Wastewater Pollution Management in Hawai'i:

Policy & Spatial Data-Based Solutions for Cesspool Conversions

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UCLA

INTRODUCTION

The Hawaiian islands are home to some of the most biodiverse ecosystems in the world, providing a broad range of ecosystem services, economic benefits, and cultural value. Hawaiʻi's coral reefs alone are estimated to provide more than $863 million in value for the islands each year[1]. This includes supporting numerous endemic species, providing food and natural protection against storms and floods, recreational and tourism attraction and income, and inherent cultural significance as a life source for the islands. However, these vital marine ecosystems, along with the populations they support, are increasingly threatened by onsite disposal systems (OSDSs), particularly cesspools, which pollute coastal and groundwaters and cause significant damage to aquatic life and human health.

Wastewater infrastructure across the state of Hawai'i relies heavily on onsite disposal systems. Some 88,000 cesspools are located across the islands (more than 80% of all OSDS). Altogether, cesspools in Hawaiʻi release 55 million gallons of untreated sewage into the ground and groundwater daily. Tracer studies have shown that in as little as four hours from disposal, groundwater can carry this sewage directly into the ocean. The pollution generated by inadequate wastewater infrastructure threatens groundwater resources, coastal ecosystems, coral reefs, and human health.

This report aims to provide a general background detailing the issue of cesspools in Hawai'i as well as explain the two-fold research that has been conducted by our team. One component was to perform a spatial analysis of existing cesspools to prioritize cesspool conversion and identify opportunities to implement water reuse. The second component was to conduct legal research in order to produce a database for legislators to use for guiding cesspool conversion to more environmentally safe systems, particularly installation of septic systems; the database outlines existing policies in Hawai'i, regulations that have been accomplished in other states, and specific factors to consider. The combination of spatial analysis and policy would help educate, inform, and provide suggestions to improve wastewater infrastructure.

BACKGROUND

Cesspool Infrastructure

A cesspool is an underground holding tank, little more than a pit, through which wastewater seeps into the ground and gravitationally separates into liquids and solids, but does not undergo filtration or treatment. Cesspools are generally used in rural areas where centralized sewer pipe systems and municipal treatment plants are inaccessible or where spatial and soil conditions are inadequate for leachfields. Naturally occurring anaerobic bacteria convert organic solids into liquids, which then percolate from the underground holding tank into the soil[2]. Since cesspools have no mechanism for waste filtration, the surrounding soil can eventually become contaminated by the wastewater effluent.

OSDSs include all household-level treatment systems, including septic systems and cesspools, which are especially prevalent in Hawaiʻi. An OSDS is a "complete wastewater system installed on a parcel of land, under the control or ownership of any person, which accepts ultimate sewage disposal under the surface of the ground of the parcel where the wastewater is generated"[3]. OSDSs pose a substantial threat to human health due to their potential to release contaminants into groundwater and coastal areas where ingestion of pathogens and contaminants may occur. Pathways of pollution include chronic or recurring pollution from land run-off, recreation, and ingestion. Effluent can mix with waters during flooding events, which can result in direct human contact[4]. Due to the lack of maintenance and poor conditions of cesspools in Hawaiʻi, they pose a higher risk to human health than any other type of OSDS[5].

Pathogens are a major concern from OSDS because pathogens in drinking water from groundwater sources are a human health risk. Typical pathogens in wastewater are bacteria, protozoa, viruses, and nematodes that affect humans through ingestion or contact with the water[6]. Pathogens such as ***E. coli***, ***salmonella***, enteric viruses, and coliphages have been found in groundwater from septic tank sources. ***E. coli*** is a bacteria commonly associated with raw wastewater pathogens, it can cause an array of symptoms ranging from skin irritations to death[7]. There are over 180 million global cases of upper respiratory disease and gastroenteritis that occur each year due to humans swimming in polluted ocean waters, especially with higher levels of human sewage in coastal waters[8].

Hawaiian Wastewater History

Hawai'i's rapid urbanization in the twentieth century, geological and geographical limitations, and the islands' popularity for tourism create an increasingly urgent demand for improved infrastructure to safely dispose of human waste. The history of colonization on the islands directly challenged Native Hawaiian's ways of life and self-governing. Disputes over water grew due to fundamentally differing concepts of resource ownership between Westerners and Native Hawaiians. Eventually, the Western government claimed rights to the water supply, which allowed them to divert water away from watersheds. This led to rapid urbanization of towns and seaports. As the population grew, infrastructure struggled to keep up. Hawai'i grappled with a changing economy and westernization, which led to inadequate urban planning and infrastructure development. As a result, rather than well-devised sewer and centralized treatment systems, residences across the islands were left without funding or planning, and built cesspools or other onsite systems. Cesspools do not adequately address environmental and human health concerns, and the consequences of improper wastewater infrastructure has become one of Hawai'i's most pressing unresolved issues[9].

Beyond the pressures of colonization and population growth, Hawai'i also has natural geographical and geological limitations to its wastewater infrastructure capabilities. Because Hawai'i is an isolated archipelago with many rural communities, building centralized wastewater disposal systems is challenging and expensive to implement. Additionally, geological constraints such as coastal soil types with poor drainage and a shallow water table make it difficult to implement advanced treatment systems, which are another extremely costly venture. These natural constraints combined with Hawai'i's history have created a major physical and economic problem in terms of improving wastewater infrastructure.[10]

The natural geological constraints to wastewater infrastructure in Hawai'i have become further exacerbated by climate change. Especially for islands like Hawai'i, sea level rise poses a severe threat to coastal infrastructure. According to the IPCC, the Hawaiian islands are projected to be extremely impacted by rising sea levels, increased sea surface temperature, and extreme weather events. Projections show sea level increasing by 10 - 12 inches by mid-century (around 2050) and up to 3.5 - 7 feet by the end of this century. Furthermore, flooding is expected to become 10 times as frequent and temperatures are expected to increase 1.5ºC or more by 2050. Hawai'i, has already experienced a sea level rise of over 10 inches since 1950, and the rate of increase is only accelerating.

Wastewater infrastructure in Hawai'i is impacted by groundwater inundation, which has increasingly worsened as a result of sea level rise. Groundwater inundation, defined as when the groundwater table rises above the surface or buried infrastructure, can happen for a variety of reasons both along or away from the coast, such as rising sea levels or heavy precipitation. Much of coastal Hawai'i has a very shallow groundwater table naturally. Several current studies claim that groundwater depth reaches a critical shallow level at <1.5m below ground level[11]. One case study in in Waikiki on the island of Oahu found that 42% of the area features groundwater depths shallower than 1.3 m[12]. Areas along the coast are highly impacted by sea level increases through rising groundwater levels that are hydraulically connected to (and fluctuate with) the marine environment and tidally-influenced water bodies[13]. Since the groundwater table is rising alongside local mean sea level, flooding of the surface is occurring more often, and is already impacting surface and buried infrastructure such as cesspools[14]. As climate change worsens, it will further exacerbate cesspool pollution of groundwater and the ocean.

Wastewater infrastructure can be broadly categorized into two primary systems: centralized sewer systems and onsite disposal systems. Wastewater treatment can be categorized as either solid treatment or liquid effluent treatment. Solids and liquids are typically moved in larger pipes, treated to remove solids, and the effluent is either injected, reused or transported offshore.

These individual wastewater systems or OSDSs include seepage pits, septic systems, and cesspools.
The EPA recognizes that OSDS can provide an alternative to centralized sewer systems, especially for rural

communities with economic barriers. However, conventional OSDS often do not properly eliminate all pathogens, chemicals, and nutrients, which creates pollution hazards. The EPA concluded in its Guidance for Federal Land Management in the Chesapeake Bay Watershed that conventional OSDS are not appropriate for communities with nutrient-sensitive watersheds, and that site-specific conditions must be analyzed in order to determine an appropriate system[15, 16].

In a septic system, solids are removed onsite and the leach field distributes the effluent which is treated by soil. The efficiency of that treatment is related to soil properties.A septic system relies upon a small-scale wastewater treatment tank that separates, stores, and treats waste and then slowly distributes the effluent into a drainage field where biological processes from bacteria further treat the wastewater. In a well-functioning septic system, wastewater and solids are mostly broken down in the septic tank from bacteria, then the effluent flows through the distribution system of pipes slowly into the drainfield and into the soil. The ground must be suitably conditioned before a septic tank can be implemented; the soil must be deep enough to treat the wastewater before it reaches the groundwater and the right texture so that water does not flow too quickly or too slowly before reaching groundwater. Septic tanks have the potential to overflow when their facility administrators are unaware of the level of wastewater distributed underground. Wastewater releases harmful toxins and pollutants into the groundwater.

There are a variety of disposal system technologies used in conjunction with septic systems. Seepage pits are oriented vertically underground and collect gray water from septic tanks, which is then slowly dispersed and absorbed by surrounding soils. A seepage pit is similar to a cesspool, except for the fact that it only receives wastewater from a septic tank. Absorption systems, or leach fields, are another important disposal system technology used by septic systems. Leach fields consist of many horizontal, perforated pipes where pretreated wastewater slowly percolates into the soil. Unlike seepage pits and cesspools, leach fields allow the wastewater to undergo a filtration process. Evapotranspiration septic systems channel treated wastewater into a drainfield lined with watertight material so that the wastewater never filters through the soil or is discharged into the groundwater.

Although some soils can treat pollutants in effluent from OSDS to varying degrees through filtration and sorption processes, this is not always the case near coastal areas, streams, or other sensitive areas. Volcanic lava tubes can additionally transport pathogens to aquifers and coastal regions, contaminating drinking water and water used for recreation. Approximately 99% of the state of Hawai'i receives drinking water from groundwater[24]. OSDS effluent can also mix with waters during flooding events and result in direct human contact or further pollute water drinking sources[25].

Hawai'i is also facing significant threats to its general water supply. Hawai'i is estimated to use 196 million gallons of water per day for domestic use[26]. However, Hawai'i has seen a decrease in overall rainfall within the last 30 years and is expected to have more droughts with climate change projections. Declines to precipitation lead to diminishing stream flows and groundwater recharge, which can reduce freshwater supply. While the state has been investigating numerous approaches to solve this issue, including conservation and wastewater recycling, supplemental strategies should be considered. Hawai'i is currently utilizing approximately 19 million gallons of recycled water per day. These efforts are still in early stages and address only a drop in the bucket of the pressing problem at hand.

Existing Law

In response to the detrimental impacts of onsite disposal systems on human and environmental health, local and state governments have prioritized cesspool removal and replacement. In 2016, Hawai'i became the last U.S. state to ban the construction of new cesspools. The state additionally mandated that all existing cesspools be converted to more sanitary waste disposal systems, such as septic systems (which pose their own risks) or sewer connections, by 2050. Implementation of this policy, however, presents complicated fiscal and spatial obstacles. For example, septic systems, while more environmentally sound than cesspools, are still OSDS and therefore subject to similar pollution concerns. Ideally, existing cesspools would be replaced and connected to public treatment systems, but this option can be more expensive and demanding than septic system conversion[17].

There is a large economic disparity relating to cesspool replacement in Hawai'i. The financial burden of upgrading cesspools to septic systems or sewer connections can range from $10,000 to $50,000 per property, a considerable concern for property owners[18]. It is generally more costly to connect to sewer lines than to implement a septic system, and despite state government efforts to provide financial assistance to the upgrades, demand far exceeds the available funding.

• ***Federal Laws***: Wastewater discharge is governed at the federal level by the Clean Water Act (CWA). The CWA is overseen by the EPA, which implements pollution control programs and sets minimum standards for water quality, including wastewater discharges, and enforces provisions of the Act[19]. Section 402 of the Clean Water Act requires that any discharge of pollutants from a point source to a water of the United States obtain a permit under the National Pollutant Discharge Elimination System (NPDES) program[20]. This includes discharges from industrial and municipal wastewater dischargers. These permits specify the effluent limitations for certain pollutants and require that dischargers employ the necessary technology to meet them.

The CWA also requires that states set water quality standards for each body of water within the state. These standards work as a safety net for discharge requirements by identifying areas where further pollution control is necessary. States also must identify as impaired any water bodies that fail to meet water quality standards[21]. For impaired waters, states must establish total maximum daily loads (TMDLs)[22], which set a daily limit on the discharge of each pollutant at a level necessary to achieve water quality standards.

• ***Hawai'i State Laws:*** At the state level, wastewater discharge in Hawai'i is governed by Chapter 342D of the Hawai'i Revised Statutes, the state's legal codes. Chapter 342D focuses specifically on water pollution. It is made up of six parts, which detail the administration, penalties, control standards and methods, and finances. Rules and regulations adopted by Hawai'i's Department of Health (DOH) under Title 11 of the Hawai'i Administrative Rules implement the state statutes and provide additional detail on wastewater standards and requirements. Four different chapters of Title 11 are relevant to wastewater. Those are chapters 23, 54, 55, and 62, which deal with underground injection control, water quality standards, water pollution control, and wastewater systems, respectively.

• ***Hawai'i County Laws:*** Each of Hawai'i's five counties (Hawai'i, Honolulu, Kalawao, Kaua'i, and Maui) have their own legal codes. The method in which each county addresses wastewater differs, ranging from focusing purely on sewers, specifically Hawai'i and Kaua'i county, to a more general focus on wastewater flow into county wastewater systems, for example, as given in chapter 20.16 in the Maui county code. While the counties do regulate smaller wastewater treatment facilities to varying extents, none of them regulate cesspools or septic systems, with the exception of Honolulu County, which sets guidelines on maintenance and servicing.

• ***Cesspool Conversion Working Group:*** The Hawaii State Legislature found that Hawai'i's groundwater, drinking water, and marine waters are being harmed from the pollution of cesspools. In response to this, Act 132 of Hawai'i House Bill 2567 (2018) was signed into law with the purpose of establishing a Cesspool Conversion Working Group (CCWG) to develop a long-term plan to upgrade, convert, or connect to sewer systems all cesspools across Hawai'i by 2050. The CCWG was created within the Department of Health and consists of experts and agencies ranging from the Hawai'i Senate, House of Representatives, U.S. EPA Region 9, and the Wastewater Branch of DOH, as well as non-profits including the Surfrider Foundation and the Coral Reef Alliance. The CCWG has a long list of objectives including, but not limited to, determining a prioritization classification of cesspools for conversion, coming up with solutions to convert cesspools to a more environmentally-focused waste treatment system or to connections to existing sewer systems, consider factors that may inhibit an owner to pay for conversion and how assistance can be provided for low-income homeowners, and provide a cost-effective approach with considering alternative wastewater equipment and technologies[23].

RESEARCH FOCUS

There are three main components to our team's research: potential for water reuse, location of sewer overflows as a proxy for collection system condition, and policy levers for expedited upgrades. These are all important aspects to consider for more sustainable wastewater management in Hawaii moving forward.

Our team has conducted an analysis of existing wastewater infrastructure to identify opportunities for conversion of cesspools to firstly improve the level of treatment and secondly consider the possibility of water reuse. We conducted an additional, separate analysis of recent sewage spills across the Hawaiian Islands to identify recurring problem spots that may be impacting water quality and public health.

While we used spatial analysis to examine sewer and cesspool data, we also considered the conversion from cesspool to septic system through the policy side of our project. Under Hawaiian legislation, specific requirements must be met for septic system installation. Our goal was to compare Hawaiian legislation or regulation to that of other states that have successfully converted from cesspools to septic systems, to further model potential changes that could be implemented in Hawai'i. This would potentially make conversions to septic more feasible and therefore more prevalent, accelerating the transition away from cesspools.

SPATIAL ANALYSIS

Background

To facilitate opportunities for conversion of cesspools into more effective and sustainable approaches for wastewater treatment, we conducted a set of spatial analyses to identify areas where existing cesspools should be prioritized for action based on a set of specific parameters, including the existence of current sewer infrastructure. To identify potential secondary benefits that cesspool conversion may provide, we also determined areas of opportunity on the island of Hawai'i where wastewater from cesspool conversions could be diverted to centralized sewer systems and captured and treated for wastewater reuse. We conducted an additional investigation into sewage overflow spills in Honolulu to assist in identifying problematic areas polluting the ground and marine water sources.

• ***Existing Cesspools:*** The Hawai'i DOH Wastewater Branch has a database of cesspools throughout the islands originally created by Robert Whittier and Aly El-Kadi, but it has not been maintained or updated. In 2017, the Hawai'i State Legislature passed House Bill 1244, Act 125 calling for the replacement of all cesspools by 2050, and giving the responsibility of evaluating which cesspools hold the highest priority for upgrades to the DOH. The CCWG then created a three-tiered prioritization for cesspools focusing on risks of human impacts, drinking water impacts, and drainage to sensitive waters.

The DOH also adopted a spatial analysis layer consisting of 83,000 cesspools across all Hawaiian islands to assess the health and environmental risks presented by OSDS. The layer was created using permit locations of OSDSs and placing them at the centroid of properties. OSDSs that had documented connections to sewer systems were removed from the database. The layer was not ground-truthed because of capacity limitations.

The layer is available to the public through the Hawai'i Statewide GIS Program Geospatial Data Portal. The last time this spatial layer was updated, however, was in 2010. It was not until

2016 that the State of Hawai'i banned the construction of new cesspools. As a result of this six-year gap, there is the potential of newly constructed cesspools not being reflected in the onsite disposal system spatial layer available to download, and OSDS that were converted to either septic or added to sewer connections are not considered. To address this discrepancy, we aimed to identify areas of new development and residences that could represent areas of newly constructed cesspools.

• ***Cesspool Prioritization:*** Both the CCWG Cesspool Conversion Plan and the University of Hawai'i have previously created cesspool prioritization tools focused on possible health impacts downstream, but did not consider which cesspools would be easier to upgrade, have most impact on coastal systems, or would be beneficial for other uses such as reuse. For this project our cesspool priority tool aimed to focus on the proximity of wastewater infrastructure such as sewer mains and wastewater treatment plants to cesspools that hold potential for conversion solutions. This prioritization investigation was conducted across all of the main islands of Hawai'i.

• ***Identifying Areas of Water Reuse:*** We wanted to identify cesspool-dense regions that could provide a high potential for water reuse by redirecting effluent to wastewater treatment plants through existing sewer lines. We identified parcels where conversion would create additional water that could be recycled into nearby areas of need.

· ***Mapping the Frequency of Sanitary Sewer Overflows (SSOs):*** As a separate analysis, we investigated the history of sewage overflow spills across all islands since 2009. Our goal was to identify and note sewage spill locations to determine if specific areas' patterns could potentially be contributing to water quality and health problems. This information could then be used to inform decisions about where infrastructure upgrades would be necessary to help mitigate spills.

Using historical sewage overflow data from the Hawai'i Department of Health's Environmental Health Portal, we were able to obtain information on sewage overflow spill location, time, cause, and effluent released. To further this analysis, we overlaid the 2020 Census county and watershed boundaries from the Hawai'i Statewide GIS Program to attribute spill locations to administrative and natural regions. The data was then integrated into a dynamic R Shiny application to allow for map and summary statistic generation.

Sewage Spill Results

Table I. Summary Statistics for Number of Spills and Total Spill Volume in Gallons by County

County	Number of Spills	Total Spill Volume (in Gallons)
Honolulu	230	54,414,412
Hawai'i	33	3,429,478
Maui	10	271,525
Kaua'i	21	34,350
Totals	**296**	**58,149,765**

Methods

• ***Identifying Cesspool Locations:*** Our first goal was to identify the location of all cesspools, given that the 2010 OSDS layer from the DOH is now outdated and likely incomplete, as mentioned above. We targeted newly developed residential areas across all islands of Hawai'i to identify new potential cesspool locations. Development that occurred after the 2010 DOH spatial data layer was updated, but before the 2016 legislative ban on cesspools, could include cesspools not identified in the DOH spatial data layer. Similarly, previously mapped cesspools could have been converted in the years since the last spatial update.

The 2005 and 2021 CCAP Regional Land Cover data obtained from NOAA uses remote sensing technology to inventory land cover and change analysis datasets. This was used to compare and identify residential areas of new development. The 2021 CCAP Impervious Surface and Land Cover dataset was used, despite cesspools being banned in 2016, because the only other dataset available for Hawai'i was from 2015. Had we used the 2015 data, there would still be a one year gap when development could have occurred, and it is also likely that cesspools were still being constructed after the 2016 ban due to pre-approved construction and development plans.

The extent of high intensity develoed areas, defined by the CCAP dataset, includes apartment complexes, housing communities, resorts, commercial, and industrial areas were isolated and compared between 2005 and 2021. These areas are likely to have the highest density of cesspools. To verify the results from this comparison, the output data layer was ground-truthed using Google Earth Pro. Areas identified as newly developed were inspected by hand using the time slider feature in Google Earth Pro to determine if and when a new structure was added. Given the sheer size of the resulting dataset for the entire state of Hawai'i, only our areas of interest were ground-truthed and the focus was primarily on new large developments, rather than individual houses.

• ***Prioritizing Cesspools:*** Once the locations of known and potentially new cesspools were mapped, we then worked to prioritize these cesspools for conversion based on a variety of geographic and demographic factors. In 2023, the Cesspool Conversion Plan produced by the CCWG updated their three-tiered cesspool prioritization classifications to additionally focus on levels of contamination hazards. While useful for identifying those contamination concerns, the prioritization tool is limited in that it does not consider the presence of existing infrastructure elements, including sewer mains. The University of Hawai'i Sea Grant had also previously developed a map-based tool that prioritized Hawai'i's cesspools for conversion based on their proximity to sensitive natural resources (coral reefs) and areas that could have a direct impact on human health (including drinking wells, beaches, and other factors). Each census tract in Hawai'i was given a priority level, ranging from 1 to 3, with 1 having the greatest potential to impact human health and the environment.

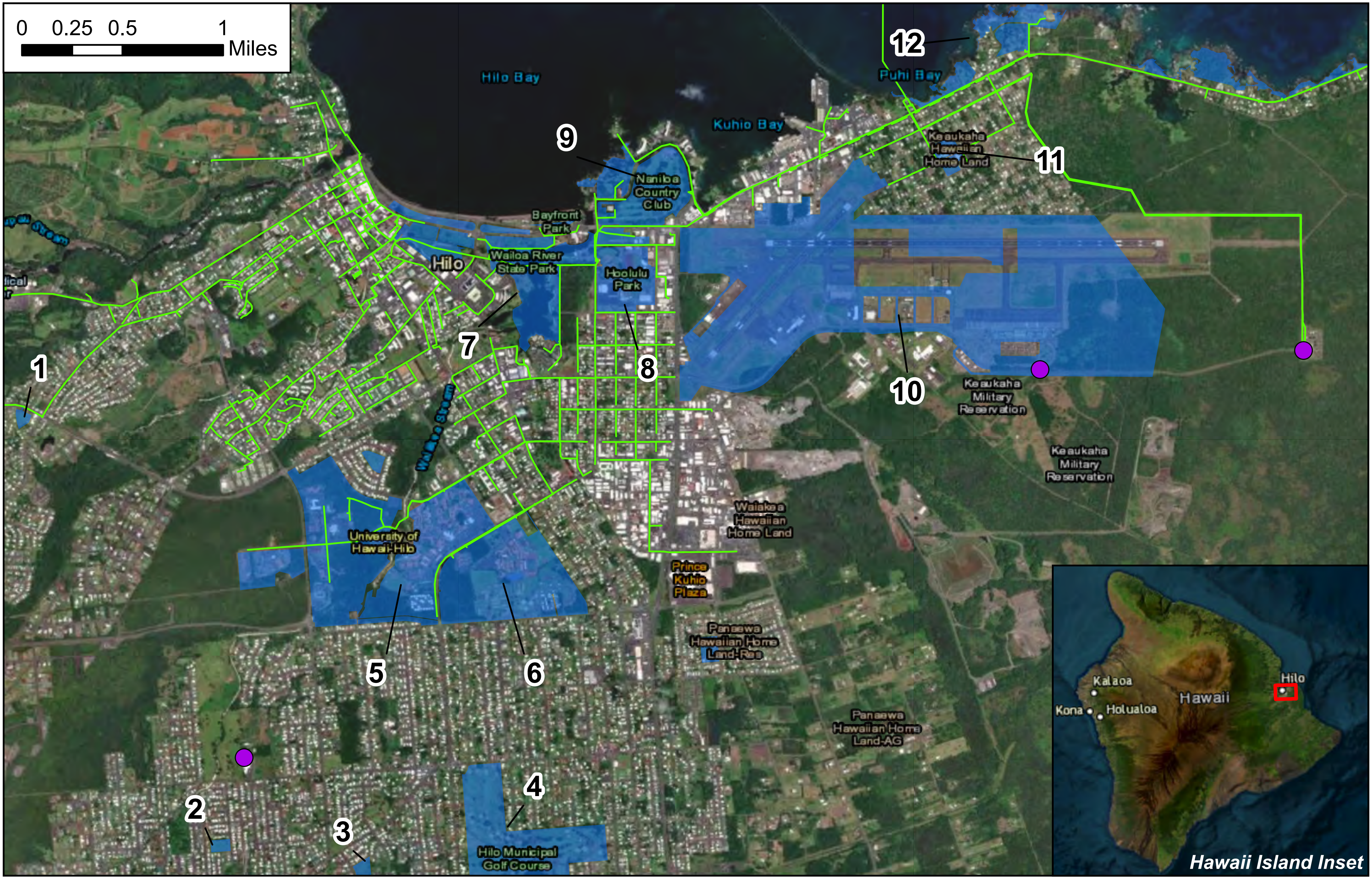
To build off of the University of Hawai'i's effort, we identified an additional set of factors that are important to consider when prioritizing cesspool upgrade and conversion efforts. The key difference between our research efforts and the University of Hawai'i's is that we focused on the proximity of cesspools to sewer mains and wastewater treatment plant locations because tying a property into existing sewer lines is often less costly, less disruptive and more environmentally friendly than upgrading on-site. Other factors in our analysis include the distance to coastline, presence of newly developed areas (as previously mentioned), and disadvantaged census tracts from the Climate and Economic Justice Screening Tool (CEJST).

Parcels consisting of cesspools that intersect within 500-ft of a sewer main and within one mile of a WWTP have a greater potential for water reuse since infrastructure exists to connect the area to sewer lines and redirect the water from a cesspool to a treatment plant. The known rise in the groundwater table associated with sea level rise also poses a risk to cesspools near the coastline, meaning cesspool parcels that fall within 500-ft of a coastline represent another high-priority area. Parcels that have been developed between 2005 and 2021 could represent new cesspools not accounted for in the 2010 OSDS layer or areas where cesspools could already have been converted to septic or sewer. Further investigation using Google Earth Pro and searching through building permits is required to determine what year this parcel was developed, and if the cesspool has been upgraded. These next steps are underway, with a project at NOAA looking to support a statewide upgrade of the DOH database with permit applications, and a project with NASA's Jet Propulsion Lab to create a finer-scale infrastructure layer using artificial intelligence. For new development identified using the C-CAP dataset, further investigations using permit data or other information would be necessary to assess whether each individual site has a cesspool or OSDS, or whether the parcel is connected to a sewer line.

Water Reuse Parcels & Cesspools

• ***Results:*** Our study aimed to address wastewater management in Hawai'i, focusing on the potential conversion of cesspools to sewer systems and identifying regions suitable for water reuse.

The results show the number of OSDS parcels within each of our AOIs, highlighting large ranges of distribution across islands. For example with proximity to sewer mains, locations including He'eia, Kahalu'u, and Kīhei have over 30% of identified OSDS parcels within 500 feet of sewer lines, while others like Anahola, Hana, and Wainiha display no parcels within 500 feet of sewer mains. This disparity in data is likely due to the lack of sewer maps available in these areas of interest, showing the regional differences in cesspool data accessibility and conversion efforts. In terms of the coastal presence of OSDS parcels, several locations like Hana, Kahalu'u, and Wainiha have a significant percentage of parcels near the coast, which raises concerns about potential marine impacts as these tend to be low-lying and close to sea level. Furthermore, Kealakehe and Wainiha stand out in access to wastewater treatment plants as over 90% of OSDS parcels in these areas are located within one mile of a treatment plant, giving them high potential for conversion and water reuse opportunities in the future. Moloka'i and Wainiha also have a high presence of OSDS parcels within CEJST Low Income Disadvantaged Communities boundaries, making them priority areas for conversion efforts. These results can inform conversion and policy efforts through the insights into the spatial distribution, accessibility, and socio-economic considerations of OSDS parcels in Hawai'i.



WWTP

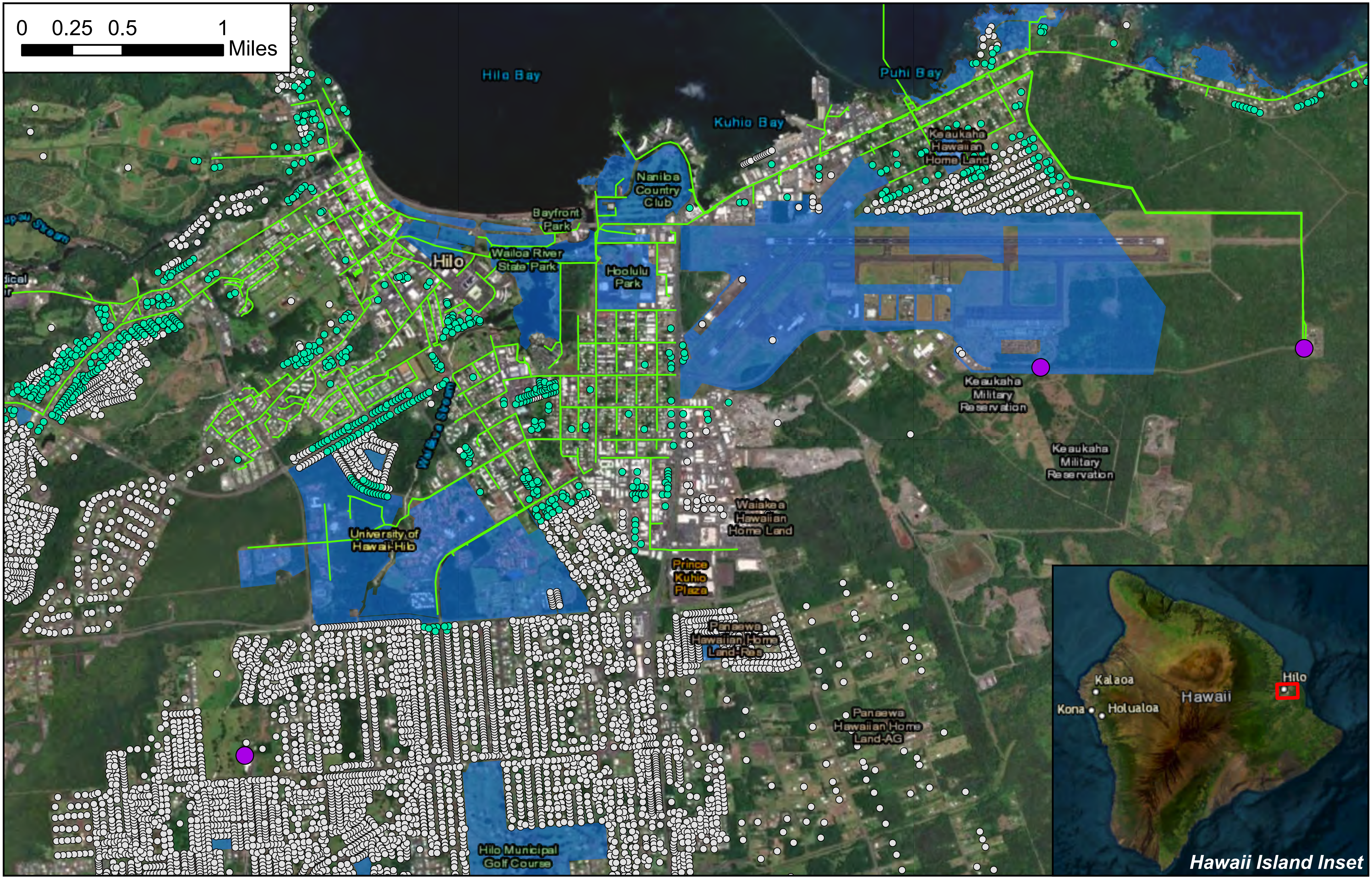
Existing Sewer Mains

Potential Water Reuse Areas

Golf Courses, Parks, Schools, Airports

Reuse Locations

1 - University Heights Park
2 - Ahualani Park
3 - Machado Acres Park
4 - Hilo Municipal Golf Course
5 - University of Hawaii, Hilo
6 - Waiakea High School
7 - Wailoa River State Park
8 - Hoolulu Park
9 - Naniloa Country Club and Golf Course
10 - Hilo International Airport
11 - Hualani Park
12 - Beach Parks



WWTP

Existing Sewer Mains

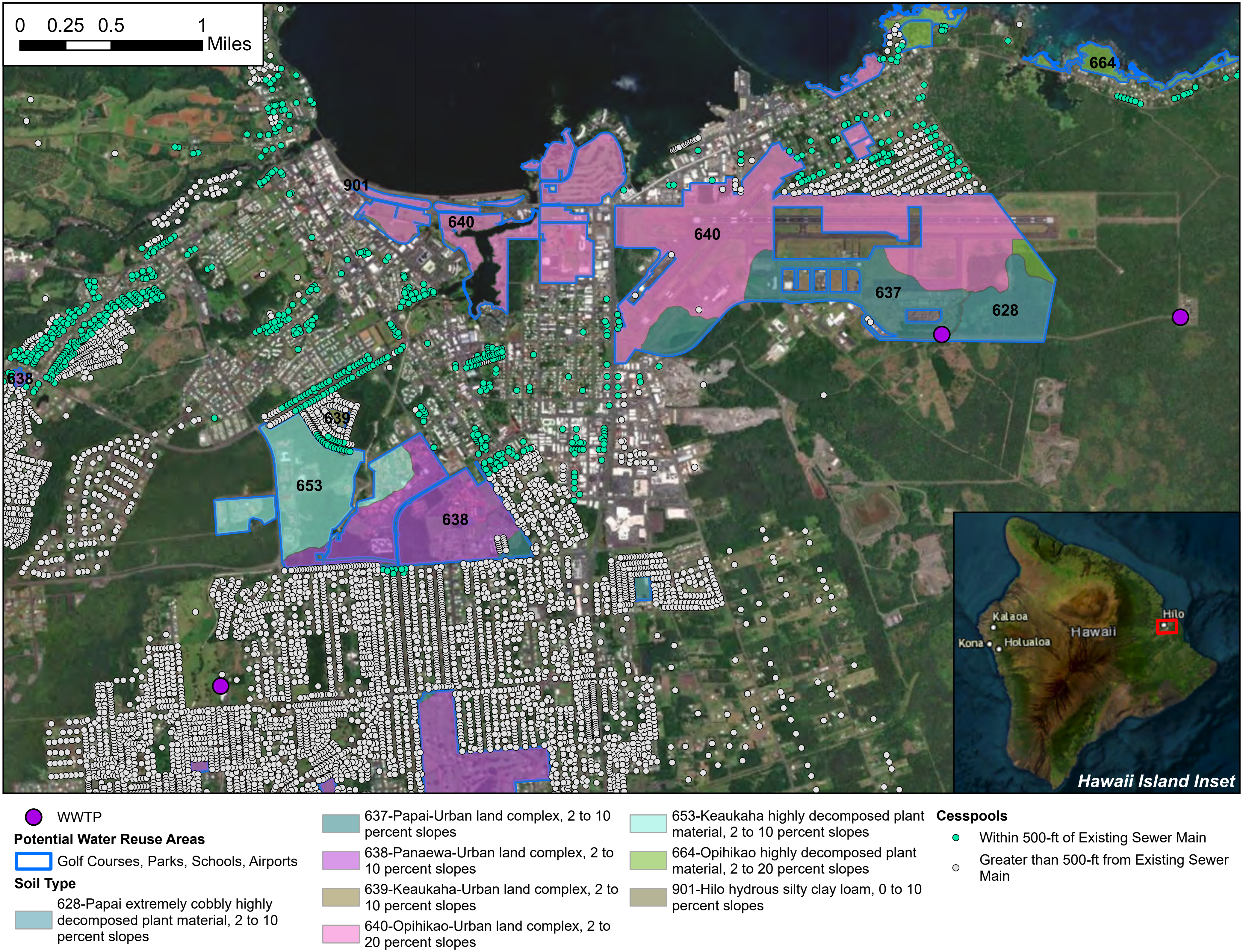
Potential Water Reuse Areas

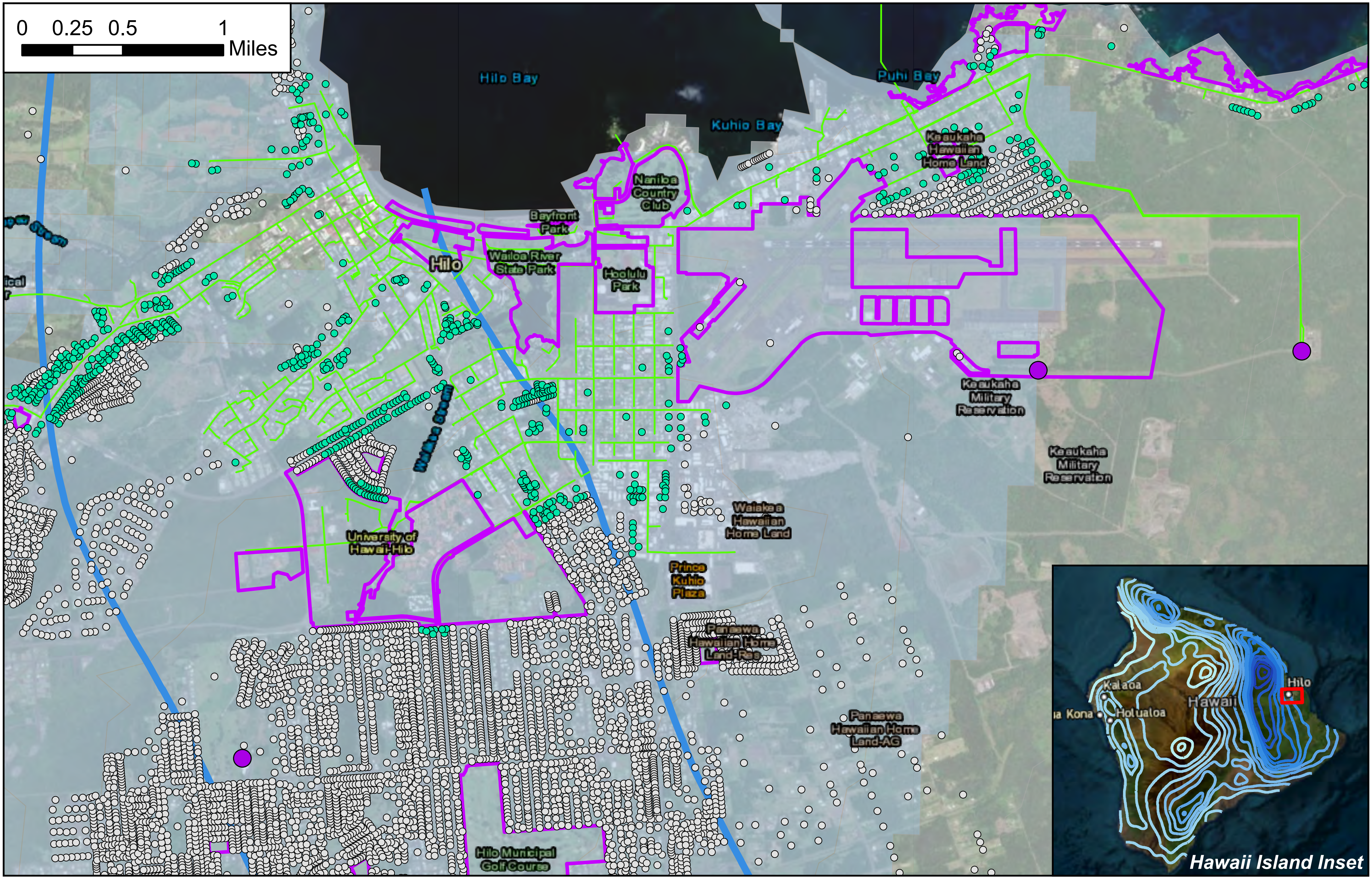
Golf Courses, Parks, Schools, Airports

Cesspools

Within 500-ft of Existing Sewer Main

Greater than 500-ft from Existing Sewer Main


0 0.25 0.5 1 Miles
901
640
640
637
628
664
638
639
653
638
Hawaii Island Inset
Kalaoa
Kona
Holualoa
Hawaii
Hilo
WWTP
Potential Water Reuse Areas
Golf Courses, Parks, Schools, Airports
Soil Type
628-Papai extremely cobbly highly decomposed plant material, 2 to 10 percent slopes
637-Papai-Urban land complex, 2 to 10 percent slopes
638-Panaewa-Urban land complex, 2 to 10 percent slopes
639-Keaukaha-Urban land complex, 2 to 10 percent slopes
640-Opihikao-Urban land complex, 2 to 20 percent slopes
653-Keaukaha highly decomposed plant material, 2 to 10 percent slopes
664-Opihikao highly decomposed plant material, 2 to 20 percent slopes
901-Hilo hydrous silty clay loam, 0 to 10 percent slopes
Cesspools
Within 500-ft of Existing Sewer Main
Greater than 500-ft from Existing Sewer Main



WWTP

Existing Sewer Mains

Potential Water Reuse Areas

Golf Courses, Parks, Schools, Airports

Annual Rainfall Contour (inches)

121 - 160

Groundwater Depth (feet)

0 - 2

2 - 10

Cesspools

Within 500-ft of Existing Sewer Main

Greater than 500-ft from Existing Sewer Main

WWTP

Potential Water Reuse Areas

Golf Courses, Parks, Schools, Airports

Hawaii County Zoning District

Agriculture

General Commercial District

Commercial Neighborhood

Family Agriculture

Industrial-Commercial Mixed District

General Industrial District

Limited Industrial District

Open

Project

Residential and Agricultural District

Residential-Commercial Mixed Use

Double-Family Residential District

Multiple-Family Residential District

Single-Family Residential District

University

Resort-Hotel

• ***Discussion:*** Water reuse presents a more long term solution when considering cesspool conversion compared to septic. Especially considering Hawai'i's growing issues with wastewater infrastructure and water supply, incorporating cesspool data is essential to determining areas with the highest potential for reuse. Based on our results, there is considerable potential for cesspool conversion to sewer in our AOIs of Hilo, Kīhei, and Mauna Kea. The figures and data for areas of potential water reuse highlight the patterns of what regions are eligible. Within our AOIs, the regions of Hilo, Hōlualoa, and Honoka'a show that water reuse parcels generally are found in open zoning land types, especially parks, where there are multiple options for each of these regions. There is also significant potential for schools and universities, and golf courses in each of these regions to consider reuse. There are additional zoning land types of residential and agricultural potential as well. In Hilo, industrial zoning areas, such as the Hilo International Airport may benefit from reuse. The Hilo region also experiences the highest rainfall compared to any other region in Hawai'i, and is one of the wettest cities nationally, reaching 130 inches of rainfall annually. Because of this, the potential for water reuse is even higher, beyond just wastewater reuse. Including the element of potential water reuse expands upon the CCWG 2023 update by incorporating wastewater infrastructure data to determine cesspool-dense regions that have high potential for water reuse.

Table II. Summary statistics for the distribution of OSDS parcels across our AOIs along with their proximity to various features such as sewer mains, coastlines, WWTPs, CEJST's Low-Income and Disadvantaged Communities (LIDAC), and newly developed parcels.

Area of Interest (AOI)	Island	Total OSDS (in AOI)	# Within 500-ft of Sewer Main	# Within 500-ft of Coast-line	# Within 1-Mi of WWTP	# Within CEJST LIDAC	# Within Newly Developed Parcel (2005 to 2021)
Note: "–" indicates no data available							
Hilo	Hawai'i	10537	969 (9.2%)	54 (0.5%)	2829	2867	74
Kahalu'u	Hawai'i	36	24 (66.7%)	19 (52.8%)	19	1	2
Kealakehe	Hawai'i	526	–	1 (0.2%)	478	54	6
Kawaihae Parcel	Hawai'i	37	–	3 (8.1%)	36	–	1
S. Kohala Hotel	Hawai'i	6752	314 (4.7%)	387 (5.7%)	1113	2027	420
Anahola	Kaua'i	376	–	38 (10.1%)	–	–	–
Wainiha	Kaua'i	618	–	277 (44.8%)	563	606	9
Hāna	Maui	542	–	152 (28%)	173	–	32
Kīhei	Maui	1046	338 (32.3%)	95 (9.1%)	149	20	102
Moloka'i	Moloka'i	670	5 (0.7%)	213 (31.8%)	382	670	28
He'eia	O'ahu	286	90 (31.5%)	61 (21.3%)	38	–	3
Total	**–**	**21246**	**1740**	**1300**	**5780**	**6245**	**677**

Introduction

While Hawai'i banned the construction of new cesspools in 2016, conversions have been slow. In 2017, Act 125 took a step further in addressing the cesspool crisis by requiring that all be upgraded, converted, or connected to a centralized sewage system by 2050. Most recently, Act 132, which passed in 2018, created the CCCWG to develop a long-term plan for Hawai'i's cesspool conversions[29]. However, the CCWG urges for earlier deadlines to capture the seriousness and imminent threat of the wastewater pollution issue; they proposed a tiered-deadline, which would push for the conversion of 14,000 highly polluting cesspools by 2030. Overall, these new mandates from the past decade have led to a host of surrounding bills in 2023 and 2024, but efforts to further legislate have generally failed to pass.

Only about 10% of proposed bills in Hawai'i become laws due to a challenging, laborious legislative process in the state. The relative difficulty of passing bills in Hawai'i is important to keep in mind when considering the history of wastewater treatment and possible legal solutions.

Over 20 bills regarding wastewater, 15 of which implicated or directly addressed cesspools, were introduced in the 2023 legislative session (although there was quite a bit of overlap between them); however, ultimately none of them passed. HB1396, which was introduced on January 25, 2023 and would have created a cesspool pilot program, educational tools for homeowners, an official cesspool conversion section in the DOH, and a new income tax credit for conversion (HB1396 HD2, 2023); the cesspool pilot program would financially assist property owners with cesspool conversions or upgrades to sewer lines. However, HB1396 died in the final conference hearings[27].

The lack of any legislative action to move forward with Act 125's mandate is unfortunate, especially in the light of CCWG's findings. Current cesspool conversion rates are far too slow to meet the 2050 deadline, which highlights the lack of legislative action given HB1396 was intended to accelerate this transition. According to a 2023 newsletter from Senator Mike Gabbard, "this comprehensive bill had huge support from both the House and Senate, and many other stakeholders," but it did not end up passing[28].

2024 Legislative Session: More than twenty wastewater bills, most of which directly address cesspools, were introduced in the 2024 legislative session. In contrast to the 2023 session, this year saw marginally more success. The five main bills of note were:

- **HB2743,** which includes the development of a wastewater management plan, investigation into areas where sewer line connections to onsite disposal system properties are feasible, and the creation of a fee for cesspool owners. The fee generates funds for assisting low-income households with cesspool conversions[30],

- **HB1892** would facilitate conversion rates by pushing for earlier deadlines for cesspools in priority 1 and 2 areas, continuing the cesspool grant program to provide financial assistance for low and moderate-income households, and developing public outreach and education programs[31],

- **SB2513** would establish a pilot program for testing and implementing wastewater technology under the University of Hawai'i Water Resources Research Center; additionally, the bill would help allocate funds for new positions with the Department of Health Wastewater Branch,

- **HB1759** created earlier deadlines for cesspools in transient-related housing and depending on location in either Priority 1 or 2 areas, but this bill also died in session[32],

- and **HB1691** required denitrification for wastewater systems located near shorelines or areas likely to contaminate groundwater, but it did not end up passing[33].

Ultimately, however, HB2743 was the only one to pass through the 2024 session with amendments.

Examples from Other States: Three common steps in the process of banning cesspools process across states have been inclusion of financial incentives, methods of identifying cesspools, and identifying or developing new technologies for upgrade. A paper studying cesspool regulatory measures in five surveyed states, with the goal of comparing their regulatory and policy approaches to Hawai'i, found that all five had offered low interest loans to aid less financially well-off homeowners with conversions[34]. In addition, some states provided tax breaks or offered lotteries for grants. The paper found that New Jersey, Massachusetts, Delaware, and Rhode Island employed a point-of-sale measure, mandating the upgrade of a cesspool one to two years – or in Delaware's case, before the occupation by the new owner – after the sale of a property[35]. Finally, most of the surveyed states prioritized development of innovative, advanced, or experimental (I/A/E) treatment systems. For example, "as of 2015, Delaware, Maryland, Pennsylvania, Virginia, and West Virginia have a Memorandum of Cooperation to share data developed to document the performance of I/A/E systems and nitrogen reduction methods"[36]. Massachusetts has a well-developed system to evaluate and approve new I/A/E OWTS technologies and Delaware has a unique program entitled the Homeowner Training Program that allows homeowners to maintain their own I/A/E system, once certified. While these are all approaches that have the potential to be successful in Hawai'i, they would require bills to be implemented.

Legal Research Questions: Creating Change Through Administrative Law

An alternate option to legislation would be to facilitate cesspool removal through changes to the state's administrative law under Title 11 Chapter 62 of the Hawai'i Administrative Rules, which governs how OSDS are permitted, including their design and planning elements. A current problem for cesspool conversion efforts is that cesspools are prohibited from being converted to septic tanks - one of the easier, more cost-effective solutions - if there is not enough distance from the bottom of the proposed absorption trench to the seasonal high groundwater level, except under specific circumstances that will be discussed in a later section.

The objective of the policy section of this paper is to provide a comprehensive overview of existing state or local regulations covering requirements for septic system placement. This includes review of numerical requirements for distance to groundwater, allowable slope, setback distances from water bodies and property lines, among other considerations. Our research covers differences in state requirements, state rationale for minimum depth to groundwater, and alternative solutions at state, city, and county levels when regulations establish an inadequate distance to groundwater that prevents conversions to septic systems. By gathering this data, we can determine not only whether Hawaiʻi's septic regulations are sufficient to protect groundwater quality, but also if they are potentially overly restrictive, precluding conversions that would provide a positive environmental outcome. If Hawaiʻi is able to alter the requirements for septic systems to make conversion more feasible, the state may be able to speed up the removal of cesspools.

• ***Using Regulation to Transition from Cesspools to Septic Systems:*** Act 125 mandates the conversion of all cesspools by 2050, but does specify who carries the burden of this task: the homeowner, the county, or the state. Counties in Hawai'i maintain control over municipal sewer systems, whereas the state oversees permitting of all individual wastewater systems, including cesspools. Yet no clear jurisdiction dictates the responsibility of upgrades. The most costly, though potentially most effective solution, is an upgrade of existing cesspools to centralized sewer systems. However, traditional gravity sewer lines are expensive, costing over $1 million per mile, and building them is challenging on the islands due to the large number of rural communities and presence of difficult terrains. In contrast, the cost to convert from a cesspool to a septic system ranges between $30,000 and $50,000 per home - resulting in an estimated total cost of $3 to $4 billion to convert every cesspool in the Hawaiian islands to a septic system[37].

Thus, though funding remains a challenge, septic tanks and leach fields appear to be in many if not most circumstances the most cost-effective option. They generally have a lower cost than sewer connections or more advanced treatment systems due their greater long-term environmental benefits[38]. As discussed above, however, under current state law, cesspools are prohibited from being converted to septic tanks in Hawai’i if there is insufficient distance to groundwater.

In order to identify potential regulatory options for permitting conversion of cesspools to septic systems, our team evaluated relevant regulations in Hawaiʻi in comparison to those of other states. Our research focused on regulatory approaches to ensuring that pollution threats from septic systems are minimized, including considerations of distance to groundwater, slope, and setback distances.

Distance to Groundwater

After wastewater enters a septic tank and solid particulates have been reduced, the substance is termed effluent. Effluent is discharged to a drainfield and then seeps out into soil at a level above groundwater. Although the effluent has been initially treated (through solid removal), the soil plays a crucial role of further treating and purifying the effluent as it percolates towards groundwater. Without this step, the soil cannot properly destroy pathogens and break down microbes within the effluent. While several factors dictate whether or not the effluent becomes properly treated, including soil type and percolation rate, a key factor is the vertical distance from the wastewater treatment system to the groundwater table. Distance to groundwater is strictly regulated across many states to ensure pollution is eliminated, or at least feasibly managed[39].

IIf distance to groundwater is not adequate, septic systems may pose risks to human health and the environment. Insufficient separation of septic systems and groundwater allows untreated or partially treated wastewater to reach the water table. This is especially problematic in areas, like much of Hawaiʻi, that have high water tables and permeable soils, which then provide minimal filtration of the wastewater before it potentially enters drinking water sources.[40]

Slope

The majority of regulations reviewed from other states assessed slope, in reference to placement of the drainfield compared to the wastewater disposal system. Slope can influence the retention and movement of water, rate and amount of effluent, and potential for erosion. Generally a level site is ideal for a septic system, but many states include maximum slope percentages that still provide safe, proper function of the septic system. If the slope is too steep, liquid might move too quickly and leave solids behind, causing clogs. Conversely, too flat of a slope could also inhibit proper functions, causing.wastewater to not flow quickly enough and to become stagnant[41].

Setback Distances

Lastly of concern, many states require setback distances between septic systems and various features at horizontal distances. The EPA specifically refers to setback distances as the horizontal distance from an OSDS to surface water bodies[42]. However, in our analysis, we include setback distances for the five most common references we found in county and state code: reservoirs, property lines, wells, surface waterbodies, and drainageways[43]. The literature widely varies on what specific distances for setbacks are deemed safe, as do the various state regulations, often due to site-specific variations. However, in general, setback distances are important to consider, especially for wells and surface water bodies, since shorter distances are associated with higher microbial contamination (pathogenic viruses and diseases). Various studies have shown that private septic systems contribute substantially to contamination of drinking and surface waters, polluting these waters with human fecal contaminants[44].

Methodology

We reviewed a sample set of state and county rules and regulations, as well as city plans, to compare other regions' septic system policy to Hawaiʻi. Our sampling of states favored Eastern states because they have the highest concentration of septic systems, but it included states from across the county. For our analysis, we focused our research on vertical distance from the seasonal high groundwater table, percent slope, and setback distances because they are established criteria for septics that are found across most states. The type of structures that septic systems and leach fields required a setback for varied by state, so we chose the five most commonly mentioned structures to list data for.

The EPA does not specifically set regulations on allowable slopes for leach fields to be built on or for minimum distances from the bottom of leach fields to seasonal high groundwater tables:

> Water quality-based performance requirements for ground water discharging systems are not clearly defined by current codes regulating OWTSs. Primary drinking water standards are typically required at a point of use (e.g., drinking water well) but are addressed in the codes only by requirements that the infiltration system be located a specified horizontal distance from the wellhead and vertical distance from the seasonal high water table.[45]

As a result, the regulations vary by state. We also made sure to note nomenclature inconsistencies, including how groundwater and leach fields are referred to, and relevant definitions, such as restrictive and limiting zones, as used in the state documents. States and local jurisdictions frequently vary in their definitions or use of terminology. For example, New Jersey defines the limiting zone as "any horizon or combination of horizons within the soil profile, or any substratum or combination of substrata below the soil profile, which limits the ability of the soil to provide treatment and/or disposal of septic tank effluent"[46]. Vermont also identifies a vertical distance from the limiting feature, but in its slightly different definition, the limiting feature pertains to the soil "that limits or intercepts the vertical movement of water, including seasonal, perched or permanent water table"[47]. Finally, we also made note of any specific instructions states gave when the distance to groundwater could not be met. Alabama, for example, requires modifications to a conventional OSDS when limitations are deemed "moderate" and an engineered OSDS when conditions are deemed "severe".

For counties, we collected **vulnerability assessments and adaptability plans** in response to future projections of climate change. We repeated this process for city/town level case studies. We looked for additional regulations, however; our approach focused less on numerical regulations and more on strategies to employ when state-level numerical regulations could not be met. For example, in Miami-Dade County "to ultimately address the vulnerability of compromised or failed septic systems it is necessary to extend sanitary sewer service to certain areas in order to protect public and environmental health. In areas where sewer extension is not desirable or feasible, there are other technical interventions such as replacing existing systems with mounded systems"[48].

Analysis of Selected Parameters

• ***Distance to Groundwater:*** States used various terminology for defining the vertical distance between wastewater treatment system and groundwater level, which led to complications in making comparisons between states from our study sample. The vertical distance measures from either (a) the surface of naturally occurring soil or (b) the bottom of the wastewater treatment system. Two of the nineteen states, Vermont and Virginia, define depth from the naturally occurring soil, while New Jersey similarly calculates the distance from ground surface, specifically. Across the states studied, the bottom of the wastewater treatment system refers to the trench or drainfield. To give insight to the slight variations in terminology for the second component of a septic system, the following nomenclatures are used: leach field trench (California), leach field system (Connecticut), drainfield (Florida), absorption field trench (Georgia), trench system (Louisiana), and disposal field (Maine). Additionally, Texas is the only state in the sample that lists the vertical separation distance from the "bottom of the excavation." Ten out of the total nineteen states refer to slight variations of the seasonal high water table or seasonal groundwater table. This includes the elevation of the water table or maximum groundwater. For example, Florida defines the elevation of the water table in accordance with the wettest season of the year. This is an important consideration given Florida's susceptibility to flooding and sea level rise in the state's coastal zones. The seasonal element takes into account fluctuations in weather phenomena, such as changes in precipitation[49]. Three of the total nineteen states, Kentucky, North Carolina, and Texas, refer simply to groundwater table and water table; due to the lack of seasonality in the regulation, the depth to groundwater appears as a more static measurement. Consequently, measurements may overestimate the distance of separation and additionally fail to take into account rising groundwater tables, which is an ever present concern in the face of climate change—especially for coastal environments that are challenged by sea level rise. Furthermore, South Carolina is the only state from our sample that references the zone of saturation, which is determined from field identification methods or wet season monitoring; wet season monitoring is used to identify maximum groundwater elevation[50]. **Two of the nineteen states studied, Delaware and New Jersey, identify the limiting zone. According to the definition of the limiting zone in Delaware's code, the zone correlates to the "maximum height of the projected seasonal high groundwater mound"[51]. In contrast, New Jersey provides a broader definition of the limiting zone, which as previously mentioned, is the area that inhabits the capacity of soil to treat and dispose of septic tank effluent[52].**

In the Hawai'i Administrative Rules, the code defines the depth to groundwater in reference to the bottom of the absorption bed, absorption trench, or seepage pit. In these three cases, the vertical distance cannot be less than three feet to the seasonal high groundwater table[53]. For ease of comparison, we focused our analysis on the depth to groundwater from the bottom of the wastewater treatment system, but we mention states that use alternative measurements from naturally occurring soil or ground surface. As for these other states, based on regulations from South Carolina, the minimum required distance is 6 inches from the bottom of the wastewater system trench to the zone of saturation[54]. The largest distance, as defined between the bottom of the leach field trench to the "high seasonal elevation of the water table" is highest at twenty feet in California. It is noteworthy that the percolation rate greatly affected the required depth to groundwater. In California, a percolation test rate larger than 5 minutes per inch sets a minimum depth to seasonally high water table at 3 feet. However, for rates between 1 and 5 minutes per inch, the depth jumps to 20 feet and for percolation rates less than 1 minute per inch, the wastewater system is prohibited altogether[55]. Percolation rate is the rate at which soil absorbs water and is thus determined by soil characteristics and composition . This rate affects the drainage capacity of the soil, ensuring that there is room for the wastewater effluent to move from septic system to drainfield. Therefore, it is significant in assessing the functionality of a septic system and its ability to treat the wastewater effluent[56]. In Hawai'i, lava tubes act as channels for groundwater flow; this poses a risk when wastewater enters the system as sewage contaminants would adversely affect groundwater quality. The lava tubes flow into reservoir spaces, which have limited filtration capacity for absorbing contaminants; additionally, these spaces percolate "nearly vertically to the basal water table". These facts highlight Hawai'i's unique geographic and hydraulic features, necessitating special consideration in wastewater system installation to ensure both adequate drainage and filtration. Moreover, flooding events increase the rapidity of wastewater transport within the lava tubes, potentially leading to high flow rates that could inhibit proper functioning of the treatment system. Furthermore, five of the eighteen other states studied require a depth to groundwater at or greater than that of Hawai'i. In addition to California, this includes Delaware at 3 feet from the bottom of the trench;[57] New Hampshire at 4 feet from the effluent disposal area[58]; Rhode Island at 4 feet from the "stone underlying the leach field" in soils classified in category 1, 2, 3, 4, or 6[59]; and Massachusetts at 4 feet for percolation rates greater than 2 minutes per inch and 5 feet for percolation rates of 2 minutes or less per inch[60].

Several states provide extensive conditions for the siting of septic systems. Based on three approaches to wastewater treatment systems, Vermont provides different sets of requirements. The three approaches are prescriptive, enhanced prescriptive and performance-based. For the prescriptive and enhanced prescriptive approach, the code sets a concrete measurement from the surface of naturally occurring soil to the seasonal high water table, which is 24 inches and 18 inches, respectively[61]. However, for the performance-based approach, the distance is set by adding 6 inches to the "calculated induced groundwater mounding" [62]. Three of the total nineteen states note critical areas in their standards for septic systems. In Connecticut, the required vertical separation distance increases from 18 to 24 inches for sites "that have a groundwater table that is tidally impacted"[63]. Additionally, the code states: "maximum groundwater determinations in tidally affected coastal areas shall take into account water level rise associated with high tides"[64]. This point highlights the need for stricter standards in coastal areas and low-lying elevations because these places are more susceptible to sea level rise and flooding events. In Maine, for systems "located within the shoreland area of major water bodies/course," the vertical separation distance increases from the minimum 9 inches to 15 inches in these restrictive areas[65]. According to the EPA, "a stream, lake, or coastal water is at greater risk of becoming contaminated if it is in the path of groundwater flow beneath the septic system"[66]. It may be useful for states to model after Maine by providing stricter standards for septic installation in sensitive areas, including those located near water bodies. Furthermore, Rhode Island has a "tiered system, where septic systems located within critical watersheds must utilize advanced nitrogen reducing technology instead of conventional systems"[67]. This once again highlights cases where septics are limited in their capacity to treat wastewater. Alternatively, North Carolina reduces depth requirements depending on the type of technology utilized in the wastewater treatment system. The vertical separation is typically set at 18 inches but this number can be decreased to 12 inches with pressure dispersal, 9 inches with advanced pretreatment, and as low as 6 inches if both pressure dispersal and advance pretreatment are utilized[68].

• *Slope Considerations*: Slope is given in the codes as a percentage, as a ratio of horizontal to vertical, or as a measurement in terms of inch per feet. Most of our sampled state codes reference slope in relation to the placement of the drainfield or trench of the wastewater system, but we note discrepancies when applicable. Hawai'i code sets slope gradient requirements based on the type of treatment system, an absorption bed, absorption trench, or seepage pit. The strictest standard is a maximum of eight percent for absorption beds, while absorption trenches cannot be installed on gradients greater than 12%[69]. When the gradient is either higher than 12% or an absorption bed and trench is not available, seepage pits are an alternative option and there is not a maximum requirement for slope gradient[70]. In relation to other states, Delaware and Louisiana set the most stringent slope requirements. According to regulations in Delaware: "bed systems cannot be sited on slopes > 2%"[71]. As for Louisiana, conventional field lines should conform to slopes of 2 to 3 inches per 100 feet, which is 2 to 3%, and gravelless pipes should be placed on slopes of 1 inch per 100 feet, which is 1%[72]. In addition to Delaware and Louisiana, one other state indicates a slope standard stricter than that of Hawai'i. This state is Florida, and construction standards state: "the drainfield absorption surface shall be constructed level or with a downward slope not exceeding one inch per 10 feet," which is 10%[73]. On the other end of the spectrum, Virginia defines the maximum slope for subsurface soil absorption trench systems at 50%[74].

Hawaiian soil consists of a similar composition to that of the southern U.S.. North Carolina, for example, classifies soil textures into four main groups. Sandy texture soils (group I) and coarse loamy texture soils (group II) are "suitable" in terms of site evaluation; fine loamy texture soils (group III) and clayey texture soils (group IV) are considered "provisionally suitable"[75]. It is useful to consider soils in the context of drainage potential and their capacity to filter harmful pathogens. Drainage is an important variable because it considers the efficacy of the septic system and its capability to withstand rainfall events. In the context of climate change and "wetter-than-normal periods," soils are expected to experience higher levels of saturation and consequently inadequate treatment of septic effluent in drainfield areas[76]. Clay soils have a relatively slow drainage rate. In addition to soil characteristics, site evaluations consider factors such as topography and landscape position. For slopes less than 15% in North Carolina, the topography is suitable; for slopes between 15 and 30%, the site is provisionally suitable; for slopes greater than 30%, the site is unsuitable[77].

Some states list modifications and alternative approaches when slope gradient is less than ideal for the installation of septic systems. Alabama sets limitation ratings for several factors, such as slope, to assess the site suitability of a conventional OSS: slight, moderate, severe, and extreme. The slope gradient ratings are as follows: 0 to 15 is slight; 16 to 25 is moderate; 26 to 40 is severe; and greater than 40 is extreme. In severe and extreme conditions, the alternative requirements are fairly lenient and broad; severe limitations may warrant the need for an Engineered OSS and "careful planning and installation of a Conventional OSS," while extreme limitations require an Engineered OSS and may warrant advanced treatment[78]. In Onsite Sewage Facility Rules Compilation Texas, a slope of less than 2% raises concerns over inadequate drainage over the disposal field so the code broadly calls for special consideration in the installation of the wastewater system[79]. New Jersey maintains a similar rule for slopes less than 10% by necessitating mounds or mounded soil replacement installations for such gradients[80]. These codes highlight the limitation regarding gentler inclines, particularly the concern for proper drainage, which as previously mentioned, ensures that wastewater effluent is adequately absorbed and treated in the soil. Additionally, a specification of highlight in the New Jersey code is that for slopes between 10 to 25%, trenches should take place of beds[81]. States generally only referenced the trench or disposal field in their standards for slope, with the exception of Hawai'i which mentioned both.

Some states mention additional specifications regarding slope and the placement of septic systems. Rhode Island sets requirements for the adjacent side slope which cannot be "steeper than a 3:1 for a twenty-five foot minimum distance from the edge of the stone in the dispersal trench" [82]. Specific consideration of adjacent slopes once again emphasizes the relevance of topographic shape and gradient in determining drainage and water flow from the septic system[83]. Massachusetts sets a similar limit for adjacent slopes at a ratio of 3:1, or converted as a percentage of 33.5. However, the code allows for an alternative installation approach on these steeper slopes given proper slope stabilization, such as a "retaining wall designed by a Massachusetts Registered Professional Engineer"[84]. South Carolina provides general guidance for the placement of wastewater trenches, which states that they should be "installed perpendicular to the direction of slope and parallel to the contours of the land"[85]. There are, however, specific slope gradient percentages based on the type of septic system, including fill cap and mounded fill.

• ***Setback Distances:*** Both setback distances and parameters vary widely between our studied states. Since many states' parameters are limited in number, while some are so extensive as to include objects as random as large trees, we chose the five most common to focus on: reservoirs, property lines, wells, surface waterbodies, and drainageways. All distances were measured in feet. A detail worthy of note is that when discussing setback distances, different states used three different terms for septic tanks: septic tank, treatment unit, and treatment tank and seven different terms for leach fields: leach field, effluent disposal field, disposal field, absorption field, soil absorption system, lateral trench, soil absorption system. Based on the context of the regulation, we were able to safely assume these all referred to the same thing; however, it is possible that the terminology differences could have accounted for numerical differences as well. To preserve the regulation's original meaning, we made our notations in the database using the same terminology as each state's regulations.

In almost all cases, leachfields require a greater degree of separation than septic tanks. Looking at the numbers themselves, across the board, reservoirs require the greatest degree of separation, although data for reservoirs was the most scarce out of the five criteria. Hawai'i has the strictest regulations out of our sample, requiring 500 feet of separation from septic tanks and 1,000 feet from leachfields, while New Jersey has the weakest, only requiring 25 feet from septic tanks and 100 from leachfields[86]. However, it is worth noting that Hawaiʻi defines reservoirs as "potable water sources serving public water systems," while New Jersey groups reservoirs and wells into the same category. This is likely to have contributed to the large amount of variance between the two states' setback distances.

On the other end of the spectrum, property lines require the least degree of separation among the studied parameters. With the exception of Maine, Rhode Island, and Vermont, no state requires more than ten feet of separation from either septic tanks or leachfields[87]. In addition to being the least restrictive parameter, property lines also differentiate the least between distances for tanks and fields (a 7.6 foot average for tanks and a 9.3 foot average for fields), with most studied states having the same requirement for both. Georgia requires five feet more for septic than leachfields, the only time for any parameter out of the sampled states that tanks had stricter requirements than fields[88]. Hawai'i fell onto the most lax end of the regulations, requiring only five feet for both septic tanks and leach fields[89].

Focusing on the three other parameters, wells mandate an average of 62.5 feet from septic tanks and 116 feet from leachfields. However, wells also have a fair amount of variation in their terminology. For example, South Carolina defines different setback distances for private as opposed public wells, while Rhode Island (the state that likely due to this also happened to have the minimum setback requirements for wells) only defines setback distances for wells "serving non-potable uses"[90]. Hawaiʻi does not define setback distances for wells. Surface waterbodies require an average of 45 feet from septic and 74 feet from disposal fields. Maine has the strictest requirements, setting tiered standards based on GPD (gallons per day) up to 100 feet for septic and 300 feet for leach fields[91]. Alabama, Kentucky, Massachusetts, and Vermont have the most lax standards, with 25 and 50 feet for tanks and fields, respectively. Hawai'i falls into the more lax side of the pack, with both 50 feet for both treatment units and soil absorption systems[92]. Drainageways mandate an average of 21.7 feet from septic tanks and 30.7 from leachfields. California has the strictest regulations out of our sample, ordering 50 feet from both tanks and fields, while Alabama and Kentucky have the laxest (10 feet) for septic tanks and Georgia has the laxest (15 feet) for absorption fields[93].

Although setback distances for parameters between states all conform to the same unit of measurement and general scale, many discrepancies exist between their methods of classification. For one, as discussed earlier, there are differences in things as simple as the names for septic tanks and leach fields. There are also differences in parameter terminologies and definitions, most notable for wells and reservoirs. Finally, some states had additional specifications for types of treatment units and disposal fields. For example, Maine broke down both treatment tanks and disposal fields into the categories of "less than 1,000 gpd," 1,000 to less than 2,000 gpd," and "2,000 gpd or more"[94]. These discrepancies are important to note when comparing setback distances between states, but do not invalidate the comparisons either. Rather, they are worth considering as possible factors when explaining extreme differences between specific setback parameters.

Solutions by Governance

Broadly, we encountered three major themes for solutions when distance to groundwater could not be met. The first was the creation of a mound system, which is the construction of a leach field above the ground. The second was the conversion to an alternative treatment system, such as aerobic, and the third was connecting to a sewer line so the septic system could be removed. Although many states, counties, and cities had mentions of these solutions, only some proposed or mandated them directly. In this section we discuss the best examples of this, as well as other specific solutions that some regions offered.

State Policy: Out of the nineteen states in our sample, only Virginia and Hawai'i gave detailed instructions on what to do when minimum regulations for depth to groundwater could not be met. When conditions prevented meeting the requirement of 18 inches from the ground surface to a limiting feature (which refers to groundwater tables, among other things), Virginia outlines that "the designer shall demonstrate that (i) the site is not flooded during the wet season, (ii) there is a hydraulic gradient sufficient to move the applied effluent off the site, and (iii) water mounding will not adversely affect the functioning of the soil treatment area or create ponding on the surface," "for large AOSSs, the department may require the owner to monitor the degree of saturation beneath the soil treatment area to verify that water mounding is not affecting the vertical separation," and "for any system in which artificial drainage is proposed as a method to meet the requirements of this chapter, the designer shall provide calculations or other documentation sufficient to demonstrate the effectiveness of the proposed drainage"[95]. On the other hand, Hawai'i's administrative law states that "in areas below (makai of) the Underground Injection Control Line established pursuant to chapter 11-23, where the vertical separation distance from the discharge to the seasonal high groundwater table is less than three feet, a new household aerobic unit may discharge its effluent into an elevated mound to achieve the vertical separation or drip irrigation system or, with a variance approved by the director and if the effluent is disinfected, to a seepage pit"[96].

County Policy: Our sample size for counties was significantly smaller than that of states: we only found data on seven. While many counties mentioned distance to groundwater as a problem, not many proposed specific actions that could be taken. Suffolk County in New York, for example, recommended raising the requirements for distance to groundwater due to sea level rise, but did not offer solutions for alternative systems[97]. The exception to this was Florida's Miami-Dade county, who, during a 2018 septic system report, stated that to "ultimately address the vulnerability of compromised or failed septic systems it is necessary to extend sanitary sewer service to certain areas in order to protect public and environmental health"[98]. Miami-Dade followed up that "in areas where sewer extension is not desirable or feasible, there are other technical interventions such as replacing existing systems with mounded systems; however, there may be potential complications with such an approach or tradeoffs in terms of increased maintenance. These solutions are less preferable to connecting to the sanitary sewer system within the Urban Development Boundary"[99].

City Policy: As with counties, our sample size for cities was also relatively small: only seven. Some of the proposed solutions were quite vague. For example, in a report on sea level rise policy, Tampa stated that it is necessary to "identify areas to remove septic and consider higher groundwater elevations for future installation"[100]. Two cities suggested upgrading to alternative treatment systems in the context of specific chemicals. One of them, Cape Cod, described how "towns can allow a mandatory septic upgrade to be imposed on homeowners who live in nitrogen-sensitive natural resources areas (NRAs). Under this scenario, homes would be required to replace existing septic systems with innovative/alternative," then gave a list of approved I/A systems. Similarly, Londonderry, New Hampshire outlines how "in areas where conventional septic systems are not appropriate due to soil or environmental conditions, alternative systems may provide adequate treatment. Alternative systems are typically upgraded from traditional septic systems by adding a component that reduces phosphorus concentrations from the effluent before it is discharged to the ground... These systems have been shown to reduce phosphorus by up to 90 percent"[101]. Finally, Guilford, Connecticut gave the most comprehensive solution for when distance to groundwater could not be met. Its community resilience plan detailed how "first and foremost, septic systems can be elevated to maintain an appropriate vertical separation between effluent leach fields and the surface of the groundwater table. . . . Engineered erosion control techniques may be needed to assist with reduction of the erosion. If elevating a system is not possible, a suitable site for a new system may be found elsewhere on a property. . . . In cases where the full area needed for renovation of wastewater is no longer available, property owners could attempt to install and maintain advanced sewage treatment facilities. . . . Incinerating toilets, composting toilet or heat-assisted composting toilet can be utilized for replacing failing subsurface sewage disposal systems. . . . In cases where septic systems cannot be improved, it may be possible to install effluent holding tanks. The tanks would then be pumped out and sanitary wastewater would be delivered to a sewage treatment plant elsewhere"[102].

APPENDIX

GIS Data Sources

Hawai'i Wastewater Pollution Mapping Datasets:
https://www.ioes.ucla.edu/wp-content/uploads/2024/06/UCLA-Practicum-TNC-Hawaii-Wastewater-Pollution-Mapping-Datasets.xlsx

Sewage Spill GitHub

For our sewage spill analysis application, the source code can be found at **https://github.com/nickleong20/SewageSpillAnalysis**. It contains the .csv file that contains all of the data that was used in our analysis as well as instructions on how to update the code for new spills.

ArcGIS Infrastructure Web Application

This map showcases available data for wastewater infrastructure across the state of Hawai'i and its various islands. More data was found and available on the islands of Hawai'i and O'ahu. Infrastructure represented here consists of wastewater treatment plants (WWTP), underground injection wells (UIC), on-site disposal systems (OSDS), sewer mains, sewer pumps, manholes, pump stations, and more.

The link for this map can be found here:
https://gisucla.maps.arcgis.com/apps/webappviewer/index.html?id=373f651e238241a09ab5313d6fb8ca45.

ArcGIS Cesspool Prioritization Web Application

The purpose of this map is to assist in identifying high-priority cesspool locations based on certain geographic and demographic attributes, like proximity to wastewater infrastructure, coastline, and disadvantaged communities.

The link for this map can be found here:
https://gisucla.maps.arcgis.com/apps/webappviewer/index.html?id=7a8d55b6fba444399e7e7e54e6ac11ee .

Water Reuse Maps

A series of maps were created for Hilo, Holualoa, Honokaa, and Papaikou on Hawaii Island, which were the only areas on the island with available sewer main data. The map series identifies the potential areas for water reuse, along with the proximity to cesspools, soils, groundwater and precipitation, zoning, and fire history for each area (if relevant).

The link for these PDF maps can be found here:
https://ucla.box.com/s/yg50fxmdb0glsgckxoinjhxzboklio95

Septic Regulation Database

The Septic System Regulation Database contains regulations from a sampling of 18 states across the county (as well as seven counties and cities) to compare them to Hawai'i to see if existing laws could change to better allow for septic conversions. The three main technical parameters in this database are distance to groundwater, slope, and setback distance to different entities.

The link for this database can be found here:
https://www.ioes.ucla.edu/wp-content/uploads/2024/06/UCLA-Practicum-TNC-Hawaii-Policy-Database-2024.xlsx

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