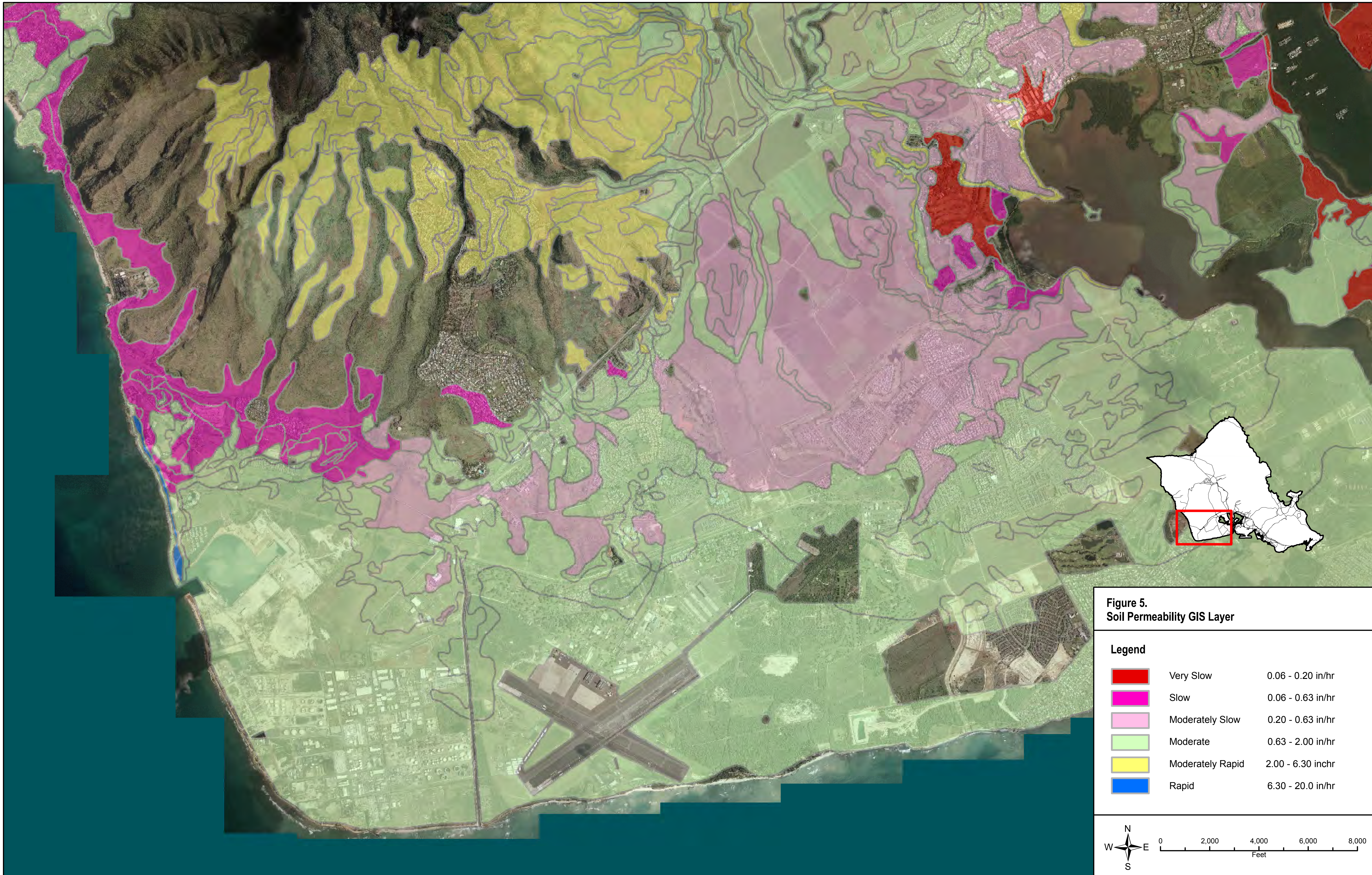


Figure 5.
Soil Permeability GIS Layer
Legend
Very Slow 0.06 - 0.20 in/hr
Slow 0.06 - 0.63 in/hr
Moderately Slow 0.20 - 0.63 in/hr
Moderate 0.63 - 2.00 in/hr
Moderately Rapid 2.00 - 6.30 inchr
Rapid 6.30 - 20.0 in/hr
N
W
E
S
0
2,000
4,000
6,000
8,000
Feet

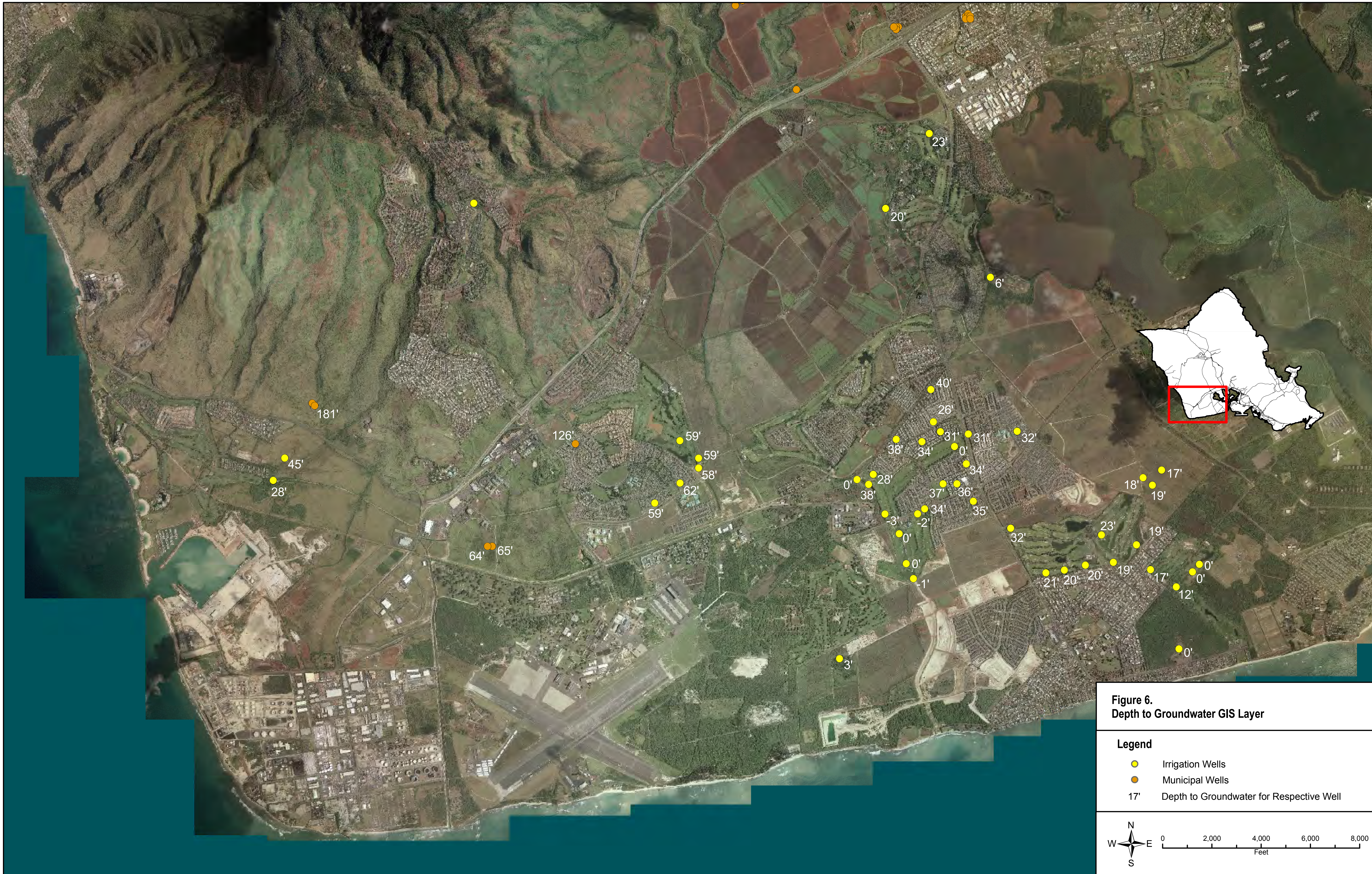


Figure 6.
Depth to Groundwater GIS Layer

Table 3. Initial Screening Criteria for Stormwater Reclamation and Reuse Opportunities (continued)

Criteria	Basis	Measure	Impact	Opportunity	GIS Layer and Figure Reference
Land Zoning	Identifies areas that may or may not be suitable locations for stormwater reclamation, based on current land use plans.	Park/Recreation	Significant land area may be available; high potential to incorporate stormwater reclamation on a larger scale, particularly aquifer recharge.	Irrigation with stormwater; detention/infiltration ponds/trenches; injection wells; subsurface infiltration chambers.	CCH, Department of Planning and Permitting (ftp://gisftp.hicentral.com/LayrZips/) **Reference Figure 7**
		Agricultural/Preservation			
		Low/Medium Density Residential	Decrease in available land; however, potential for stormwater reclamation still exists on a smaller scale.	Incorporate into low-impact developments; use BMPs such as permeable paving, recessed lawns, subsurface infiltration chambers, and eliminating roof drains. Injection wells may be possible if hidden and protected.	
		High Density Residential	Minimal land area available for stormwater reclamation; potential for significant increases in runoff.	Vegetated roofs, rain catchment for landscaping and/or toilet use, subsurface infiltration chambers, landscape/planter boxes, aesthetic ponds incorporated into landscape.	
		Commercial	Minimal land area available for stormwater reclamation; potential for significant increases in runoff.		
		Industrial	Minimal land area available for stormwater reclamation; potential for significant increases in runoff. Hazardous material operations may prohibit stormwater reclamation.		
		Military	Stormwater reclamation opportunities depend on land usage.	Depending on land use plan for military areas, the above recommendations may be used.	
Well Locations	May prohibit stormwater reclamation infrastructure such as injection wells or recharge trenches in the immediate vicinity of potable wells.	> 1/4 mile from potable well	Least restrictive to groundwater recharge infrastructure.	More freedom to utilize more direct recharge methods such as injection wells and recharge trenches.	DLNR, Division of Water Resource Management wells database (maintained in dBase) October, 1998 (Received from State of Hawaii - CWRM) **Reference Figure 8**
		< 1/4 mile from potable well	Most restrictive to groundwater recharge infrastructure.	May be limited to indirect recharge methods only such as surface infiltration.	
	Abandoned wells may provide a means for direct injection of stormwater utilizing existing infrastructure.	Available	Provides existing infrastructure that could potentially be used for direct injection of stormwater.	Cost savings from utilizing existing infrastructure.	
		Not available	New infrastructure would be required for direct injection of stormwater.	No cost savings. New Infrastructure required.	

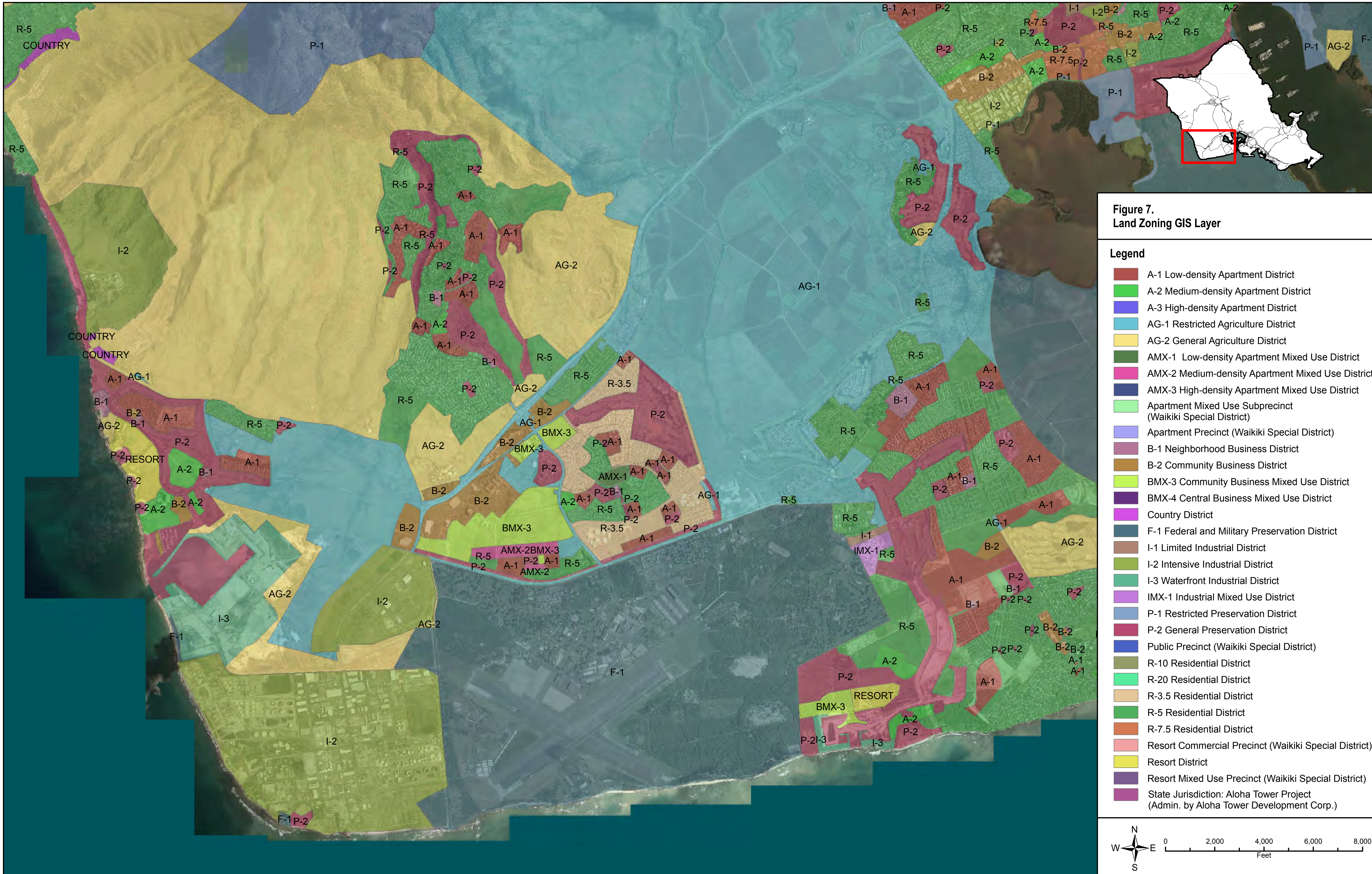


Figure 7.
Land Zoning GIS Layer

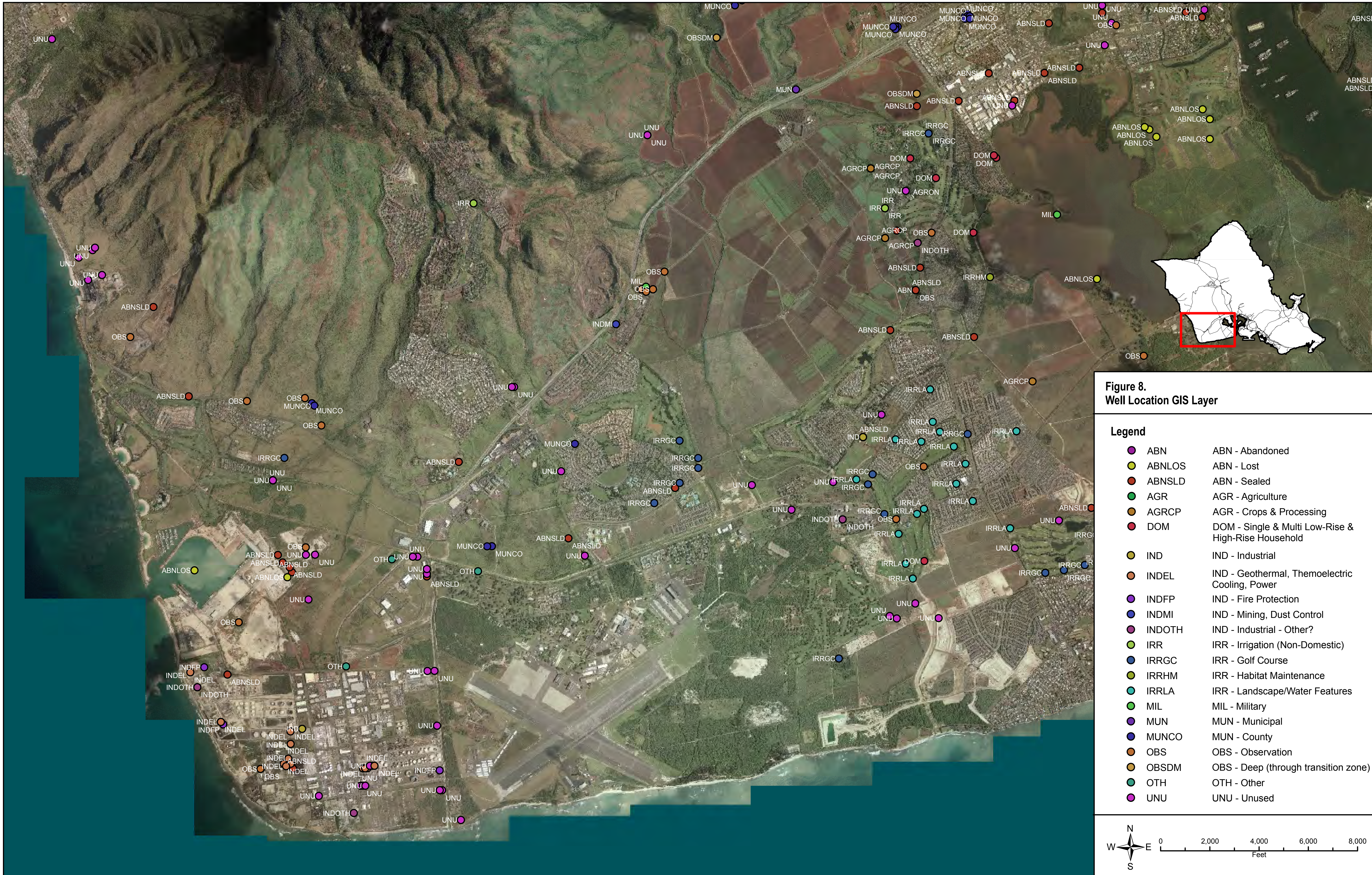


Figure 8.
Well Location GIS Layer
Legend
ABN — ABN - Abandoned
ABNLOS — ABN - Lost
ABNSLD — ABN - Sealed
AGR — AGR - Agriculture
AGRCP — AGR - Crops & Processing
DOM — DOM - Single & Multi Low-Rise & High-Rise Household
IND — IND - Industrial
INDEL — IND - Geothermal, Themoelectric Cooling, Power
INDFP — IND - Fire Protection
INDMI — IND - Mining, Dust Control
INDOTH — IND - Industrial - Other?
IRR — IRR - Irrigation (Non-Domestic)
IRRGC — IRR - Golf Course
IRRHM — IRR - Habitat Maintenance
IRRLA — IRR - Landscape/Water Features
MIL — MIL - Military
MUN — MUN - Municipal
MUNCO — MUN - County
OBS — OBS - Observation
OBSDM — OBS - Deep (through transition zone)
OTH — OTH - Other
UNU — UNU - Unused
N
W
E
S
0
2,000
4,000
6,000
8,000
Feet

Table 3. Initial Screening Criteria for Stormwater Reclamation and Reuse Opportunities (continued)

Criteria	Basis	Measure	Impact	Opportunity	GIS Layer and Figure Reference
Underground Injection Control (UIC) Lines	Locations within the UIC Line may be more restrictive to certain recharge methods such as direct injection and large recharge trenches.	Below UIC Line	Least restrictive area for groundwater recharge.	More freedom to utilize more direct recharge methods such as injection wells and recharge trenches.	State of Hawaii - DOH (Received directly from DOH) **Reference Figure 9**
		Above UIC Line	Extent of restrictions unknown. Recharge methods such as direct injection may require treatment to R-1 standards.	May be limited to indirect recharge methods such as surface infiltration.	
Annual Rainfall	The higher the rainfall in a given area, the greater the opportunity for stormwater collection.	> 30inches	Greatest opportunity for capturing stormwater	Infrastructure for capturing, conveying, and storing stormwater may be beneficial as a water resource.	Giambelluca, T.W., Nullet, M.A., and Schroeder, T.A. 1986. Hawaii Rainfall Atlas, Report R76, Hawaii Division of Water and Land Development, DLNR, Honolulu. Vi + 267 p.(http://www.hawaii.gov/dbedt/gis.htm) **Reference Figure 10**
		< 30 inches	Cost of building infrastructure for stormwater capture may outweigh the benefits.	May need to focus more on increasing surface infiltration and decreasing runoff to address the times when rainfall does occur.	
Proximity to Hazardous Waste Sites	HAR 11 Chapter 23 prohibits injection wells from hazardous waste sites within ¼ mile of the subsurface collection system of a drinking water source. This distance has been extended to ½ mile for a known hazardous waste site due to the potential of spreading contamination deeper into the subsurface.	Within 1/2 mile	Groundwater recharge may not be feasible. A study of the contaminant plume should be performed.	Very limited to no opportunity.	No Data
		> 1/2 mile	Represents the minimum safe distance from a known hazardous waste site. A study of the contaminant plume should be performed.	No limitations to groundwater recharge due to hazardous waste.	
Proximity to Recycled Water Infrastructure	May provide a means for conveying captured stormwater to existing recharge or reuse sites.	Within 1/2 mile	Provides existing infrastructure that could potentially be used for conveying stormwater	Cost savings from utilizing existing infrastructure.	BWS GIS database **Reference Figure 11**
		> 1/2 mile	Additional infrastructure would be required to hook up to existing lines	No cost savings. New Infrastructure required.	

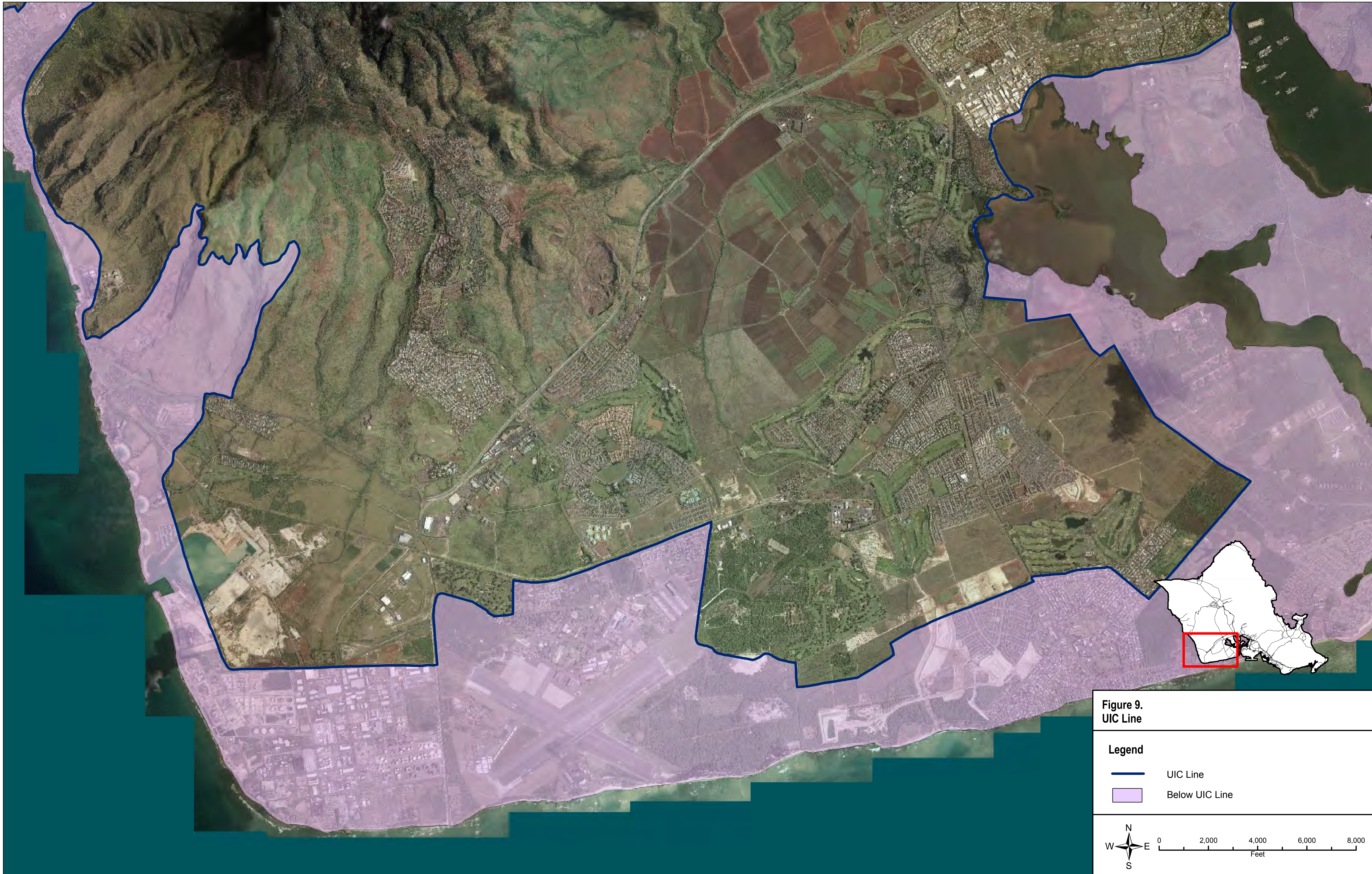


Figure 9.
UIC Line
Legend
UIC Line
Below UIC Line
N
W
E
S
0
2,000
4,000
6,000
8,000
Feet

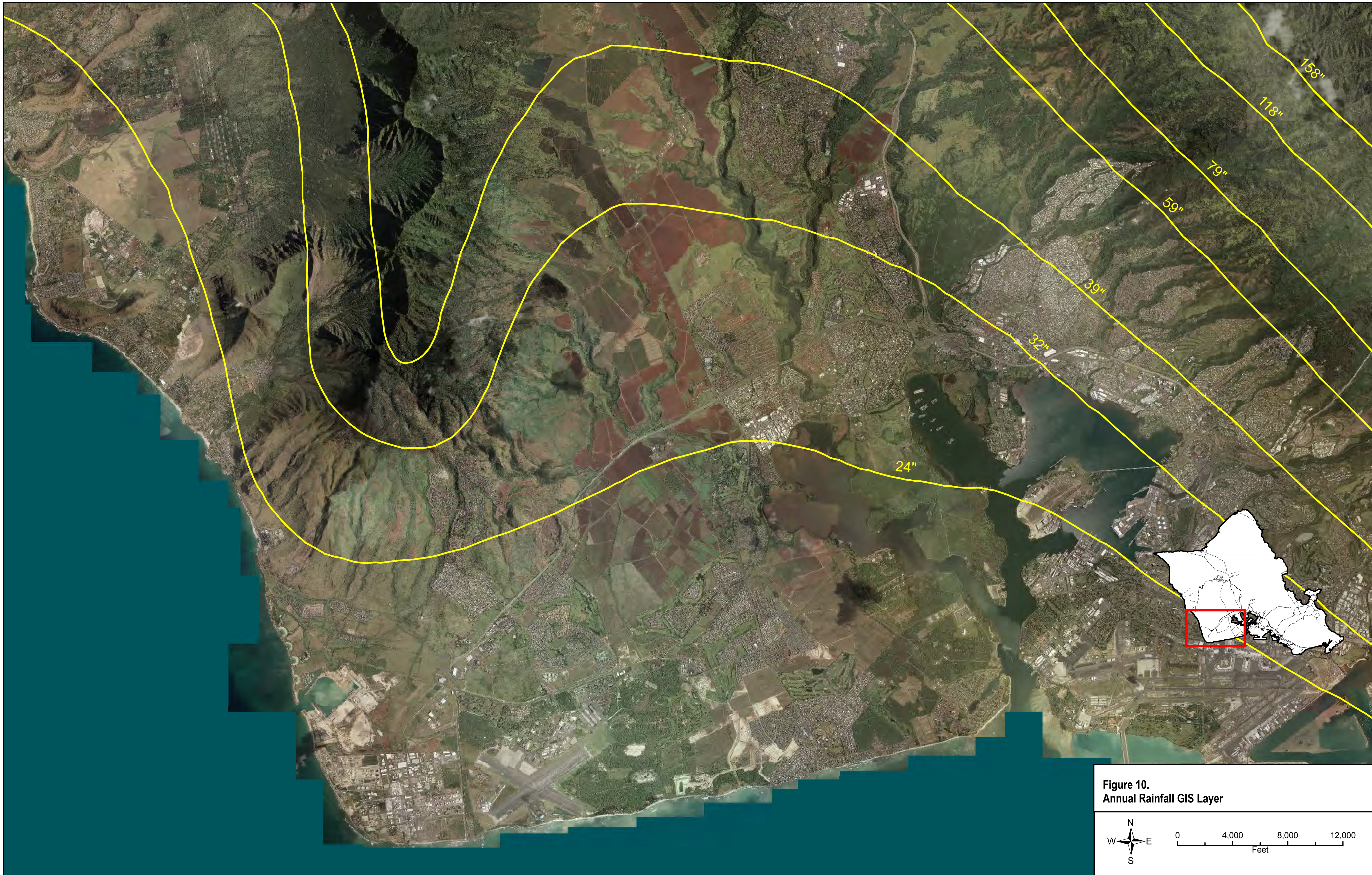


Figure 10.
Annual Rainfall GIS Layer

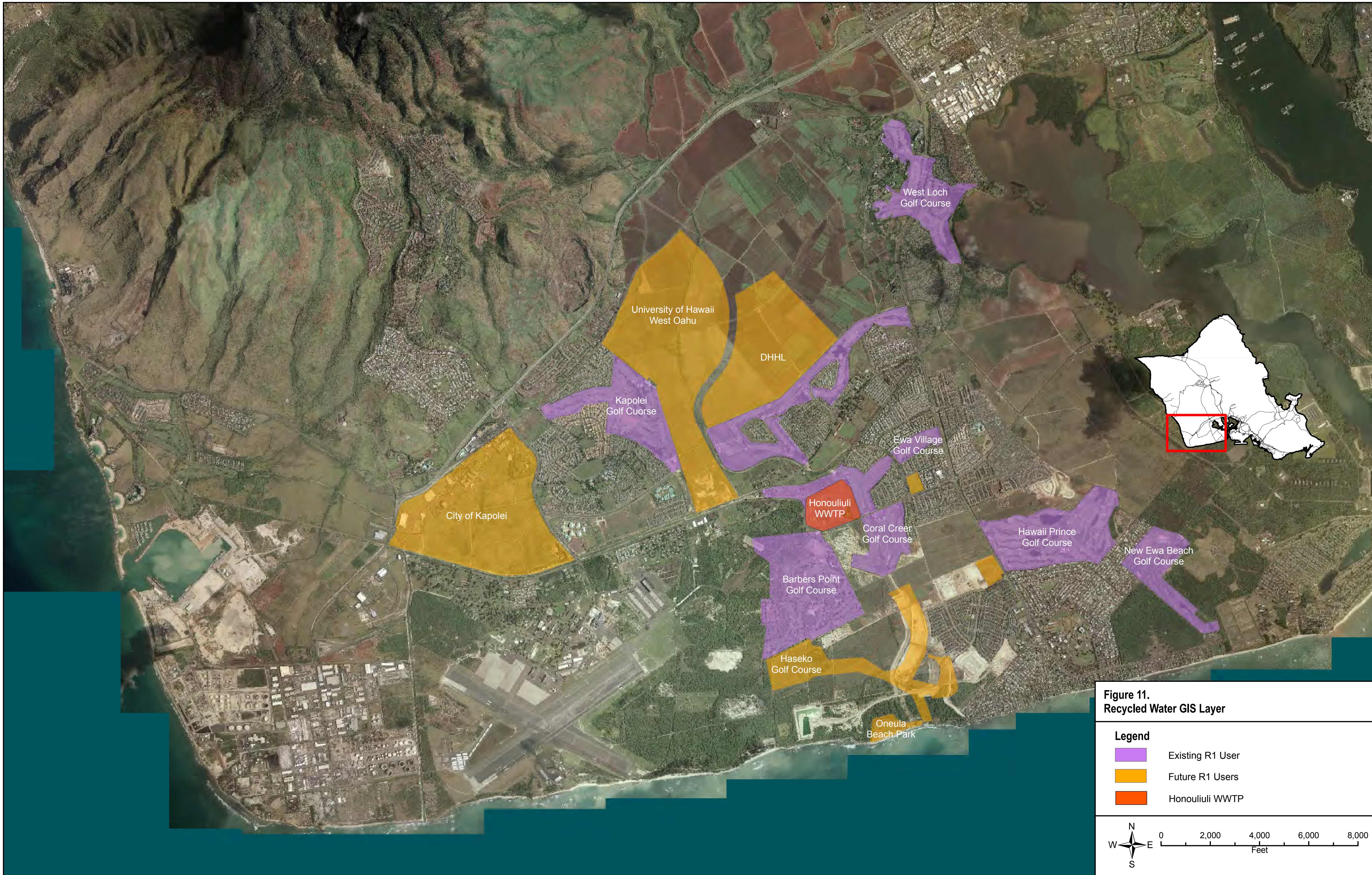


Figure 11.
Recycled Water GIS Layer

Table 3. Initial Screening Criteria for Stormwater Reclamation and Reuse Opportunities (continued)

Criteria	Basis	Measure	Impact	Opportunity	GIS Layer and Figure Reference
Proximity to Critical Habitats	May present an obstacle to groundwater recharge efforts, especially if disturbance to existing habitat is required.	Within 1 mile	Groundwater recharge may not be feasible. An EIS of the critical habitat should be performed.	Very limited to no opportunity.	U.S. Fish and Wildlife Service, Pacific Islands Office, 2004. (Received directly from State of Hawaii - CWRM) **Reference Figure 12**
		> 1 mile	Represents the minimum safe distance from a known critical habitat area. An EIS of the critical habitat may need to be performed.	Should not limit stormwater reclamation and reuse.	
Proximity to Historic Cultural Sites	May present an obstacle to groundwater recharge efforts, especially if disturbance to existing cultural sites is possible.	Within 1/2 mile	Groundwater recharge may not be feasible. An EIS of the cultural site should be performed.	Very limited to no opportunity.	DLNR, Historic Preservation Division, 1996. **Reference Figure 13**
		> 1/2 mile	Represents the minimum safe distance from a known cultural site. An EIS of the cultural site may need to be performed.	Should not limit stormwater reclamation and reuse.	

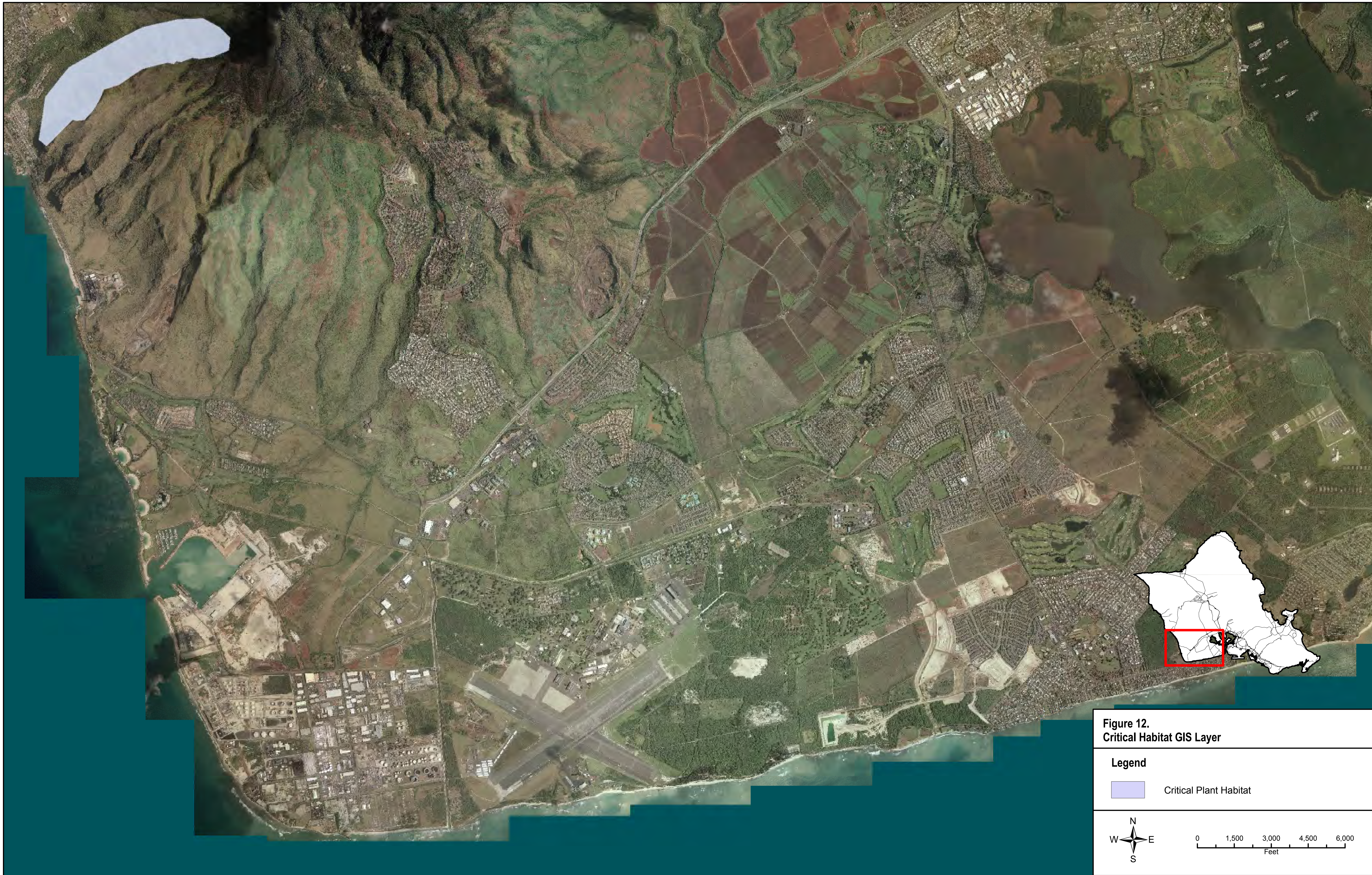


Figure 12.
Critical Habitat GIS Layer
Legend
Critical Plant Habitat
N
W
E
S
0
1,500
3,000
4,500
6,000
Feet

Nanakuli
Ho`ae`ae
Waiawa
Manana
Waikele
Waipi`o
Honouliuli
Figure 13.
Historical Cultural Divisions GIS Layer
Legend
Ho`ae`ae
Honouliuli
Manana
Nanakuli
Waiawa
Waikele
Waipi`o
N
W
E
S
0
2,000
4,000
6,000
8,000
Feet

Infrastructure Needs

Infrastructure needs for stormwater reclamation and reuse can be separated into five general categories: collection, conveyance, treatment, storage, and distribution. Each of these infrastructure categories is discussed in this section.

Collection

Stormwater collection begins when rainfall hits impervious surface area or ground that is sufficiently saturated to cause runoff. Stormwater collection infrastructure is integral to most existing residential, commercial, and industrial developments, and is a requirement of new developments. This infrastructure consists of impervious area (e.g., roads), curbs and gutters, and stormwater pipes and channels. Use of existing stormwater collection systems is ideal to avoid the need to fund and construct infrastructure specifically for stormwater reclamation and reuse.

There are often multiple points of stormwater discharge from a developed area since existing stormwater collection systems are designed to simply move stormwater to the nearest point of conveyance for discharge into streams or the ocean. In some cases (Figure 14) the multiple discharge points enter common stormwater drainage or flood control channels. In other cases, stormwater discharges to the most convenient location such as streams, open ground, or normally dry gulches. Stormwater collection systems with a small number of discharge pipes requires less additional infrastructure for collection.

Figure 14. Kapolei Flood Control Channel

Conveyance

Once stormwater is collected it must be conveyed to a point of treatment, storage, or use. Two important aspects of stormwater conveyance systems are their size and location. The size of the conveyance system must be sufficient to convey enough stormwater to make reclamation and reuse practical. The location of the conveyance system should be in close proximity to treatment or storage to minimize the need for additional infrastructure.

If a residential, commercial, or industrial development has few points of stormwater discharge, the collection system itself might serve the need for collection and conveyance. Conversely, as the number of stormwater discharge points increases, some means of integrating the discharge points into a conveyance system is required.

As shown in Figure 14, large stormwater conveyance or flood control channels can move large quantities of stormwater. These channels are typically designed for a 100-year storm. Some are undersized due to the failure to expand or build additional channels as the runoff from new developments has increased over time. An example of how a stormwater conveyance or flood control channel could be integrated into a stormwater reclamation and reuse opportunity is shown in Figure 15. Similar structures have been used for decades to divert stream flow to irrigation ditches (Figure 16).

Figure 15. Stormwater Channel Collection Sump Conceptual Design

Figure 16. Stream Diversion Channel

Agricultural irrigation ditches can also be effective means of conveyance since they often transport water over large geographic areas to multiple points of use. All of Hawaii's main islands have agricultural irrigation ditches that are still in use or abandoned. Agricultural irrigation ditches have become controversial in recent years as the sugar industry for which they were constructed has subsided. Many of these irrigation ditches divert from local streams and convey the water to points of use far from their origin. These diversions have affected stream flow, local groundwater recharge, and Hawaiian cultural activities. Any use of irrigation ditches for conveyance of stormwater would need to include operational strategies that would not affect (reduce) existing water allocations to users, and not increase or give the perception of increasing diversions from streams.

Treatment

The type of treatment required for stormwater reclamation and reuse will depend on the quality of the stormwater and its intended use. For example, stormwater collection from an existing residential, commercial, or industrial development would require some form of screening as a minimum. This would be necessary to remove trash, debris, and objects that could cause operational problems to downstream equipment (e.g., pumps, irrigation nozzles, etc.) or be a barrier to reuse applications. On the other extreme, groundwater recharge of stormwater into a potable water aquifer would require a full array of treatment technologies similar to those used by potable surface water treatment plants.

There are six general categories of treatment: screening, grit removal, sedimentation/floatation, chemical addition, filtration, and disinfection. The size of each treatment unit would depend on the concentration of pollutants and the expected stormwater flow to be treated. Each of these treatment categories is discussed below.

Screening. Screening is intended to remove trash (i.e., manmade material such as cups, paper, cans) and debris (i.e. natural material such as limbs and leaves) from the stormwater. Trash and debris can plug or damage pumps and subsequent treatment units. Screening can be accomplished by manual or automatic means, and usually consists of some type of rack or screen with a spacing of less than 1/4-inch. Larger, more robust screens may be needed in front of the finer screens to protect the finer screen from damage by large, heavy objects. Figure 17 shows an example of a mechanical screening device. Screened material that is collected would need to be recycled or disposed in a landfill.

Figure 17. Screening Device

Grit Removal. Grit consists of sand, gravel, rocks, and other similar material. Grit can plug and cause abrasion of downstream treatment units. Grit is removed by settling (i.e., slowing the stormwater flow to less than 2 feet per second), or by vortex action. Grit removal can be accomplished with aerated grit tanks, gravity settling channels, and vortex systems. Figure 18 shows a vortex-type grit removal system. Grit that is collected and removed must be recycled or disposed in a landfill.

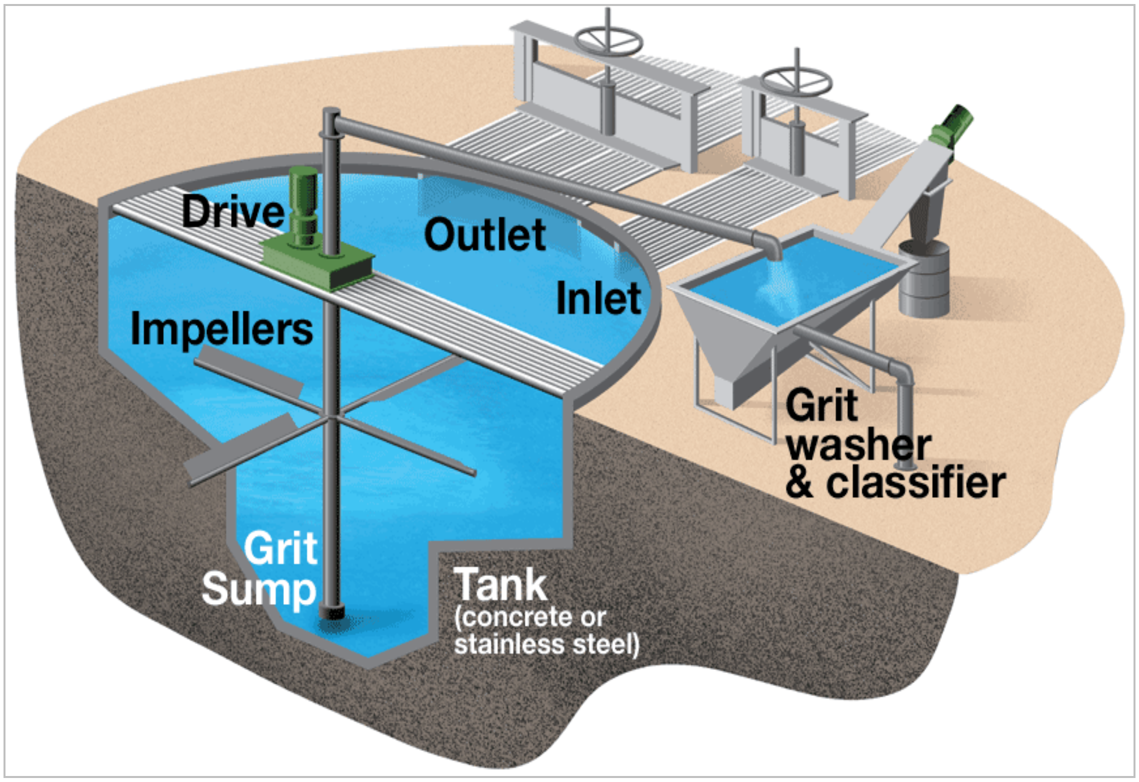


Figure 18. Vortex Grit Removal Device

Photo: JWC Environmental

Sedimentation/Floatation. Sedimentation typically involves a basin that slows the velocity of the water to allow solids to settle out, and floatable material (e.g., grease and oil) to float. The basin can be a pond, or it can be a concrete structure with mechanical components. The sediment and floatable material that collects in the basin is removed on a routine basis, depending on the actual load. Figure 19 shows two means of removing sediment and floatable material: Mechanical clarifiers and ponds. The collected material must be recycled or disposed in a landfill.

Sedimentation basins are not effective for removal of colloidal material or dispersed solids.

Figure 19. Sedimentation/Floatation – Mechanical Clarifier / Sedimentation Pond

Chemical Addition. Chemical addition is often used to remove dissolved or colloidal materials that might affect the intended use of the reclaimed stormwater. These materials could include nutrients, metals, and fine suspended solids. Chemical addition would involve chemicals that are used commonly in potable water treatment and would require on-site storage of chemicals and a chemical feed system. Chemicals might be in a liquid or solid form, depending on the material to be removed from the stormwater. Chemical addition would be integrated with sedimentation/floatation, or applied immediately prior to filtration. The chemical solids would need to be removed and disposed in a landfill.

Figure 20. Disc Filtration System

Filtration. Filtration is intended to remove solids, whether suspended or colloidal, that might affect the intended water use. Filtration might also be necessary as pretreatment for disinfection. Filters use a range of media for solids removal including cloth, sand, and plastic discs. More advanced forms of filtration such as microfilters could also be used. Figure 20 shows a plastic disc filter system that is common to agricultural irrigation practices. Solids that are collected on filter media would need to be removed routinely (typically automated) and disposed in a landfill.

Disinfection. There are no specific regulations for disinfection of stormwater for reclamation and reuse. However, end uses that would involve direct human contact might require disinfection. Though there are a number of possible disinfection methods, including ultraviolet radiation and ozonation, chlorination would likely be the most reliable for intermittent stormwater flows. Chlorine is commonly used for the disinfection of public swimming pools, public drinking water supplies, and treated wastewater. Since chlorine is a hazardous gas, security for the system would be necessary to protect from vandalism. Figure 21 shows a typical chlorination system.

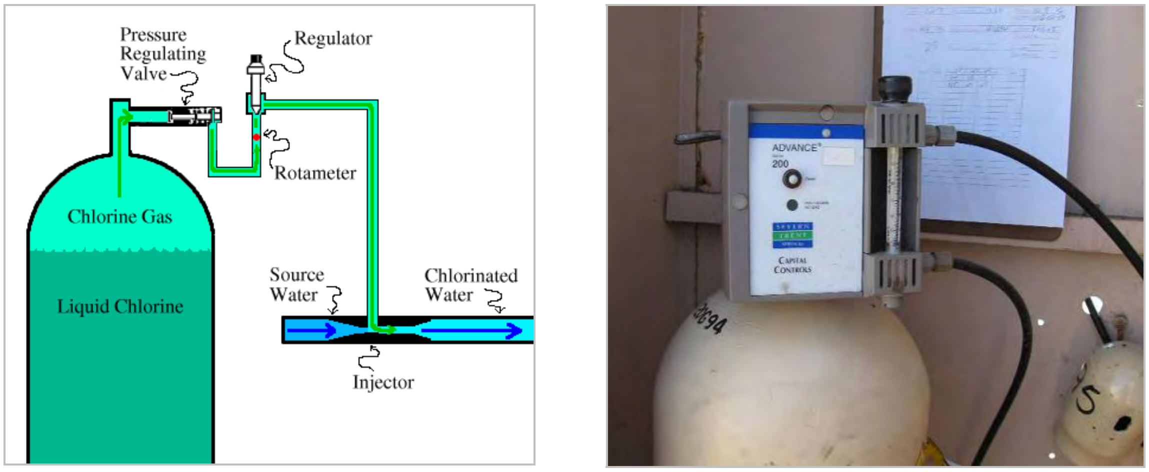


Figure 21. Chlorine Disinfection

Storage

Matching supply and demand is a critical issue for any type of water use. When it is raining, the water demand for irrigation of agricultural and recreational areas decreases. If desired stormwater cannot be conveyed from the point of collection to a point of immediate use, then some form of storage is necessary.

Figure 22. Portable Reservoirs

Storage can include open surface reservoirs, ponds, and above- or below-ground closed tank reservoirs. Aquifer storage and recovery can also be used, particularly for non-potable aquifers. Figure 22 shows an example of portable 50,000-gallon “storage bags” that could be used singly or in combination at multiple locations. Existing infrastructure that could be used potentially include tanks at abandoned wastewater treatment plants, and abandoned fuel storage reservoirs.

Distribution

Distribution systems convey reclaimed stormwater from storage to the point of application. Such systems would necessarily be non-potable. It might be necessary to add infrastructure that would connect reclaimed stormwater storage to existing distribution systems used for irrigation, such as parks, golf courses, and agricultural lands.

Integrated Infrastructure Use

It is possible that some infrastructure could be used for multiple purposes. Stormwater drainage and flood control channels are the best examples of the potential for multiple uses. Flood control channels are designed typically for 100-year storms. Consequently, the channel is oversized for most rainfall events.

Many of the flood control channels are long with standard geometrical shapes (e.g., trapezoidal and rectangular) that could serve a combination of uses including conveyance, treatment, and storage. This could be accomplished by using separation devices (such as the inflatable dam shown in Figure 23) to compartmentalize the channels for each need.

Some flood control channels have paved segments and some have both paved and native soil embankments. Using devices such as berms to pond water in the areas of native soil embankments could aid in groundwater recharge.

To accomplish integrated use of flood control channels effectively, it would be essential to have an operational strategy that would allow multiple use of the channels, while eliminating any chance of upstream flooding.

Figure 23. Inflatable Dam

End Use

The end use of reclaimed stormwater could take many forms, but the most likely options are direct irrigation and non-potable groundwater recharge. Direct irrigation would likely integrate with existing irrigation systems for recreational areas, such as parks and golf courses, or agricultural areas. Reclaimed stormwater could have other end uses as well, depending on the level of treatment provided. Table 4 shows the level of treatment that would be required for various end uses, including groundwater recharge.

Table 4. Level of Treatment Required Based on End Use

End Use	Treatment						Comments
	Screening	Grit Removal	Sedimentation	Chemical Addition	Filtration	Disinfection	
Injection Well (Potable)	Y	Y	Y	Y	Y	Y	
Injection Well (Non-Potable)	Y	Y	Y	*	N	N	
Recharge Trench	Y	Y	Y	N	N	N	
Spreading Basin	Y	N	N	N	N	N	O&M required to ensure infiltration
Excavated Pond	Y	N	N	N	N	N	Series operation
Industrial Reuse	Y	Y	Y	Y	Y	N	
Direct Irrigation:							
Contact with edible portion of crop	Y	Y	Y	Y	Y	Y	Not specific to stormwater; based on Hawaii's recycled water guidelines
No contact with edible portion of crop	Y	Y	*	N	N	N	
Human contact	Y	Y	Y	Y	Y	Y	

* Depends on quality of stormwater

Groundwater recharge of stormwater could be used for several purposes:

- Establish saltwater intrusion barriers in coastal aquifers,
- Provide treatment for future reuse,
- Augment potable or nonpotable aquifers,
- Provide storage of stormwater for subsequent retrieval and reuse, and
- Control or prevent ground subsidence.

Guidance documents for stormwater recharge are sparse compared to those for the reclamation and indirect reuse of treated municipal wastewater. This report therefore relies heavily on the latter. This is a conservative approach, which may be relaxed when site-specific data are available in the feasibility and implementation stages. Many guidance documents are also designed for Mainland soils, vadose zone, and aquifer systems, which are typically alluvial sediments composed of clay, silt, sand, and/or gravel, rather than Hawaiian volcanic and caprock terrains. As a result, Pacific Northwest, Northeast, or Florida state guidance documents may be more useful than desert Southwest state guidance documents. Site-specific investigation and pilot testing are therefore even more critical to ultimate project acceptance and success.

The specific groundwater recharge technique that is most suitable for a given location depends on a number of factors, including:

- Quality of the recharge water
- Topography
- Soil permeability
- Physical characteristics of the vadose zone
- Depth to groundwater
- Land zoning and availability
- Proximity to potential contaminant sites
- Underlying aquifer classification, characteristics (particularly vertical and horizontal permeability), and uses (potable vs. non-potable)
- Conveyance and storage infrastructure
- Proximity to critical habitats or historic cultural sites
- Water residence time and the amount of blending with other sources prior to extraction for use

The above factors are discussed as appropriate for each of the following recharge techniques.

Recharge Techniques

The appraisal considered a variety of groundwater recharge measures including: unlined canals, stream-bed enhancement, various surface recharge techniques (flooded fields, shallow spreading basins, and excavated basins), infiltration trenches, drywells, and injection wells. Based on cost, environmental setting, and the project goal of recharging periodic floodwaters, four primary measures were selected for detailed descriptions in this Appraisal:

- Surface spreading (including flooded fields or bermed shallow spreading basins)
- Excavated basins (including existing or new golf course ponds)
- Infiltration trenches (such as that present at the Honouliuli Wastewater Treatment Plant [WWTP])
- Injection wells

These four methods are shown schematically in Figure 24.

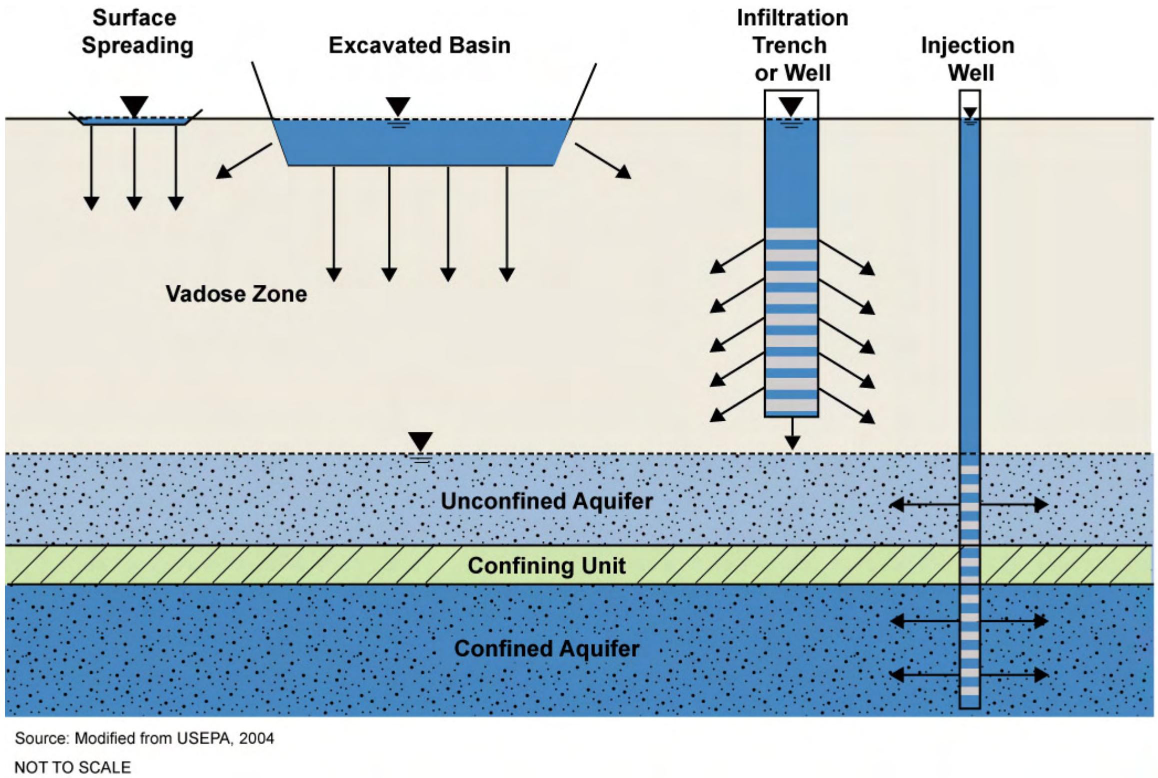


Figure 24. Recharge Techniques

In general, the selection of a recharge technique requires balancing competing factors. For example, the above list (from surface spreading to injection wells) would require decreasing land area and disturbance, but increasing levels of treatment for the same level of protection of the aquifer water quality. A comparison of the major factors for groundwater recharge methods is presented in Table 5.

Table 5. Comparison of Major Engineering Factors for Groundwater Recharge

	Surface Spreading	Excavated Basins	Vadose Zone Trenches or Wells	Direct Injection Wells
Aquifer type	Unconfined	Unconfined	Unconfined	Unconfined or confined
Pretreatment requirements	Minimal	Low technology	Removal of solids	High technology
Estimated major capital costs (US$)	Land and distribution system	Land, excavation and distribution system	$25,000-75,000 per well	$500,000-1,500,000 per well
Capacity	40-8,000 m^3/acre-day	40 - 8,000 m^3/acre-day	1,000-3,000 m^3/d per well	2,000-6,000 m^3/d per well
Maintenance requirements	Drying, scraping, and/or ripping	Drying and scraping	Drying and disinfection	Disinfection and flow reversal
Estimated life cycle	>100 years	>100 Years	5-20 Years	25-50 Years
Soil aquifer treatment	Surface soils, vadose zone and saturated zone	Vadose zone and saturated zone	Vadose zone and saturated zone	Saturated zone only
Subject to USEPA Class V UIC requirements	No	No	Sometimes	Yes

Source: Modified from USEPA, 2004

Surface Spreading

This measure involves applying water to a relatively undisturbed field and allowing it to infiltrate. Depending on water availability, the field could be flooded quickly to a standing depth of about 1 foot, or water could be delivered continuously at a rate that nearly matches the infiltration rate. The field may be surrounded by a small (two- to three-foot tall) berm and may also include several interior berms to regulate the water levels and flow across the field. Interior berms would be needed on gradually sloped sites. The ridge and furrow variation uses narrow ridges to maintain recharge rates even when the intervening flat bottom ditches plug over time, and is more suitable on sloping land. Figure 25 shows a conceptual layout for surface spreading.

This technique is most suitable in the following circumstances:

- Relatively flat to gentle terrains (< 3% slopes), which can be identified on USGS topographic maps
- Hard rocky terrains in which excavation would be expensive
- Areas with moderate (0.63 to 2.0 in/hr) to rapid (6.3 to 20.0 in/hr) soil permeability, which includes most basaltic terrains and much of the Ewa Plain Caprock
- Rural or open areas with land availability since it requires the most area/volume of infiltration
- Suitable geology such as an absence of impermeable layers between the surface and the water table aquifer
- Absence of surficial contamination, critical habitats or historic cultural sites
- A potable or non-potable aquifer
- If above a potable aquifer, an absence of expanding-contracting clays or fractures in the vadose zone that could allow short-circuiting of the soil horizon, and sufficient clay, organic-rich sediments, and/or available carbon for adsorption and biodegradation processes (or pretreatment).

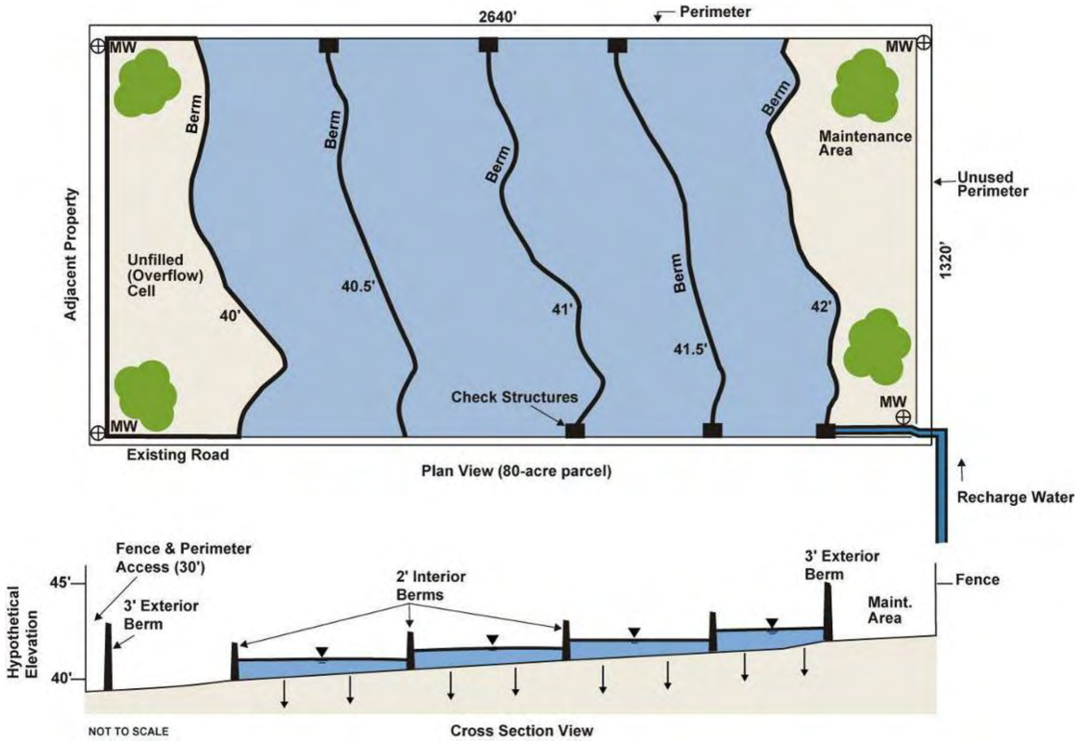


Figure 25. Spreading Basin Conceptual Design

Excavated Basins

This measure includes the construction of ponds or other basins by excavating to depths on the order of 10 to 20 feet below ground surface. This measure is most appropriate in areas where vertical impediments such as low permeability soils are thick or where existing ponds are present, such as at golf courses or parks, which may double as temporary stormwater storage facilities. This technique may be applicable in cases where additional purposes, such as flood control, can be developed, since the basins provide water storage. Since the amount of stormwater recharge is dependent on contact time of the water with the basin bottom, total recharge is typically higher than for surface spreading methods. Figure 26 shows a conceptual layout for excavated basins.

This technique is most suitable in the following circumstances:

- Vadose zones with moderate (0.63 to 2.0 in/hr) to rapid (6.3 to 20.0 in/hr) soil permeability, which includes most basaltic terrains and much of the Ewa Plain Caprock
- Rural or open areas with moderate to high land availability since it requires a moderate area/volume of infiltration
- Suitable geology such as an absence of impermeable layers between the base of the aquifer and the water table aquifer
- Absence of surficial contamination, critical habitats or historic cultural sites
- A potable or non-potable aquifer
- If above a potable aquifer, an absence of expanding-contracting clays or fractures in the vadose zone that could allow short-circuiting of the soil horizon, and sufficient clay, organic-rich sediments, and/or available carbon for adsorption and biodegradation processes (or pretreatment).

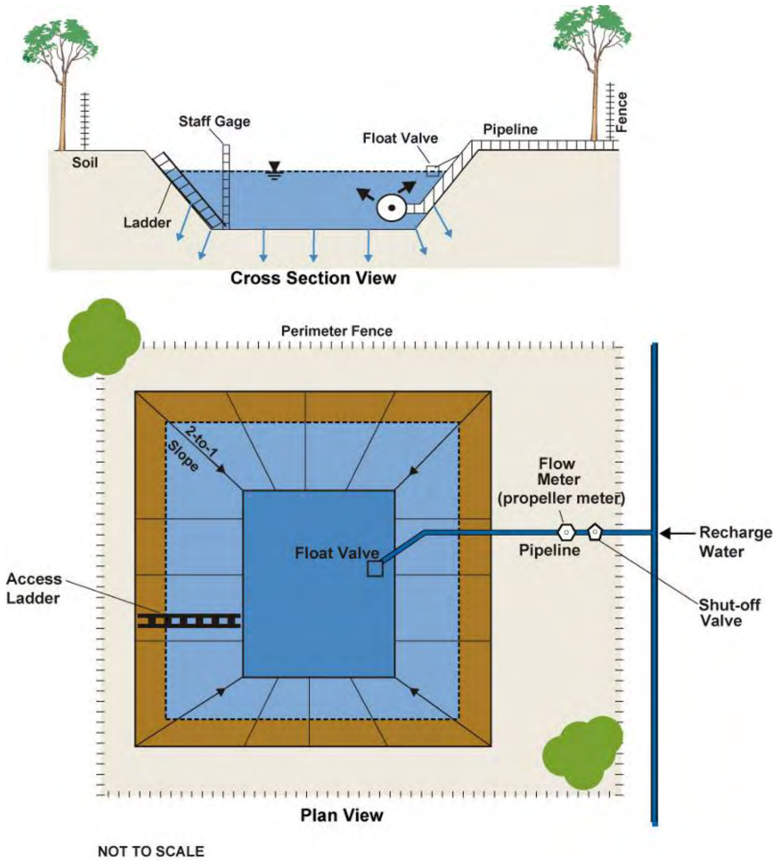


Figure 26. Excavated Basin Conceptual Design

Infiltration Trenches

Typical vadose zone infiltration trenches are wider than they are deep, and therefore are not considered Class V injection wells by the USEPA. They are backfilled with porous media. Water may enter at one end into a perforated pipe for distribution along the length of the trench. Alternatively a riser pipe is used to allow water to enter at the bottom of the infiltration trench to prevent air entrainment. An advantage of vadose zone infiltration trenches is the significant cost savings as compared to direct injection wells. A significant disadvantage is that they cannot be backwashed and a severely clogged trench can be permanently destroyed. Therefore, reliable pretreatment is considered essential to maintaining the performance. Since vadose zone infiltration trenches allow for percolation of water through the vadose zone, water quality improvements commonly associated with soil aquifer treatment can be expected.

Dry wells, also known as vadose zone infiltration wells, are wells installed above the water table but below low permeability soils such as clay. The dry well typically contains a perforated pipe that extends from approximately 1-2 feet below ground surface to the bottom of the trench. The entire well is filled with a permeable material, usually a gravel pack consisting of cobbles, which allows water to percolate through the well to lower, more permeable underlying soils, such as sand and gravel. Dry wells would be installed with a direct water supply to each well. Operation of infiltration trenches or wells would likely not cause any significant adverse environmental impacts. Figure 27 shows a conceptual layout for an infiltration trench.

This technique is most suitable in the following circumstances:

- Vadose zones with moderate (0.63 to 2.0 in/hr) to rapid (6.3 to 20.0 in/hr) soil permeability, which includes most basaltic terrains and much of the Ewa Plain Caprock
- Areas with moderate land availability since it requires a moderate area/volume of infiltration
- Suitable geology such an absence of impermeable layers between the base of the aquifer and the water table aquifer
- Absence of surficial contamination, critical habitats or historic cultural sites
- A potable or non-potable aquifer
- If above a potable aquifer, and absence of expanding-contracting clays or fractures in the vadose zone that could allow short-circuiting of the soil horizon, and sufficient clay, organic-rich sediments, and/or available carbon for adsorption and biodegradation processes (or pretreatment).

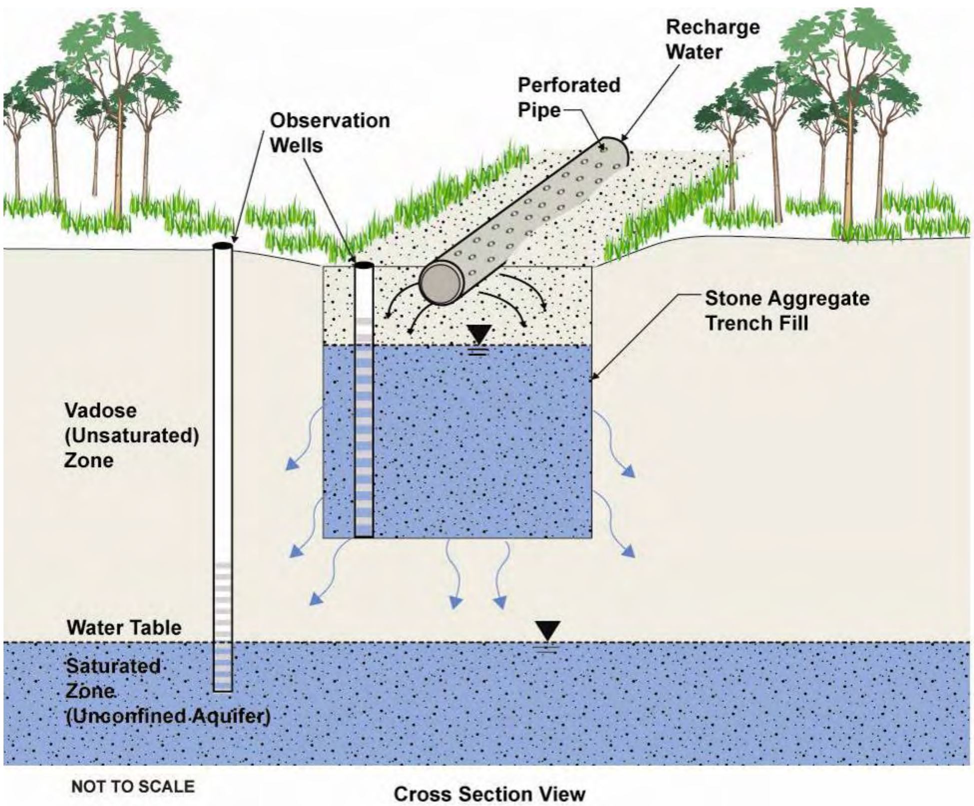


Figure 27. Recharge Trench Conceptual Design

Injection Wells

Direct injection involves conveying stormwater directly into the groundwater aquifer, which is usually a confined aquifer. Direct injection is used where groundwater is deep or where hydrogeological or other conditions are not conducive to surface spreading. Such conditions might include unsuitable soils of low permeability, unfavorable topography for construction of basins, the desire to recharge confined aquifers, or scarcity of land. Direct injection into a saline aquifer can create a freshwater “plume” from which water can be extracted for reuse, particularly in aquifer storage and recovery (ASR) systems. Direct injection is also an effective method for creating barriers against saltwater intrusion in coastal areas.

The DOH identifies Class V wells as those used to inject non-hazardous fluids underground. Most Class V wells are shallow disposal systems that depend on gravity to drain fluids directly in the ground. There are over 20 well subtypes that fall into the Class V category and these wells are used by individuals and businesses to inject a variety of non-hazardous fluids underground. The Class V well category includes complex injection wells that are typically deeper and often used at commercial or industrial facilities. Figure 28 shows a conceptual layout for an injection well.

This technique is most suitable in the following circumstances:

- Steep terrains and/or areas with slow or vadose zone permeability, which includes parts of the Ewa Plain Caprock
- Urban areas with limited land availability since it requires the least area/volume of infiltration)
- Unsuitable geology for surface infiltration due to impermeable confining layers above the targeted aquifer
- Presence of surficial contamination, critical habitats or historic cultural sites since the surface disturbance is minimal
- A non-potable aquifer (since no soil or vadose zone treatment occurs).

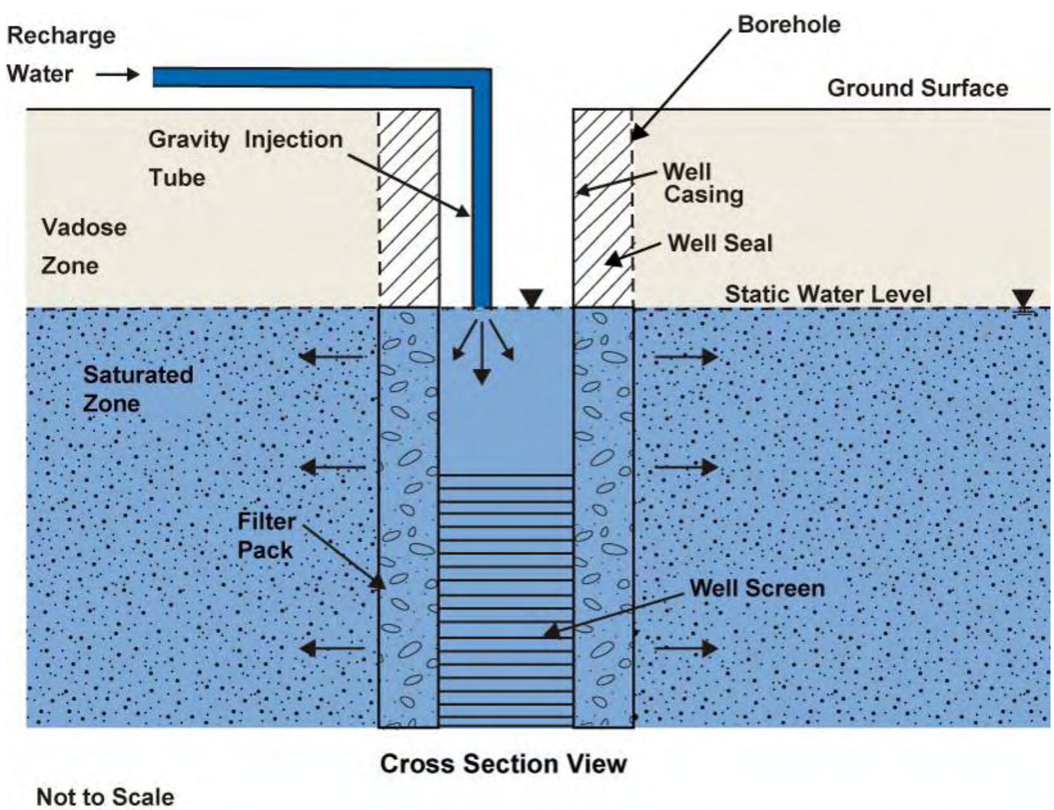


Figure 28. Injection Well Conceptual Design

Opportunity Development

The preceding information was used to develop stormwater reclamation and reuse opportunities. The alphabetic character references the Ewa Plain of Oahu and the number references a specific opportunity in the Ewa Plain.

Six opportunities were developed for the Ewa Plain of Oahu and are shown in Figure 29 (except E-7):

- E-1 – Makakilo Ridge
- E-2 – Kapolei Flood Control Channel
- E-3 – Fort Barrette Road Swale
- E-4 – Honouliuli Recharge Trench
- E-5 – Fort Weaver Road Swale
- E-7 – Waiahole Ditch Conveyance to Ewa Recharge Trench

Opportunity E-7 is not a stand-alone opportunity. It is an additional consideration for integration with opportunities in Central Oahu, and is discussed in a separate report *An Appraisal of Stormwater Reclamation and Reuse in Hawaii*.

Each of the opportunities was evaluated for the criteria presented in Table 6. These criteria are discussed further in Opportunity Ranking.

Table 6. Opportunity Prioritization Criteria

Criterion	Discussion
Potential Reuse Demand	Potential reuse demand is determined by the amount of land that the opportunity could serve with non-potable water irrigation. The available land could include parks, golf courses, and agriculture. Opportunities adjacent to agricultural areas are given higher priority that opportunities located in urban areas.
Cost Estimate	Cost estimates were based on bid tabulations from recent Oahu water projects were used to determine the potential cost of common elements associated with the opportunities, including unit cost of conveyance and collection pipe, reservoirs, infiltration trenches, and pumping stations. The cost estimates are not absolute planning level costs, but are relative costs to each opportunity.
Potential Stormwater Volume	The potential stormwater volume is based on the collection area of the opportunity and the annual average rainfall in the collection area.
Potential Partnerships	Potential partnerships include public agencies and private companies that would possibly support implementation of a stormwater reclamation and reuse opportunity through direct funding or indirect funding (e.g. use of land or existing infrastructure). Potential partnerships do not consider public water supply agencies that would benefit from reduced demand on potable water supplies since all opportunities would result in this benefit.
Likelihood of Implementation	Likelihood of implementation includes non-economic benefits and constraints associated with the opportunity, including, but not limited to, public acceptance and environmental impacts.
Institutional Constraints	Institutional constraints include policies, regulations, laws, and social or cultural issues that would be potential barriers to implementation of any opportunity. They also include potential barriers from agencies that are responsible for infrastructure associated with the opportunity.

Each of the opportunities listed above is presented in a tabular format in Tables 7 through 11 on the following pages and are supported with figures showing their locations.

Table 7. E-1 –Makakilo Ridge

Description	This opportunity would collect stormwater from the Makakilo area development north of the H-1 freeway, treat it in an existing, but abandoned wastewater treatment plant, and then use the water for distribution or recharge: ▪ Collect stormwater from an existing stormwater collection system in a large residential and commercial neighborhood. ▪ Convey the collected stormwater to the abandoned Makakilo WWTP located between the H-1 freeway and the Makakilo area. ▪ Recharge the caprock aquifer or distribute the treated stormwater for irrigation.
Figure	Figure 29. Ewa Plain Stormwater Reclamation and Reuse Opportunities Figure 30. E-1 - Makakilo Ridge
Existing Infrastructure	▪ Stormwater collection system in the Makakilo residential/commercial development. ▪ Abandoned Makakilo WWTP.
Needed Infrastructure	▪ Conveyance system from the residential/commercial development to the Makakilo WWTP. The GIS layer for the existing collection system appears to have multiple points of discharge into drainage gulches on the east and west side of development, rather than a single, combined conveyance system leaving the development. ▪ Recharge trench (possibly located to the east of the treatment plant and north of the H-1 freeway). ▪ Distribution system to points of use if the recharge option is not chosen.
Benefits	▪ Reduce stormwater runoff and pollution. ▪ Collects stormwater from a large impervious urban area. ▪ Potential recharge (freshening) of the Ewa Plain caprock aquifer.
Issues Needing Resolution	▪ Buy-in of key stakeholders. ▪ Determination of potential stormwater volume. ▪ Means of collecting stormwater and conveying to the WWTP. ▪ Ownership of the Makakilo WWTP. ▪ Location of the recharge trench in relation to the caprock aquifer; based on maps of the caprock aquifer, its boundary is below H-1 freeway. ▪ Option of recharge or distribution for irrigation.
Stakeholders	*Key Stakeholders:* ▪ CCH Department of Public Works – Manages the stormwater collection system. ▪ CCH Department of Environmental Services – Owns the abandoned Makakilo WWTP (NOTE: It is uncertain whether the ownership of the WWTP was returned to the developer, so ownership needs to be resolved).

Table 7. E-1 –Makakilo Ridge (continued)

Additional Considerations	There is an existing BWS non-potable water reservoir located approximately 1 and ½ miles from the Makakilo WWTP. The reservoir stores water from a non-potable well located on-site. A pipeline would need to be constructed from the Makakilo WWTP to the reservoir to benefit from its use, but since the distribution system from the reservoir is non-potable, it would provide a means of distributing the treated stormwater.	
Ranking Considerations	**Ranking Criterion**	**Discussion**
	Potential Reuse Demand	This opportunity involves recharge of the non-potable water aquifer in the Ewa Plain. The benefits of recharge extend beyond actual reuse of the non-potable water, to include decreasing the increase in chlorides from overpumping and seawater intrusion. Demand for a source of freshwater recharge is unlimited.
	Potential Stormwater Volume	Makakilo Ridge receives an average rainfall of 20 to 30 inches per year. The lower portion of the Ridge that would most likely be included in this opportunity receives less than 24 inches per year. The lower portion of the Ridge is also a residential development, with a significant amount of impervious surface.
	Potential Partnerships	The CCH is a potential partner for this opportunity through the use of the abandoned Makakilo WWTP. Since the County is responsible for stormwater management also, there is benefit for partnering to achieve compliance with future TMDLs.
	Likelihood of Implementation	Since this opportunity is located above the UIC line for Oahu, and the design of the stormwater drainage system for the Ridge is not contiguous to a single discharge point, implementation would be difficult to collect and convey stormwater below the UIC line for recharge.
	Institutional Constraints	This opportunity would require putting a conveyance line underneath the H-1 freeway. Though this is not a barrier, it would take time to get permission from the Hawaii Department of Transportation.
	Cost Estimate	$4.2 million Please read discussion of cost estimates in the section Using Criteria to Evaluate Opportunities before relying on this cost estimate for decision making.

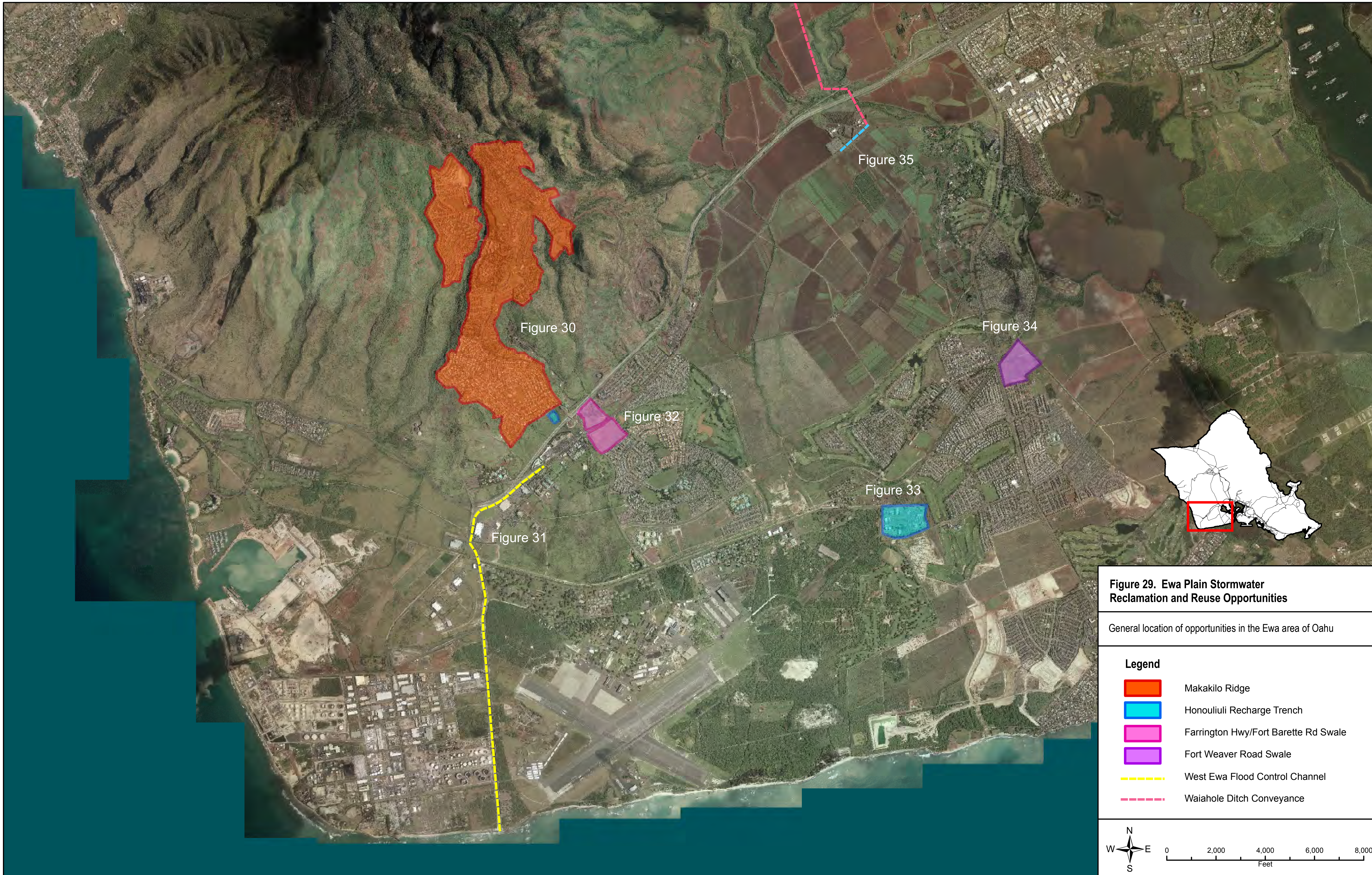


Figure 35
Figure 30
Figure 34
Figure 32
Figure 33
Figure 31
Figure 29. Ewa Plain Stormwater Reclamation and Reuse Opportunities
General location of opportunities in the Ewa area of Oahu
Legend
Makakilo Ridge
Honouliuli Recharge Trench
Farrington Hwy/Fort Barette Rd Swale
Fort Weaver Road Swale
West Ewa Flood Control Channel
Waiahole Ditch Conveyance
N
W
E
S
0
2,000
4,000
6,000
8,000
Feet

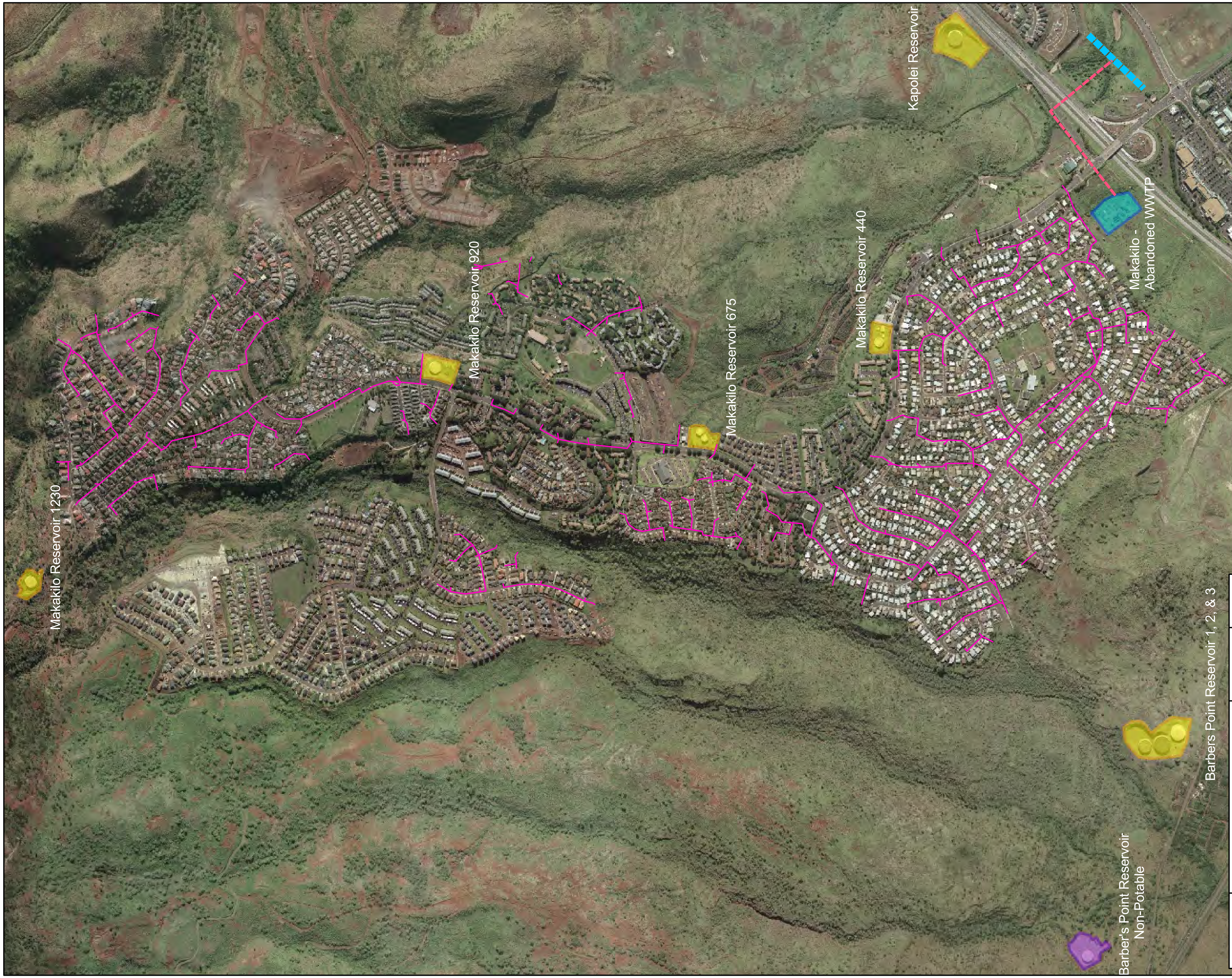


Figure 30.
E-1 - Makakilo Ridge

Convey stormwater from the Makakilo Ridge development to the abandoned Makakilo WWTP for treatment and use the treated stormwater for recharge of the Ewa caprock unconfined aquifer.

Legend

Proposed Stormwater Treatment
Potable Water Reservoir
Non-Potable Water Reservoir
Proposed Pipeline
Recharge Trench
Stormwater Collection System

N E S W
0 250 500 1,000 1,500 2,000
Feet

Table 8. E-2 – Kapolei Flood Control Channel

Description	This opportunity would use a portion of a large flood control channel to pool water for conveyance to injection wells for recharge of the caprock aquifer. The channel originates in Kapolei and collects stormwater from the residential and commercial development in that area. The first mile of the channel (approximation) is concrete lined, including the bottom. The last two miles of the channel (approximation) are unlined. This opportunity would include the following elements: ▪ Install an inflatable dam in the concrete line portion of the flood control channel to pool water. If this were done, more extensive treatment, as well as pumping and distribution would be required. ▪ Provide treatment necessary for recharge of the caprock aquifer. ▪ Convey the treated stormwater to injection wells on the site of Kapolei Irrigation Wells I and II.
Figure	Figure 29. Ewa Plain Stormwater Reclamation and Reuse Opportunities Figure 31. E-2 - Kapolei Flood Control Channel
Existing Infrastructure	Flood Control Channel between Barber's Point Naval Air Station and Campbell Industrial Park.
Needed Infrastructure	▪ Inflatable dam in the flood control channel. ▪ Treatment system to ensure stormwater is suitable for recharge. ▪ Pipeline and new injection wells at the site of the Kapolei Irrigation Wells I and II.
Benefits	▪ Reduce stormwater runoff and pollution. ▪ Collects stormwater from a large impervious urban area. ▪ Recharge the caprock aquifer in the Ewa Plain.
Issues Needing Resolution	▪ Buy-in of key stakeholders. ▪ Determination of potential stormwater volume. ▪ Best management practices plan for reducing stormwater contamination. ▪ Means of incorporating possible treatment into the recharge modifications. ▪ Location and spacing of injection wells.
Stakeholders	*Key Stakeholders:* ▪ CCH Department of Environmental Services – Manages the stormwater collection system. ▪ BWS – Owns and operates the Kapolei Irrigation Wells I and II. ▪ The Estate of James Campbell – Landowner.

Table 8. E-2 – Kapolei Flood Control Channel (continued)

Ranking Considerations	Ranking Criterion	Discussion
	Potential Reuse Demand	This opportunity involves recharge of the non-potable water aquifer in the Ewa Plain. The benefits of recharge extend beyond actual reuse of the non-potable water, to include decreasing the increase in chlorides from overpumping and seawater intrusion. Potential recharge of the caprock aquifer with freshwater (stormwater) is unlimited.
	Potential Stormwater Volume	The drainage area for this opportunity receives approximately 20 inches of rainfall a year. The area is commercial primarily with a significant amount of impervious surface area. The area is also expanding to include more commercial, institutional, and residential development, with equally high impervious surface area.
	Potential Partnerships	The BWS is a potential partner for this opportunity. Chlorides are increasing in two non-potable wells that are owned and operated by BWS. The BWS also owns the pilot desalination plant that is located adjacent to the flood control channel.
	Likelihood of Implementation	Groundwater recharge in this area will directly benefit two non-potable wells that have increasing chloride concentrations.
	Institutional Constraints	There are no apparent institutional constraints associated with this opportunity, as long as the means of collecting stormwater in the flood control channel does not impede flow that would contribute to flooding.
	Cost Estimate	$3.2 million Please read discussion of cost estimates in the section Using Criteria to Evaluate Opportunities before relying on this cost estimate for decision making.
Additional Considerations	The bottom of the unlined section would be modified to allow recharge into the caprock aquifer.	

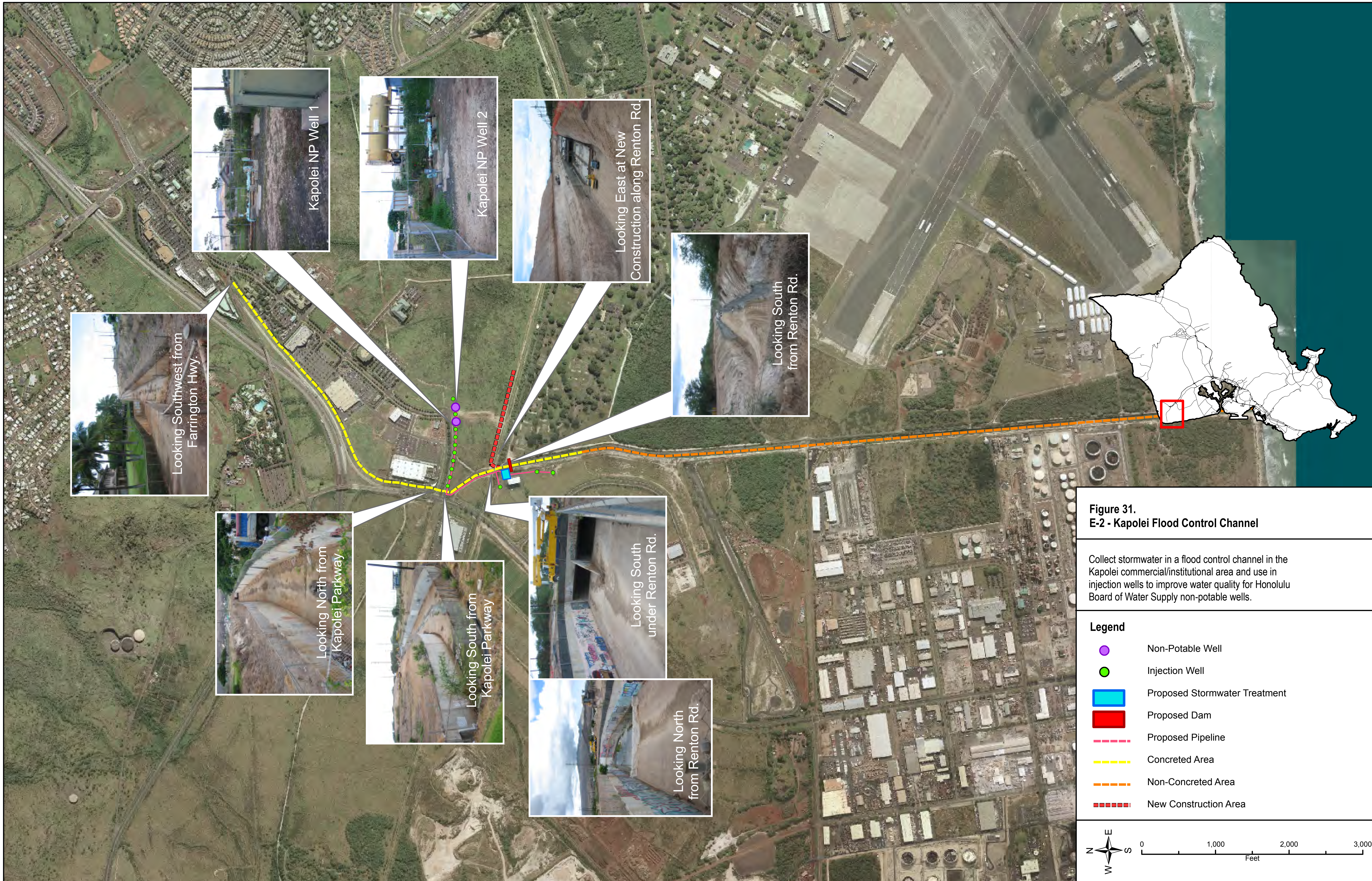


Figure 31.
E-2 - Kapolei Flood Control Channel

Collect stormwater in a flood control channel in the Kapolei commercial/institutional area and use in injection wells to improve water quality for Honolulu Board of Water Supply non-potable wells.

Table 9. E-3 – Fort Barrette Road Swale

Description	This opportunity would collect stormwater that drains through two gulches from the Makakilo Ridge area and pump it to a large swale on the corner of Farrington Highway and Fort Barrette Road. It would involve pooling water in an existing storm drainage channel and pumping the stormwater underneath Farrington Highway to the swale.
Figure	Figure 29. Ewa Plain Stormwater Reclamation and Reuse Opportunities Figure 32. E-3 - Fort Barrette Road Swale
Existing Infrastructure	▪ Stone lined channel for pooling stormwater prior to discharge under Farrington Highway. ▪ Approximate 25-acre grassy swale on the north side, and approximate 26-acre grassy swale on the south side off the corner of Farrington Highway and Fort Barrette Road.
Needed Infrastructure	▪ Inflatable dam in the stone-line channel to pool water. ▪ A pump station and pipeline to convey the pooled water underneath Farrington Highway (using an existing culvert) to the grassy swale. ▪ Fence or barrier to minimize hazards when water is diverted to swale.
Benefits	▪ Reduce stormwater runoff and pollution. ▪ Recharge the caprock aquifer in the Ewa Plain. ▪ Requires no treatment. ▪ Potential recreational area.
Issues Needing Resolution	▪ Ownership of the grassy swale. ▪ Control strategy for regulating
Stakeholders	*Key Stakeholders:* ▪ Kapolei Property Development LLC. ▪ Hawaii Housing Finance & Development Corp. *Potential Stakeholders:* ▪ Kapolei Golf Course.

Table 9. E-3 – Fort Barrette Road Swale (continued)

Ranking Considerations	**Ranking Criterion**	**Discussion**
	Potential Reuse Demand	This opportunity involves recharge of the non-potable water aquifer in the Ewa Plain. The benefits of recharge extend beyond actual reuse of the non-potable water, to include decreasing the increase in chlorides from overpumping and seawater intrusion. Demand for a source of freshwater recharge is unlimited.
	Potential Stormwater Volume	This swale is at the terminus of a normally dry gulch that receives rainfall from the Waianae Range. The area at the source of the drainage receive between 30 and 40 inches of rainfall a year.
	Potential Partnerships	There are no potential partners for this opportunity.
	Likelihood of Implementation	Since the 25-acre swale that would be used for surface recharge is zone commercial, its use might be met with resistance for use as a stormwater recharge area even if the cost of the land could be met. Re-zoning of this land for park space or a "land swap" for designated park space could off-set this concern.
	Institutional Constraints	The current zoning is a potential institutional constraint. Since this opportunity would result in standing water for a period of time, the depth of water would need to be limited to less than 6 inches, and/or the area fenced and isolated during rain events.
	Cost Estimate	$44.8 million Please read discussion of cost estimates in the section Using Criteria to Evaluate Opportunities before relying on this cost estimate for decision making.
Additional Considerations	None.	

Figure 32.
E-3 - Fort Barette Road Swale

Collect stormwater from a drainage gulch on the east side of Makakilo Ridge and surface spread on a grassy swale along Fort Barette Road for recharge of the Ewa caprock unconfined aquifer.

Table 10. E-4 – Honouliuli Recharge Trench

Description	This opportunity would collect stormwater from the area on and around the Honouliuli WWTP and convey it to an existing recharge trench on the plant site. The recharge trench was originally designed for recycled water recharge into the caprock aquifer, but was never used due to possible designation of the entire aquifer as recycled water if recycled water was used for recharge.
Figure	Figure 29. Ewa Plain Stormwater Reclamation and Reuse Opportunities Figure 33. E-4 – Honouliuli Recharge Trench
Existing Infrastructure	▪ Honouliuli Recharge Trench (partially demolished due to construction of a new treatment process unit). ▪ Two unused caprock wells at the WWTP site.
Needed Infrastructure	▪ Collection and conveyance of stormwater to the recharge trench. ▪ Extraction well if integrated with the Honouliuli WRF R-1 water system.
Benefits	▪ Improve the quality of the caprock aquifer. ▪ Integration with the Honouliuli WRF R-1 water system.
Issues Needing Resolution	▪ Area of stormwater collection and volume. ▪ Regulatory input for recycled water integration. ▪ Means of integrating with recycled water.
Stakeholders	*Key Stakeholders:* ▪ CCH Department of Environmental Services – Owns and operates the Honouliuli WWTP. ▪ BWS – Owns and operates the Honouliuli WRF. ▪ DOH Wastewater Branch – Administers the State's recycled water program.

Table 10. E-4 – Honouliuli Recharge Trench (continued)

	Ranking Criterion	Discussion
Ranking Considerations	Potential Reuse Demand	This opportunity involves recharge of the non-potable water aquifer in the Ewa Plain. The benefits of recharge extend beyond actual reuse of the non-potable water, to include decreasing the increase in chlorides from overpumping and seawater intrusion. Demand for a source of freshwater recharge is unlimited.
	Potential Stormwater Volume	This recharge trench is in an area of the Ewa Plain that receives 20 inches of annual rainfall or less.
	Potential Partnerships	The CCH is a potential partner for this opportunity. Their cooperation would be required since the recharge trench is located on the Honouliuli WWTP site.
	Likelihood of Implementation	This opportunity would require some significant piping configurations to get the stormwater from the collection points to the point of recharge. The area is surrounded by development and golf courses with detention ponds that could be potential sources of stormwater. This is the most likely opportunity for integration with recycled water in the Ewa Plain.
	Institutional Constraints	There are no apparent institutional constraints for this opportunity, but one half of the recharge trench has been demolished due to expansion at the Honouliuli WWTP.
	Cost Estimate	$3.8 million Please read discussion of cost estimates in the section Using Criteria to Evaluate Opportunities before relying on this cost estimate for decision making.
Additional Considerations	None.	

Figure 33.
E-4 - Honouliuli Recharge Trench

Collect stormwater from the area in and around the Honouliuli WWTP for recharge of the Ewa caprock unconfined aquifer through an existing recharge channel.

Legend

Proposed Stormwater Treatment

Recharge Trench

N W E S

0 300 600 900 1,200
Feet

Table 11. E-5 – Fort Weaver Road Swale

Description	This opportunity would use a large swale along Fort Weaver Road as a spreading basin for groundwater recharge of the caprock area. Stormwater from a development south of the swale and across Fort Weaver Road from the swale could potentially be conveyed for recharge.	
Figure	Figure 29. Ewa Plain Stormwater Reclamation and Reuse Opportunities Figure 34. E-5 - Fort Weaver Road Swale	
Existing Infrastructure	▪ Approximate 40 acre swale on the east side of Fort Weaver Road. ▪ Old irrigation channel that crosses Fort Weaver Road and extends along the north side of the swale.	
Needed Infrastructure	▪ Distribution pipe (this could possibly be addressed with the old irrigation channel).	
Benefits	▪ Reduce stormwater runoff and pollution. ▪ Recharge the caprock aquifer in the Ewa Plain. ▪ Requires no treatment. ▪ Potential recreational area.	
Issues Needing Resolution	▪ Optimum source of stormwater for recharge. ▪ Ownership of the swale. ▪ Operation and Maintenance needs.	
Stakeholders	*Key Stakeholders:* ▪ Gentry Investment Properties – Landowner.	
Ranking Considerations	**Ranking Criterion**	**Discussion**
	Potential Reuse Demand	This opportunity involves recharge of the non-potable water aquifer in the Ewa Plain. The benefits of recharge extend beyond actual reuse of the non-potable water, to include decreasing the increase in chlorides from overpumping and seawater intrusion. Demand for a source of freshwater recharge is unlimited.
	Potential Stormwater Volume	This swale is served by residential and commercial development in an area of the Ewa Plain that receives 20 inches of annual rainfall or less.
	Potential Partnerships	There are no potential partnerships for this opportunity.
	Likelihood of Implementation	Since the 40-acre swale that would be used for surface recharge is zoned residential, its use might be met with resistance as a stormwater recharge area even if the cost of the land could be met. Re-zoning of this land for park space or a “land swap” for designated park space could off-set this concern.
	Institutional Constraints	The current zoning is a potential institutional constraint. Since this opportunity would result in standing water for a period of time, the depth of water would need to be limited to less than 6 inches, and/or the area fenced and isolated during rain events.
	Cost Estimate	$15.6 million Please read discussion of cost estimates in the section Using Criteria to Evaluate Opportunities before relying on this cost estimate for decision making.
Additional Considerations	None.	

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Figure 34.
E-5 - Fort Weaver Road Swale

Collect stormwater from residential areas and surface spread on a swale for recharge of the Ewa caprock unconfined aquifer.

Table 12. E-7 – Waiahole Ditch Conveyance or Ewa Recharge Trench

Description	This opportunity combines stormwater collection opportunities in Central Oahu (e.g., O-1 and O-2) with recharge of the caprock aquifer in the Ewa Plain. The key element of this opportunity would be to extend a pipe from the current terminus of Waiahole Ditch to a proposed recharge trench above the caprock aquifer. The basis for this opportunity is to more closely match supply and demand. If the volume of stormwater introduced into Waiahole Ditch exceeds the irrigation demand (i.e., during high rainfall), the excess water can be conveyed to the Ewa Plain for recharge.
Figure	Figure 29. Ewa Plain Stormwater Reclamation and Reuse Opportunities Figure 35. E-7 - Waiahole Ditch Conveyance to Ewa Recharge Trench
Existing Infrastructure	▪ Waiahole Ditch ▪ Infrastructure associated with opportunities O-1 and O-2, though additional infrastructure would be needed for their implementation.
Needed Infrastructure	▪ Approximate 2.5 mile pipeline from the terminus of Waiahole Ditch to the Ewa Plain (the pipeline could vary in length depending on the desired location for the recharge trench). ▪ Recharge trench in the Ewa Plain.
Benefits	▪ Reduce stormwater runoff and pollution. ▪ Recharge the caprock aquifer in the Ewa Plain. ▪ Match supply and demand more closely.
Issues Needing Resolution	▪ Routing for pipeline. ▪ Location and size of recharge trench. ▪ Control strategy for determining when to recharge. ▪ Capacity of Waiahole Ditch for conveyance of stormwater from Central Oahu.
Stakeholders	*Key Stakeholders:* ▪ Agribusiness Development Corporation. *Potential Stakeholders:* ▪ Agricultural interests who use the water. ▪ Windward interests (provide assurance that this opportunity does not involve recharge of water from the Windward side of Oahu).

Table 12. E-7 – Waiahole Ditch Conveyance or Ewa Recharge Trench (continued)

Ranking Considerations	Ranking Criterion	Discussion
	Potential Reuse Demand	This opportunity involves recharge of the non-potable water aquifer in the Ewa Plain. The benefits of recharge extend beyond actual reuse of the non-potable water, to include decreasing the increase in chlorides from overpumping and seawater intrusion. Demand for a source of freshwater recharge is unlimited.
	Potential Stormwater Volume	This opportunity is contingent upon development of stormwater reclamation and reuse opportunities in central Oahu. There are three opportunities that could be implemented, and their service areas received between 40 and 60 inches of rainfall per year.
	Potential Partnerships	Since this is not a stand-alone opportunity, the potential partnerships would be the same as those for the opportunities in central Oahu.
	Likelihood of Implementation	This opportunity requires implementation of stormwater opportunities in the Mililani area of Central Oahu. It increases the potential greatly for stormwater reclamation and reuse on Oahu, by providing a use of reclaimed stormwater when demand for water is otherwise low.
	Institutional Constraints	This opportunity would require putting a conveyance line underneath the H-1 freeway. Though this is not a barrier, it would take time to get permission from the Hawaii Department of Transportation.
	Cost Estimate	$2.9 million **Please read discussion of cost estimates in the section Using Criteria to Evaluate Opportunities before relying on this cost estimate for decision making**.
Additional Considerations	None.	

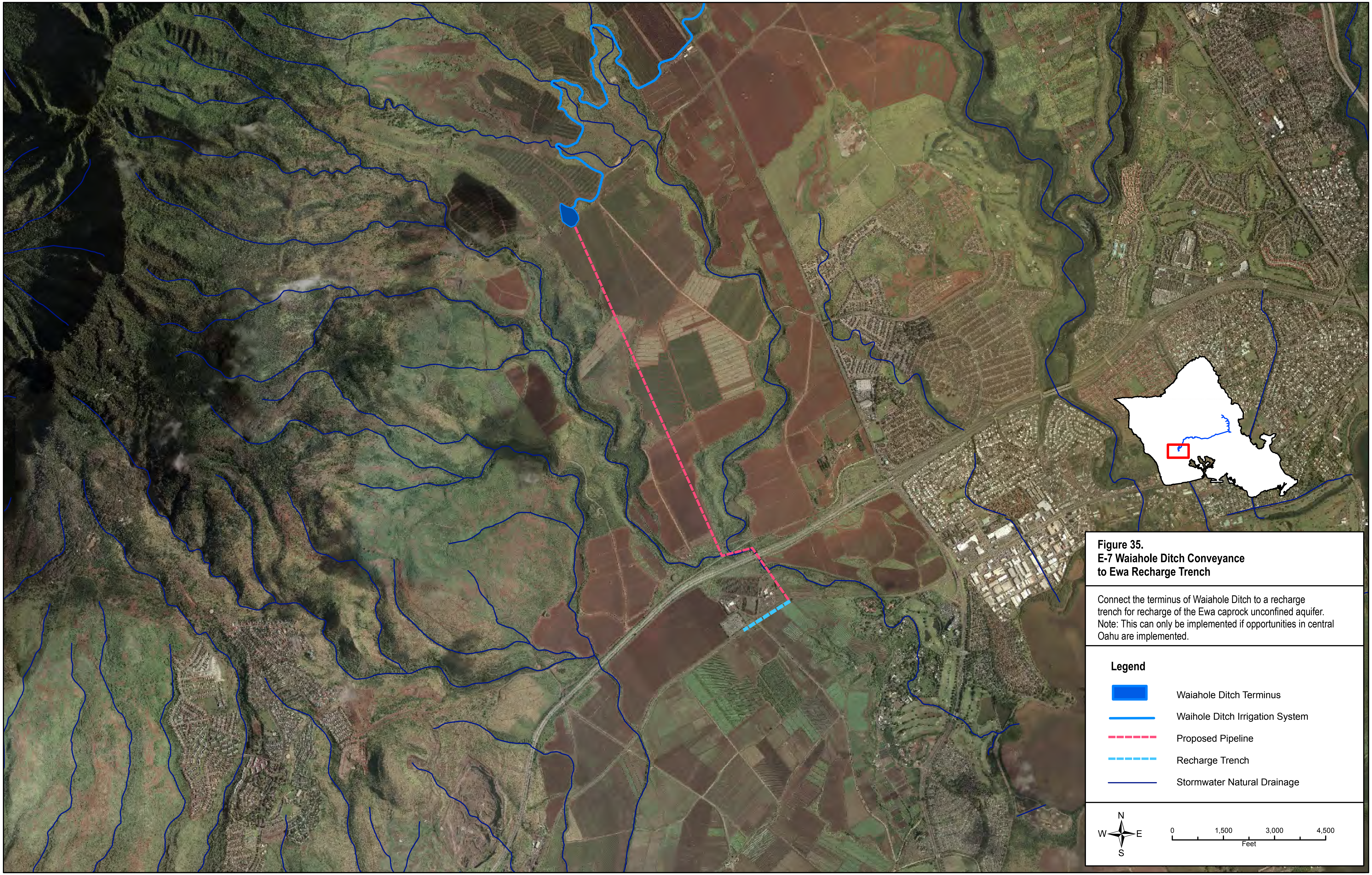


Figure 35.
E-7 Waiahole Ditch Conveyance to Ewa Recharge Trench

Connect the terminus of Waiahole Ditch to a recharge trench for recharge of the Ewa caprock unconfined aquifer. Note: This can only be implemented if opportunities in central Oahu are implemented.

Potential Integration with Recycled Water

The Honouliuli Water Recycling Facility (WRF) is owned by the BWS and is operated under contract by Veolia North America. The WRF receives secondary (biologically oxidized) effluent from the Honouliuli WWTP that is owned and operated by the City and County of Honolulu's Department of Environmental Services.

The Honouliuli WWTP provides up to 13.0 million gallons per day (mgd) of secondary effluent to the Honouliuli WRF. A maximum of 10.0 mgd is treated through a process of coagulation/flocculation, filtration, and disinfection to R-1 quality, the highest quality of recycled water in Hawaii. An additional 2.0 mgd is treated by reverse osmosis and is used by industries that require high purity water (i.e. low dissolved solids such as silica and chlorides) in Campbell Industrial Park. As much as 1.0 mgd is high chloride reject water from the reverse osmosis process.

Expansion of the Honouliuli WRF to produce additional R-1 water would first require that the Honouliuli WWTP secondary treatment capacity be increased. The definition of R-1 water includes oxidation, which is accomplished by biological secondary treatment at the WWTP. Though the Honouliuli WWTP treats a wastewater flow of approximately 36 mgd, the WWTP only has a secondary treatment capacity of 13 mgd. The remainder of the wastewater is provided primary treatment only. The WWTP's NPDES permit currently includes a 301h waiver, which allows discharge of primary effluent through a deep ocean outfall. EPA has issued a tentative decision to deny the 301h waiver in the future, which could require the facility to be upgraded to provide secondary treatment to the entire flow. The City and County of Honolulu disagrees with EPA's position and has stated that it will challenge the tentative decision. If the EPA's decision is upheld, upgrade of the WWTP to full secondary treatment could take up to 10 years to complete. Consequently, any upgrade of the WRF to produce additional R-1 water would also not be completed for up to 10 years.

The WRF's recycled water is used to irrigate golf courses, highway median strips, and parks in the Ewa Plain. Because of the potential for public exposure to recycled water, R-1 water must meet very low bacteriological and turbidity limits. These are discussed in a separate report titled *An Appraisal of Hawaii's Framework for Stormwater Reclamation and Reuse.*

Figure 36 shows the use of R-1 water in the Ewa Plain and use by the Honouliuli WWTP from November 2005 through October 2007. Any R-1 water that is produced, but not used, is returned to the Honouliuli WWTP for in-plant use or ocean discharge. As the demand for recycled water increases, the amount returned to the Honouliuli WWTP decreases, and vice versa. Heavy, consistent rainfall occurred in March 2006, which accounts for the significant decrease in recycled water use for that month. The latter part of the period illustrates that the supply of recycled water is at or near its maximum capacity, depending on the needs of the Honouliuli WWTP.

Figure 11 shows the existing and potential users of recycled water in the Ewa Plain. The potential demand is greater than the current supply. Reclamation and reuse of stormwater could potentially help match supply and demand.

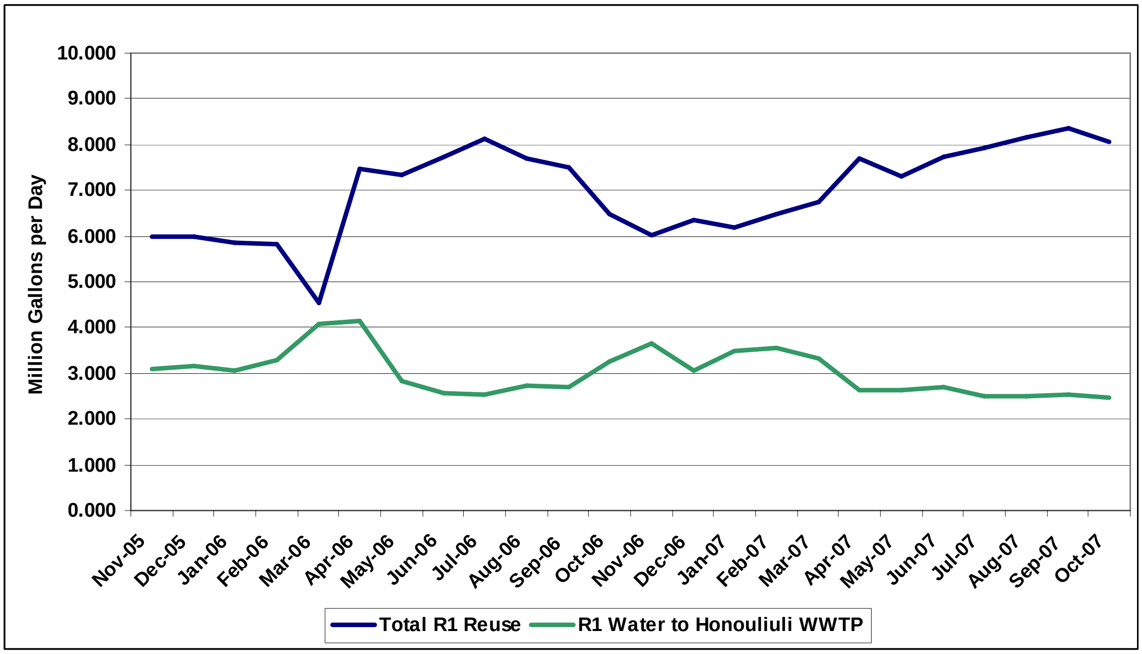


Figure 36. R-1 Recycled Water Use

Recycled Water-Stormwater Integration Issues

There are three potential issues associated with integrating stormwater and R-1 recycled water:

- Regulatory requirements for reuse
- Infrastructure available for integration
- Supply and demand of irrigation water

Each of these issues is discussed below.

Regulatory Requirements for Reuse. As stated previously, R-1 recycled water must meet very low bacteriological and turbidity limits. Though there is not a similar requirement for stormwater, the DOH could require that an integrated stormwater-R-1 water system meet a certain level of quality. During the January 18, 2007, Agency-Stakeholder Consultation Meeting associated with this project, a representative of the DOH stated that reuse water resulting from the integration of stormwater and R-1 water would need to meet R-1 water quality requirements.

Infrastructure Available for Integration. There are several networks of stormwater collection and drainage systems in the Ewa Plain. Some of these drain stormwater from residential and commercial areas, and some drain stormwater from recreational areas such as golf courses. Though some of these systems are in close proximity to the Honouliuli WWRF, none are integrated with the R-1 water system.

The July 2005, *Hawaii Stormwater Reclamation Appraisal Report* (CH2M, 2005) included a deep infiltration trench as a possible stormwater reclamation and reuse opportunity in the Ewa Plain. The objective of this opportunity was to recharge the aquifer during storm events and extract the groundwater from wells any time of year.

A site east of Fort Weaver Road and north or south of Iroquois Point Road was identified as a possible site for such an infiltration trench. This location is approximately ½-mile east of the existing R-1 distribution system that runs north-south along Fort Weaver Road. Though the concept of an infiltration trench is viable for charging and withdrawing from the aquifer, this particular location would make full integration with the recycled water system more difficult and more expensive.

The same concept could be applied more effectively by using an existing recycled water recharge trench located on the Honouliuli WWTP site, immediately adjacent to the Honouliuli WRF. The recharge trench was originally intended to be used to recharge disinfected secondary effluent from the Honouliuli WWTP. However, the DOH determined that any recharge of recycled water to the non-potable aquifer would classify the entire aquifer as recycled water, and the same restrictions on recycled water would apply to all users of the aquifer. The recharge trench, though constructed, was never used.

The original Honouliuli Recharge Trench was 450 feet long, from 9 to 12 feet deep, and capable of recharging up to 3.0 million gallons per day. Approximately one-half of the trench was demolished during construction of solids handling process units. Despite this setback, the trench could be reconfigured on adjacent land to its full capacity. Its close proximity to the Honouliuli WRF would allow integration with the recycled water system from the point of origination, and allow the entire R-1 water distribution system to be used.

Supply and Demand of Irrigation Water. Normal rainfall for the Ewa Plain is less than 20 inches per year. When rainfall occurs in the Ewa Plain, R-1 water irrigation is reduced as a result of reduced demand. When rainfall stops, R-1 irrigation returns to normal. Supply of stormwater does not coincide with the demand for irrigation water. Consequently, some form of stormwater storage would be needed. This could be accomplished with off-site, above-ground storage; on-site, above-ground storage; or aquifer storage. These are described briefly below:

- The WRF has two 3.0 mgd above-ground reservoirs for storage of R-1 water. Integrating these reservoirs with stormwater reuse would require an operating strategy that balances the need for R-1 water storage with the supply of stormwater during and immediately after a stormwater event. This would be a difficult strategy to implement since the demand for R-1 water decreases during rainfall events.
- Off-site above-ground storage could consist of constructed reservoirs (similar to those at the WRF), existing or constructed detention basins, or ponds. Funding for construction of this type of storage would be a key consideration.
- Aquifer storage would involve infiltration or recharge of the caprock, brackish water aquifer during storm events and then withdrawal from the aquifer based on demand. The stormwater would be expected to improve the quality of the brackish water (i.e., dilute the chlorides). Two possible approaches using new and existing infrastructure for this form of storage were discussed in the previous section.

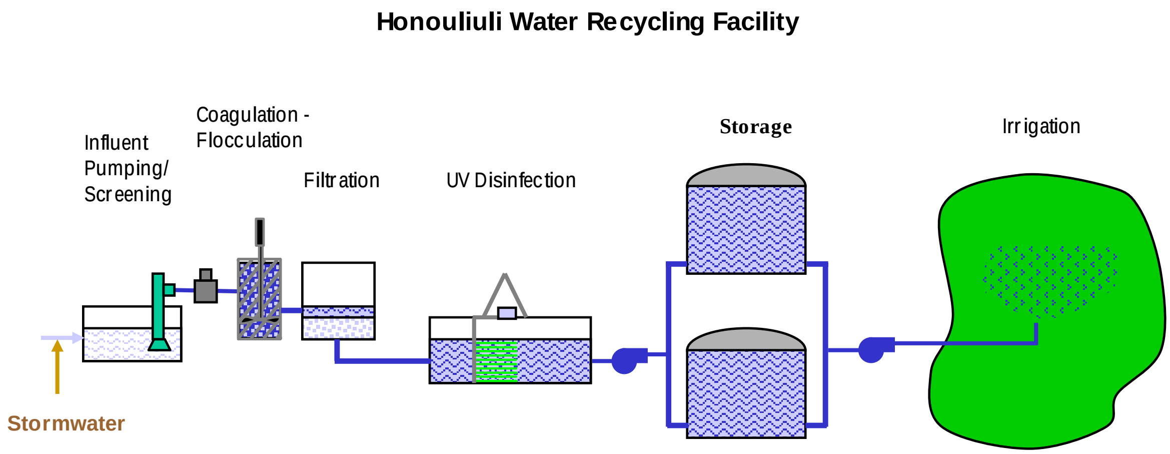
Integration Alternatives

Six preliminary alternatives were identified for integrating stormwater with R-1 recycled water in the Ewa Plain. These are described graphically and narratively in Tables 13 through 18.

Table 13. Integration with Recycled Water - Alternative 1

Alternative	Introduce Stormwater into Honouliuli WWRF Influent
Description	Stormwater would be introduced into the influent to the Honouliuli WRF and provided the same level of treatment as recycled water.

Schematic



Advantages	Disadvantages
▪ Stormwater is provided full treatment to the same level as recycled water. ▪ Existing recycled water distribution system and future expansions could be used fully.	▪ Honouliuli WWTP does not have sufficient capacity to treat stormwater. ▪ Does not address supply and demand issues.

Additional Issues

Since the Honouliuli WWTP can provide a constant 13.0 mgd, the lack of capacity above this amount for the WRF makes this alternative unrealistic.

Table 14. Integration with Recycled Water - Alternative 2

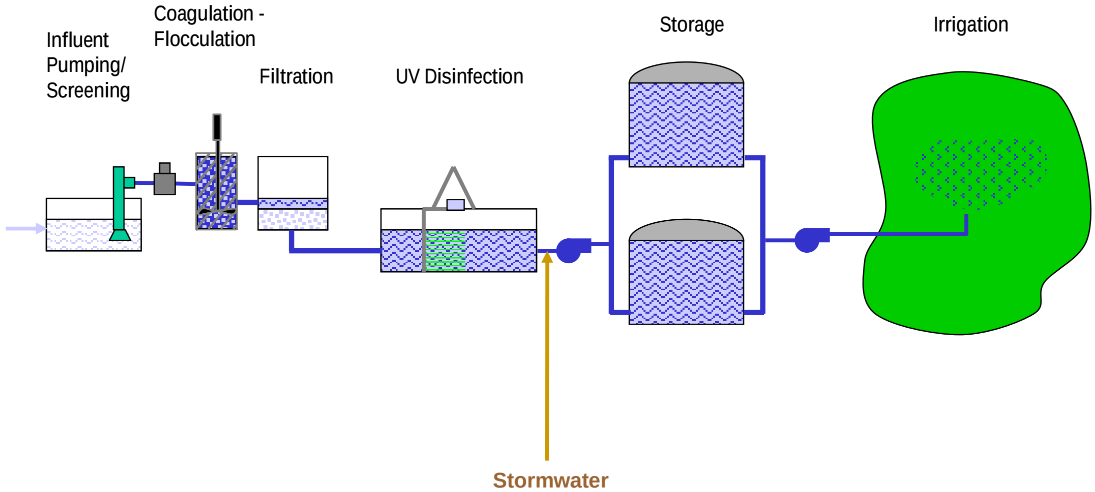
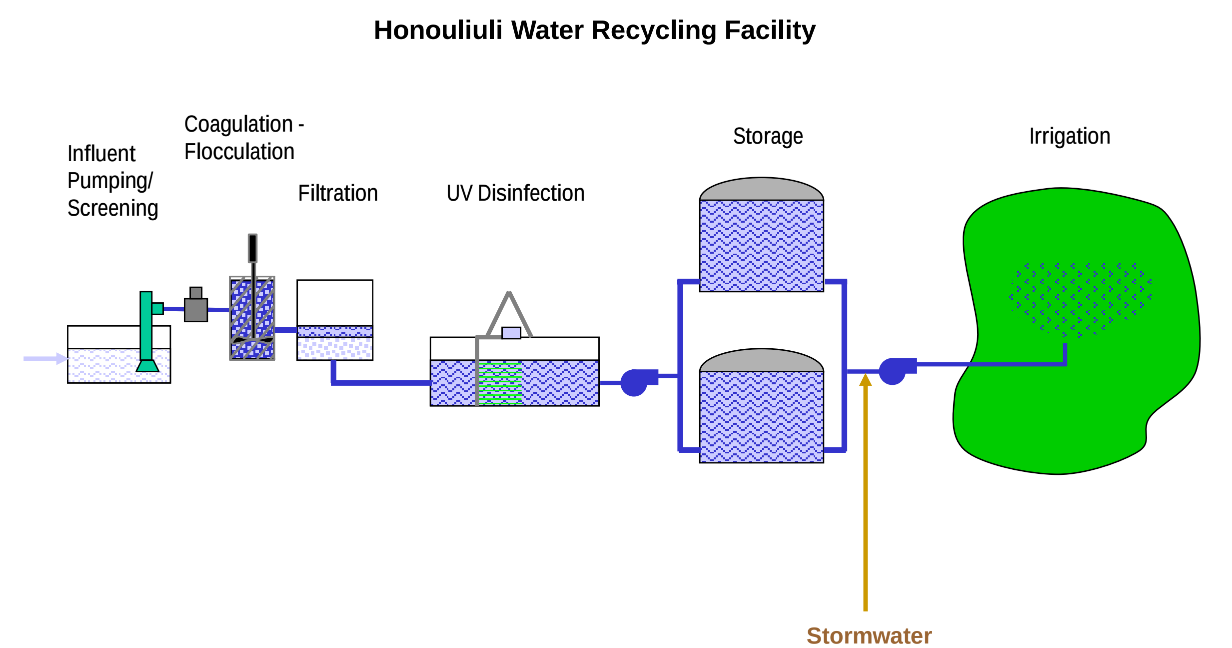
<table>
<tr><td>Alternative</td><td colspan="2">Introduce Stormwater after Honouliuli WWRF Treatment – Option 1</td></tr>
<tr><td>Description</td><td colspan="2">Stormwater would be introduced post-treatment at the Honouliuli WWRF, but prior to storage.</td></tr>
<tr><td colspan="3">Schematic</td></tr>
<tr><td colspan="3">Honouliuli Water Recycling Facility

</td></tr>
<tr><td colspan="2">Advantages</td><td>Disadvantages</td></tr>
<tr><td colspan="2">▪ Existing recycled water storage, pumping, and distribution system, as well as future expansions could be used.
▪ Recycled water demand could be supplemented without expanding the Honouliuli WRF or WWTP.</td><td>▪ Supply of stormwater does not match demand for irrigation.
▪ Additional on-site storage might be necessary, in addition to possible off-site storage needs.
▪ Stormwater would not meet the same quality requirements as recycled water unless treatment is provided for stormwater separately.</td></tr>
<tr><td colspan="3">Other Considerations</td></tr>
<tr><td colspan="3">Supply of stormwater occurs when demand for irrigation is low. The existing on-site storage is based on R-1 recycled water needs only. A carefully managed operating strategy would be needed to balance the supply and demand issues associate with stormwater. Otherwise, additional on-site or off-site storage would be required. A source of funding for this infrastructure would be a key consideration.</td></tr>
</table>

Table 15. Integration with Recycled Water - Alternative 3

Alternative	**Introduce Stormwater after Honouliuli WWRF Treatment – Option 2**
Description	Stormwater would be introduced post-treatment and storage at the Honouliuli WWRF.

Schematic



Advantages	Disadvantages
▪ Existing recycled water pumping and distribution system and future expansions could be used.	▪ Off-site stormwater storage might be necessary. ▪ Stormwater would not meet recycled water quality without treatment of the stormwater separately.

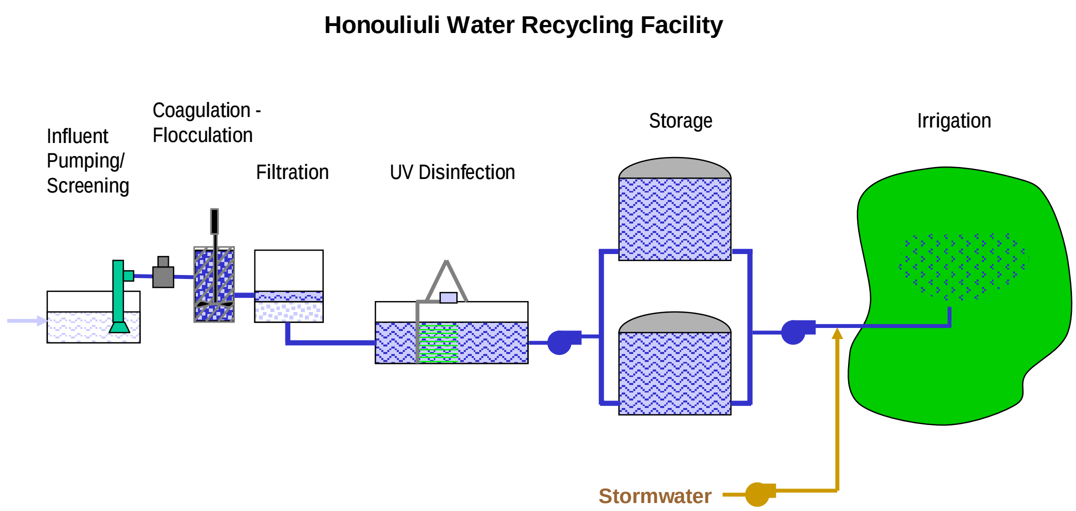
Other Considerations

Supply and demand issues associated with stormwater and R-1 water are critical for this alternative. A source of funding for the infrastructure necessary to address these issues is a key consideration.

Table 16. Integration with Recycled Water - Alternative 4

Alternative	**Introduce Stormwater after Honouliuli WWRF Treatment – Option 2**
Description	Stormwater would be introduced post-treatment and storage at the Honouliuli WWRF.

Schematic



Advantages	Disadvantages
▪ Existing recycled water distribution system and future expansions could be used. ▪ Stormwater could be introduced into the recycled water distribution system at different locations throughout the system.	▪ Off-site stormwater storage might be necessary. ▪ Stormwater would not meet recycled water quality without treatment. ▪ Introduction of stormwater at points along the distribution system would not utilize the full capacity and expanse of the distribution system.

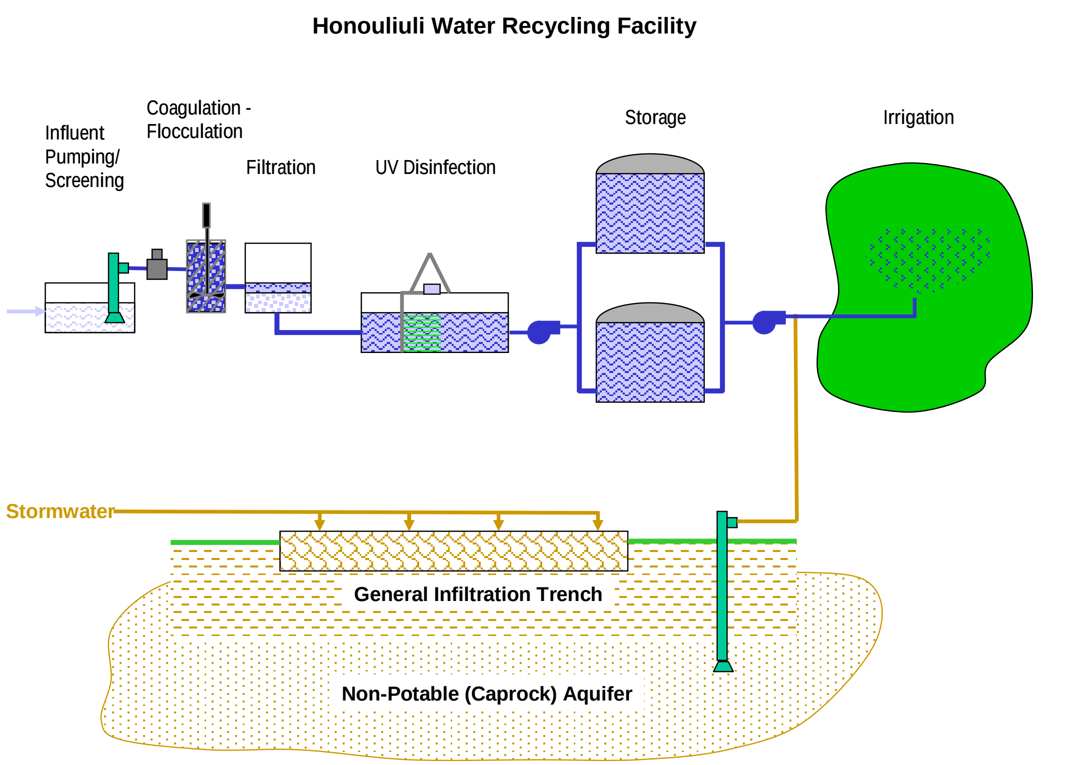
Other Considerations

A stormwater pumping system would be needed to match the pressure requirements of the R-1 distribution system. A source of funding for this infrastructure would be a key consideration.

Table 17. Integration with Recycled Water - Alternative 5

Alternative	**Use Aquifer Storage and Recovery for Stormwater – Option 1**
Description	Stormwater would be recharged into a groundwater infiltration or recharge trench and withdrawn for supplementing recycle water needs during high demand periods.

Schematic



Advantages	Disadvantages
▪ Existing recycled water distribution system and future expansions could be used. ▪ Supply and demand could be closely managed. ▪ Infiltration/recharge trenches could be located throughout the Ewa Plain.	▪ Some level of stormwater treatment might be necessary to ensure water quality in the aquifer is not degraded. ▪ Some customers may object to increased chloride content of recycled water. ▪ Recharge/infiltration trench would need to be constructed.

Other Considerations

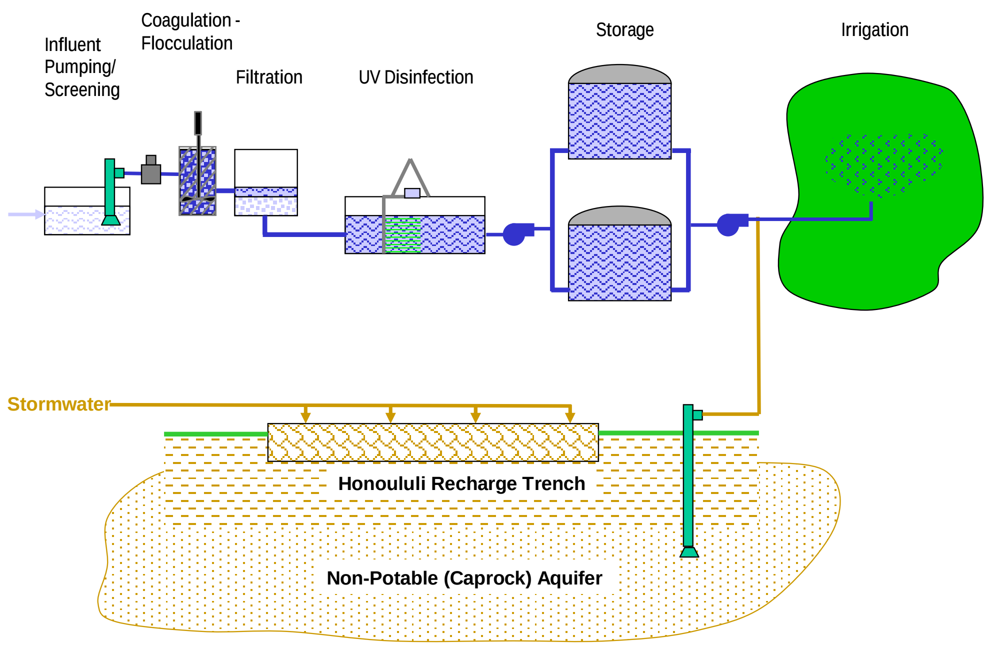
This alternative could potentially improve caprock water quality over a larger area than Alternative 6, and utilize existing non-potable water infrastructure in the Ewa Plain to supplement R-1 water use rather than full integration with the R-1 system. A source of funding for infrastructure would be a major issue.

Table 18. Integration with Recycled Water - Alternative 6

Alternative	**Use Aquifer Storage and Recovery for Stormwater – Option 2**
Description	Stormwater would be recharged into the Honouliuli Recharge Trench adjacent to the Honouliuli WRF and withdrawn for supplementing recycle water needs during high demand periods.

Schematic

Honouliuli Water Recycling Facility



Advantages	Disadvantages
▪ Existing recycled water distribution system could be used. ▪ Existing infrastructure could be used for recharge. ▪ Supply and demand could be closely managed.	▪ Some level of stormwater treatment might be necessary to ensure water quality in the aquifer is not degraded. ▪ Some customers may object to increased chloride content of recycled water.

Other Considerations

Though the Honouliuli Recharge Trench is an existing structure with supporting infrastructure, there are plans to construct sludge treatment units in the location of the trench, which might preclude its future use.

Opportunity Ranking

Once the Ewa Plain opportunities for stormwater reclamation and reuse were identified, prioritization was necessary to differentiate and rank the opportunities. The approach used for the prioritization process is known as a Pairwise Comparison.

The first step for ranking the opportunities was to identify the criteria that will be used to evaluate the opportunities. A draft of criteria was submitted to Reclamation and CWRM for review and comment. These criteria were presented in Table 6 and will be discussed further in this section.

After the criteria were identified, they were ranked using a method known as a Pairwise Comparison. The approach for a Pairwise Comparison is to compare each criterion with every other criterion by asking the following questions, and by assigning points based on the response to the questions.

1. Is criterion A much more important than criterion B? If the answer was “yes”, five points were assigned to criterion A, and 1 point was assigned to criterion B.

2. Is criterion A more important than criterion B? If the answer was “yes”, four points were assigned to criterion A, and two points were assigned to criterion B.
3. Is criterion A equal in importance to criterion B? If the answer was “yes”, three points were assigned to criterion A, and 3 points were assigned to criterion B.

4. Is criterion A less important than criterion B? If the answer was “yes”, two points were assigned to criterion A, and four points were assigned to criterion B.

5. Is criterion A much less important than criterion B? If the answer was “yes”, one point were assigned to criterion A, and five points were assigned to criterion B.

Two representatives from Reclamation and three representatives from CWRM performed the Pairwise Comparison to rank the criteria. The point totals for all five raters were averaged to determine the final ranking and value.

Table 19 presents the final ranking of the criteria and the average points from all raters. The average points were normalized to 1.0. The normalized value was used as a weighting factor for further evaluation of each opportunity.

Table 19. Evaluation Criteria Ranking

Criterion	Average Points	Weighting Factor
Potential Reuse Demand	17.0	0.19
Cost Estimate	16.6	0.18
Potential Stormwater Volume	15.2	0.17
Potential Partnerships	14.8	0.16
Likelihood of Implementation	14.4	0.16
Institutional Constraints	12.0	0.13

Using the Criteria to Evaluate Opportunities

Once the evaluation criteria were ranked, Brown and Caldwell conducted additional Pairwise Comparisons. Each opportunity was compared with all other opportunities for each evaluation criterion.

Six separate Pairwise Comparisons were conducted. A discussion of how each criterion was used in these comparisons is discussed below:

Potential Reuse Demand

There are a number of potential end-uses for stormwater, which makes comparisons difficult, particularly given the cost that some end-uses might incur (e.g., use in industrial processes). Regardless, all opportunities involve groundwater recharge and the long-range master plan includes significant residential/commercial development throughout the Ewa Plain. Consequently, the potential reuse demand is comparable for all opportunities. Though the Honouliuli Recharge Trench is in close proximity to existing golf courses and planned parks, the limited rainfall and the availability of recycled water do not increase the potential reuse demand for this opportunity.

Cost Estimate

Cost estimating range of accuracy is defined based on level of project definition. The Association for the Advancement of Cost Engineering (AACE) International has created a Cost Estimate Classification System (Recommended Practice No. 18R-97) that defines 5 classes of cost estimates. Using this matrix as a guide, the opportunities discussed in this report should vary from -50% to +100%.

The construction cost estimates developed for these opportunities considered the following cost information resources and assumptions:

- Comparable bid tabs from similar Hawaii projects
- Conceptual cost estimates
- Fifty percent adjustment for level of project definition
- 2008 dollars

In addition, capital cost estimates (as distinguished from construction cost estimates) accounted for engineering and construction management services based on the following assumptions using construction cost as a base:

- Design fees – 10 %
- Engineering services during construction – 5 %
- Construction management – 7%

The number of opportunities and the uncertainties associated with their construction at an appraisal level posed difficulties for cost estimates and their comparisons. To accomplish relative cost comparisons among the opportunities, the following assumptions were made:

- Pumping of stormwater from each opportunity would be equal at a 3.0 million gallon per day capacity. Two differentiations were made with regard to pumping stormwater: a low head pump station (e.g., one that would need to pump to only and slightly higher elevation and a shorter distance) and a high head pump station (e.g., one that would need to pump to higher elevations and longer distances.
- Treatment costs were assumed to be equal. No attempt was made to estimate treatment costs since the stormwater quality is unknown.

- Each opportunity would need a 3.0 million gallon reservoir, unless some form of rapid groundwater infiltration were used. Opportunities that had some form of possible storage were assigned a lower cost for reservoir than those that did not have any storage.
- Unit costs (per foot) were developed for collection and conveyance piping, including excavation, pipe, gravel, and appurtenances.
- Land costs were included if private land was required for the opportunity, and not included if public lands were available.
- No planning, engineering, and design costs were included since they would simply be percentages of the estimated costs.
- At this stage of opportunity development, cost estimates have an accuracy of +50 to -30 percent.

The cost estimates used in this report are preliminary and are based on data developed by Brown and Caldwell. The estimates are intended to be used as an assessment of the general magnitude of facilities and costs associated with stormwater reclamation and reuse needs in Hawaii.

Reclamation does not endorse these estimates and cautions against their use to assess the feasibility of developing stormwater reclamation and reuse facilities.

The basis for cost estimates is provided in Appendix A.

Potential Stormwater Volume

The potential stormwater volume was based on the potential stormwater collection area and the average annual rainfall for the area. Due to limitations in GIS information about stormwater collection systems in urban environments, the size of stormwater conveyance channels was also considered for some of the opportunities. For example, the North Mililani Stormwater Channel is significantly larger than the South Mililani Stormwater Channel. Since both channels are designed for a 100-year storm and have similar average annual rainfalls, the potential stormwater volume from the North Mililani Stormwater Channel was assumed to be greater.

Potential Partnerships

Some of the opportunities will directly or indirectly benefit public or private organizations that might, in turn, drive their willingness to be a partner in implementation of the opportunity. An example of a direct benefit is the availability of reclaimed stormwater to augment existing non-potable water supplies, such as agricultural users of non-potable water from the Waiahole Ditch. An example of an indirect benefit is one that might promote one of their organizational objectives such as promoting sustainability concepts and improving public relations through environmental stewardship. Such partnerships might result in direct funding of opportunities, or indirect funding through use of existing infrastructure.

No discussion has occurred to determine the interest of any potential partnerships. The respective County water supply agencies would all benefit potentially from reduced reliance on potable water supplies, but are not included as potential partnerships since this would apply equally to all opportunities.

Likelihood of Implementation

Many factors will determine the likelihood of implementation of any opportunity. Some of these factors, including cost, partnerships, institutional constraints, and potential demand, are covered by other evaluation criteria. This criterion considers other barriers and benefits that could influence implementation. These could be positive or adverse public acceptance, potential for multiple reuse approaches, and environmental benefits.

Institutional Constraints

Institutional constrains include rules and regulations, laws, and policies that would adversely affect an opportunity. Possible institutional constraints are discussed in a separate report titled Statewide Framework for Stormwater Reclamation and Reuse – Study Element 1.

Final Ranking of Opportunities

Once the Pairwise Comparison for each criterion was complete, the total points each opportunity received was multiplied by the weighting factor for the respective criterion. The products of the weighted values for each criterion were totaled, and the totals were used to rank the opportunities. The results of the combined Pairwise Comparisons are provided in Appendix B. The final ranking of each of the opportunities is shown in Table 20.

Table 20. Final Ranking of Stormwater Reclamation and Reuse Opportunities

Rank	Opportunity	Summary Description
1	**E-2 Kapolei Flood Control Channel**	Collect stormwater in a flood control channel in the Kapolei commercial/institutional area and use in injection wells to improve water quality for BWS non-potable wells.
2	**E-4 Honouliuli Recharge Trench**	Collect stormwater from the area in and around the Honouliuli WWTP for recharge of the Ewa caprock unconfined aquifer through an existing recharge channel.
3	**E-1 Makakilo Ridge**	Convey stormwater from the Makakilo Ridge development to the abandoned Makakilo WWTP for treatment and use the treated stormwater for recharge of the Ewa caprock unconfined aquifer.
4	**E-5 Fort Weaver Road Swale**	Collect stormwater from residential area and surface spread on a swale for recharge of the Ewa caprock unconfined aquifer.
5	**E-3 Fort Barrette Road Swale**	Collect stormwater from a drainage gulch on the east side of Makakilo Ridge and surface spread on a grassy swale along Fort Barrette Road for recharge of the Ewa caprock unconfined aquifer.

Appendix A - Cost Estimate Spreadsheet

Opportunity	Diversion	Low Head PS	Collection System	Conveyance System	Infiltration Trench	Injection Well	Fence	Land	Total Cost
E-1 - Makakilo Ridge	0	1,000,000	719,600	171,370	400,000	0	0	0	$4.2
Units	0	1	4233	2,016	1	0	0	0	
E-2 - Kapolei Flood Channel	50,000	1,000,000	0	233,750	0	426,000	0	0	$3.2
Units	1	1	0	2,750	0	8	0	0	
E-3 - Fort Barette Swale	50,000	1,000,000	0	25,500	0	0	120,800	23,000,000	$44.8
Units	1	1	0	300	0	0	3,920	0	
E-4 - Honouliuli Recharge	0	1,000,000	0	850,000	200,000	0	0	0	$3.8
Units	0	1	0	10,000	0.5	0	0	0	
E-5 - Fort Weaver Road Swale	0	1,000,000	0	279,225	0	0	153,200	7,000,000	$15.6
Units	0	1	0	3285	0	0	5,000	0	
E-7 - Waiahole Ditch Conveyance	0	0	0	1,165,690	400,000	0	0	0	$2.9
Units	0	0	0	13714	1	0	0	0	

Appendix B - Potential Reuse Demand Pairwise

Opportunity	E-1 Makakilo Ridge	E-2 Kapolei Flood Control Channel	E-3 Fort Barrette Road Swale	E-4 Honouliuli Recharge Trench	E-5 Fort Weaver Road Swale	Total
E-1 Makakilo Ridge		3	3	3	3	12
E-2 Kapolei Flood Control Channel	3		3	3	3	12
E-3 Fort Barrette Road Swale	3	3		3	3	12
E-4 Honouliuli Recharge Trench	3	3	3		3	12
E-5 Fort Weaver Road Swale	3	3	3	3		12

Appendix B - Cost Estimate Pariwise

Opportunity	E-1 Makakilo Ridge	E-2 Kapolei Flood Control Channel	E-3 Fort Barrette Road Swale	E-4 Honouliuli Recharge Trench	E-5 Fort Weaver Road Swale	Total
E-1 Makakilo Ridge		2	5	2	5	14
E-2 Kapolei Flood Control Channel	4		5	4	5	18
E-3 Fort Barrette Road Swale	1	1		1	1	4
E-4 Honouliuli Recharge Trench	4	2	5		5	16
E-5 Fort Weaver Road Swale	1	1	5	1		8

Appendix B - Potential Stormwater Volume Pairwise

Opportunity	E-1 Makakilo Ridge	E-2 Kapolei Flood Control Channel	E-3 Fort Barrette Road Swale	E-4 Honouliuli Recharge Trench	E-5 Fort Weaver Road Swale	Total
E-1 Makakilo Ridge		2	1	3	3	9
E-2 Kapolei Flood Control Channel	4		2	4	4	14
E-3 Fort Barrette Road Swale	5	4		1	2	12
E-4 Honouliuli Recharge Trench	3	2	5		3	13
E-5 Fort Weaver Road Swale	3	2	4	3		12

Appendix B - Potential Partnerships Pairwise

Opportunity	E-1 Makakilo Ridge	E-2 Kapolei Flood Control Channel	E-3 Fort Barrette Road Swale	E-4 Honouliuli Recharge Trench	E-5 Fort Weaver Road Swale	Total
E-1 Makakilo Ridge		1	3	2	3	9
E-2 Kapolei Flood Control Channel	5		4	3	4	16
E-3 Fort Barrette Road Swale	3	2		2	3	10
E-4 Honouliuli Recharge Trench	4	3	4		4	15
E-5 Fort Weaver Road Swale	3	2	3	2		10

Appendix B - Likelihood of Implementation Pairwise

Opportunity	E-1 Makakilo Ridge	E-2 Kapolei Flood Control Channel	E-3 Fort Barrette Road Swale	E-4 Honouliuli Recharge Trench	E-5 Fort Weaver Road Swale	Total
E-1 Makakilo Ridge		1	2	2	3	8
E-2 Kapolei Flood Control Channel	5		4	4	4	17
E-3 Fort Barrette Road Swale	4	2		2	3	11
E-4 Honouliuli Recharge Trench	4	2	4		4	14
E-5 Fort Weaver Road Swale	3	2	3	2		10

Appendix B - Institutional Constraints Pairwise

Opportunity	E-1 Makakilo Ridge	E-2 Kapolei Flood Control Channel	E-3 Fort Barrette Road Swale	E-4 Honouliuli Recharge Trench	E-5 Fort Weaver Road Swale	Total
E-1 Makakilo Ridge		2	3	2	3	10
E-2 Kapolei Flood Control Channel	4		4	3	4	15
E-3 Fort Barrette Road Swale	3	2		2	3	10
E-4 Honouliuli Recharge Trench	4	3	4		4	15
E-5 Fort Weaver Road Swale	3	2	3	2		10

Appendix B - Combined Pairwise

Opportunity	Potential Reuse Demand	Weight	Total	Cost Estimate	Weight	Total	Potential Stormwater Volume	Weight	Total	Potential Partnerships	Weight	Total	Likelihood of Implementation	Weight	Total	Institutional Constraints	Weight	Total	Total
E-1 Makakilo Ridge	12	0.19	2.28	14	0.18	2.52	9	0.17	1.53	9	0.16	1.44	8	0.16	1.28	10	0.13	1.3	10.4
E-2 Kapolei Flood Control Channel	12	0.19	2.28	18	0.18	3.24	14	0.17	2.38	16	0.16	2.56	17	0.16	2.72	15	0.13	1.95	15.1
E-3 Fort Barrette Road Swale	12	0.19	2.28	4	0.18	0.72	12	0.17	2.04	10	0.16	1.6	11	0.16	1.76	10	0.13	1.3	9.7
E-4 Honouliuli Recharge Trench	12	0.19	2.28	16	0.18	2.88	13	0.17	2.21	15	0.16	2.4	14	0.16	2.24	15	0.13	1.95	14.0
E-5 Fort Weaver Road Swale	12	0.19	2.28	8	0.18	1.44	12	0.17	2.04	10	0.16	1.6	10	0.16	1.6	10	0.13	1.3	10.3

Final Ranking

E-2 Kapolei Flood Control Channel	15.1
E-4 Honouliuli Recharge Trench	14.0
E-1 Makakilo Ridge	10.4
E-5 Fort Weaver Road Swale	10.3
E-3 Fort Barrette Road Swale	9.7