2022 Hawaiʻi Cesspool Hazard Assessment & Prioritization Tool

2022 Updated Report & Technical Appendices

October 2022
SPECIAL REPORT WRRC-SR-2022-02 (Revised)
UNIHI-SEAGRANT-TT-21-03 (Revised)

Prepared For:
State of Hawaiʻi Department of Health Wastewater Branch
State of Hawaiʻi Cesspool Conversion Working Group

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This paper is funded, in part, by a grant/cooperative agreement from the National Oceanic and Atmospheric Administration, Project A/AS-1, which is sponsored by the University of Hawai'i Sea Grant College Program, SOEST, under Institutional Grant No. NA18OAR4170076 from NOAA Office of Sea Grant, Department of Commerce. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its subagencies. UNIHI-SEAGRANT-TT-21-03.

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Background

In 2017, the Hawaiʻi State Legislature passed Act 125 mandating that all of Hawaiʻi's estimated 80,000+ cesspools be replaced by 2050. Cesspools are a substandard sewage disposal method and are widely recognized to harm human health and the environment. An essential step in meeting this critical goal is defining a replacement prioritization method for different geographic areas and social categories. This project and its deliverables will help the State use its limited resources which are spread over a large and diverse landmass, to determine the most vulnerable areas of contamination more efficiently. The data and information presented in this report will assist the Cesspool Conversion Working Group (CCWG) and the Hawaiʻi State Department of Health (DOH) reevaluate and replace older statewide cesspool prioritization methods developed between 2009 and 2017. Though this report and the former prioritization efforts share some overlap in their approaches to evaluate the hazards cesspools pose, including using some of the same inputs and assumptions involved in individual calculations, there are significant differences concerning the methodology and results. This project will provide the CCWG and its Data and Prioritization Subgroup with updated information and data to make informed planning and preparation decisions through the geographic information system (GIS) tool titled: the Hawaiʻi Cesspool Prioritization Tool (HCPT) and this report and technical appendices.

Objectives

The HCPT and the associated report and recommendations will assist the CCWG in creating a long-term cesspool upgrade plan for delivery to the Hawaiʻi State Legislature in 2022. The HCPT's top three objectives are to:

1. Identify a comprehensive list of risk factors and develop a new cesspool prioritization and hazard assessment for the four main Hawaiian Islands;
2. Examine and categorize previously uncategorized (Priority Level 4) cesspools;
3. Reevaluate the 2017 DOH Cesspool Prioritization Report and provide recommendations based on new findings where appropriate.

Methodology

A simplified geospatial hazard-based model (data with a geographical or map-based component) was developed to integrate multiple types of risk factors to visualize, assign, and rank each factor at the individual cesspool level and collectively. The data used for the tool includes physical drivers and impacts on social and ecological assets. Physical drivers were defined as elements that control the movement of pollution, reduce capacity, or otherwise affect the overall level of impact a cesspool has on the land and also the water quality nearby. Social and ecological drivers represent quantifiable human and environmental values within the areas affected by the discharge of cesspool effluent. The tool applies high-confidence groundwater models (currently used by DOH) to determine effluent (human waste) flow paths and to link each cesspool unit to the estimated location along the coastline most affected by its discharge. Due to the model framework and request from the DOH, the current HCPT does not evaluate other sources of groundwater pollution, including agriculture or injected wastewater, or integrate observed coastal or groundwater quality observations as did the previous report. A total of fifteen risk factors were included in the model:

1. Distance to municipal or domestic drinking water wells;
2. Well capture zones;
3. Distance to streams and wetlands;
4. Distance to the coastline;
5. Sea level rise zones;
6. Precipitation;
7. Depth to groundwater;
8. Groundwater flow paths;
9. Soil characteristics;
10. Cesspool density;
11. Coral cover;
12. Fish biomass/recovery potential;
13. Beach user-days;
14. Proximity to a lifeguarded beach; and
15. Coastal ocean circulation proxy

Although the method chosen assigns a cumulative hazard score to each cesspool in the inventory, combination effects from nearby cesspools and the practicalities of management approaches make it more beneficial to group scores by pre-defined geographic areas from the United States Census. The HCPT categorizes priority areas based on existing census-designated boundaries, including census tracts, block-groups, and blocks where the number of cesspools exceeds a minimum threshold. The HCPT was designed to be as objective as possible with prioritization based solely on the relationships between datasets, thereby reducing human bias as much as possible. All data used in the HCPT is at the statewide scale, normalized, and based on regulatory rules or modeling outputs.

Results

The HCPT prioritization method (Figure ES1) places each geographic area into three Prioritization Categories that include:

1. **Priority Level 1:** Greatest contamination hazard (map color of red).
2. **Priority Level 2:** Significant contamination hazard (map color of orange).
3. **Priority Level 3:** Pronounced contamination hazard (map color of yellow).

The total number of cesspools in the state categorized as Priority Level 1 was 13,821, with 12,367 and 55,237 as Priority Level 2 and Priority Level 3, respectively. Approximately 35%, 7%, 21%, and 37% of cesspools in the Priority Level 1 group are located on Oʻahu, Maui, Kauaʻi, and Hawaiʻi Island, respectively. All results are updated as of 2022, See Appendix C for details.

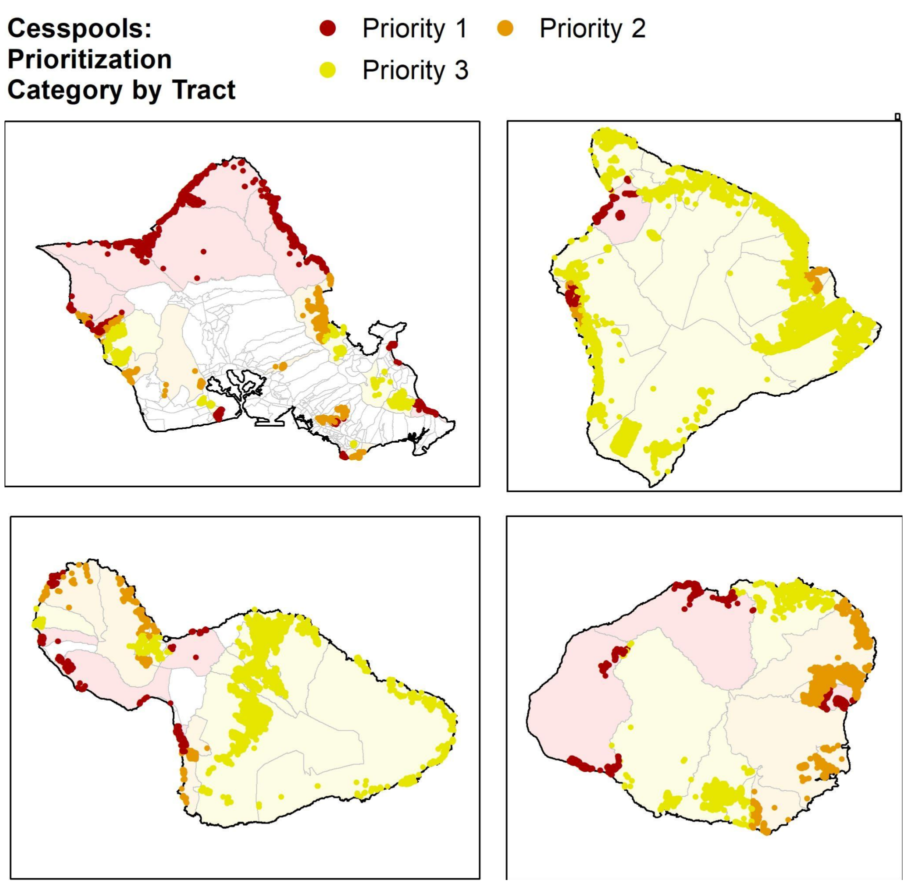

Figure ES1. *Statewide map highlighting the simplistic design of the three-tiered categories, census tracts, and their respective colors to signify a priority score.* (Updated 2022)

Key Takeaways:

1. A shift in priority ranking is to be expected due to the amount of available data and the use of census tract areas to frame the overall scores. The few areas with previous scientific data supporting the presence of wastewater pollution should be treated accordingly and factored in separately when developing conversion schemes.

2. Results and information from the 2017 prioritization effort are not part of the HCPT and are included in this report for reference and comparative purposes only, including using the 2017 priority category titles, i.e., Priority Level 1, 2, and 3.

3. Observation-based tracer (water quality) datasets were intentionally excluded from the HCPT algorithm used to calculate prioritization scores.

4. The authors recommend that all statewide cesspool inventory continue to be refined and, if possible, ground-truthed to ensure the most accurate results of the tool and for future statewide OSDS management and cesspool conversion.

5. All cesspools are substandard sewage disposal systems and pose some threat to their surroundings. Therefore, each cesspool in the inventory was assigned a priority ranking, and this analysis considers none to be exempt from conversion.

6. The tool is merely a starting point for assessing the areas with the most significant hazards and is meant to support the development of a thorough and thoughtful cesspool conversion plan. The tool cannot make decisions regarding cesspool conversion prioritization timelines.

Abstract

Cesspools are a substandard sewage disposal method and widely recognized to harm human health and the environment. The state of Hawaiʻi has an estimated 82,000 cesspools. To address pollution concerns, the Hawaiʻi State Legislature mandated replacement of all cesspools by 2050. A major step in achieving this goal is to categorize cesspools based on potential or realized harm to humans and the environment. This report details a comprehensive tool designed for this purpose. After researching similar efforts, methods and datasets were chosen that met the needs of state government, cultural values, and environmental sensitivities. The Hawaiʻi Cesspool Prioritization Tool (HCPT) was developed by integrating fifteen risk-factors that either control or relate to how cesspool impacts are distributed across communities and the environment. These factors were processed with a geospatial model to calculate a single prioritization score for every cesspool in Hawaiʻi. Because sewage pollution impacts are cumulative, individual scores were consolidated by census boundary areas. Results from the HCPT prioritization were validated through comparison with a statewide assessment of nearshore wastewater impacts funded by Hawaiʻi Act 132. Future data, organized within census area frameworks, can be layered onto the results to address equity and outreach challenges.

The HCPT was designed to be as objective as possible with prioritization based solely on the relationships between datasets, thereby reducing human bias as much as possible. All data used in the HCPT is at the statewide scale, normalized, and based on regulatory rules or modeling outputs. The total number of cesspools in the state categorized as Priority Level 1 was 13,821, with 12,367 and 55,237 as Priority Level 2 and Priority Level 3, respectively. Approximately 35%, 7%, 21%, and 37% of cesspools in the Priority Level 1 group are located on Oʻahu, Maui, Kauaʻi, and Hawaiʻi Island respectively. (*Updated* 2022)

Background and Motivation

In 2017, the Hawaiʻi State Legislature passed Act 125 mandating that all cesspools be replaced by 2050. A report produced by the Hawaiʻi Department of Health Environmental Management Division in 2017 titled: Report To The Twenty-Ninth Legislature State of Hawaiʻi 2018 Regular Session: Relating To Cesspools and Prioritization for Replacement (DOH Cesspool Prioritization Report) detailed a prioritization method to identify high-priority cesspools across the state (Hawaiʻi State Department of Health: Environmental Management Division, 2017). However, new data and recent directives by the

Cesspool Conversion Working Group (CCWG) and Hawaiʻi State Department of Health (DOH) have provided the necessary information and catalyst to reevaluate the original prioritization methods and framework. Prioritization of cesspool areas helps the State use its limited resources spread over a large diverse archipelago more efficiently, reducing any uncertainties to determine vulnerable areas of contamination. This project aims to provide the CCWG and its Data and Prioritization Subgroup with updated information and data through the creation of a geographic information system (GIS) tool titled: the Hawaiʻi Cesspool Prioritization Tool (HCPT).

Objectives

The HCPT will assist the CCWG in creating a long-term cesspool upgrade plan for delivery to the Hawaiʻi State Legislature in 2022. This project's main objectives are to:

1. Identify a comprehensive list of factors that will assist in the creation of a new cesspool prioritization and hazard assessment for the four main Hawaiian Islands;
2. Examine and categorize previously uncategorized (Priority Level 4) cesspools;
3. Reevaluate the 2017 DOH Cesspool Prioritization Report. Provide recommendations based on new findings where appropriate;
4. Identify possible exemption criteria for cesspools in areas not in need of time-sensitive cesspool upgrades;
5. Develop a web-based tool to prioritize and view specific cesspools based on identified attributes and data.

Comparison to 2017 Prioritization

The DOH requested that the results of previous efforts to categorize cesspools not be included in the new priority ranking methodology. Nonetheless, 2017 priority areas are overlaid onto the HCPT maps for comparison purposes and transparency.

The two prioritization efforts share some overlap in their methods to evaluate the hazards cesspools pose, including using some of the same inputs and assumptions involved in individual calculations. However, there are also significant differences concerning the methodology and results. For example, the previous prioritization effort evaluated the risk ranking of onsite sewage disposal systems (OSDS) at the resolution of broad geographic regions, e.g. Upcountry Maui. The HCPT treats all cesspools as nonpoint pollution sources, lumping them into finer scale frameworks of United States Census Bureau tracts, blocks and block-groups. Additionally, the HCPT algorithm does not require inputs in the form of documented impacts from cesspools, as previous assessments have. Doing so would limit where the tool can be applied, and would inherently result in bias towards places that have previously been selected for scientific studies or routine monitoring. The method in the HCPT decreases subjectivity in defining prioritization areas and simplifies public interactions with the tool, while still maintaining in-depth analysis of individual cesspools for DOH personnel. Additionally, the HCPT did not evaluate existing infrastructure elements such as nearby sewer mains, injection wells, or future sewer plans. However, these are essential elements that should be included in an overall conversion scheme.

There is some usefulness in understanding the process used for previous efforts to prioritize cesspools as a mechanism to evaluate the new results. **The information provided below is not part of the HCPT and included for reference and comparative purposes only.** The 2017 DOH Cesspool Prioritization Report identified fourteen critical locations that should receive priority when implementing a replacement plan. The previous report's prioritization method relied upon the following five factors:

1. The density of cesspools in an area;
2. Soil characteristics;
3. Proximity to drinking water sources, streams, and shorelines;
4. Groundwater inputs (agriculture and injected wastewater); and
5. Physical characteristics of coastal waters that may compound the impacts of wastewater.

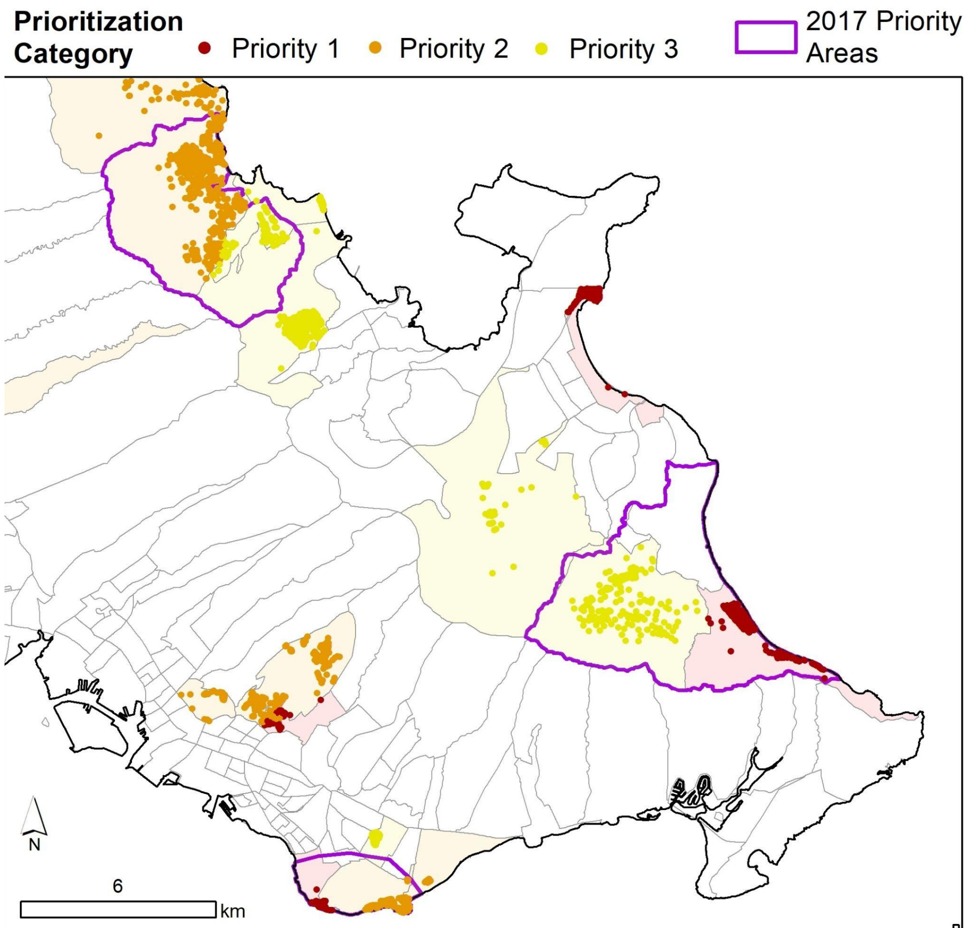

Figure 1. *Example map of Oʻahu highlighting the locations of previous 2017 priority areas paired with the newly developed priority scheme, synthesized by census tracts. (Updated 2022)*

In order to demonstrate how the newly designated priority areas overlap with the 2017 priority areas from DOH, the authors also performed a comparative analysis, detailed in Appendix A. There readers can view how the HCPT results fit into previous efforts. Further discussion of why and how the schemes differ follows in subsequent sections. **Finally, with direction from DOH and the CCWG, the HCPT continued use of the 2017 priority category titles, i.e. Priority Level 1, 2 and 3. However, the definitions that accompany the old 2017 priority categories are not continued and do not apply to the HCPT.**

Conceptual Model

Before continuing, it is important to clarify the language used in this report. The terms risk and hazard are often used interchangeably. However, for this exercise, the term hazard will be used to denote potential for harm. The Canadian Centre for Occupational Health and

Safety (2021) defines a hazard as "any source of potential damage, harm or adverse health effects on something or someone." Risk is defined as "the chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard, see Equation 1 (Canadian Centre for Occupational Health and Safety, 2021). Identifying specific risks, such as the number of people who will contract an illness from cesspool pollution is beyond the capability of this assessment. We can, however, estimate the risk of a hazard that may cause harm to people or the environment and offer a priority ranking to achieve this goal. In our prioritization, this was done through evaluation of the cesspool distance to a hazard or potential for exposure to wastewater contaminants through mechanisms such as swimming or drinking water. A complete evaluation and integration of exposure science is beyond the scope of this project.

$$\text{Risk} = \text{hazard} \times \text{exposure}$$

Equation 1. *Risk equals hazard times exposure.*

Tool Structure

The current report and HCPT expand on the previous efforts to provide a quantitative, up-to-date hazard assessment of geographic areas that may be adversely impacted by cesspool pollution. The HCPT uses the most up-to-date data available and its methods are reproducible and transparent. Relevant information, including source code, is publicly accessible through published notes books located on GitHub (click here to view). It was developed in consultation with local experts, engineers, and government associates to prioritize cesspools in the allotted time frame of the contract and CCWG needs. Though the prioritization process is inherently contextual, every effort has been made to create a non-biased objective evaluation of cesspool hazards in an equitable and fact-based methodology. There will be shifts in ranking between the old prioritization method and the new method. **The shift in ranking is to be expected due to the amount of available data and the use of census tract areas to frame the overall scores. For the few areas that have previous scientific data supporting the presence of wastewater pollution, they should be treated accordingly and factored in separately when developing conversion schemes.** The current HCPT does not evaluate other sources of groundwater pollution (agriculture or injected wastewater) or integrate observed coastal or groundwater quality observations as did the previous report. It was determined that other sources of groundwater pollution can significantly complicate the behavior of wastewater tracers, and the geographic extent of water quality data availability is very limited for statewide application.

Therefore, observation-based tracer datasets were intentionally excluded from the algorithm used to calculate prioritization scores. Instead, the HCPT's results are validated against the most robust statewide assessment of coastal wastewater impact available using observed and modeled nitrogen impacts from the Hawai'i Act 132 statewide study of sewage contamination.

The HCPT uses the following criteria (risk factors) to calculate a geographic prioritization score:

1. Distance to municipal or domestic drinking water wells;
2. Well capture zones;
3. Distance to streams and wetlands;
4. Distance to coastline;
5. Sea level rise zones;
6. Precipitation;
7. Depth to groundwater;
8. Groundwater flow paths;
9. Soil characteristics;
10. Cesspool density;
11. Coral cover;
12. Fish biomass/recovery potential;
13. Beach user-days;
14. Proximity to lifeguarded beach; and
15. Coastal ocean circulation proxy

As mentioned previously, adverse impacts from cesspools are cumulative. Therefore, it was important to identify a proper scale to evaluate the updated priority ranks. The HCPT frames cumulative cesspool pollution within United States Census Bureau tract boundaries to achieve this goal. The United States Census Bureau (n.d.) identifies census tracts as "small, relatively permanent geographic entities within counties (or the statistical equivalents of counties) delineated by a committee of local data users. Generally, census tracts have between 2,500 and 8,000 residents, and boundaries that follow visible features." Using census tract boundaries allows for more detailed resolution and increases objectivity from previous efforts. There are approximately 320 census tracts within the state of Hawai'i, and of these, just over 100 have a sufficient number of cesspools (greater than 25) to be ranked by the HCPT. Two additional census layers are available for analysis and include census block groups with 837 total and 236 ranked (greater than 20 cesspools) and census blocks with 22,780 total and 1,107 ranked (greater than 10 cesspools).

The new prioritization method utilized in the HCPT tool places each geographic area into three priority categories (Figure 1):

1. **Priority Level 1:** Greatest contamination hazard (map color of red).
2. **Priority Level 2:** Significant contamination hazard (map color of orange).
3. **Priority Level 3:** Pronounced contamination hazard (map color of yellow).

When homeowners use the HCPT web-based map tool they will enter a property TMK or address into a search bar. The HCPT will display the cesspool location(s) on a map with a color-coded dot of the corresponding priority. In addition, the surrounding census tract will be highlighted in the hazard category color to further help display the data. The public portion of the HCPT was designed to help homeowners obtain the most pertinent information in the fastest method possible. The DOH will have access to individual layers and ranking of cesspools in a similar online map tool for planning and management purposes.

While updating the prioritization method, the authors were asked to make recommendations to identify potential exemption criteria for groups of cesspools that are unlikely to severely impact the environment and human health. **In reality, all cesspools are substandard sewage disposal systems and pose some threat to their surroundings. Therefore, each cesspool in the inventory was assigned a priority ranking, and none are considered by this analysis to be exempt from conversion**. However, from a policy perspective, it is untenable to review every single system on an individual level. Therefore, the tool results are consolidated into prioritization areas using census boundaries at multiple different resolutions. In order to not skew the census area priority ranks by including areas with a small number of cesspools, a minimum number of cesspools within each census area was established, and those census areas with less than the minimum number were not ranked. Specifically, the cesspools in census tracts with less than 25 units were not ranked on the tract level, cesspools in census block-groups with less than 20 units were were not ranked on the block-group level, and cesspools in census blocks with less than 10 units were were not ranked on the block level. **Despite the fact that these more isolated cesspool units are likely to be less prone to contributing to cumulative effects, they nonetheless do receive a priority score, but only at the individual cesspool level.**

Tool Development

After researching related legal, academic, and gray literature via internet searches and academic databases including Google Scholar, Web of Science, and Pubmed, a simplified geospatial hazard-based model was developed to visualize, assign, and rank multiple factors to point locations on a map. This method assigns a cumulative hazard score to each cesspool in the inventory. Similar tools for OSDS prioritization described in the literature were considered when developing this methodology for Hawai‘i, and include Hawai‘i Department of Health (2017); Flanagan et al. (2019); Kinsley et al. (2004); and Oosting & Joy (2013). Although the HCPT provides a hazard score for every individual cesspool in the inventory, combination effects of nearby units, as well as the practicalities of management approaches mean it is more beneficial to aggregate these scores by pre-defined geographic areas, similar to Kinsley et al. (2004) and Oosting & Joy (2013). However, Hawai‘i has a unique political structure and both highly urbanized and rural populations, making traditional ecological/political aggregate frameworks, such as watershed boundaries, incompatible. Instead, the HCPT uses existing census-designated boundaries as described in the Background and Motivation section. The prioritization scores of all cesspools within each census area are averaged, and this average score is then assigned to the census-boundary area to represent the cumulative hazards from all cesspools in that unit. **Although the variables used likely have various interrelationships, each input in the tool is distinct in its representation of hazards and treated as independent of one another for simplicity.**

By using an aggregated risk and hazard assessment methodology, the tool estimates the likelihood of adverse impacts or pressures to a given area resulting from human activities (cesspool effluent discharge). Additionally, the HCPT differs from other models by incorporating societal and environmental values such as beach visitor use, fishery health, coral cover, and the potential for cesspool remediation to improve coastal ecosystems. The tool cannot evaluate all social and environmental information relevant to cesspool pollution or decision-making associated with cesspool conversion, nor is the tool intended to replace robust planning, policy, and management processes. **The tool is merely a starting point for assessing the areas with the most significant hazards and is meant to support development of a thorough and thoughtful cesspool conversion plan. The tool cannot make decisions regarding cesspool conversion prioritization timelines.**

Developing a tool that is unique to Hawai‘i means there are several differences from the method(s) used previously to prioritize cesspool hazards in Hawai‘i, and methods that exist across the continental United States. These differences include:

- Incorporating high-confidence groundwater models to determine effluent flow paths and to link each cesspool unit to the location along the coastline most affected by its discharge. These models have previously been validated through the sampling of coastal wastewater indicators, and are considered to be relevant for this purpose.

- Considering impacts to social and ecological assets located downgradient from each cesspool as a part of the overall ranking. These include lifeguarded beaches, coral reef habitat, fish biomass, and a proxy for coastline usage.
- Calculating cumulative hazard scores (based on nonpoint source pollution dispersion) using non-arbitrary census-designated areas at multiple resolutions to develop a more realistic nonpoint source pollution framework.
- Excluding parameters such as lot size or system age. Hawaiʻi is an outlier when comparing continental models to evaluate OSDS priority zones because of limited real estate space and the high density of OSDS per acre. Age was excluded because cesspools have similar impacts irrespective of maintenance or system age.
- Assumes all properties are occupied year-round versus actual property use (i.e., seasonal, vacation rental)
- Excludes commercial and industrial properties.
- Incorporates sea level rise projections from the Hawaiʻi Sea Level Rise Viewer.

The HCPT moves beyond qualitative methods and assessments using water quality impact research, which is subject to sampling bias and limited for statewide analysis. The focus is instead on measurable environmental factors, regulations, and values (with statewide data) tied to water quality to create a quantitative assessment that can add future data to refine scores if needed. However, not all areas have data for measurable impacts. Therefore, some assumptions were made when data gaps existed or simplifications were required, which will be discussed further in elements of the Methodology section.

The HCPT development team aims to use an iterative user design process for its web-based map/public viewer. Our goal is to understand human dimensions and needs regarding cesspool prioritization information. Because the process is iterative, several updates of the tool may be created to serve different audiences. The audience for the public map tool is primarily homeowners, while the advanced map tool is developed for internal DOH scientists, and other state employees indirectly involved in the cesspool conversion issue and associated wastewater challenges.

Methodology/Dataset Categories

This section will describe the framework and systems used to create the HCPT as well as the challenges encountered. The results of the tool rely on the best publicly available data.

As the tool was being developed, several challenges were identified regarding data consistency and quality. These include:

- TMK number discrepancies with county tax data and DOH database.
- Accuracy of OSDS classification (cesspool, septic, aerobic treatment unit).
- Accuracy of the number of OSDS.
- Limited statewide data regarding water quality indicators/impacts.
- Limited data on sewer laterals (private/municipal).

Physical Drivers and Environmental Quality Hazards

Physical drivers, for this report, are elements that control the movement, reduce capacity, or otherwise affect the overall level of impact a cesspool has on the land and also the water quality nearby. Much of the data used in the HCPT is also used by agencies like DOH or county water supply departments for source water protection and public health. The impact an individual cesspool has on its surroundings depends on many factors. Even with readily available data, it is difficult to assess impact due to various environmental factors and complex interactions. No tool can fully predict or assess all environmental variables. Primary factors that contribute to the HCPT include physical factors such as soil suitability and surrounding geology, location, and proximity to environmentally sensitive areas like wetlands and coastlines. Additional factors include social and ecological assets affected through the coastal discharge point of effluent, and cumulative impacts of other nearby cesspools. **Importantly, the tool's concept is based on the hypothesis that the more cesspools in an area, the less effective natural soil and subsurface systems will be at degrading cesspool effluent.**

Because this project was designed to assess cesspools statewide, only data that was at the statewide scale were used. Though this may exclude other important datasets, DOH requested a statewide methodology. Where these datasets had missing values, gaps were filled using the best available proxies described below in their categories. **Generally, only datasets with a minimum of 90% geographic coverage of the state were used.** Often, the geographic coverage of many of these datasets only extended across the four main Hawaiian Islands. While it is recognized that there are cesspool impacts on the outer islands of Moloka'i, Lanai, and Ni'ihau, these islands were not included in a number of key datasets necessary to this analysis. The authors recommend that DOH establish a ranking system for these islands when time and funding allows. The relationship between the cesspool location and the geographic distribution of the hazard or risk-factor was either defined as a scalar value (1 to 100) or a categorical value (0 or 100) through individual scaling factors based on regulatory or evidence-based thresholds. For example, any cesspool within 50 feet of the coastline was assigned a scalar score of 100 based on the state regulatory setback distance.

Value-Based Environmental/Human Hazards

While the physical factors can control the level of impact a cesspool typically has, other factors can help quantify human and environmental value within the areas affected by the discharge of cesspool effluent. In order to develop scores for these values, the HCPT uses groundwater models developed by DOH. The models assess where cesspool effluent will discharge along the coast and where impacts will be realized. Because DOH is tasked with protecting human and environmental health, the following ecological and social factors were included in the calculation of priority scores:

1. Lifeguard tower locations/swimming beaches
2. Coral cover/recovery potential
3. Resource fish biomass/recovery potential
4. Coastline usage and visitation (user-days)

More detailed information about each input is provided in the sections below.

Cesspool Locations/Grouping

The basis of the HCPT begins with cesspool locations. Cesspool location data was obtained from the State of Hawaiʻi Geospatial Data Portal. Oʻahu cesspool location data was created in 2008 and the other island(s) cesspool data was developed in 2010. However, it was evident that updates would be needed to develop an accurate assessment of cesspool prioritization in 2021. Efforts were made to update known errors, incorporate data from 2020, add cesspools installed before the 2016 statewide ban of new cesspools, and remove cesspools that have been converted. **The authors recommend that all statewide cesspool data continue to be refined and, if possible, ground-truthed to ensure the most accurate results of the tool and for future statewide OSDS management and cesspool conversion.**

The prioritization framework and algorithms rely on having accurate information regarding the location and number of cesspools. Updates include the incorporation of recent (up to 2020) permitting data from the DOH Individual Wastewater System Database (IWD) including newly (before 2017) permitted cesspools and units that have been converted to septic tanks or other treatment systems. County tax records and dwelling database information was also used to exclude parcels that did not contain residential buildings with at least one bathroom and bedroom. Additionally, the cesspool inventory was originally created at the TMK level, resulting in tens of thousands of TMK's with multiple cesspool units on some parcels. These units were extracted out and defined as individual geospatial points, thereby ensuring that each individual cesspool was represented as a discrete point on the landscape. While these updates provided greater confidence in the inventory used, significant work on the cesspool inventory is still required to remedy inconsistencies in the database. Future database research development is warranted. However, doing so is outside of this project's scope and is recommended for completion when sufficient time and funding can be made available.

In order to develop a cumulative hazard score, cesspools need to be grouped into appropriate and logical clusters. Several methods were explored, including using watershed or aquifer boundaries. For the final analysis, United States Census tract data was chosen. Census tracts are small, statistical subdivisions updated by local participants prior to each decennial census to provide a stable set of geographic units to present statistical data. (U.S. Census Bureau, 2021). According to the United States Census Bureau, census tracts cover areas with fairly standardized population sizes between 1,200 and 8,000 people. A census tract usually covers a contiguous area, however, the spatial size of census tracts varies widely depending on the density of settlement. Census tract boundaries are defined with the intention of long-term stability so statistical comparisons can be made through time, though census tracts are occasionally split due to population growth or merged following substantial population decline (U.S. Census Bureau, 2021). Additionally, census tract boundaries generally follow visible and identifiable features, though they can follow nonvisible legal boundaries, such as a minor civil division or incorporated place boundaries to allow for census-tract-to-governmental-unit relationships since these boundaries tend to remain unchanged between censuses (U.S. Census Bureau, 2021).

Synthesis: Prioritization and Ranking

To combine data from multiple risk factors, such as depth to groundwater or soil suitability at the individual cesspool level, the tool overlays the individual fifteen input data layers (risk factors) onto each cesspool point's attribute data table. Each layer's data values are then normalized to a 0-100 score specific to the risk factor at each cesspool point. Individual methods used to convert various input data values to 0-100 priority scores are described in the Input Data section below. For clarity, these individual scores will be referred to as **Risk-Factor Scores**.

Next, the fifteen **Risk-Factor Scores** are averaged to generate a single **Cesspool Prioritization Score** for each cesspool. Therefore, each of the 82,000+ cesspools in the inventory has an individual prioritization score, making it possible to resolve differences at the individual cesspool level. However, because the impacts of wastewater effluent are cumulative, the tool then aggregates cesspools into census-based geographic areas, as described in the section above, and uses the arithmetic mean **Cesspool Prioritization Score** of all cesspools within each census unit to assign a **Census Unit Prioritization Score** to every census unit that contains more than a minimum number of twenty-five cesspools. **Census Unit Cesspool Prioritization Scores** are calculated at the census tract, census block group, and census block levels to provide flexibility in management applications. To further digest these scores for management purposes, it was decided to use the final **Census Unit Prioritization Scores** to categorize each census unit into one of three priority levels, which will be referred to as **Prioritization Categories.**

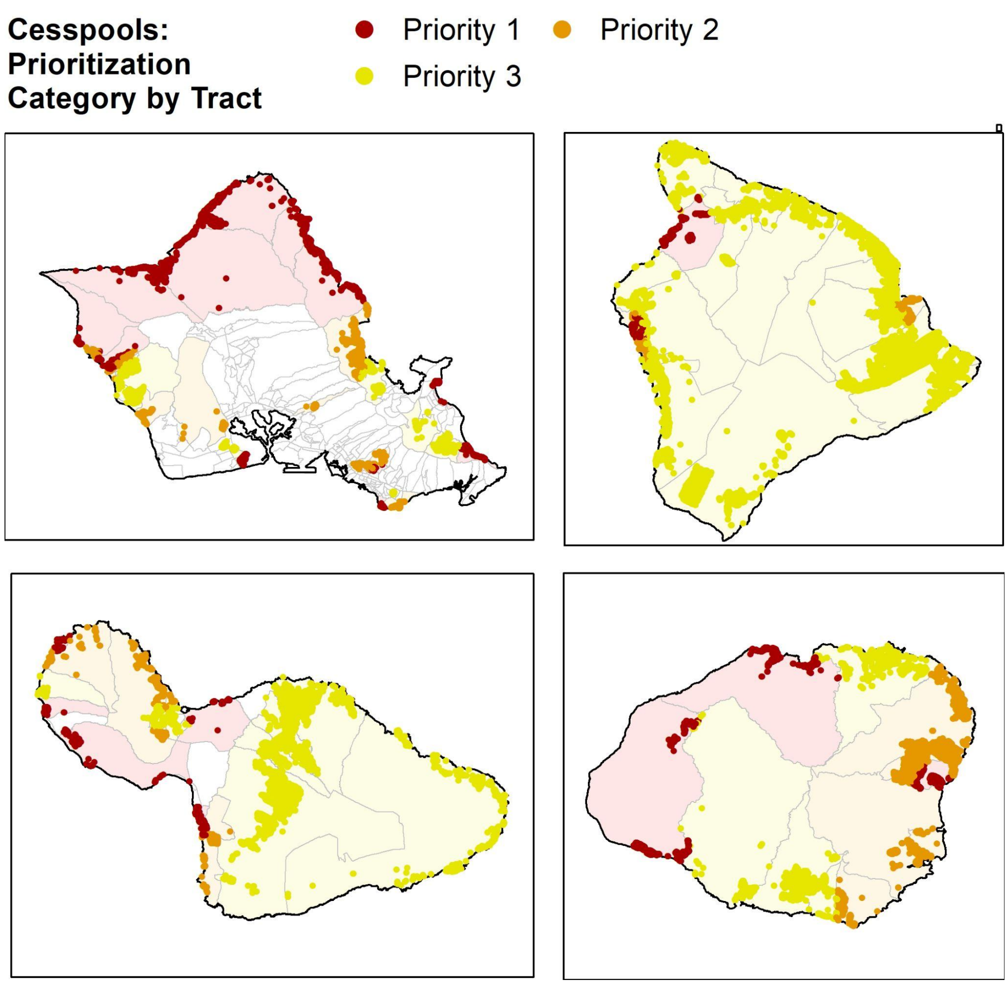

Figure 2. *Statewide map highlighting the simplistic design of the three-tiered categories, census tracts, and their respective colors to signify a priority score. (Updated 2022)*

The new prioritization method (Figure 2) places each geographic area into three Prioritization Categories that include:

4. **Priority Level 1:** Greatest contamination hazard (map color of red).
5. **Priority Level 2:** Significant contamination hazard (map color of orange).
6. **Priority Level 3:** Pronounced contamination hazard (map color of yellow).

After reviewing the prioritization score results, the findings revealed a fairly normally distributed pattern among the three groups. And, through review of Oosting & Joy's (2013) use of raster data preparation and risk contouring –which represent the mean risk and increments of the standard deviation above and below the mean– it was determined that quartiles were an appropriate way to categorize the HCPT results based on our methodology and data. The difference in how to categorize the results may be because of the available HCPT cesspool location data, versus Oosting & Joy's (2013) need to identify a geographic area of risk. HCPT categories are defined by the mathematical quartiles of 25% and 50% with the top 25% highest scoring areas designated with the Priority Level 1 ranking, the next lower 75% to 50% with Priority Level 2, and the bottom 50% as Priority Level 3. The breakpoint categories can be revised based on management strategies, policy needs, or updated research and data.

A cutoff was used to exclude census units with few to no cesspools. Tracts with less than twenty-five cesspools, block groups with less than twenty, and census blocks with less than ten were excluded from the analysis to reduce bias from small sample sizes. They are displayed with a white color. Individual cesspools in these locations were still ranked and results can be visualized in the DOH Input Data application. Additionally, a sensitivity analysis was performed to assess the effect of changing the importance (weights) of the different input data in the overall ranking, and the results are discussed in Appendix B.

Validation Methods

The accuracy of models is typically tested through comparing results to real-world observations. For example, an atmospheric climate model can be adjusted or validated based on rainfall amounts observed throughout the model area. However, the prioritization results produced by the HCPT lack a single observable indicator to compare. Cesspool discharge produces impacts across many sectors such as drinking water aquifers and coastal ecosystems. The impacts on people and the places that are valued manifest in multiple ways that often do not overlap. Therefore, there is no single criteria or tracer dataset that can be used to calibrate elements within the HCPT to determine how important, or not, the factors used actually are. While there is existing precedent from the previous 2017 prioritization efforts to use documented impacts to drinking water or human health as a component in the former prioritization; **the HCPT authors determined that observations or study-based datasets (e.g. water quality data) are too geographically limited to be included in the prioritization algorithm without leading to significant sampling bias and skewing of the results.**

The HCPT team concluded that validation with the Hawaiʻi Act 132 sewage study, was the best method to compare results to a statewide physical indicator dataset. Hawaiʻi Act 132 sought to fill a statewide data gap by funding a study led by Smith et al. (2021) targeted at detecting OSDS wastewater in coastal waters. The study provides the most comprehensive and reliable nearshore nutrient availability and source tracking data of any effort completed to date in the state of Hawaiʻi. While the geographic extent of this study is vast, limitations relating to its sampling extent and the utility of the tracer datasets used (nearshore algal $\delta^{15}N$ and algal %N measurements), still preclude its application as a driving factor in the prioritization score calculation. However, it does provide the best opportunity to validate how reasonable the HCPT prioritization results are in terms of addressing areas with observed impacts from OSDS derived nitrogen. As of August 2021, the Act 132 study is under review by the CCWG, and provisional results were provided for use in validating this prioritization effort.

The authors would also like to acknowledge the existence of other statewide datasets that relate to possible nutrient or pathogen impacts from OSDS. These include nearshore Enterococcus data collected by the DOH Clean Water Branch Hawaiʻi Beach Monitoring Program, groundwater nitrate data collected by water system operators and reported to the DOH Safe Drinking Water Branch in compliance with the federal Clean Water Act, and repositories such as National Water Quality Monitoring Council database which includes data from studies conducted by the United States Geological Survey and the United States Environmental Protection Agency. Every effort was made to analyze available data to test relationships with possible impacts from cesspools. These efforts indicated that either the geographic extent of most study-based tracer datasets was too limited, or that the primary drivers of variability in statewide monitoring datasets were not sufficiently driven by OSDS impacts. Coastal Enterococcus data was found to be primarily driven by surface water runoff quality (Strauch et al. 2014; Byappanahalli, Roll & Fujioka, 2012; Byappanahalli et al. n.d.), and groundwater nitrate data on the statewide scale appears to be primarily driven by agricultural influences (Mair and El-Kadi, 2013; Moon, 2021). While OSDS prevalence may be a factor in these datasets, it was far beyond the scope of this work to deconstruct.

Input Data: Functions

This section will describe the data that was incorporated into the tool as well as provide summaries on why and how certain types of data or methods were used to evaluate and create a prioritization scheme. Formerly, the 2021 HCPT weighted each risk factor equally in the prioritization calculation, with each factor normalized to have a score of zero to one hundred; this process was created through collaborative meetings with DOH and CCWG input. An update was performed in mid-2022 to better represent the disparity in importance of each of the input risk-factors. An expert-informed process was used to identify new weights for each risk factor, see appendix C for details, and the tool was re-run with the new weights. All figures and tabular results in this report reflect this 2022 revision of the tool and present results generated with the new weighting methods.

Threshold-Decay Function

In order to convert scalar data values associated with each risk factor (e.g. the distance in meters to the coast or a stream) to a 0 to 100 prioritization score, customized algorithms were developed. In general, the vector distances or other scalar data geographically derived from cesspool locations was used as a variable in a combination approach that both applies existing regulatory thresholds as well as a more physically based decay function. The decay part of the function approximates the behavior of solute transport through underlying geology via a highly simplified version of the one-dimensional convective-dispersive solute transport equation (Van Genuchten, 1982). This equation describes contaminant concentrations with travel distance through an aquifer (Figure 3). The function is simplified here by excluding the scale-dependent parameters that control the movement and attenuation of individual solutes in aquifers. The simplified function only applies the median value of each risk-factor distribution as a control parameter on the rate of decay with distance from the feature of interest. This method ensures that cesspools just past the threshold values are still deemed to be at higher risk than units that are significantly farther away. For additional information on the threshold-decay function used for calculating priority scores for some risk factors, and for the Python code that executes it, please see the Code Notebook associated with this report.

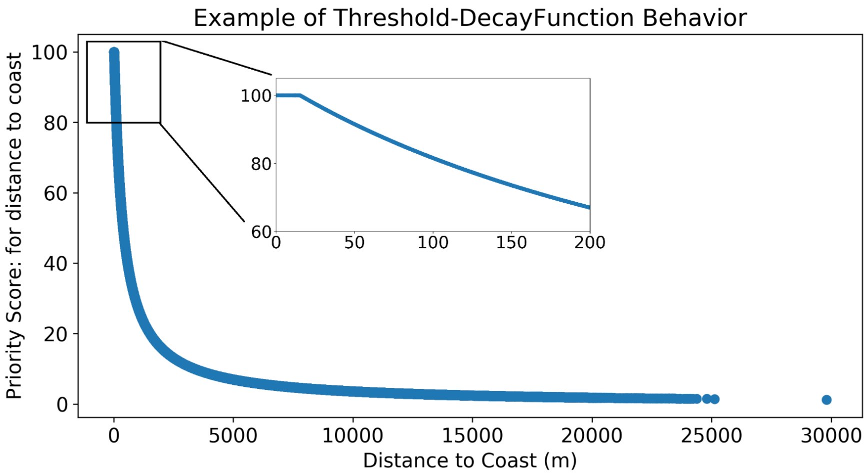

Figure 3: *Plot showing how the threshold decay function converts data from each risk factor (in this case Distance to Coastline in meters) to a 0-100 score. Note the inset showing how the priority score equals 100 for all units within 50 ft (15.24m) from the coast (the state's regulatory threshold), and how the score decays with greater distances from the coast.*

Groundwater Flow Paths

For the HCPT, groundwater flow paths were not considered as an independent risk factor. Instead, they are used to link each cesspool location to a corresponding location along the coastline where the cesspool's effluent is estimated to be discharged. The calculation of flow paths was done by application of island-wide, MODFLOW-based groundwater models provided by DOH and thoroughly documented in Whittier and El-Kadi (2009, 2014). While these groundwater models are the best available models for the entire state, the results are subject to their own assumptions and limitations presented in their respective documentation. Groundwater flow paths originating from model cells containing cesspools were calculated using the MODPATH code within the Groundwater Modeling System (GMS) graphical user interface (Pollock, 2012). Each flow path eventually discharges to the coastline. The flowpath vector traveled from the cesspool-containing cell center to the cell center of the end-cell that intersected the coastline. End cells were defined as square polygons with center points distributed evenly every 250 meters along the coastline of O'ahu, Maui, and Kaua'i, and every 500 meters on Hawai'i Island. **In theory, a cesspool located on the land surface can be linked directly to the coastline location to which its effluent will eventually discharge after traveling through the aquifer.**

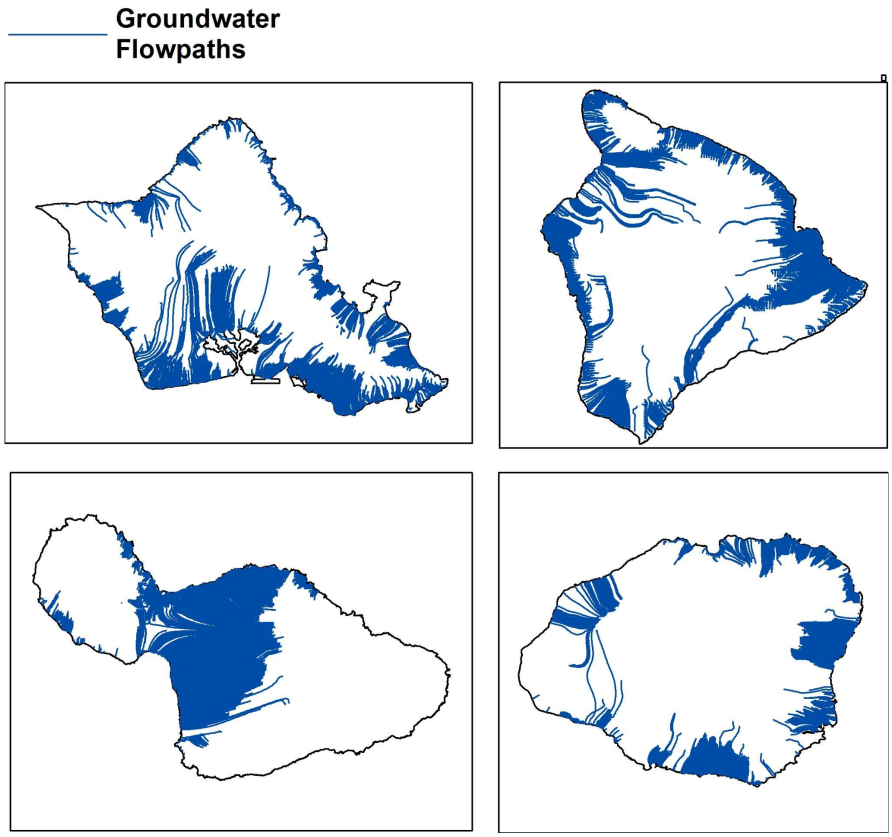

Figure 4. *Example map of four major Hawaiian Islands highlighting groundwater flow paths to the coast.*

Input Data: Risk Factors

Coastline/Distance to Coastline

Cesspools adjacent to the coastline face numerous challenges such as sea level rise, erosion, and shallow depth to groundwater. Studies such as Abaya et al. (2018) have demonstrated that distance to the coast and geology can have dramatic effects on the travel time of wastewater pollution entering the ocean. The HCPT uses a basic geographic distance calculation to the nearest point on a Hawaiʻi coastline GIS shapefile to assign a distance to each cesspool in the inventory.

Coastline Prioritization Score Algorithm

For the conversion of distance to coastline to a prioritization score, the threshold-decay function was applied with the maximum risk score (score of 100) assigned to cesspools located closer to the coast than the regulatory threshold of 50 feet or 15.24 m (HAR 11-62).

For cesspool points farther than 50 feet, the score was exponentially reduced with additional distance.

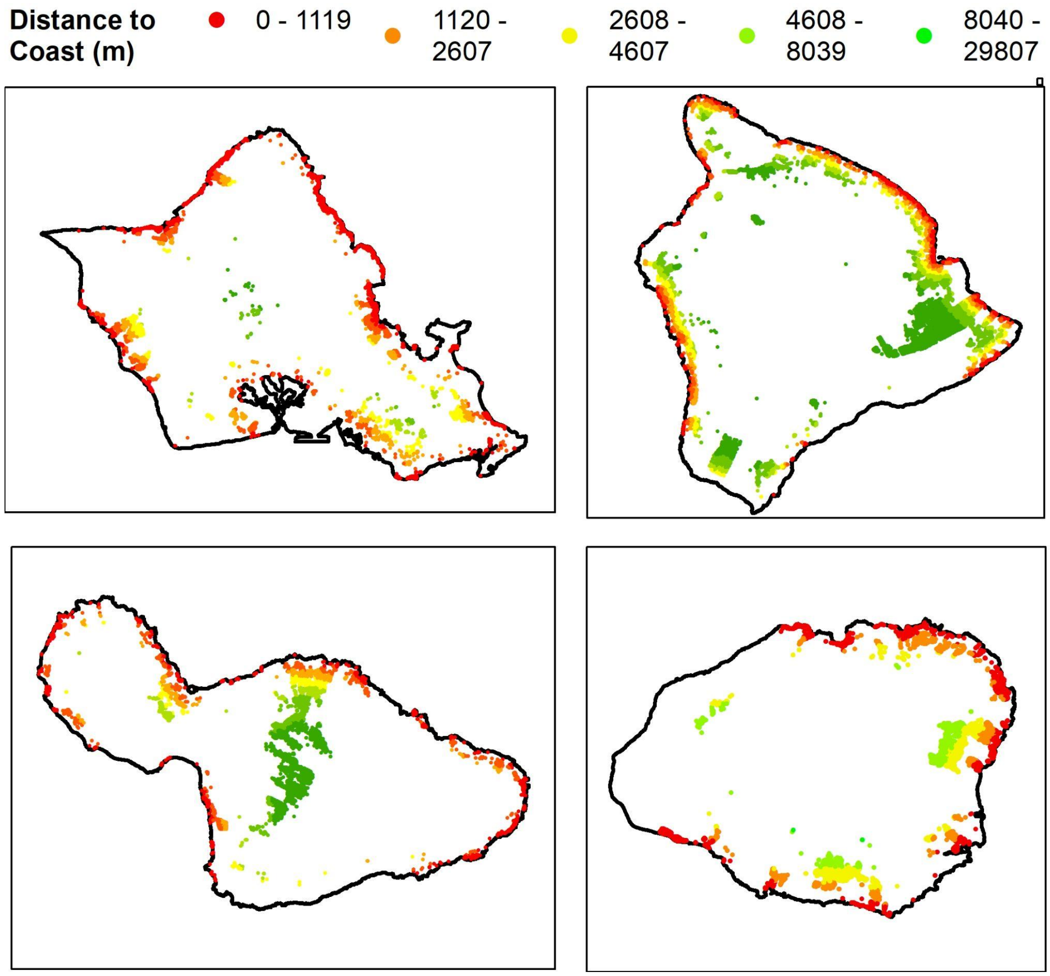

Figure 5. *Example map of four major Hawaiian Islands highlighting cesspool proximity (distance) to the coastline. Red indicates a cesspool is near the coastline, in decreasing order, orange, yellow, and green signify a further distance from the coast.*

Drinking Water Well Locations/Distance to Drinking Water Wells

According to the Environmental Protection Agency (2020), a failing onsite sewage disposal system or cesspool that is located too close to a drinking water well can contaminate the source. Protecting drinking water is especially important in Hawai'i, where much of the state's drinking water comes from underground aquifers, some of which are the sole source (Gingerich and Oki, 2000). Previous studies such as Mair and El-Kadi (2013); Verstraeten et al. (2004); Oluwasola et al. (2017); and Schaider et al. (2016) indicate that the OSDS distance to a drinking water well is an important factor to ensure a clean and safe drinking water supply. Additionally, Hawai‘i Administrative Rules Title 11, Chapter 62 (HAR 11-62) dictates that a potable water source serving public water systems must be a minimum horizontal distance of 1,000 feet (304 meters) from a cesspool. The Hawai'i Wellhead Protection Program (Whittier et al., 2010) uses U.S. EPA (2006) guidance to identify near-wellhead (Zone A) and source-water (Zones B and C) zones that require protection from contaminants. Zone A is delineated through a geographic distance from the wellhead and Zones B and C are delineated through modeled capture zones or aquifer boundaries. Finally, the DOH ranks protecting human health and drinking water as one of its most important duties (Pruder, personal communication July 2, 2021). Therefore, this factor is vital in the HCPT updated prioritization scheme.

To incorporate this type of hazard into the tool, locations of pumping wells were acquired from the state well inventory from the Commission on Water Resources Management (CWRM). Each well is associated with a use code (agricultural, domestic, industrial, irrigation, military, and observation) as well as an identifier for abandoned and unused wells. After analysis, 910 of the 5,286 wells within the CWRM dataset were designated as domestic use, and 534 were designated as municipal, for a total of 1,444 active wells that were considered in the HCPT.

Drinking Water Well Prioritization Score Algorithm

The distance to domestic drinking water wells was assessed separately from the distance to municipal wells, and each cesspool received separate scores for proximity to any well and for intersection with municipal well capture zones as described in the section below. This is because municipal wells serve proportionally larger numbers of people, and domestic wells are often within close proximity to homes using OSDS. Each cesspool unit was assigned the distance between its location and the distance to the nearest domestic well, and a separate value for its distance to the nearest municipal well. The threshold value of 56 feet (17 meters) was used for municipal wells based on guidance from the Hawai'i Wellhead Protection Program (EPA, 2006; Whittier et al., 2010), which uses this distance as the Zone-A radius for the near source zone that provides protection against direct introduction of contaminants through and around the well casing. This distance was cut in half to 28 feet (8.5 meters) for domestic wells because of their generally smaller size and proximity to residential units. These threshold distances were applied within the threshold-decay function to calculate separate priority scores at each cesspool point for municipal and for domestic wells.

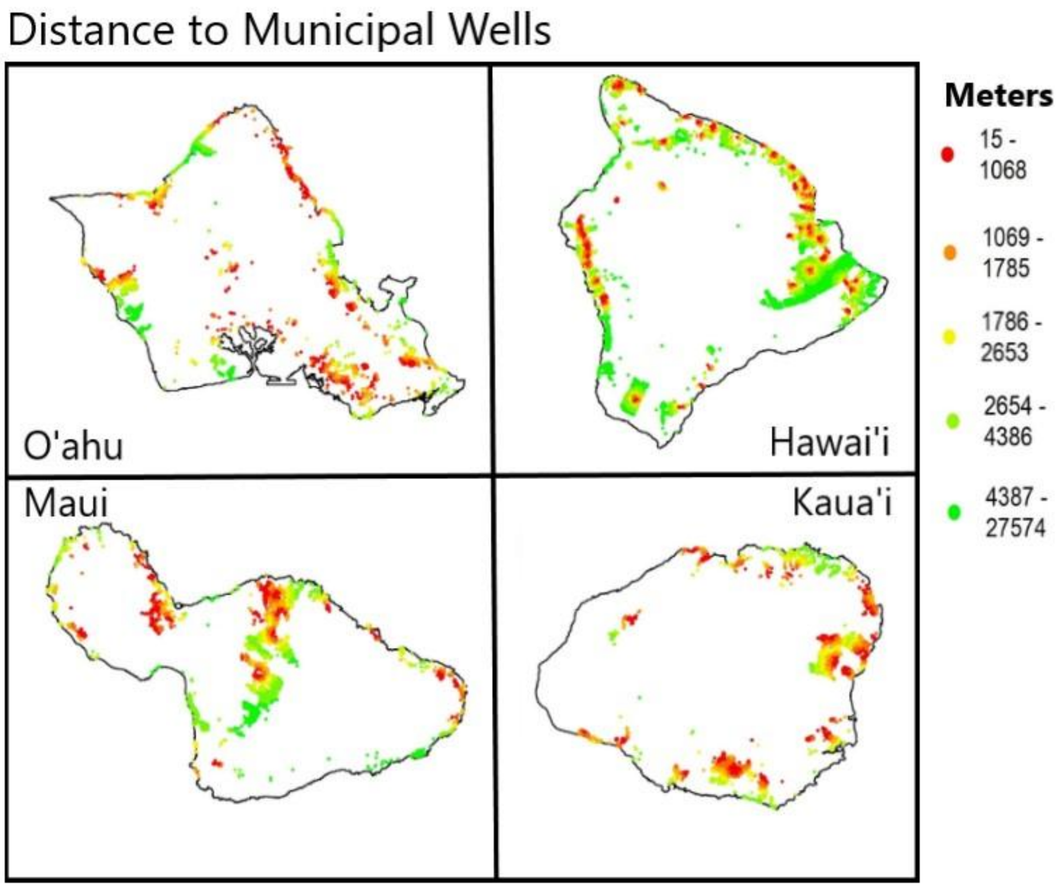

Figure 6. *Example map of four major Hawaiian Islands highlighting cesspool proximity (distance) to a municipal drinking water well. Red indicates a cesspool is near the associated wells, in decreasing order, orange, yellow, and green signify a further distance from a well.*

Well Capture Zones

Knowledge of the location and shape of a well capture zone is a fundamental element of groundwater management (Nagheli, Samani & Barry, 2020). To most accurately convey potential risks to drinking water supplies, the HCPT evaluated if a cesspool was located within a municipal well capture zone. This is largely because cesspool and OSDS effluent have the potential to contaminate drinking water supplies with enteric viruses and other pathogens that can withstand long travel times. Data on capture zone locations was provided by DOH and CWRM.

A capture zone defines the land area from which infiltrated recharge may ultimately contribute to the groundwater produced at a given well. These capture zones were calculated through reverse particle tracking of flow in a groundwater model using MODPATH code. While the inclusion of a geographic distance factor and assessment of the modeled well capture zones has the potential to be duplicative, it was deemed reasonable considering:

1. The importance of drinking water and high risk of contamination cesspools pose to aquifers, and;
2. The inherent uncertainties of, and relatively low resolutions of available groundwater models in critical regions near pumping wells where groundwater gradients are extremely high.

Therefore, the chosen method considers both risks of contamination from nearby cesspools, even if they are not defined to be within a capture zone, as well as risk from geographically distant cesspools located directly upgradient from wells.

Well Capture Zone Prioritization Score Algorithm

Cesspools that fell within a 2-year travel time capture zone (Zone B) and the 10-year travel time capture zone (Zone C), were identified and scored accordingly. A 2-year travel time has the potential to have contamination reach the water supply more rapidly than a 10-year travel time. Units in the 2-year zone are assigned a numerical score of 100, those in the 10-year zone a numerical score of 50, and all other units received a score of 0.

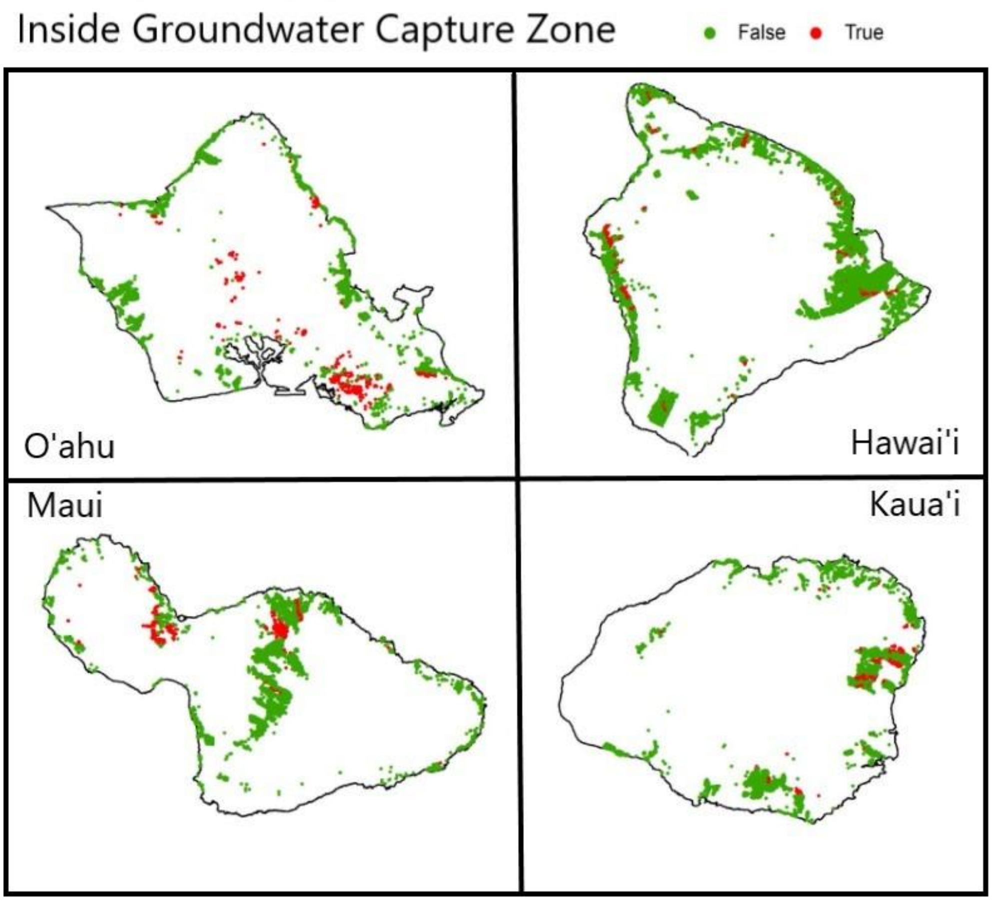

Figure 7. *Example map of four major Hawaiian Islands highlighting if a cesspool is located inside or outside the 10-year well capture zone. Red indicates the cesspool is in a capture zone, while green indicates the cesspool is not.*

Soil/Geological Data

Soil is essential for wastewater treatment systems to function properly and generally a hostile environment for bacteria in sewage (Hygnstrom et al. 2011). In typical onsite wastewater treatment fields, soil provides space for biological activity and filters pathogens and chemicals through its physical characteristics (Hygnstrom et al. 2011). Soil particles provide the necessary surface area for biological treatment to occur.

Soil suitability is an important factor around cesspools. Cesspools are substandard systems because they lack a primary treatment tank where non-oxygen demanding bacteria digest some of the waste and solids settle out. Additionally, cesspools do not have an engineered soil space (treatment field) to complete treatment, as an adequate wastewater treatment system would. The soil surrounding cesspools may provide limited filtration and space for microbial activity, but this depends on the underlying geology and water holding capacity, along with the types of waste inputs from the home. In general, saturated soil or bedrock is a conduit that transmits pollutants to nearby water bodies. Many risk factors must be taken into account when evaluating how soils and geology influence pollution risk. Regulatory horizontal and vertical setback distances away from OSDS, though important, provide limited protection (Borchardt et al. 2010).

Statewide soil data was extracted from the Natural Resources Conservation Service (NRCS) database as part of the HCPT efforts. The NRCS has developed a methodology for assessing the suitability of soil for siting an OSDS unit based on properties recorded in nationwide soil surveys (NRCS, 2020). The NRCS suitability is based on the eight factors that control the treatment and infiltration of OSDS leachate, as well as the ease of treatment field installation. This method was previously used in Hawaiʻi's 2017 cesspool prioritization process (Hawaiʻi State Department of Health: Environmental Management Division, 2017), and its specific use for Hawaiʻi has been documented in Whittier and El-Kadi (2014). The HCPT modifies the methods used by Whittier and El-Kadi (2014) to assign a single soil-suitability score to each cesspool based on the factors and thresholds defined by NRCS, specifically, these parameters include:

1. **Depth to bedrock**: A measurement from the ground surface to the contact with continuous bedrock or cement pan;
2. **Flood frequency**: The degree to which the soil is subject to flooding or ponding;
3. **Filtering characteristics**: How well the soil filters out particulates and bacteria;
4. **Water infiltration rate**: How well water moves through the soil;
5. **Bottom seepage rate**: How quickly water will move from the lowest soil layer to the bedrock;
6. **Slope:** Measurement of the direction and the steepness of the ground surface. A slope of more than 15% is considered problematic for OSDS installation;
7. **Rock fragmentation:** Measurement of the fraction of rock fragments in the soil. A percentage of 3-inch rock fragments of more than 50% is problematic for OSDS pollution.

Consolidated Soil Prioritization Score Algorithm

To incorporate the seven soil parameters into the HCPT framework, a similar approach used by Whittier and El-Kadi (2014) was followed. The specific approach used thresholds based on the NRCS soil suitability assessment with an independent calculation based on the categorical values provided in Table 1. Specifically, a value for each parameter (except subsidence) was extracted from the soil-survey GIS polygon features. Then a categorical value (1 to 4) based on the limitation classes below were assigned to each. The parameter values were averaged with Depth to Bedrock, Flooding, Filtering Capacity, and Slow Water Movement each having a weight of 1. Seepage From Bottom Layer, Slope, and Percent Rock Fragments (> 3 inches) each were given a weight of 0.33 in order to score these less important parameters together with a lower weight each. The averaged soil suitability score for each cesspool unit was then scaled through a minimum to maximum scaler to obtain relative values between 0-100.

Described below are the methods used to fill the flood-frequency parameter, which is important in terms of surface transport of contamination from OSDS and cesspools. The flood frequency of many locations is already defined by the NRCS soils database, though about fifty percent of the cesspool points were missing the data from the NRCS database. Therefore, rainfall amounts (from data described in the Rainfall section below) and saturated hydraulic conductivity (known as ksat in the tool) values from the NRCS soil parameters were used to fill in the likelihood of flooding only in those areas where it was not defined by the NRCS database. The following logic was established through consultation with DOH and engineering professionals to fill in the flood frequency values where they were missing.

- If rainfall is above 135 inches AND ksat is less than 1.1 = Frequent Flooding
- If rainfall is below 15 inches AND ksat is less than 1.1 = Frequent Flooding
- If rainfall is above 135 inches OR ksat is less than 1.1 = Occasional Flooding

Table 1. *Limitation class thresholds for soil characteristics as they relate to the appropriateness of siting OSDS in soils with different properties. Where soil parameters are favorable for OSDS development, the limitation classification is slight or none. Where soil parameters are unfavorable for OSDS placement, functioning limitation classifications are moderate to severe. Total subsidence, the amount the soil sinks after treatment field installation, was not considered to be relevant in Hawai'i's young volcanic soils. Table taken directly from Whittier and El-Kadi (2014).*

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

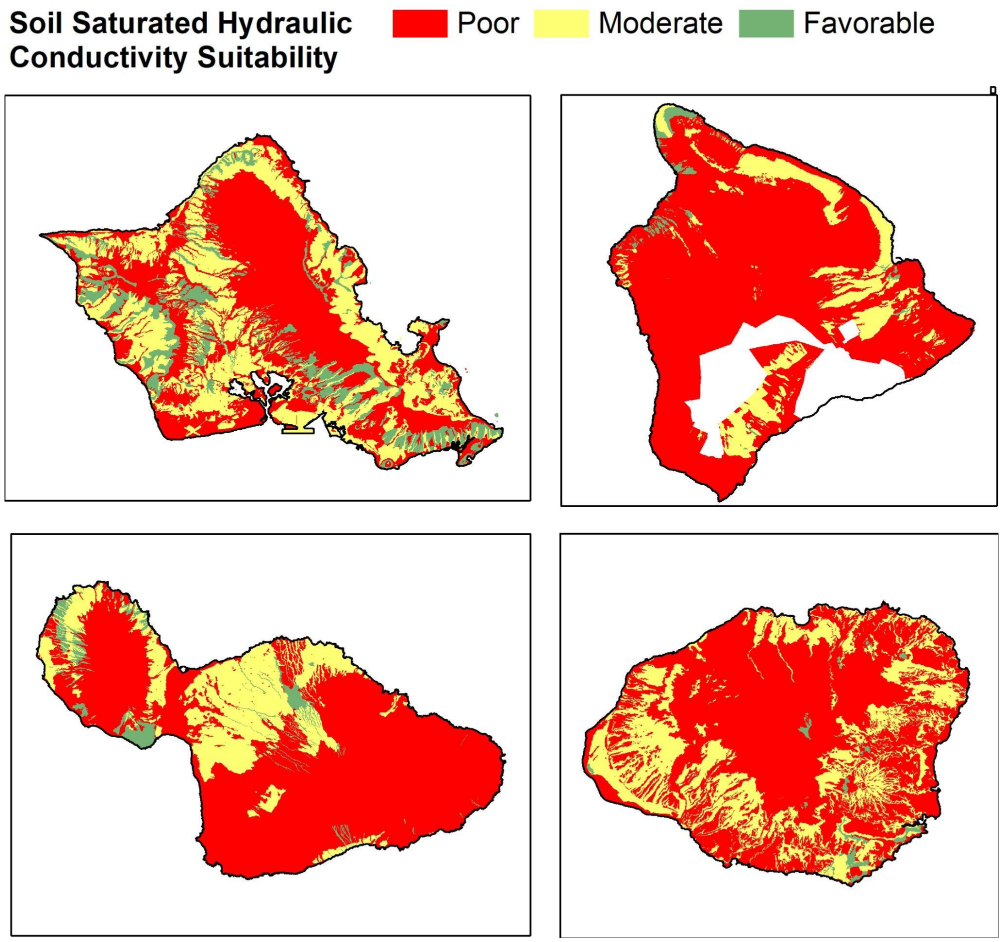

Figure 8. *Example map of the geographic distribution of one of the most important soil properties (hydraulic conductivity) in the soil suitability analysis. The values on this map show where saturated hydraulic conductivity values are favorable in consideration of the parameter values from numbers 3, 4, and 5 in Table 1 above. Red is least favorable, yellow is moderately favorable, and green is most favorable.*

Precipitation (Rainfall)

It was determined through research and consultation with engineers that local rainfall by itself does not directly affect the suitability of OSDS placement. However, once wastewater effluent is in the subsurface aquifer, the amount of effluent compared to the quantity of groundwater recharge controls how diluted the pollution will be and how concentrated and impactful contaminants from each system are upon discharge. The best proxy to estimate groundwater recharge in the Hawaiian Islands is rainfall. The HCPT assumes that areas with high rainfall were considered to be more favorable, or less impacted, by each cesspool. Average annual rainfall datasets were collected from the Hawaiʻi Climate Atlas (Giambelluca et al. 2013) as statewide grids of annual rainfall totals and rainfall rates were extracted at each cesspool location.

Rainfall Prioritization Score Algorithm

Because there is no established relationship between the acceptable amount of groundwater recharge (and thus rainfall) to sufficiently dilute effluent from an OSDS unit, the threshold-decay function was applied to determine a relative score for each cesspool, with the threshold value set at 8 inches (0.2m)/year, the lowest value in the rainfall dataset.

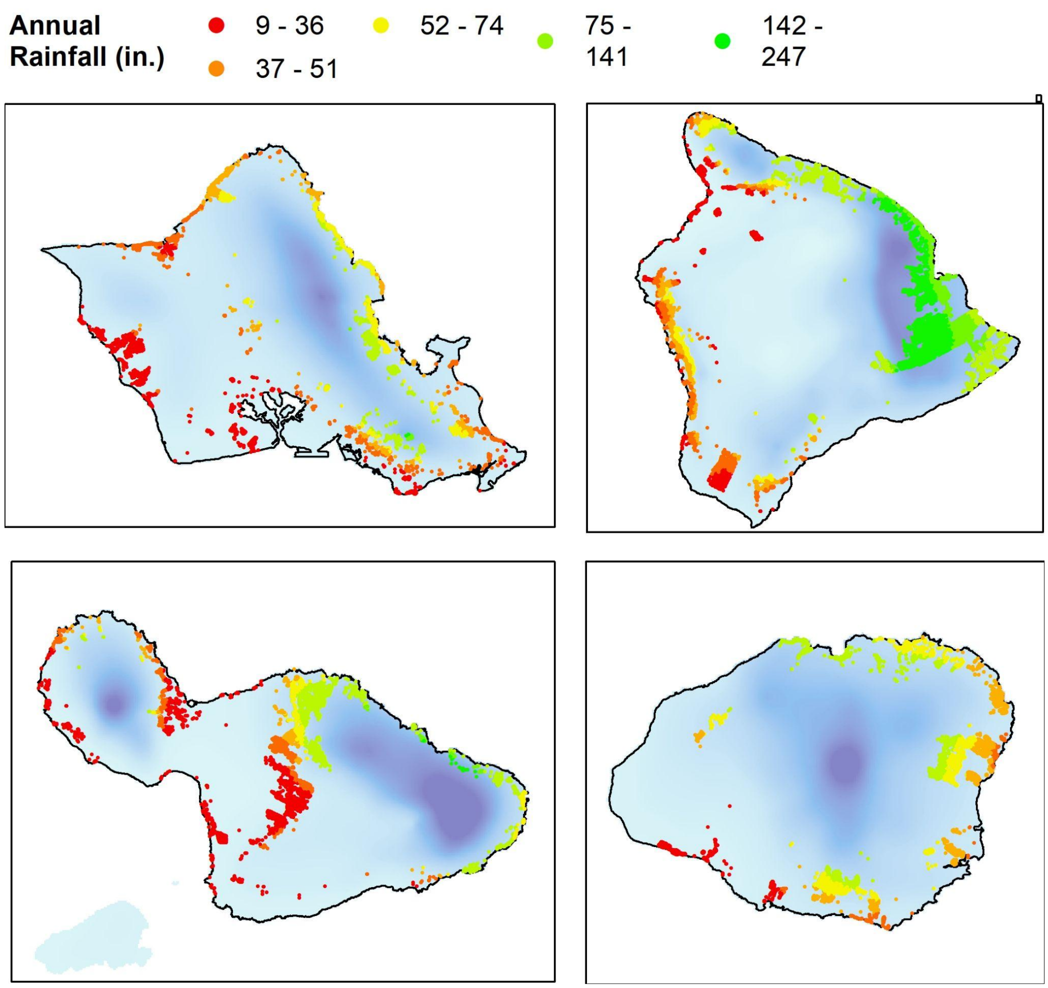

Figure 9. *Example map of the geographic distribution of rainfall amounts as it relates to cesspool impact. Rainfall is used as a proxy for groundwater recharge, and higher recharge rates will dilute the effluent from OSDS, potentially reducing the impact of pollution in areas of higher rainfall. Red locations indicate unfavorable rainfall conditions, with orange, yellow, and green indicating increased favorability, in that order.*

Stream/Wetland Locations & Distance to Streams or Wetlands

The benefits of streams and wetlands are numerous and include trapping floodwaters, recharging groundwater supplies, filtering pollution, and providing habitat for fish and wildlife (EPA, 2017). Studies show that streams and wetlands are vitally important to the health of larger downstream waterways like lakes and oceans (EPA, 2017; McKenzie et al. 2019). The DOH recognizes that wastewater can increase the biologic productivity in streams and nearshore waters, causing problems like eutrophication (Whittier & El-Kadi, 2009). Because of the complexity of environmental processes, it is difficult to quantify specific risk to these systems from wastewater pollution. Instead, we identify hazards through distance to understand the potential risks to these systems. The HCPT uses a basic geographic distance calculation to the nearest stream or wetland by using data from the statewide Hawaiʻi GIS Portal. The stream's layer is generally representative of perennial flowing waters in the state. Streams were ultimately joined with wetland features, including emergent ponds, to simplify the score. The HCPT assumes that streams and wetlands are equally important even though certain streams or wetlands may be of greater importance based upon location, cultural significance, development, and ecosystem services provided.

Streams and Wetlands Prioritization Score Algorithm

The threshold-decay function was used to calculate priority scores at each cesspool point according to the distance from either a stream or a wetland. The distance of 50 feet (15.24 meters) was used as the threshold based on the regulatory limit in HAR 11-62.

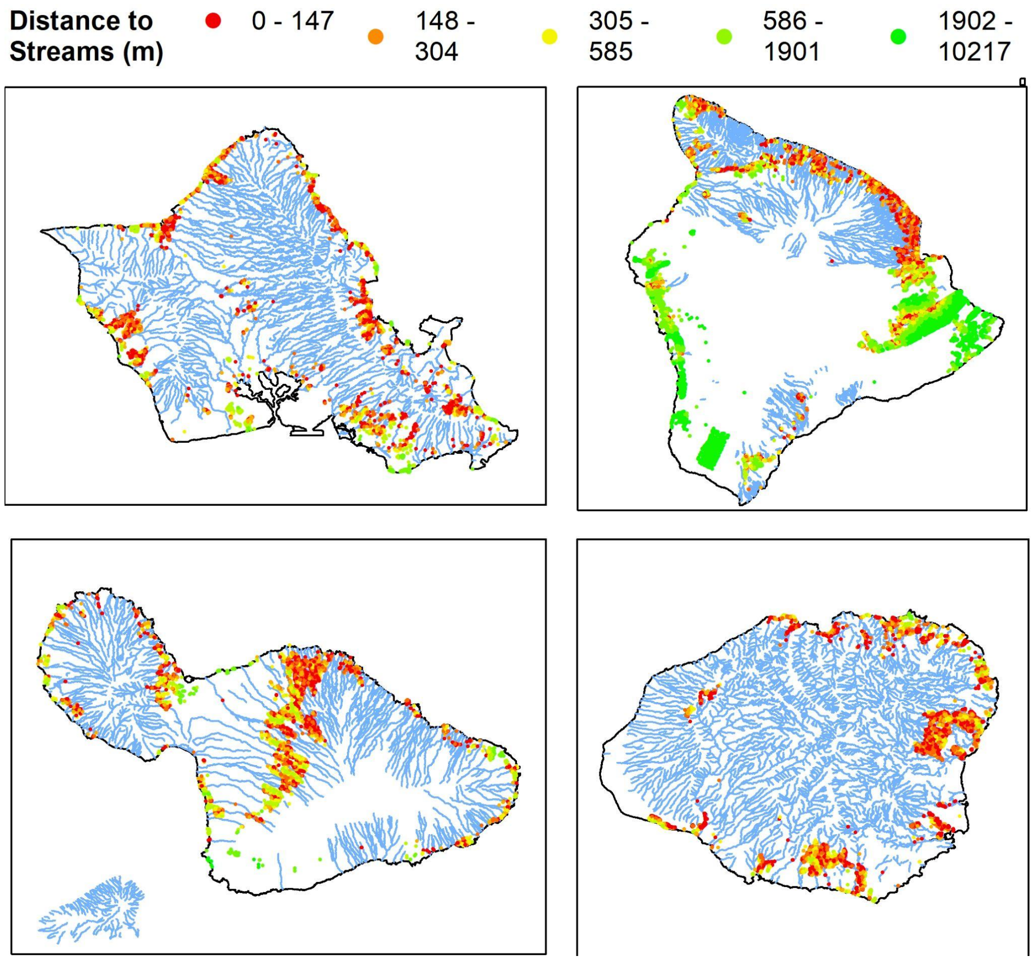

Figure 10. *Example map of the distance from each cesspool point to a nearby stream or wetland. Red locations indicate cesspools near a stream or wetland, with orange, yellow, and green indicating increasing distance to a stream or wetland, in that order.*

Cesspool Density

Density calculation/analysis is subject to bias based on the available landmass and the thresholds set in a calculation. Density is defined as the number of cesspools per unit of land area. Many of the calculations to establish density-dependent risk factors are based upon studies outside of Hawaiʻi. However, the density of OSDS is a critical variable and has been subject to debate for decades. A 1977 report from the U.S. EPA identified density of OSDS greater than $15.4/km^2$ ($40/mi^2$) could result in groundwater contamination (Flanagan et al. 2019). Density is often a question of both wastewater science and policy decisions.

Though the minimum lot size to install an OSDS in Hawaiʻi is 10,000sqft, that does not mean that all systems will perform equally, nor that environmental damage will not occur at the minimum standards. Wastewater systems are inherently site-dependent (geographic, climatic, etc.). Hawaiʻi has limited land and requiring minimum lot sizes of one acre (as done in places like Suffolk County, NY) is not feasible for future or current development. Calculating the recommended OSDS density for Hawaiʻi is beyond the scope of this project. However, there are examples of successful development of local density per acre recommendations. Hansen Allen and Luce Engineers Incorporated (2016) identified recommended densities for an area in Utah using local risk analysis, mass balance calculation, and local regulatory management/development review. **The authors recommend the state of Hawaiʻi conduct such analysis for a more accurate prioritization output and future planning.** However, for this statewide tool, a single density cutoff was used to estimate the impacts across the landscape from cesspools.

To develop the density calculation for the HCPT, the authors investigated current and past literature. Bicki and Brown (1991) conclude that groundwater monitoring and modeling demonstrate a correlation between contamination and septic system density, suggesting a minimum lot size of one-half (0.5) to one (1) acre is needed to prevent groundwater contamination. These recommendations may be true if an area has lower hazards (drinking water aquifer is not a factor/not adjacent to ecologically sensitive areas). Advanced technology may allow smaller lot sizes to meet water quality standards. However, because cesspools have no primary treatment mechanism and have limited/no soil treatment field, the recommended density for OSDS does not neatly apply when evaluating cesspool hazards for priority areas. Previous density calculations in Whittier and El-Kadi (2009) identified an estimated OSDS density that should not exceed 40 units/mi^2 (1 system per 16 acres) based upon EPA reports. The HCPT uses a density calculation of the number of cesspools per acre.

Cesspool Density Prioritization Score Algorithm

To calculate a density hazard score, the threshold-decay function was applied to calculate priority scores at each cesspool point based on the number of cesspools per acre. The threshold value was set at one cesspool per acre, meaning that cesspools in areas with a greater density were assigned a score of 100.

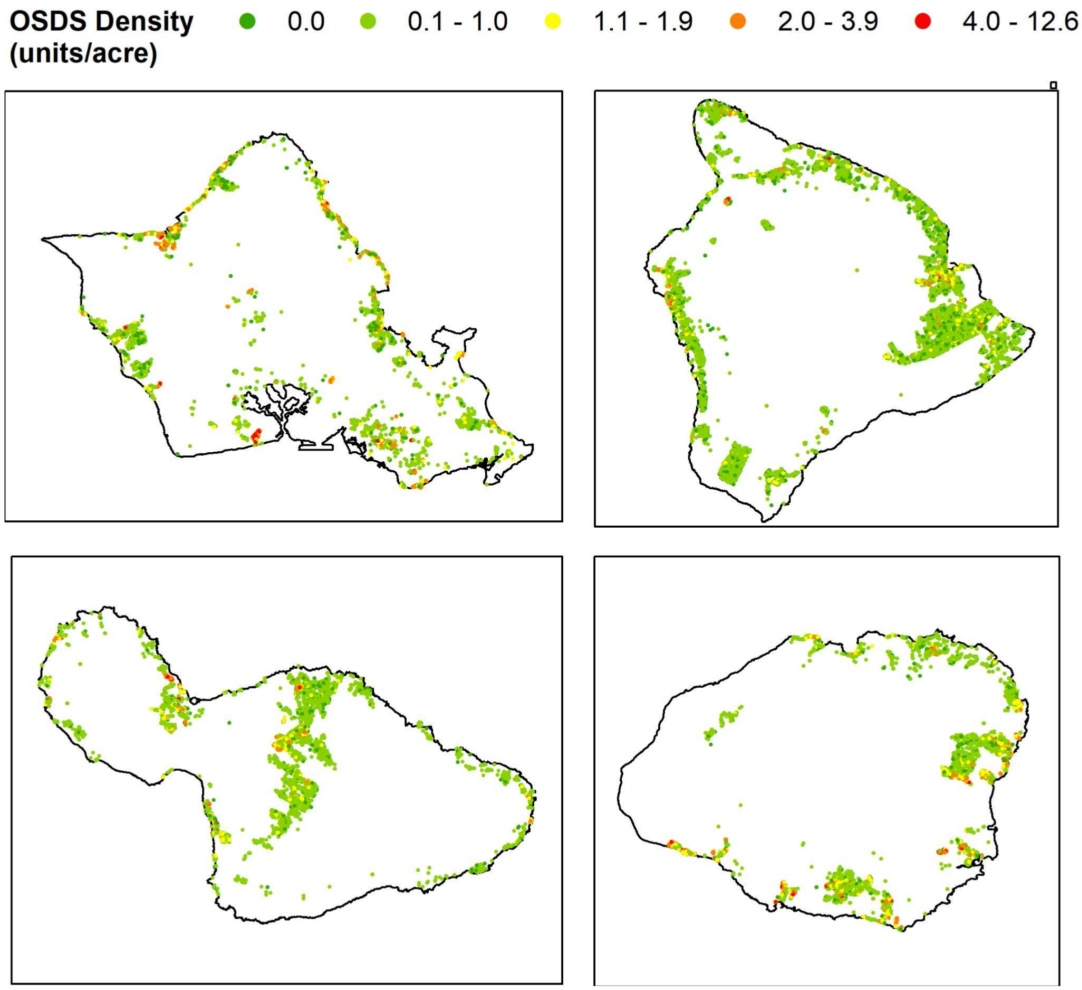

Figure 11. *Example map of cesspool density. Red locations indicate the highest density areas, with orange, yellow, and green indicating lower density per acre, in that order.*

Water Table Elevation (Depth to Groundwater)

Unsaturated soil space is essential for proper wastewater treatment. The unsaturated soil zone (dry area) underlying a cesspool or treatment field is the primary site of subsurface treatment and contaminant reduction. The thickness of the unsaturated zone below a wastewater treatment technology is a limiting factor in the ability of a given system to treat wastewater and limit the transport of contaminants. Recent rises in the groundwater table are already impacting subsurface infrastructure, such as cesspools and sewer lines, in Hawaiʻi (Habel et al. 2020). Sea level rise considerations are discussed in its respective section.

To obtain an estimate of the depth to groundwater below all cesspools in the state, island-wide groundwater models developed by DOH and documented in Whittier and

El-Kadi (2009; 2014) were evaluated for the HCPT. These models were developed to calculate statewide nutrient transport to the coast. The models have a large spatial scale which imparts low resolutions on their outputs. Regardless, the water table elevation is a key output provided by these models and useful for this exercise. To assess the depth to groundwater, or thickness of the unsaturated zone below each cesspool, the water table elevation at each point was subtracted from the land surface elevation at the cesspool location. Land surface elevations were calculated along the coastline using a statewide high-resolution (<1 meter) LiDAR Digital Elevation Model (DEM) obtained from Hawaiʻi GIS Online Portal. Where the LiDAR DEM was missing elevation data, it was filled with lower resolution (10 meter) data. Statewide-coverage 10 meter-DEMs are readily available from the UH Coastal Geology Group. The calculated depth to groundwater through the use of the high-confidence land surface elevation data with modeled water table elevations should be considered an estimate, subject to the assumptions and limitations of the groundwater models. Currently, this method contains the best available data for a parameter that is difficult to accurately measure.

Depth to Water Table Prioritization Score Algorithm

To calculate the depth to water table hazard score the threshold-decay function was applied to calculate priority scores based on the calculated thickness of the unsaturated zone beneath each cesspool point. The threshold value was set at 14.4 feet (4.4 meters), which is a regulatory threshold set forth by HAR 11-62. Priority scores exponentially decayed with greater unsaturated zone thickness.

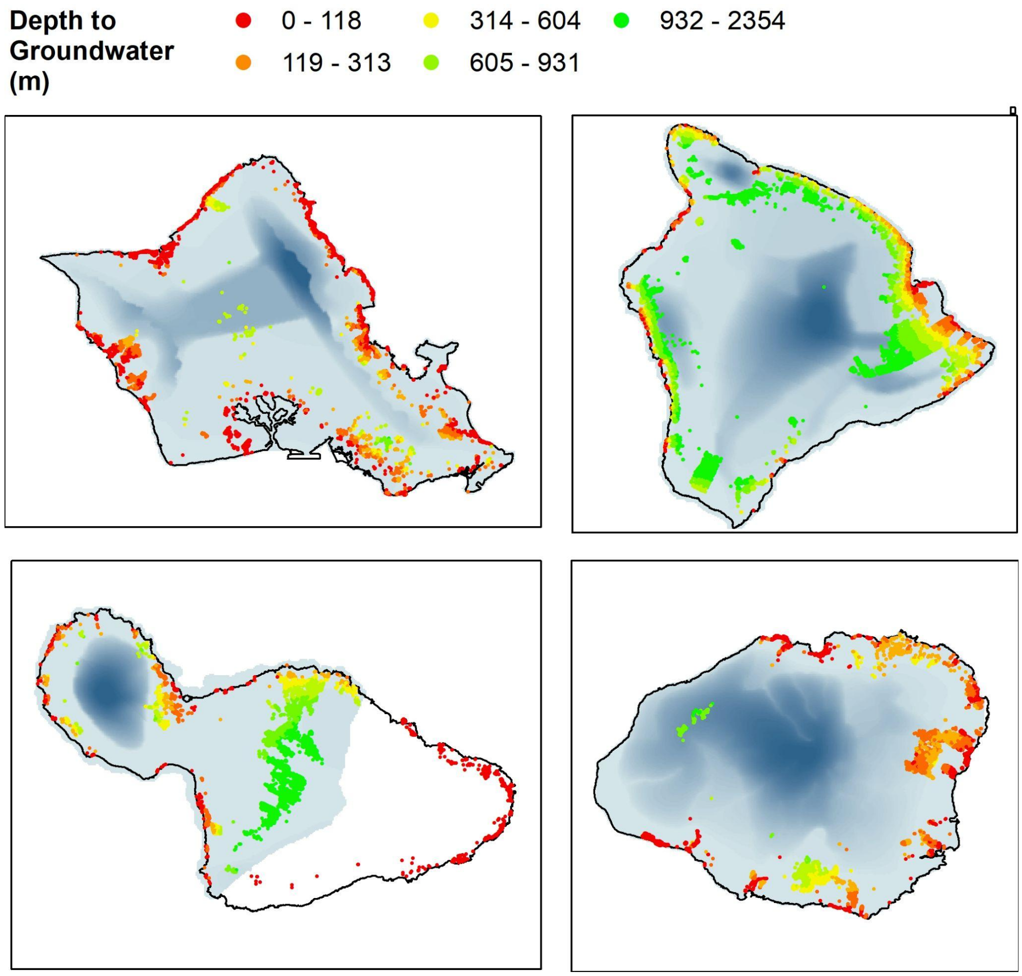

Figure 12. *Example map of the depth to the groundwater table for each cesspool. Red locations indicate the narrowest depth to the groundwater table, with orange, yellow, and green indicating increasing depth, in that order. Dark blue areas indicate an overall deeper depth to groundwater, lighter colors indicate a shallower depth.*

Sea Level-Rise Projections

Sea level rise (SLR) has the potential to impact surface and subsurface infrastructure like cesspools and other types of OSDS through mechanisms such as groundwater inundation and flooding (Cooper et al. 2016; Habel et al. 2020). Habel et al. (2020) provide a framework to understand the hazards cesspools and OSDS pose from SLR-induced flooding in Hawaiʻi. An OSDS that is flooded cannot function properly and poses a hazard to public safety and human health (National Agricultural Safety Database, N.D.) Because OSDS have life spans between 30-60 years, it is important to plan for future scenarios to ensure proper operation, cost efficiency for the homeowner, and environmental protection (Schneider, personal communication, July 2, 2021). Thus, SLR projections are an important data point in evaluating cesspool hazards and prioritization.

The available data was based on the methodology/modeling used in the Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report and the [Hawaiʻi Sea Level Rise Viewer](). The products have undergone peer review and publication in the Scientific Reports Journal: Nature. The hazard and vulnerability data and maps provided were based on observational data and computer-based models. According to data layer authors, the data modeling did not account for: (1) existing seawalls or other coastal armoring in the backshore; (2) increasing wave energy across the fringing reef with sea level rise; (3) possible changes in reef accretion and nearshore sediment processes with sea level rise; and (4) possible changes to sediment supply from future shoreline development and engineering, such as construction or removal of coastal armoring or other coastal engineering. This project incorporates sea level rise projection data layers for the years 2030, 2050, and 2100. The 2030 layer depicts coastal flooding using the 0.5 feet (0.15-meters) sea level rise scenario. The 2050 layer depicts coastal flooding using the 1.1 feet (0.33-meters) scenario. The 2100 layer depicts coastal flooding using the 3.2 feet (0.9767-meters) scenario.

Additionally, since cesspools are located underground, the distribution of direct surface flooding does not completely capture the effects of subsurface groundwater inundation, which essentially reduces the unsaturated zone underneath a unit to either nothing or an unacceptable depth, defined as 14.4 feet (4.4 meters) below ground surface based on regulatory standards outlined in HAR 11-62. Therefore, to assess whether a cesspool will be affected by SLR at the dates of calculated projections, both the horizontal extent of surface flooding and the vertical extent of subsurface inundation were considered. Specifically, a cesspool was deemed to be impacted by SLR either if it is located in a surface flooding zone defined by data from the Hawaiʻi Sea Level Rise Viewer, or if the unsaturated zone below the cesspool as calculated in the Depth to Water Table section is reduced to less than 14.4 feet (4.4 meters) with a given increase in sea level (assuming purely linear hydrodynamic buoyancy of the freshwater lens under an increase in present-day base sea level).

Sea Level-Rise Projection Prioritization Score Algorithm

Cesspool units are assigned the highest priority score (100) if located within the 2030 sea level rise zone with descending ranks if located in the 2050 zone (score of 66) or 2100 zone (score of 33).

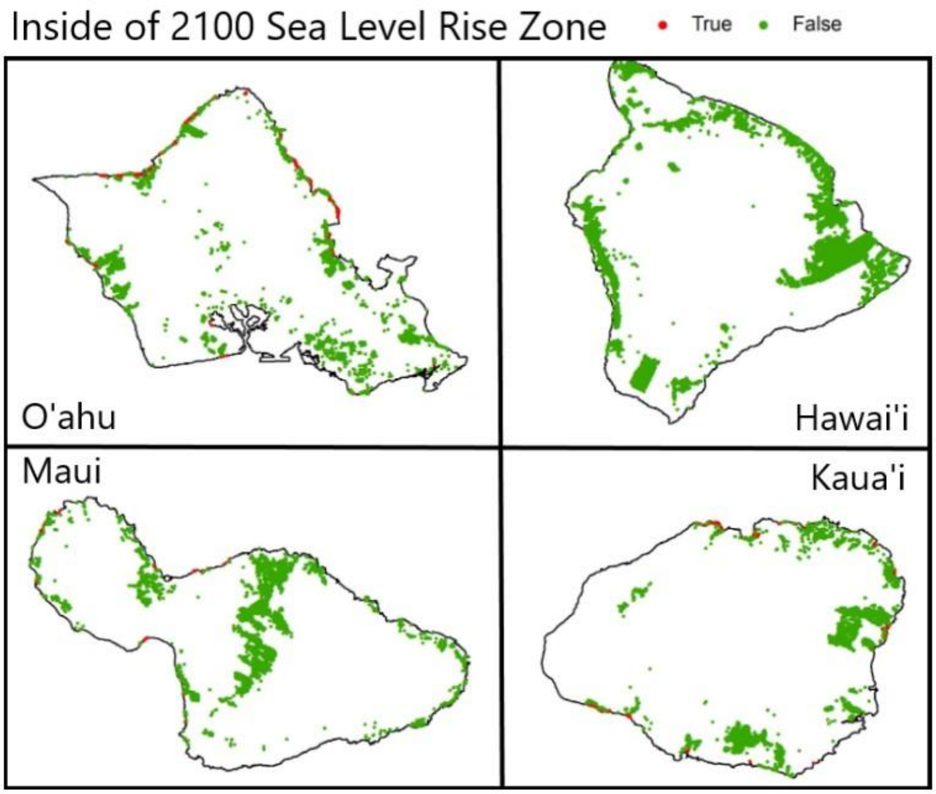

Figure 13. *Example map of four major Hawaiian Islands highlighting areas within the predicted zone of the 2100 SLR scenario, based on the methodology/modeling from the Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report and the Hawaiʻi Sea Level Rise Viewer. Red indicates that the cesspool is within the SLR zone, green indicates the cesspool is not within a SLR zone.*

Coral Cover

Coral is essential to the habitat of most tropical reef ecosystems, supporting biological diversity throughout the ocean. However, corals are undergoing rapid change from ocean warming and nearshore human activities (Reef Advisory Group, personal communication, July 20, 2021). Corals provide a host of ecosystem services for societies including coastal erosion protection, fishing, and cultural practices. Recent work by Asner et al. (2020) and others have shown that wastewater pollution from OSDS (namely cesspools) negatively impacts live coral across the main Hawaiian Islands.

To ensure the importance of coral is included in the cesspool conversion prioritization process, the authors worked with the Hawai'i Monitoring and Reporting Collaborative (HIMARC) and the Reef Advisory Group (Jamison Gove, Ph.D., Joey Lecky, Greg Asner, Ph.D., Mary Donovan, Ph.D., Tom Oliver, Ph.D., Eric Conklin, Ph.D., and Kim Falinski Ph.D.) to develop a coral reef condition metric specifically for use in this study. The metric was developed by combining two spatially continuous live coral datasets for the four main islands. The first dataset represented intact habitat through current live coral cover, and the second represented baseline coral via historical coral cover data, taken before the 2015 coral bleaching event.

The current live coral information was provided by Arizona State University's Global Airborne Observatory (GAO). GAO used state-of-the-art high-resolution aerial mapping to provide near-continuous information on live coral cover across the main Hawaiian Islands in 2019 (Asner et al., 2020). Historical coral data are provided by HIMARC, which were derived from in-water observations from a broad network of monitoring programs and agencies, including the Division of Aquatic Resources (DAR), spanning the 2004 - 2014 date range (Donovan et al., 2020). The historical coral cover data is representative of reefs before the mass coral mortality event stemming from the 2015 marine heatwave and thereby represents baseline conditions from before the devastating 2015 event that caused widespread coral mortality in several locations.

Coral Prioritization Score Algorithm

The two coral datasets were summarized by median coral cover within zones spanning 0 - 15 meter depth corresponding to 1 km segments of shoreline. These values were then lumped into four categories according to the following percentile breaks:

Table 2. *Table describing the coral prioritization ranking methods through specific percentiles and associated values.*

Rank	Percentile	Value
1	95 - 100	**Highest priority**
2	80 - 95	↓
3	50 - 80	↓
4	0 - 50	**Lowest priority**

Then the two ranked datasets were combined into a single one-through-four ranking where shoreline segments with differing rank values between the two datasets were assigned the higher priority rank of the two, as illustrated below:

GAO Coral (Rank)	HIMARC Coral (Rank)			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	2	3	3
4	1	2	3	4

Figure 14. *Visualization of how coral ranking datasets were combined to form a single 1-4 ranking scheme.*

To format the categorical ranks into a 0-100 prioritization score, all priority one shoreline segments were given a score of 100, all priority two shoreline segments were given a score of 66, all priority three shoreline segments were given a score of 33, and all priority four shoreline segments given a prioritization score of 0. This data was linked to individual cesspools by connecting individual cesspool points to their coastal discharge locations via the model calculated groundwater flow paths, as described in the Groundwater Flowpaths section above. This allowed a coral cover value to be assigned to each cesspool based on the corals offshore of the part of the coastline to which each cesspool's effluent drains.

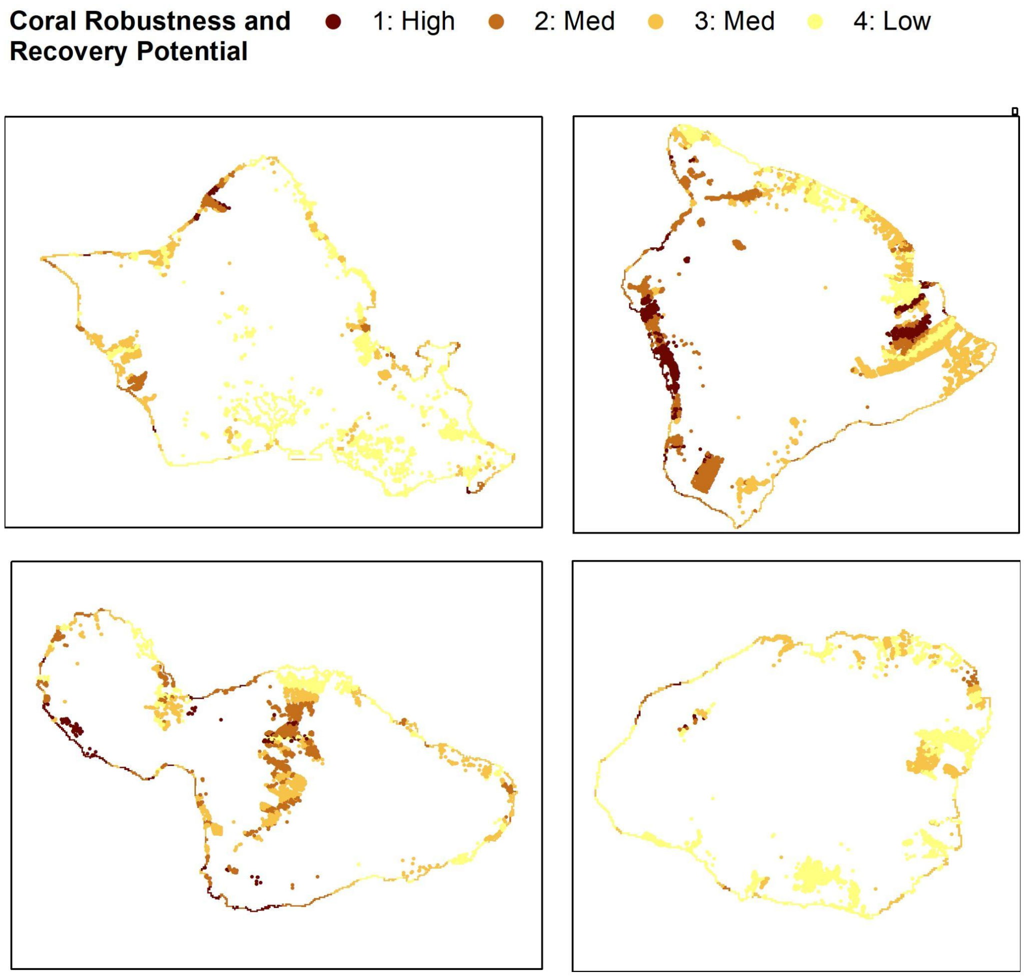

Figure 15. *Example map of four major Hawaiian Islands highlighting areas within the highest current and historical coral cover. Red areas indicate areas with the greatest baseline and current coral cover, while orange and yellow areas indicate areas with lower current or baseline cover.*

Resource Fish Biomass / Recovery Potential

The Resource Fish Biomass layer describes coral reef fish species that make up a substantial proportion of the non-commercial and commercial catch. Therefore, this does not represent total fish biomass on the reef, but the subset of fish biomass that directly supports fishing and feeds local communities. Reef fish biomass has been shown to negatively correlate with effluent from OSDS in the Hawaiian Islands (Donovan et al. 2020 & Foo et al., 2021).

The Reef Advisory Group produced predictive maps of standing resource fish biomass and the theoretical recovery potential of resource fish biomass if effluent from OSDS were eliminated (Donovan et al., 2020). Recovery potential from reducing OSDS effluent therefore represents the areas with the greatest potential for restoration of fisheries most directly related to cesspool remediation.

Resource Fish Prioritization Score Algorithm

A combined ranking of these two resource fish biomass datasets was derived for the cesspool conversion prioritization. Each of these datasets was summarized by median biomass within zones spanning 0 - 15 meter depth corresponding to 1 km segments of shoreline. These values were then lumped into four categories according to the following percentile breaks:

Table 3. *Table describing the fish prioritization ranking methods through specific percentiles and associated value priority.*

Rank	Percentile	Value
1	95 - 100	Highest priority
2	80 - 95	↓
3	50 - 80	↓
4	0 - 50	Lowest priority

Then the two ranked datasets were combined into a single 1-4 ranking where shoreline segments with differing rank values between the two datasets were assigned the higher priority rank of the two, as illustrated below:

Resource Biomass Recovery Potential (Rank) \ Resource Biomass (Rank)	**1**	**2**	**3**	**4**
1	1	1	1	1
2	1	2	2	2
3	1	2	3	3
4	1	2	3	4

Figure 16. *Visualization of how resource biomass datasets were combined to form a single 1-4 ranking scheme.*

Assignment of priority scores based on categorical ranks was done in the same way as above for corals where all priority number one were given a score of 100, all number two were given a score of 66, all number three given a score of 33, and all number 4 given a prioritization score of 0. This data was linked to individual cesspools by connecting individual cesspool points to their coastal discharge locations via the model calculated groundwater flow paths as described in the Groundwater Flowpaths section above. This allowed a resource fish value to be assigned to each cesspool based on the fish data offshore of the part of the coastline to which each cesspool's effluent drains.

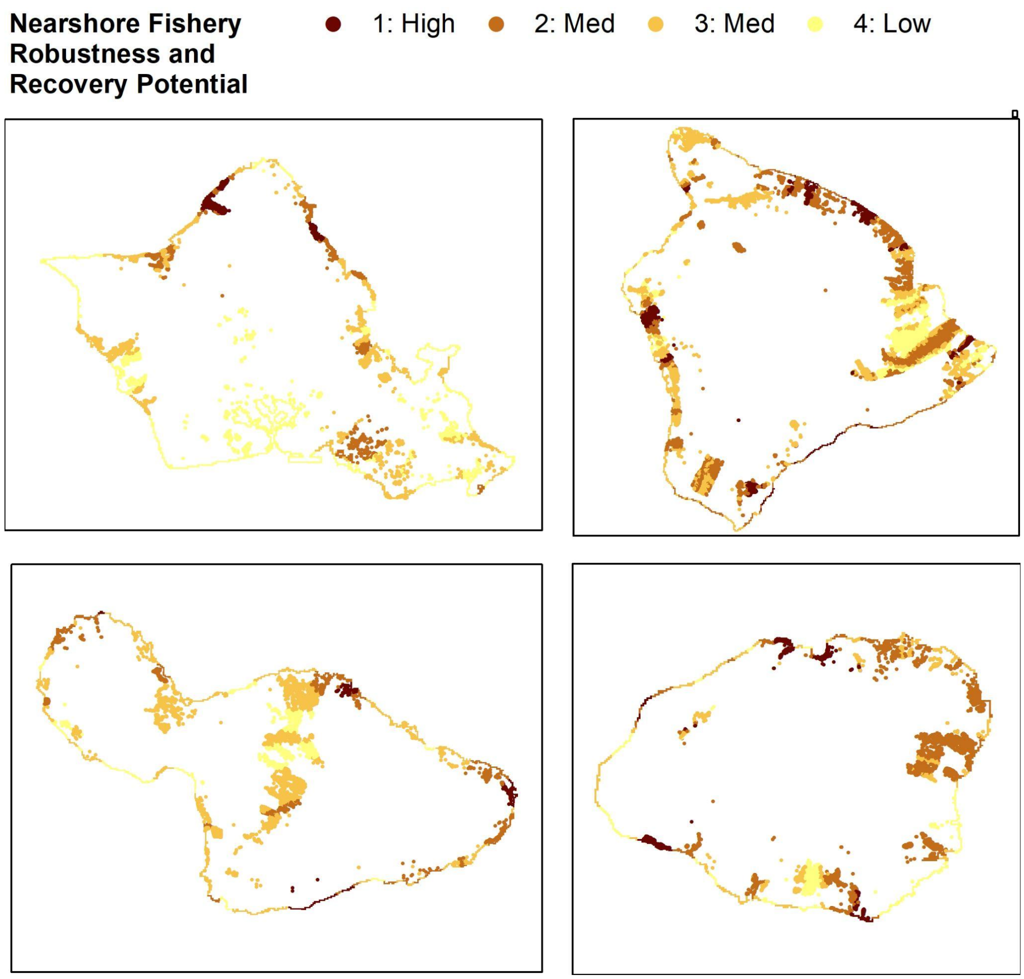

Figure 17. *Example map of four major Hawaiian Islands highlighting areas within the highest fish biomass robustness and recovery potential. Red areas indicate the greatest biomass of resource fishes and the greatest potential to improve biomass through cesspool remediation, while orange and yellow areas indicate a reduced robustness and recovery potential when OSDS effluent is eliminated.*

Coastline Visitation (User-days)

The DOH Wastewater Branches' mission is to protect public health and the environment (Hawai'i State Department of Health: Wastewater Branch, 2021). To best update the previous priority areas, it was essential to develop inputs that incorporate recreational, subsistence, and other human-associated values relating to the usage of the coastal zone into the prioritization scheme. These are a critical driver of prioritization as they are part of both public and environmental health. A widely used method to assess the usage of a geographic location is crowdsourcing information from either cell phone data or social media applications. For the HCPT, the peer-reviewed methodology of Wood et al. (2013) was chosen to calculate the relative visitation rate to areas along the coastline through a proxy of photo-sharing data scraped from the popular website Flickr. These methods are robust and have been widely applied as the core framework of the recreational module of the INVeST Model. The method essentially tracks human visitation along the coastline, and with this data, it is possible to apply the logic that the more visitation to an area, the more important it is, both in terms of public health and protection of ecological value.

The online photo-sharing website, Flickr, offers an application programming interface (API) which is a service that allows users to search photos based on their geotagged locations. The authors developed computer code to assign points every 250 meters along the coastline of O'ahu, Maui, and Kaua'i, and every 500 meters on Hawai'i Island. A search was run for all photos uploaded onto Flickr that fell within 250/500 meters of each point along the coast between the years 2010 and 2020. Photo metadata was then converted to a usable form by calculating the average number of user-days recorded at each location. A user-day is a count of the number of unique users visiting a given site on a given day so that the count would not be biased by users who took large amounts of photos at one location. For example, if a tourist takes any number of photos at any one location and uploads it to Flickr, this is considered one user-day for that location. The data was refined by evaluating the username of the photo owner and date to calculate the user-days for each point.

This data was linked to individual cesspools by connecting individual cesspool points to their coastal discharge locations via the model calculated groundwater flow paths as described in the Groundwater Flowpaths section above. This allowed a coastline user-days value to be assigned to each cesspool based on the visitation experienced by the part of the coastline to which each cesspool's effluent drains.

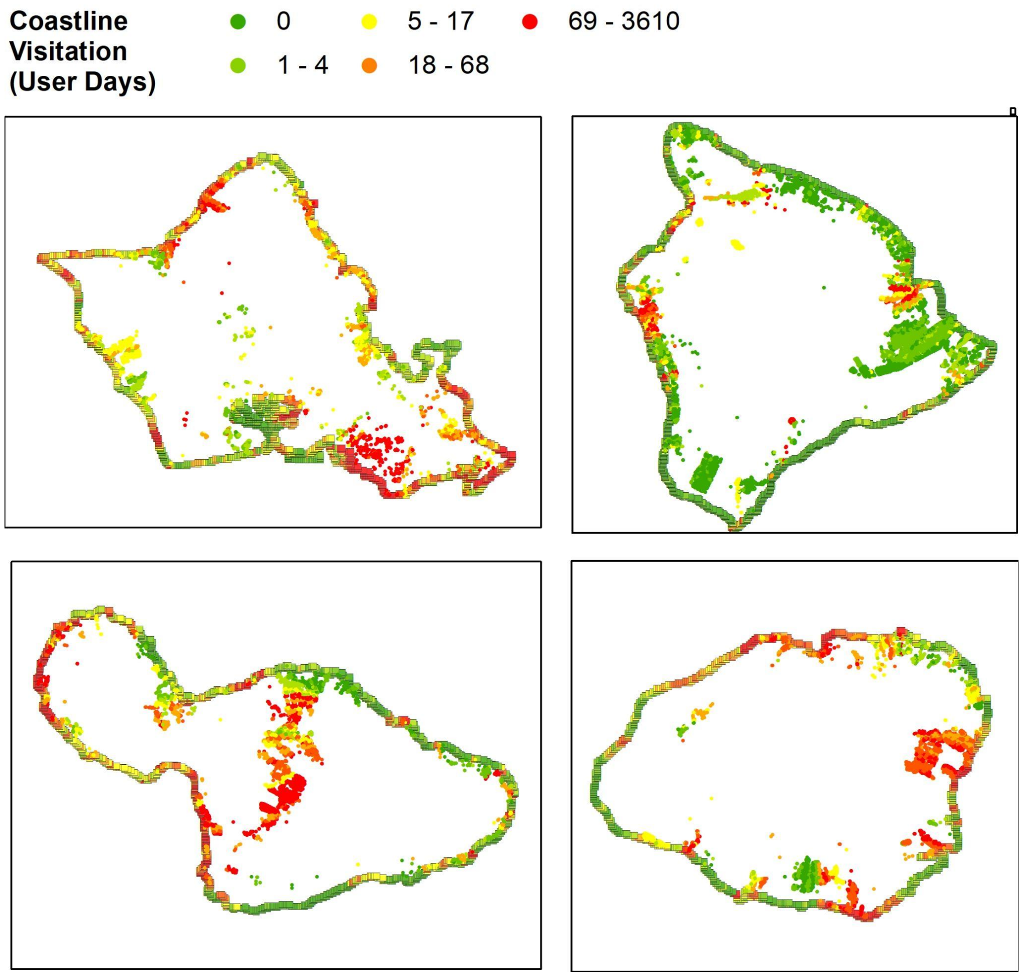

Figure 18. *Example map of four major Hawaiian Islands highlighting areas with the highest coastline usage (units of user-days). Cesspools are colored based on the coastline usage in the area to which their effluent drains, via groundwater flow paths. Red indicates the highest coastline usage, and orange, yellow, and green represent decreasing numbers of user-days.*

Coastline Visitation Prioritization Score Algorithm

Because of the highly skewed distribution of coastline usage (see associated Code Notebook for specifics) the threshold-decay function was applied to calculate priority scores and a carefully chosen threshold was then applied. Specifically, the authors used a trial and error approach to examine how different threshold values produced different numbers of 'hot-spot' areas or locations with high-value visitation characteristics.

The threshold value was chosen by assuming that if one percent of O'ahu's approximately 200,000-250,000 visitors/day are using Flickr (a total of 2,000-2,500 people per day), and that if each visitor only visits one 'location' per day, this should yield 20-25 'hotspot' areas where those visits are concentrated. By taking the low end of this range, the Flickr data shows that a 'hotspot' or 'top-priority visitation area' should be defined as a location where 100 or more Flickr users visit the site every day. Thus the value of 100 user-days was chosen as the threshold value in the threshold-decay function. Results yielded about nine percent of the total number of cesspools in the state receiving a visitation priority score of 100, with other cesspools receiving scores that exponentially decay with a decrease in the number of user-days at the coastline locations to which their effluent drains.

Lifeguard Tower Location/Swim Beaches

Recreational water quality, both for residents and visitors, is vitally important to the state of Hawaiʻi. According to Conservation International (2021), about eighty percent of visitors to Hawaiʻi participate in some type of beach activity, and more than half snorkel or dive. Though access to all beaches is guaranteed by a constitutional right (HRS 115), it is assumed that lifeguarded beaches are favored and more frequented than others. However, each county determines which areas have staffed lifeguard towers, and only a handful of state parks have lifeguard towers. Placement of lifeguard towers may be determined due to the number of incidents responded to at sites, visitation levels, or requests by the state government. Because it is assumed that lifeguarded beaches have a higher in-water activity usage (swimming, surfing, diving, wading) than unguarded beaches, cesspools discharging to these beaches are ranked a higher priority in the assessment. This metric is assessed separately from coastline usage because the prevalence of in-water activities at these sites greatly increases the human-health risks from exposure to contamination from wastewater effluent.

Swimming Beaches Prioritization Score Algorithm

For this study, the authors examined county websites and databases to compile a statewide inventory of lifeguard towers. Any area of coastline within 500 meters on either side of a lifeguard tower was considered to be a swimming beach. A binary value (100 or 0) was assigned to each cesspool depending on if its groundwater flow path terminated at a swimming beach or not. Those cesspools draining to swim beaches received a priority score of 100, whereas those not draining to swim beaches received a score of 0.

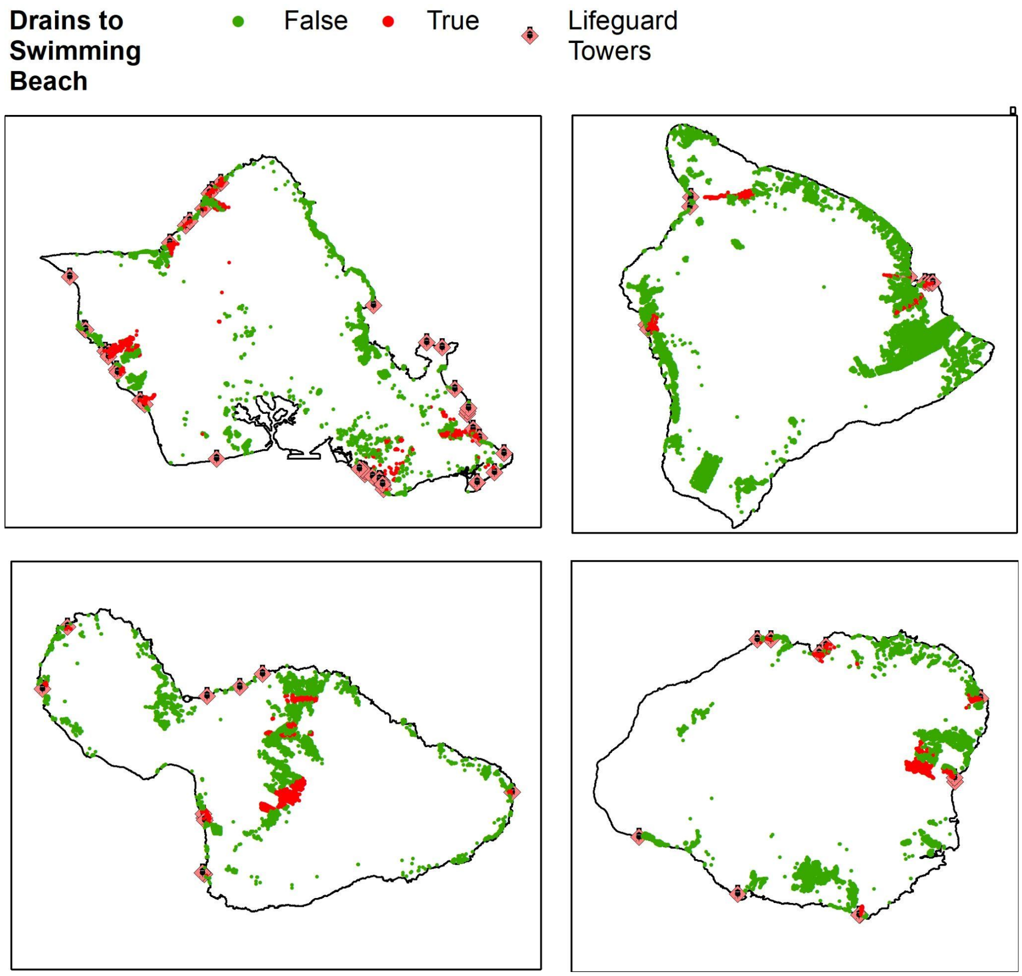

Figure 19. *Example map of four major Hawaiian Islands highlighting each cesspool point as it corresponds to the lifeguarded beach along the coast via groundwater flow path locations. Red dots indicate a cesspool effluent drains near a lifeguard tower, green indicates the cesspool effluent does not drain near a lifeguard tower.*

Coastal Ocean Circulation and Residence Time Proxy

Incorporating coastal geography and specifically the residence time of coastal features such as bays or inlets is an important element to include in the HCPT. However, after reviewing available data and consulting with oceanography experts, it was determined that accurate, statewide data regarding the residence time of coastal waters do not meet the standards and format needed for use in the HCPT. The most feasible way to incorporate an element of ocean circulation was to use wave power as a best-available proxy. This proxy will help determine whether coastal areas are either more exposed or sheltered to ocean currents. In general, this is based on the theory that wave power is correlated with nearshore water movement, and thus will correspond with factors that control mixing and dispersion of pollution, including that of cesspools.

The authors acknowledge that wave power is highly seasonal in Hawaiʻi and may vary significantly throughout the year. Coastal residence time is not simply a function of the wave field, but is also controlled by tidal, wind-driven, and larger-scale currents. Furthermore, the latest science doesn't fully understand the time-dependent aspects of wastewater pollution on reefs and the potential impact on coral reef ecosystem function and thus, cannot be used in the HCPT. However, there is a strong policy-based need to include a factor regarding ocean circulation. Therefore, even a proxy dataset provides value to the overall prioritization process and was included at the request of CCWG members.

The HCPT uses a statewide wave power (in KW/m) long-term mean dataset from the years 2000-2013. Although coastal currents and transport are extremely complicated, scale-dependent, and vary widely depending on the timing of measurements, wave energy is generally correlated with the primary drivers of currents such as wind-swell, and rip currents driven by groundswell. Wedding et al., (2018) developed a statewide long-term mean wave power dataset, which was made publicly available through the Ocean Tipping Points Project. This dataset was determined by the authors to be the best available proxy for determining if a coastal area was geographically sheltered versus exposed at the scale examined in this report. Originally, wave power data were developed by the University of Hawaiʻi at Mānoa School of Ocean and Earth Science and Technology SWAN model (Simulating WAves Nearshore). Hourly 500 meter SWAN model runs of wave power were converted to maximum daily wave power from 1979-2013, and the long-term mean wave power was calculated by taking the average of the maximum daily time series of wave power data from 2000-2013 for each 500 meter grid cell.

Coastal Ocean Circulation / Wave Power Prioritization Score Algorithm

Raster-based (matrix of cells organized into rows and columns) wave power values (in KW/m) were mapped to gridded 250/500 meter cells along the coastline which are related to individual cesspools through groundwater flow paths. To calculate a priority score, the threshold-decay function was applied with the threshold set at the ten percent quartile of the wave power dataset (1.59 KW/m) with the idea that this would capture the top ten percent of most sheltered areas as the highest priority.

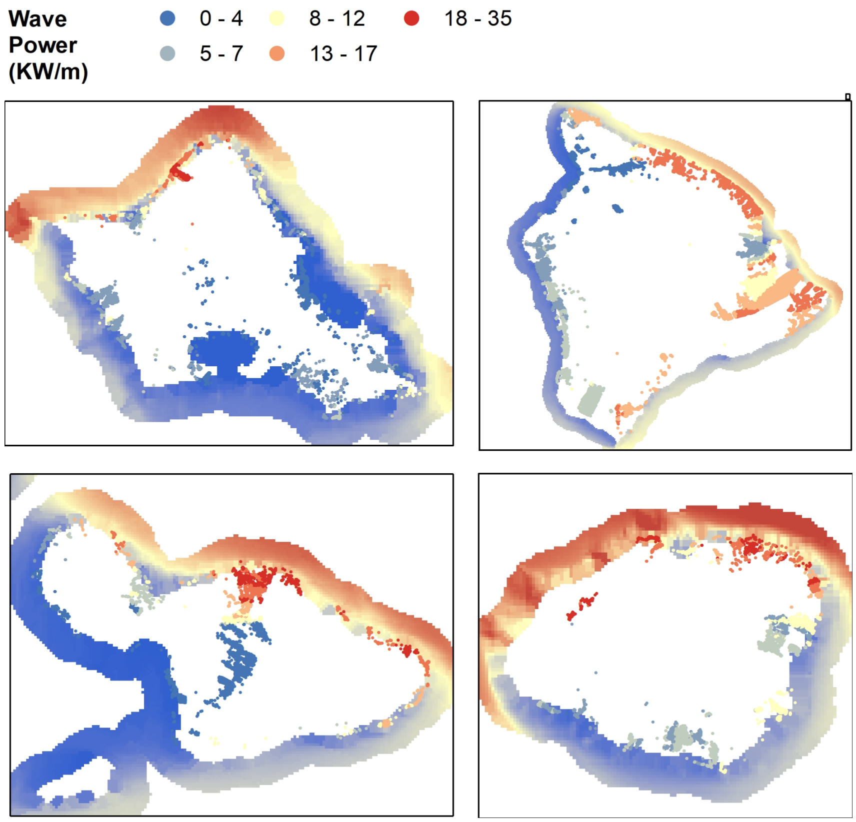

Figure 20. *Example map of four major Hawaiian Islands highlighting wave power mapped to each of the gridded 250/500 meter coastal cells, red indicates greater wave power, blue indicates lower wave power.*

Results and Validation

A major goal in the design of the HCPT was to be able to assess and prioritize every cesspool in the state. To accomplish this goal, the HCPT used a site-based process to evaluate relevant factors that help determine if a cesspool at any given location has a higher or lower potential to cause negative social and environmental impacts. The tool considers credible hazardous outcomes from cesspool contamination through a lumped interdisciplinary approach. The end result is a single prioritization scheme that organizes census-based regions into Priority Level 1, Priority Level 2, and Priority Level 3 categories.

Categories are defined by the mathematical quantiles of 25% and 50% with the top 25% highest scoring areas designated with Priority Level 1, the next lower 75% to 50% with Priority Level 2, and the bottom 50% as Priority Level 3. Figures 21 - 24 provide island-specific maps of the statewide prioritization categories, synthesized by census tracts. Appendix A provides similar maps, but synthesized by census block-group and census block areas. Block-groups provide a higher resolution for ranking at the neighborhood scale, however, the quantity of prioritized block-groups (252) makes this resolution more difficult to manage through a policy lens. Prioritization by census blocks provides ranking at the individual city block level, but results in almost 2,000 individually ranked areas. Tables 4-7 below display a tabular inventory of the census tract prioritization categories and ranks. Appendix B also presents state- and island-wide risk-factor pivot tables that show how final prioritization scores were calculated based on the averaged scores for each of the fifteen Risk Factors.

The four main Hawaiian Islands contain an estimated 82,141 cesspools and have a total of 319 census tracts, although only 103 tracts contained more than 25 cesspools and were categorized within the HCPT. All results are updated as of 2022, See Appendix C for details.

Statewide Breakdown:
25% (26 tracts)**/13,821** cesspools (17%) = **Priority Level 1**
25% (26 tracts)**/12,367** cesspools (15%) = **Priority Level 2**
50% (51 tracts)**/55,237** cesspools (69%) = **Priority Level 3** (*Updated* 2022)

Results: O‘ahu

The island of O‘ahu contains an estimated 7,491 cesspools and has a total of 242 census tracts, although only 34 tracts contained more than 25 cesspools and were categorized within the HCPT.

O‘ahu Breakdown:

38% (13 tracts)**/4,779** cesspools (64%) = **Priority Level 1**

32% (11 tracts)**/1,640** cesspools (22%) = **Priority Level 2**

28% (10 tracts)**/1,072** cesspools (14%) = **Priority Level 3** *(Updated 2022)*

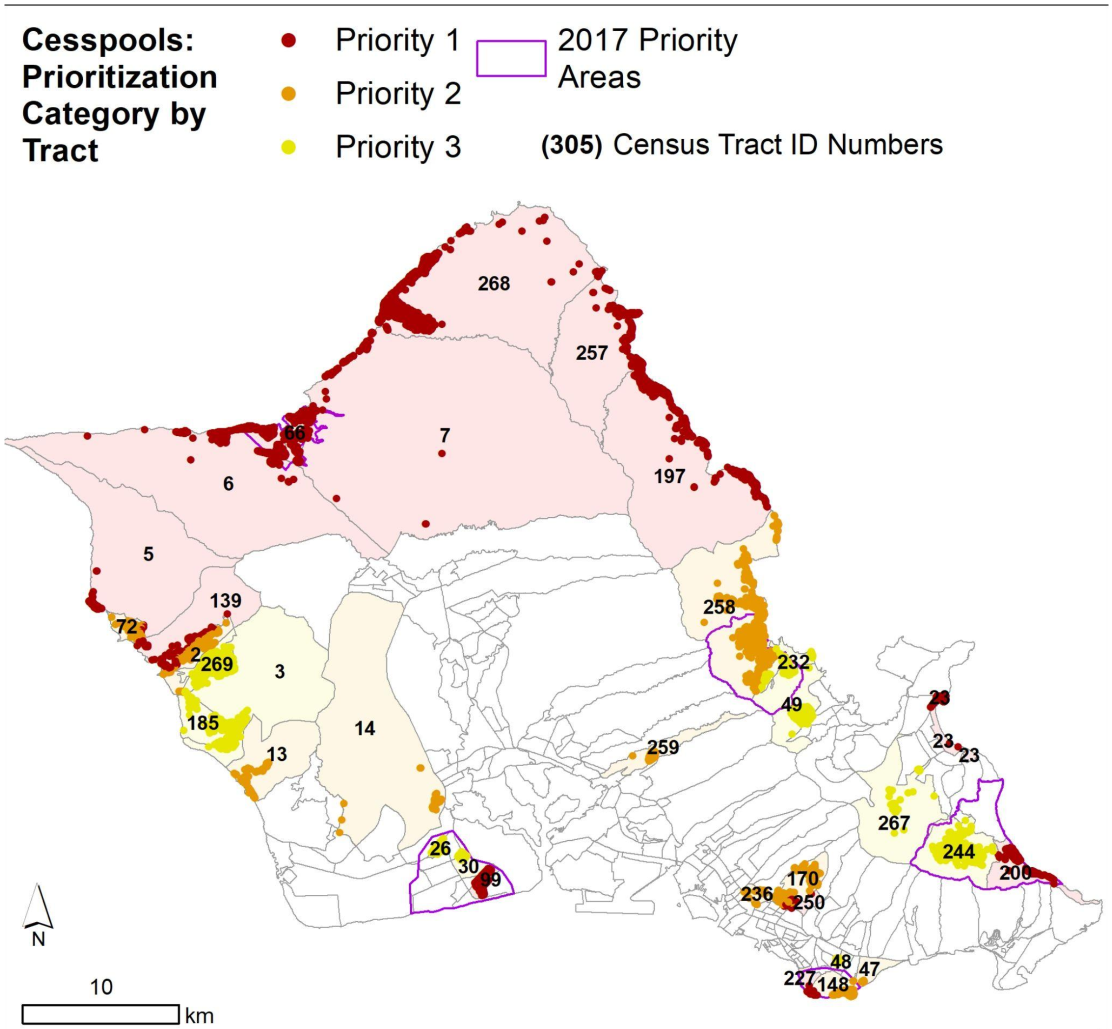

Figure 21: *O‘ahu cesspools (dots) colored by prioritization category, arranged by census tracts. Tracts are shown as lightly colored areas where the tract contains greater than 25 cesspools, and are shown as white areas where the tract contains less than 25 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

Table 4: *Prioritization categories and island-specific ranks for O'ahu tracts. (Update 2022)*

Tract Name	Tract ID	Cesspool Count	Priority Category	Island-Specific Priority Rank
Hauula-Kaaawa	197	628	**Priority 1**	1
Haleiwa	66	324	**Priority 1**	2
Makua Valley	5	98	**Priority 1**	3
Laie	257	338	**Priority 1**	4
Waimanalo Beach-Homesteads	200	255	**Priority 1**	5
Kaena Point	6	847	**Priority 1**	6
Waimea-Kahuku	268	773	**Priority 1**	7
Kalaheo Avenue	23	132	**Priority 1**	8
Kawailoa	7	209	**Priority 1**	9
Campbell High School	99	893	**Priority 1**	10
Judd Hillside-Lowrey Avenue	250	78	**Priority 1**	11
Waianae Kai	139	172	**Priority 1**	12
Kapiolani Park	227	32	**Priority 1**	13
Nanakuli	13	96	**Priority 2**	14
Diamond Head	148	120	**Priority 2**	15
Kahaluu-Waikane	258	670	**Priority 2**	16
Lualualei-Camp Waianae	2	213	**Priority 2**	17
Makaha	72	89	**Priority 2**	18
Kunia West	14	54	**Priority 2**	19
Waialae-Kahala	47	39	**Priority 2**	20
Makiki Heights	176	55	**Priority 2**	21
Aiea Heights	259	106	**Priority 2**	22
Punchbowl	236	39	**Priority 2**	23
Round Top-Tantalus	170	159	**Priority 2**	24
Maili	185	100	**Priority 3**	25
Hawaii Prince Golf Course	30	51	**Priority 3**	26
Lualualei Transmitter	3	88	**Priority 3**	27
Haiku	49	146	**Priority 3**	28
Lualualei: Halona Road	269	232	**Priority 3**	29
Ahuimanu	232	99	**Priority 3**	30
Waimanalo	244	159	**Priority 3**	31
Ewa Gentry	26	94	**Priority 3**	32
Kapiolani Community College	48	65	**Priority 3**	33
Maunawili	267	38	**Priority 3**	34

Results: Maui

The island of Maui contains an estimated 11,038 cesspools and has a total of 31 census tracts, although only 23 tracts contained more than 25 cesspools and were categorized within the HCPT.

Maui Breakdown:

30% (7 tracts)**/924** cesspools (8%) = **Priority Level 1**
17% (4 tracts)**/3,148** cesspools (12%) = **Priority Level 2**
52% (12 tracts)**/6,971** cesspools (79%) = **Priority Level 3** *(Updated 2022)*

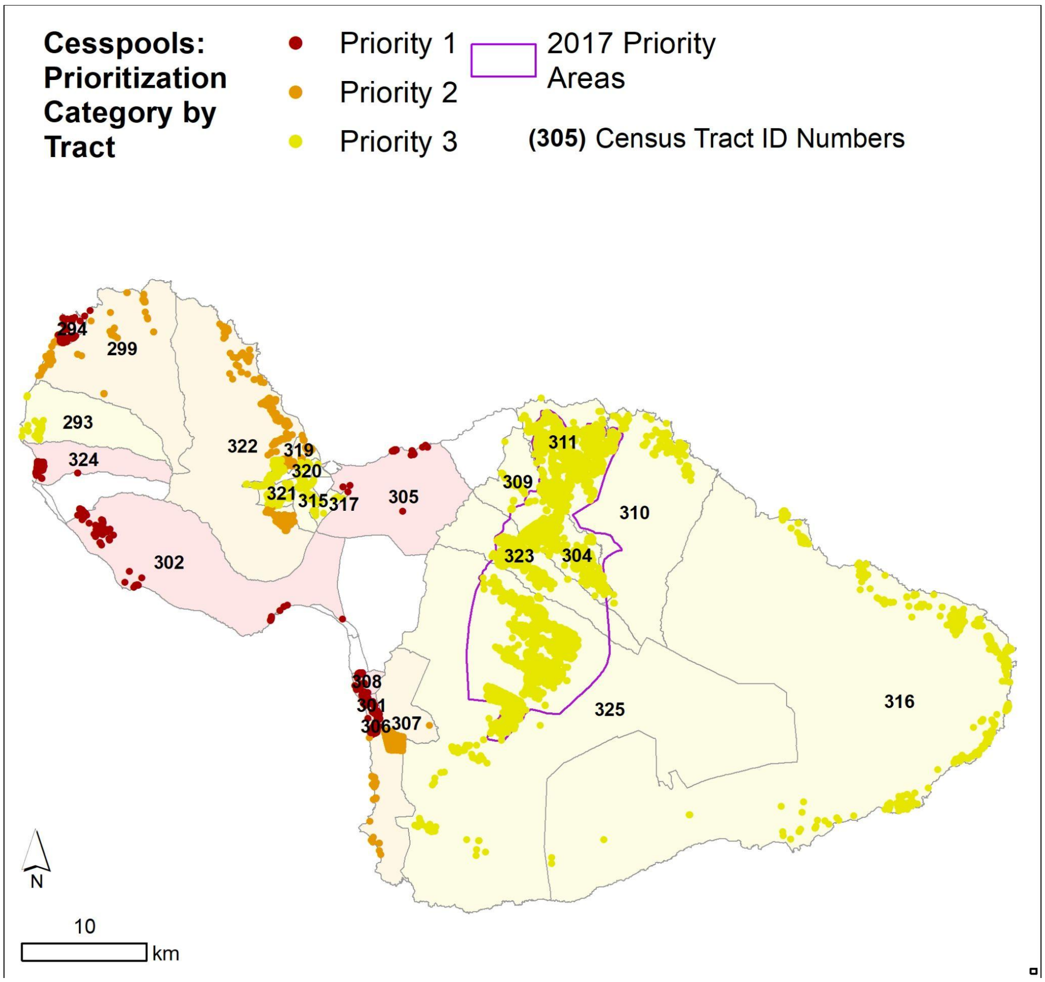

Figure 22: *Maui cesspools (dots) colored by prioritization category, arranged by census tracts. Tracts are shown as lightly colored areas where the tract contains greater than 25 cesspools, and are shown as white areas where the tract contains less than 25 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

Table 5: *Prioritization categories and island-specific ranks for Maui tracts. (Updated 2022)*

Tract Name	Tract ID	Cesspool Count	Priority Category	Island-Specific Priority Rank
Halama	308	84	**Priority 1**	1
Kahoma	324	280	**Priority 1**	2
Spreckelsville	305	35	**Priority 1**	3
Kamaole	301	134	**Priority 1**	4
Kapalua	294	223	**Priority 1**	5
Keawakapu	306	90	**Priority 1**	6
Launiupoko	302	78	**Priority 1**	7
Honokahua	299	85	**Priority 2**	8
Wailea	307	659	**Priority 2**	9
North Wailuku	319	69	**Priority 2**	10
Waihee-Waikapu	322	590	**Priority 2**	11
Honokowai	293	62	**Priority 3**	12
Kula	325	2268	**Priority 3**	13
Hana	316	537	**Priority 3**	14
West Kahului	315	60	**Priority 3**	15
Hali'imaile	309	1146	**Priority 3**	16
South Wailuku	321	281	**Priority 3**	17
Southeast Kahului	317	31	**Priority 3**	18
East Central Wailuku	320	64	**Priority 3**	19
Pukalani	323	1492	**Priority 3**	20
Makawao	304	891	**Priority 3**	21
Ha'iku	311	1413	**Priority 3**	22
Huelo	310	466	**Priority 3**	23

Results: Hawai'i Island

Hawai'i Island contains an estimated 48,596 cesspools and has a total of 33 census tracts. All 33 tracts contained more than 25 cesspools and were categorized within the HCPT.

Hawai'i Island Breakdown:

9% (3 tracts)**/5,119** cesspools (11%) = **Priority Level 1**

15% (5 tracts)**/2,619** cesspools (6%) = **Priority Level 2**

76% (25 tracts)**/40,858** cesspools (84%) = **Priority Level 3** *(Updated 2022)*

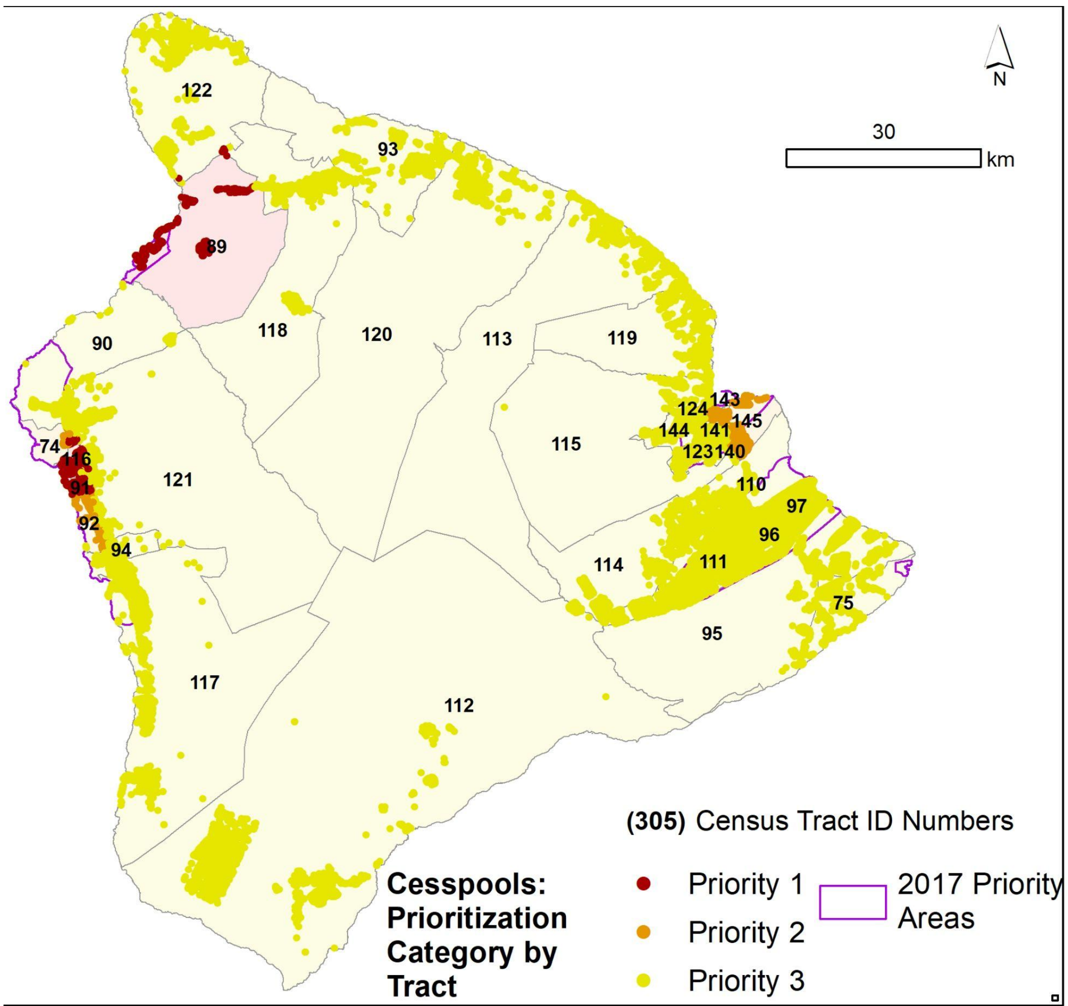

Figure 23: *Hawai'i Island cesspools (dots) colored by prioritization category, arranged by census tracts. Tracts are shown as lightly colored areas where the tract contains greater than 25 cesspools, and are shown as white areas where the tract contains less than 25 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

Table 6: *Prioritization categories & island-specific ranks for Hawaiʻi tracts. (Updated 2022)*

Tract Name	Tract ID	Cesspool Count	Priority Category	Island-Specific Priority Rank
Holualoa	91	1761	**Priority 1**	1
Kailua	116	1334	**Priority 1**	2
Kawaihae-Waikoloa	89	2024	**Priority 1**	3
Hilo: Keaukaha-Pana'ewa	145	934	**Priority 2**	4
Hilo: Villa Franca-Kaiko'o	142	151	**Priority 2**	5
Kaumalumalu-Keahou	92	654	**Priority 2**	6
Hilo: University-Houselots	141	549	**Priority 2**	7
Kealakehe	74	530	**Priority 2**	8
Hilo: Puainako	140	1582	**Priority 3**	9
Hilo: Pu'u'eo-Downtown	143	350	**Priority 3**	10
Hualalai	121	1141	**Priority 3**	11
Pauka'a-Wailea	119	963	**Priority 3**	12
Konawaena	94	1059	**Priority 3**	13
Waimea-Pu'u Anahulu	118	2375	**Priority 3**	14
North Hilo	113	855	**Priority 3**	15
Upper Waiakea Forest Reserve	115	670	**Priority 3**	16
Kalaoa	90	1916	**Priority 3**	17
Hilo: Haihai	123	1510	**Priority 3**	18
South Kona	117	1999	**Priority 3**	19
Hilo: Kawailani	125	1608	**Priority 3**	20
Hilo: Piihonua-Kaumana	124	1828	**Priority 3**	21
Hawaiian Paradise Park	97	4187	**Priority 3**	22
North Kohala	122	2131	**Priority 3**	23
Honoka'a-Kukuihaele	93	1329	**Priority 3**	24
Pahoa	95	2137	**Priority 3**	25
Hilo: Kahuku-Kaumana	144	1192	**Priority 3**	26
Ka'u	112	2481	**Priority 3**	27
Kea'au	110	1515	**Priority 3**	28
Pa'auhau-Pa'auilo	120	971	**Priority 3**	29
Kalapana-Kapoho	75	1175	**Priority 3**	30
Orchidland-Ainaloa	96	1663	**Priority 3**	31
Volcano-Mt. View	114	1371	**Priority 3**	32
Upper Puna (Puna Mauka)	111	2651	**Priority 3**	33

Results: Kauaʻi

The island of Kauaʻi contains an estimated 14,300 cesspools and has a total of 13 census tracts. All 13 tracts contained more than 25 cesspools and were categorized within the HCPT.

Kauaʻi Breakdown:

23% (3 tracts)**/2,999** cesspools (20%) = **Priority Level 1**
46% (6 tracts)**/6,144** cesspools (45%) = **Priority Level 2**
31% (4 tracts)**/5,157** cesspools (33%) = **Priority Level 3** *(Updated 2022)*

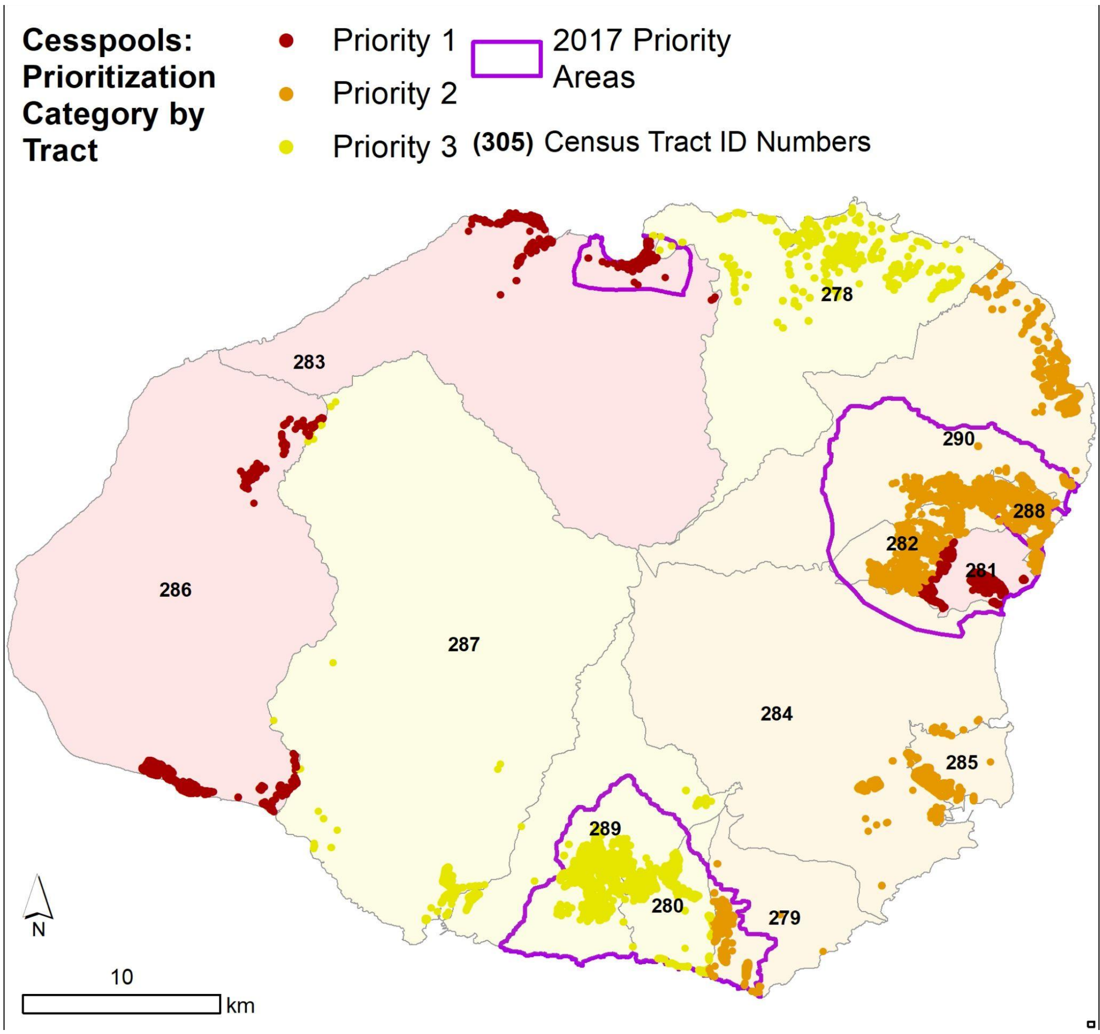

Figure 24: *Kauaʻi cesspools (dots) colored by prioritization category, arranged by census tracts. Tracts are shown as lightly colored areas where the tract contains greater than 25 cesspools, and are shown as white areas where the tract contains less than 25 cesspools. Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

Table 7: *Prioritization categories and island-specific ranks for Kaua'i tracts. (Updated 2022)*

Tract Name	Tract ID	Cesspool Count	Priority Category	Island-Specific Priority Rank
Ha'ena-Hanalei	283	554	**Priority 1**	1
Kekaha-Waimea	286	1210	**Priority 1**	2
Wailua Homesteads	281	1235	**Priority 1**	3
Kapa'a	288	2276	**Priority 2**	4
Wailua Houselots	282	1616	**Priority 2**	5
Koloa-Po'ipu	279	671	**Priority 2**	6
Anahola	290	980	**Priority 2**	7
Lihu'e	285	601	**Priority 2**	8
Puhi-Hanama'ulu	284	362	**Priority 2**	9
Kaumakani-Hanapepe	287	457	**Priority 3**	10
Omao-Kukui'ula	280	916	**Priority 3**	11
Princeville-Kilauea	278	1233	**Priority 3**	12
Eleele-Kalaheo	289	2189	**Priority 3**	13

Validation of Results

Hawai'i Act 132 funded a study led by Smith et al. (2021) to detect OSDS pollution in coastal waters. The study titled, the State-Wide Assessment of Wastewater Pollution Intrusion Into Coastal Regions of the Hawaiian Islands, used the $\delta^{15}N$ values of algal tissue collected in the nearshore environment to determine where nitrogen from wastewater was chronically present within the coastal water column. The study represents the most comprehensive and geographically widespread assessment of nearshore nitrogen source tracing in the state. The authors determined its value is most appropriately applied to a qualitative validation of the prioritization results. Though Smith et al. (2021) provides the best validation dataset available, it should be remembered that the geographic scale and physical drivers of the dataset have significant differences from the statewide, multi-factor extent of the HCPT.

Smith et al. (2021) were able to sample across approximately 50 km of coastline. However, this is still only a small percentage of the state's 1,600 km of coastline. These algal sampling results are extremely high resolution, showing high variability between sites within hundreds of meters of each other. This exemplifies the complexity and spatial variability of water chemistry and OSDS impacts across large and complicated ecosystems. Nonetheless, generalizations can be made. Act 132 study results were formatted to be comparable to the HCPT results by averaging algal sample site $\delta^{15}N$ values into sample 'swath' averages, which represent swaths of coastline roughly 2 km in length. These were categorized by Smith et al. into:

1. Areas dominated by wastewater nitrogen ($\delta^{15}N$ values > 6‰);
2. Areas with mixed inputs of nitrogen ($\delta^{15}N$ values > 4‰ and < 6‰), and;
3. Areas with limited detection of wastewater N ($\delta^{15}N$ values < 4‰), based on breakpoints listed here.

$\delta^{15}N$ can inform us of the amount of bioavailable nitrogen from different sources. However, it is not necessarily representative of the level of nitrogen flux. Additionally, the $\delta^{15}N$ indicator is subject to limitations, most importantly mixing of nitrogen from other sources, especially agriculture which reduces the clarity of the wastewater nitrogen signature. This tracer only provides information related to coastal water nitrogen chemistry in the immediate sampling location, whereas the HCPT includes multiple other factors, including value-based considerations, that are not related to nitrogen flux. Therefore, algal data results cannot, and should not, fully explain the HCPT categorization results. However, the qualitative comparison remains a useful and thought-provoking exercise.

Table 8 provides a qualitative assessment of how prioritization categories from the HCPT match with the Smith et al. (2021) wastewater impact categories based on the geographic proximity of cesspools and known nitrogen transport factors such as groundwater flow paths and coastal water movement. Overall, the results of this validation indicate 25 of 33 swaths (≈75%) have HCPT prioritization and wastewater impact categories that match reasonably well. Whereas, eight swaths (≈25%) have differing categorizations. Explanations for a number of these outliers are provided in Smith et al. (2021). There are many limitations to comparing very different types of data. Differences in results should be expected. Figure 25 provides a map view of cesspool prioritization categories, aggregated by census blocks alongside the wastewater impact categories of algal sampling swaths produced by Smith et al. (2021).

Table 8: *Qualitative validation results comparison between HCPT prioritization categories and Smith et al. (2021) wastewater impact categories. Wastewater impact categories are based on observed algal δ*^{15}*N values averaged across 2 km nearshore swaths and are compared to the HCPT calculated categories of proximal cesspools.*

Swath	Average Algal $\delta^{15}N$ value (‰)	Wastewater Impact Category	HCPT Prioritization of Nearby Cesspools	Matching	Comments for non-matching areas
HPP, Puna	2.12	Limited	3	yes	--
Hamakua Coast	3.17	Limited	3	yes	--
Holualoa, Kona	4.9	Mixed	1/2	yes	--
Kailapa, S.Kohala	4.14	Mixed	3/2/1	yes	--
Keaukaha, Hilo	3.48	Limited	3/1	no	Flow paths may not intersect
Mahaiula, Kona	2.4	Limited	3/None	yes	--
Mauna Lani, Kohala	4.33	Mixed	1	yes	--
NELHA,Kailua-Kona	4.22	Mixed	3	no	Large numbers of upslope CP
Puako, S. Kohala	6.48	Dominated	1	yes	--
Wailoa River, Hilo	4.98	Mixed	3/2/1	yes	--
Kapaa	5.86	Mixed	3/2/1	yes	--
Nawiliwili	8.11	Dominated	2	yes	--
Waiohai	8.44	Dominated	1/2	yes	--
Paia	3.2	Limited	3/None	yes	--
Kihei North	1.91	Limited	3/None	yes	--
Kihei South	5.11	Mixed	1/2	yes	--
Lahaina Control	2.21	Limited	No CP	yes	--
North Shore Control	1.9	Limited	1	no	Few cesspools, high water currents.
South Maui Control	2.58	Limited	3/None	yes	--
Waiehu	6.88	Dominated	3	no	Wetland denitrification
Waihee Control	1.71	Limited	3	yes	--
Wailea	6.36	Dominated	1/2	yes	--
Wailea South	4.81	Mixed	2	yes	--
Diamond Head	5.96	Mixed	2	yes	--
Hauula	9.23	Dominated	1	yes	--
Kaaawa	10.3	Dominated	1	yes	--
Kalaeloa	5.37	Mixed	1/None	unclear	Other sources, undocumented OSDS?
Makua	2.29	Limited	3	yes	--
Mokapu	2.89	Limited	1	no	Unclear, complex geology?
Sunset Beach	3.67	Limited	1	no	Unclear, complex currents?
Waialua	9.81	Dominated	1	yes	--
Waianae	5.43	Mixed	2	yes	--
Wailupe	6.09	Dominated	No CP	no	Other, undocumented OSDS?

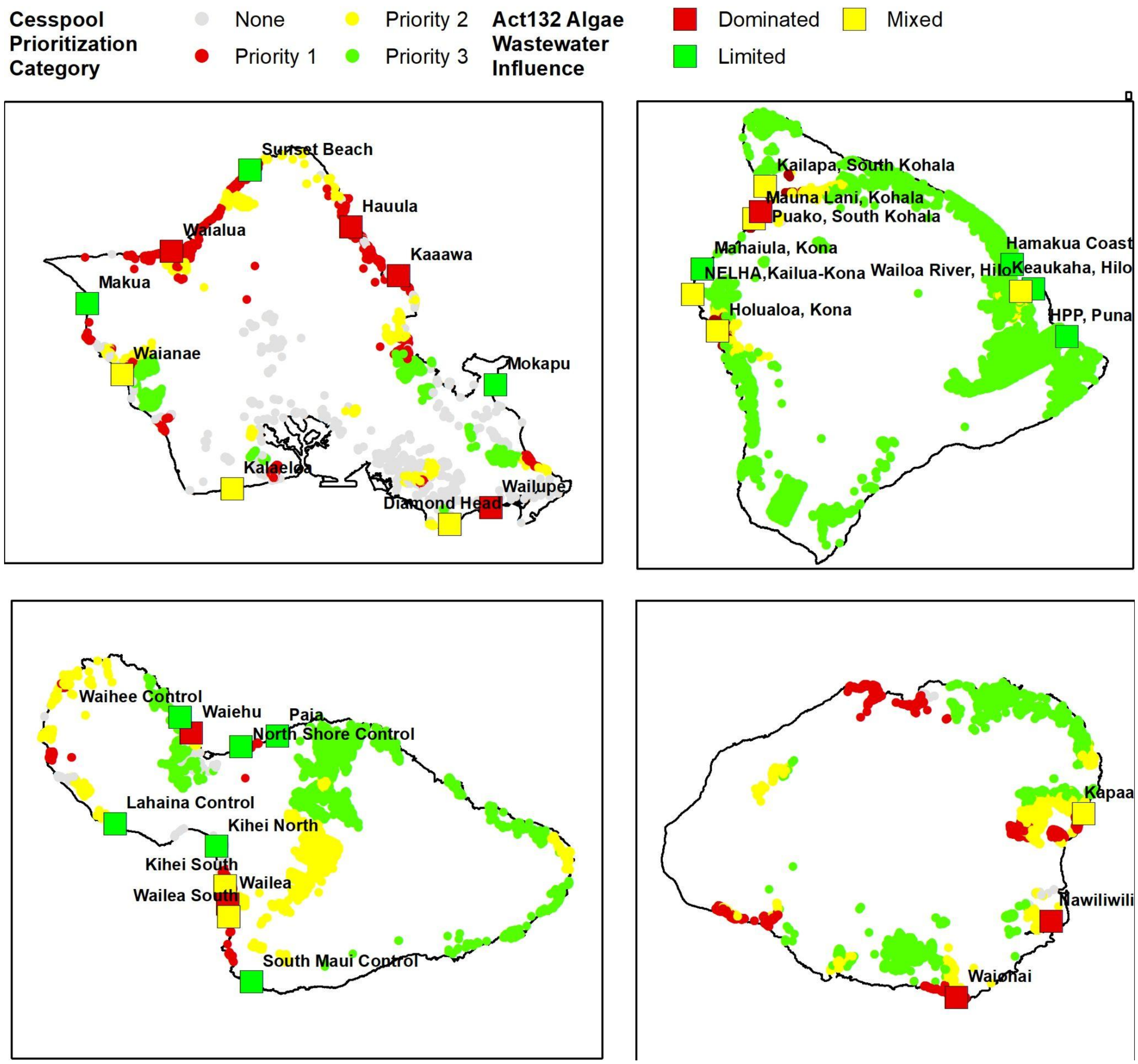

Figure 25: *Cesspool locations (circles) color coded by HCPT prioritization categories and aggregated by census blocks alongside algal sampling swaths (squares) from Smith et al. (2021) color coded by observed wastewater impact categories.*

Sensitivity Analysis of Priorities

Each factor used in the HCPT interacts with the environment in various ways and has different levels of importance to stakeholders and the community. For example, ocean conservation organizations may heavily prioritize coral reef protection, whereas the Board of Water Supply may prioritize impacts to drinking water wells more heavily. Unfortunately, it is impossible to weigh the factors proportionally to meet the demands of all stakeholders. Yet, it is acknowledged that each factor isn't equal in terms of its potential hazard and impact on the environment or human health. Because DOH is tasked with protecting human health and the environment, the tool includes factors that relate to these outcomes (i.e. distance to drinking water wells). A sensitivity analysis was performed to understand how weighting different factors may or may not change the score results. The process is an important way to test the robustness of the method and the types of factors chosen. If the weight of one factor disrupted the overall results disproportionately, it could compromise the structure of the tool. The sensitivity analysis was conducted using three scenarios where different weights were assigned to each risk factor, based on a hypothetical conceptual model of how different priorities might be expressed through adjustment of weights to different factors based upon the DOH mission and need.

The three weighting scenarios that were developed include:

1. **All inputs equally weighted:** Base scenario to which all others are compared.
2. **Human health priority:** Drinking water and human recreation are prioritized.
3. **Ecological health priority:** Ecosystem services and wildlife are prioritized.

It is recognized that some overlap exists between the scenarios, for example, factors that support ecological health often also benefit human health. Every effort was made to thoughtfully categorize the scenarios. Though imperfect, this method allows comparison for use and lends validity to future policy development. Ideally, the science in this tool would be straightforward enough for 'evidence-based policymaking.' However, with that, there is a level of pragmatism needed and an ability to combine scientific evidence with governance principles to translate the complex scientific principles into simple explanations for decision-making (Cairney & Oliver, 2017). The authors recognize the balance needed between robustness of the scientific methodology and the ability to make informed decisions to overcome problems.

Overall, it is the authors' opinions that using an equal weight method is feasible and acceptable for this exercise at this time. Sensitivity testing suggested that there may be about a six to seven percent uncertainty in the final ranks of the census tracts if different risk factors are weighted reasonably, as was done with these three scenarios. Individual census tracts can change more, warranting further exercises to determine appropriate weighting. Specifically, through this type of test, the authors found that the rank of individual census tracts (when tracts are ordered by priority score) has a standard deviation of 6.2 ranks when the ecological health scenario is compared to the base scenario, and 6.3 ranks when the human health scenario is compared to the base scenario. Essentially, the further this deviation is from zero, the less the scenarios match or agree. Complete results and specifics about the sensitivity testing are provided in Appendix B.

Conclusion/Next Steps

The current report and the HCPT expand on the previous efforts to provide a sound, quantitative, up-to-date hazard assessment of geographic areas at risk from cesspool pollution. The hazard categories provide a framework to prioritize cesspool conversions by the CCWG. The HCPT uses the best available data and method, developed in consultation with local experts and DOH associates, to prioritize cesspools in the allotted time frame of the contract and CCWG needs. Though the prioritization process is inherently contextual, every effort has been made to create an objective evaluation of cesspool hazards in an equitable and fact-based methodology. The HCPT should be used in consultation with a suite of iterative decision-making strategies.

The HCPT is a dynamic data tool that can support additional analysis of cesspool conversion strategies and policies. Because additional data can be layered onto the prioritization results, there are numerous possibilities to explore interdisciplinary connections between cesspool conversion and social factors such as household income, language spoken, or internet connectivity. By analyzing various data types with priority conversion areas, outreach and education methods can become highly specialized and targeted to have the greatest impacts, saving money, time, and human resources.

Because the HCPT relies on accurate cesspool numbers and locations, future database refinement is warranted and recommended, including some level of ground-truthing. This will ensure that the HCPT results are accurate, but also allow DOH to track maintenance and upgrades more efficiently and effectively. The identified hazard areas can also inform future permit requirements and prioritization plans, including mandating larger lot sizes for future development, increased setback distances to the coast, and requiring advanced technologies where appropriate. County offices may wish to use the tool for future planning of subdivisions to avoid carrying capacity issues on the land, such as poor soil or proximity to sensitive habitat or drinking water. Watershed or conservation organizations may find value in understanding areas most at risk from cesspool pollution and use the data for educational or management strategies. Finally, the HCPT can also identify areas where maintenance and inspection of OSDS will be critical to preserving water quality.

Acknowledgements

This work would not have been possible without the teamwork, advice, and dedication of many individuals and organizations who collaborated, contributed, and reviewed this product. We deeply thank and acknowledge the contributions provided by the following individuals:

Kaitlin Allen
Alyssa Renteria
Robert Whittier
Sina Pruder
Christin Reynolds
Roger Babcock, Ph.D.
Jamison Gove, Ph.D.
Joey Lecky
Greg Asner, Ph.D.
Mary Donovan, Ph.D.
Tom Oliver, Ph.D.
Eric Conklin, Ph.D.
Kim Falinski Ph.D.
Joachim Schneider
Christina Comfort
Stuart Coleman
Darren T. Lerner Ph.D.
Cindy Knapman
Quinn Moon
Hal Richman
Gretchen Chiques
Darren Okimoto Ph.D.
Aly El-Kadi Ph.D.
Kirsten Oleson Ph.D.
Celia Smith Ph.D.
Seth Foldy M.P.H. M.D.
Mary Donohue Ph.D.

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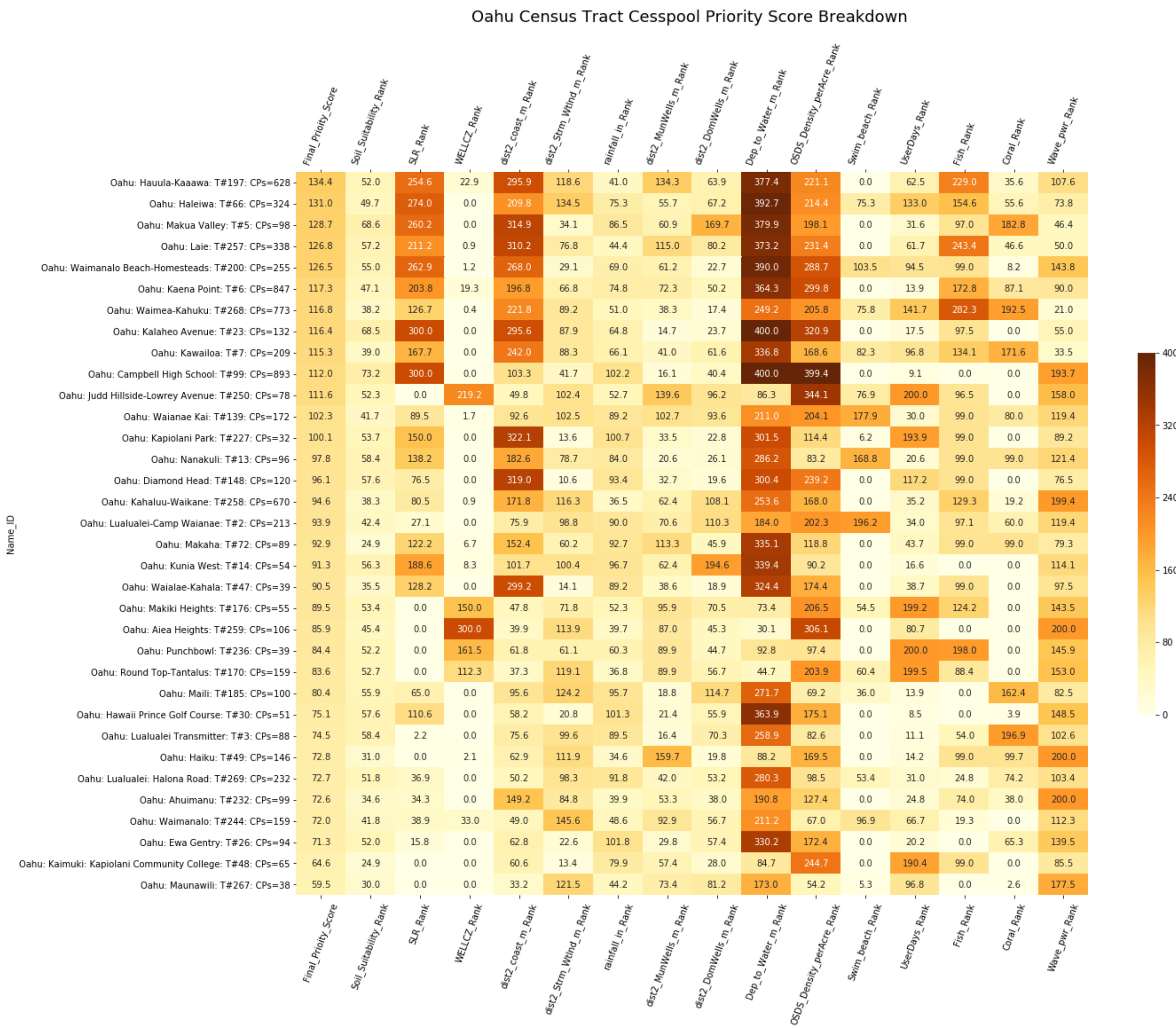
Appendix A: Additional Results

Additional Figures and tables are provided below. All results are updated as of 2022, See Appendix C for details.

Additional Results: O'ahu



Name_ID	Final_Prioity_Score	Soil_Suitability_Rank	SLR_Rank	WELLCZ_Rank	dist2_coast_m_Rank	dist2_Strm_Wtlnd_m_Rank	rainfall_in_Rank	dist2_MunWells_m_Rank	dist2_DomWells_m_Rank	Dep_to_Water_m_Rank	OSDS_Density_perAcre_Rank	Swim_beach_Rank	UserDays_Rank	Fish_Rank	Coral_Rank	Wave_pwr_Rank
Oahu: Hauula-Kaaawa: T#197: CPs=628	134.4	52.0	254.6	22.9	295.9	118.6	41.0	134.3	63.9	377.4	221.1	0.0	62.5	229.0	35.6	107.6
Oahu: Haleiwa: T#66: CPs=324	131.0	49.7	274.0	0.0	209.8	134.5	75.3	55.7	67.2	392.7	214.4	75.3	133.0	154.6	55.6	73.8
Oahu: Makua Valley: T#5: CPs=98	128.7	68.6	260.2	0.0	314.9	34.1	86.5	60.9	169.7	379.9	198.1	0.0	31.6	97.0	182.8	46.4
Oahu: Laie: T#257: CPs=338	126.8	57.2	211.2	0.9	310.2	76.8	44.4	115.0	80.2	373.2	231.4	0.0	61.7	243.4	46.6	50.0
Oahu: Waimanalo Beach-Homesteads: T#200: CPs=255	126.5	55.0	262.9	1.2	268.0	29.1	69.0	61.2	22.7	390.0	288.7	103.5	94.5	99.0	8.2	143.8
Oahu: Kaena Point: T#6: CPs=847	117.3	47.1	203.8	19.3	196.8	66.8	74.8	72.3	50.2	364.3	299.8	0.0	13.9	172.8	87.1	90.0
Oahu: Waimea-Kahuku: T#268: CPs=773	116.8	38.2	126.7	0.4	221.8	89.2	51.0	38.3	17.4	249.2	205.8	75.8	141.7	282.3	192.5	21.0
Oahu: Kalaheo Avenue: T#23: CPs=132	116.4	68.5	300.0	0.0	295.6	87.9	64.8	14.7	23.7	400.0	320.9	0.0	17.5	97.5	0.0	55.0
Oahu: Kawailoa: T#7: CPs=209	115.3	39.0	167.7	0.0	242.0	88.3	66.1	41.0	61.6	336.8	168.6	82.3	96.8	134.1	171.6	33.5
Oahu: Campbell High School: T#99: CPs=893	112.0	73.2	300.0	0.0	103.3	41.7	102.2	16.1	40.4	400.0	399.4	0.0	9.1	0.0	0.0	193.7
Oahu: Judd Hillside-Lowrey Avenue: T#250: CPs=78	111.6	52.3	0.0	219.2	49.8	102.4	52.7	139.6	96.2	86.3	344.1	76.9	200.0	96.5	0.0	158.0
Oahu: Waianae Kai: T#139: CPs=172	102.3	41.7	89.5	1.7	92.6	102.5	89.2	102.7	93.6	211.0	204.1	177.9	30.0	99.0	80.0	119.4
Oahu: Kapiolani Park: T#227: CPs=32	100.1	53.7	150.0	0.0	322.1	13.6	100.7	33.5	22.8	301.5	114.4	6.2	193.9	99.0	0.0	89.2
Oahu: Nanakuli: T#13: CPs=96	97.8	58.4	138.2	0.0	182.6	78.7	84.0	20.6	26.1	286.2	83.2	168.8	20.6	99.0	99.0	121.4
Oahu: Diamond Head: T#148: CPs=120	96.1	57.6	76.5	0.0	319.0	10.6	93.4	32.7	19.6	300.4	239.2	0.0	117.2	99.0	0.0	76.5
Oahu: Kahaluu-Waikane: T#258: CPs=670	94.6	38.3	80.5	0.9	171.8	116.3	36.5	62.4	108.1	253.6	168.0	0.0	35.2	129.3	19.2	199.4
Oahu: Lualualei-Camp Waianae: T#2: CPs=213	93.9	42.4	27.1	0.0	75.9	98.8	90.0	70.6	110.3	184.0	202.3	196.2	34.0	97.1	60.0	119.4
Oahu: Makaha: T#72: CPs=89	92.9	24.9	122.2	6.7	152.4	60.2	92.7	113.3	45.9	335.1	118.8	0.0	43.7	99.0	99.0	79.3
Oahu: Kunia West: T#14: CPs=54	91.3	56.3	188.6	8.3	101.7	100.4	96.7	62.4	194.6	339.4	90.2	0.0	16.6	0.0	0.0	114.1
Oahu: Waialae-Kahala: T#47: CPs=39	90.5	35.5	128.2	0.0	299.2	14.1	89.2	38.6	18.9	324.4	174.4	0.0	38.7	99.0	0.0	97.5
Oahu: Makiki Heights: T#176: CPs=55	89.5	53.4	0.0	150.0	47.8	71.8	52.3	95.9	70.5	73.4	206.5	54.5	199.2	124.2	0.0	143.5
Oahu: Aiea Heights: T#259: CPs=106	85.9	45.4	0.0	300.0	39.9	113.9	39.7	87.0	45.3	30.1	306.1	0.0	80.7	0.0	0.0	200.0
Oahu: Punchbowl: T#236: CPs=39	84.4	52.2	0.0	161.5	61.8	61.1	60.3	89.9	44.7	92.8	97.4	0.0	200.0	198.0	0.0	145.9
Oahu: Round Top-Tantalus: T#170: CPs=159	83.6	52.7	0.0	112.3	37.3	119.1	36.8	89.9	56.7	44.7	203.9	60.4	199.5	88.4	0.0	153.0
Oahu: Maili: T#185: CPs=100	80.4	55.9	65.0	0.0	95.6	124.2	95.7	18.8	114.7	271.7	69.2	36.0	13.9	0.0	162.4	82.5
Oahu: Hawaii Prince Golf Course: T#30: CPs=51	75.1	57.6	110.6	0.0	58.2	20.8	101.3	21.4	55.9	363.9	175.1	0.0	8.5	0.0	3.9	148.5
Oahu: Lualualei Transmitter: T#3: CPs=88	74.5	58.4	2.2	0.0	75.6	99.6	89.5	16.4	70.3	258.9	82.6	0.0	11.1	54.0	196.9	102.6
Oahu: Haiku: T#49: CPs=146	72.8	31.0	0.0	2.1	62.9	111.9	34.6	159.7	19.8	88.2	169.5	0.0	14.2	99.0	99.7	200.0
Oahu: Lualualei: Halona Road: T#269: CPs=232	72.7	51.8	36.9	0.0	50.2	98.3	91.8	42.0	53.2	280.3	98.5	53.4	31.0	24.8	74.2	103.4
Oahu: Ahuimanu: T#232: CPs=99	72.6	34.6	34.3	0.0	149.2	84.8	39.9	53.3	38.0	190.8	127.4	0.0	24.8	74.0	38.0	200.0
Oahu: Waimanalo: T#244: CPs=159	72.0	41.8	38.9	33.0	49.0	145.6	48.6	92.9	56.7	211.2	67.0	96.9	66.7	19.3	0.0	112.3
Oahu: Ewa Gentry: T#26: CPs=94	71.3	52.0	15.8	0.0	62.8	22.6	101.8	29.8	57.4	330.2	172.4	0.0	20.2	0.0	65.3	139.5
Oahu: Kaimuki: Kapiolani Community College: T#48: CPs=65	64.6	24.9	0.0	0.0	60.6	13.4	79.9	57.4	28.0	84.7	244.7	0.0	190.4	99.0	0.0	85.5
Oahu: Maunawili: T#267: CPs=38	59.5	30.0	0.0	0.0	33.2	121.5	44.2	73.4	81.2	173.0	54.2	5.3	96.8	0.0	2.6	177.5

Figure A1: *Pivot table showing census-tract based priority scores, (leftmost column) and individual risk factor scores, which were averaged to calculate the overall priority score of each census tract for O'ahu. (Updated 2022)*

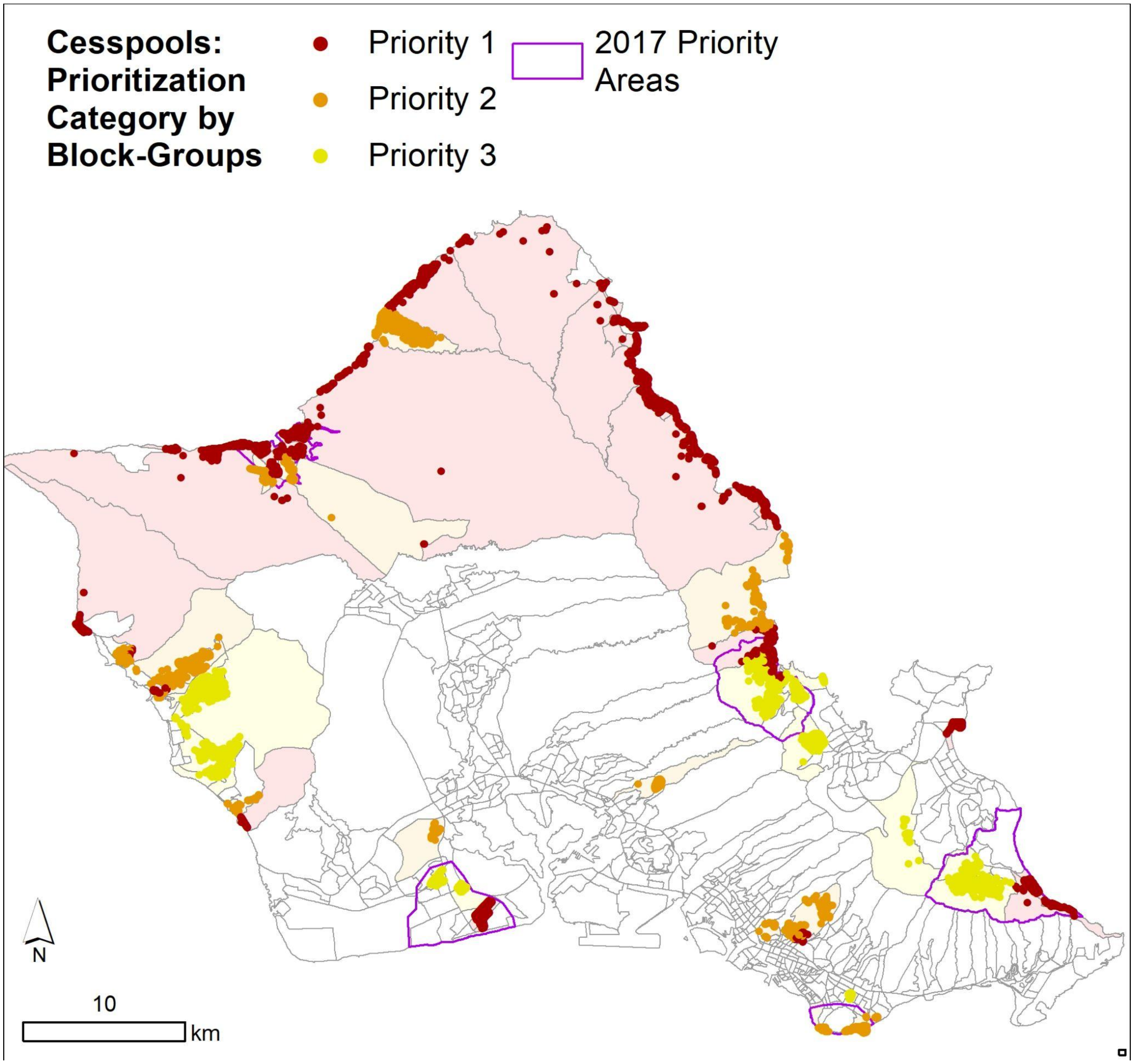


Figure A2: *Oʻahu cesspools (dots) colored by prioritization category, arranged by census block-groups. Block-groups are shown as lightly colored areas where the block-group contains >20 cesspools. White areas signify the block-group contains <20 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

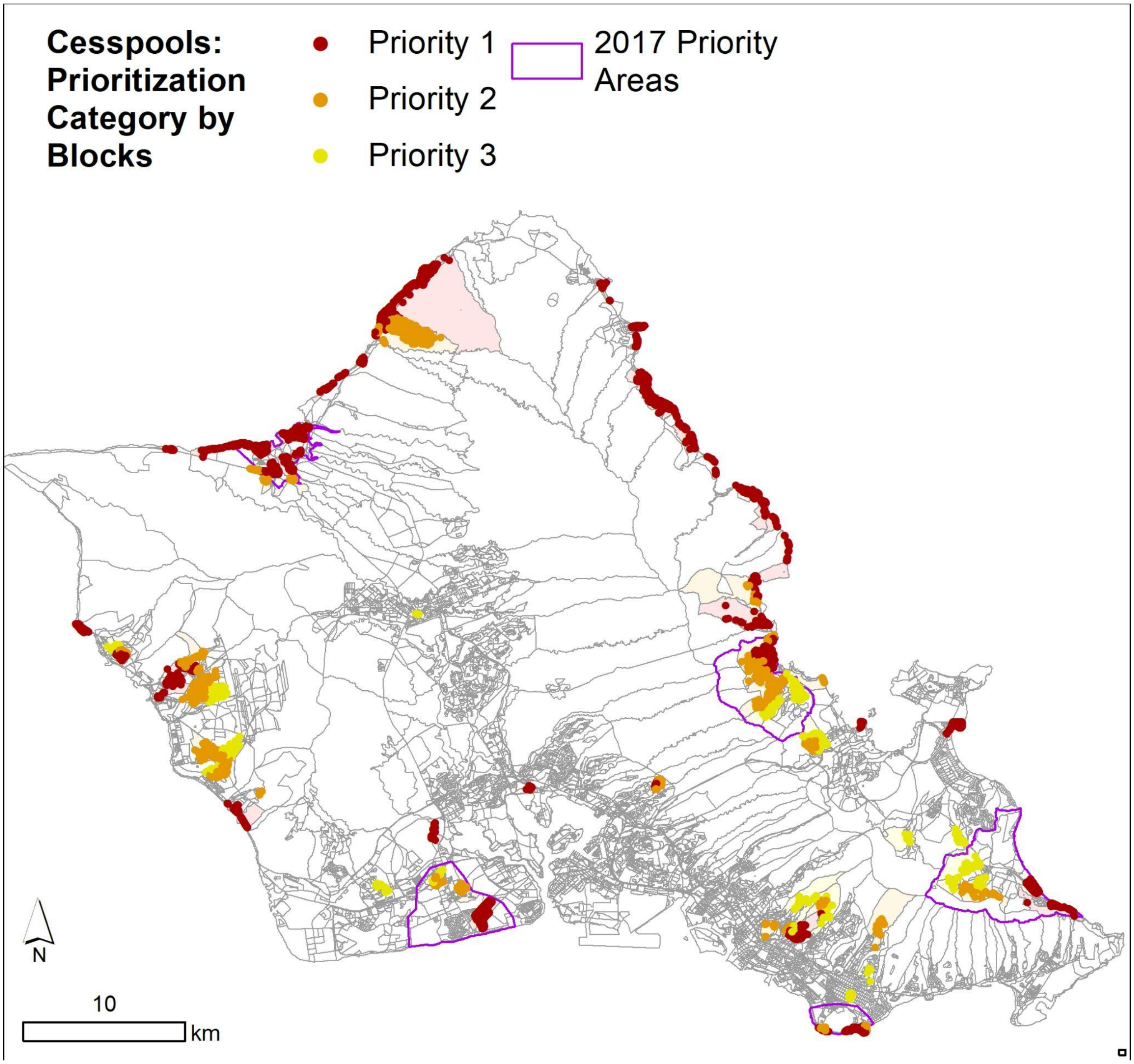
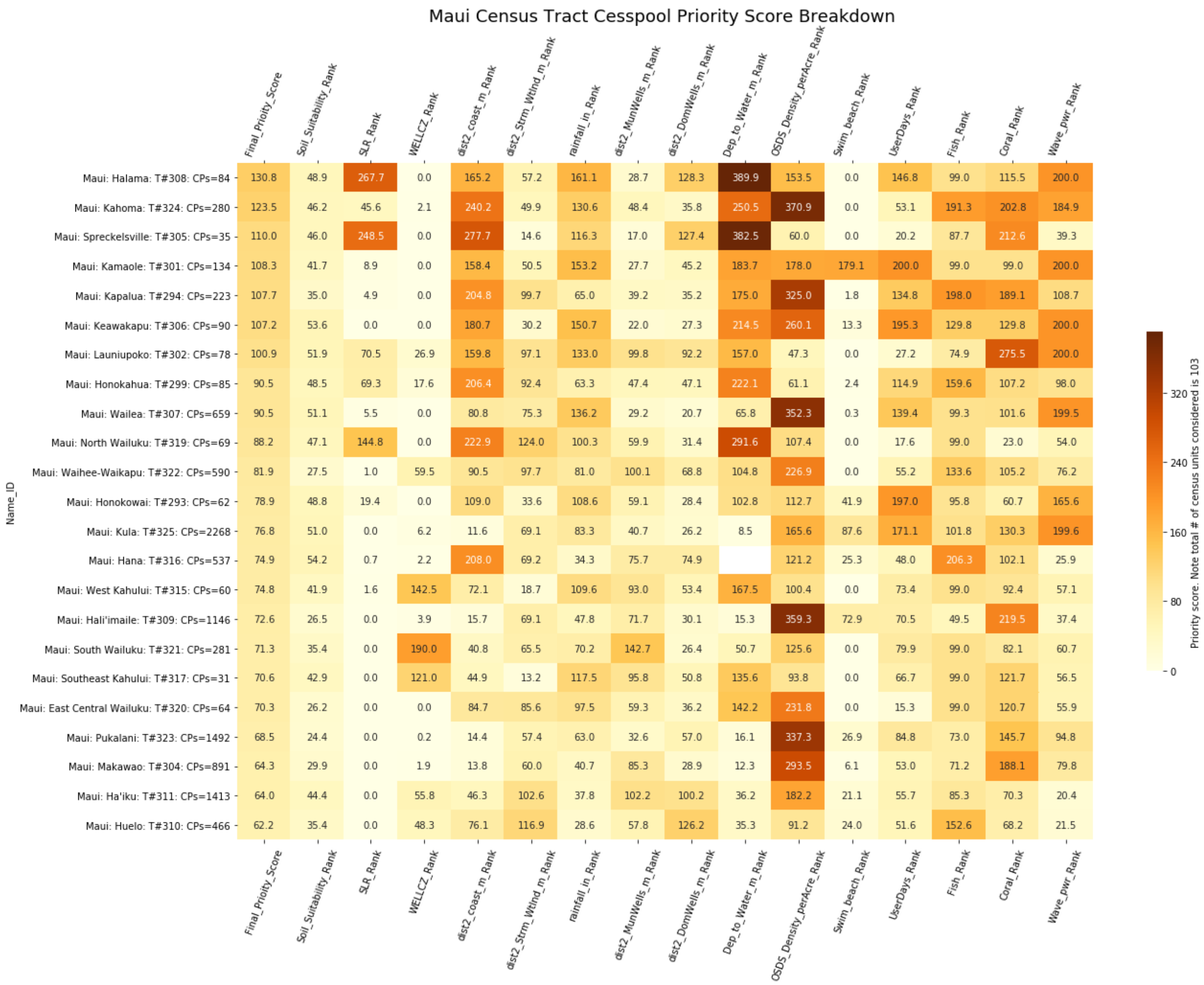


Figure A3: *O'ahu cesspools (dots) colored by prioritization category, arranged by census blocks. Blocks are shown as lightly colored areas where the block contains >10 cesspools. White areas signify the block contains <10 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

Additional Results: Maui



Name_ID	Final_Prioity_Score	Soil_Suitability_Rank	SLR_Rank	WELLCZ_Rank	dist2_coast_m_Rank	dist2_Strm_Wtlnd_m_Rank	rainfall_in_Rank	dist2_MunWells_m_Rank	dist2_DomWells_m_Rank	Dep_to_Water_m_Rank	OSDS_Density_perAcre_Rank	Swim_beach_Rank	UserDays_Rank	Fish_Rank	Coral_Rank	Wave_pwr_Rank
Maui: Halama: T#308: CPs=84	130.8	48.9	267.7	0.0	165.2	57.2	161.1	28.7	128.3	389.9	153.5	0.0	146.8	99.0	115.5	200.0
Maui: Kahoma: T#324: CPs=280	123.5	46.2	45.6	2.1	240.2	49.9	130.6	48.4	35.8	250.5	370.9	0.0	53.1	191.3	202.8	184.9
Maui: Spreckelsville: T#305: CPs=35	110.0	46.0	248.5	0.0	277.7	14.6	116.3	17.0	127.4	382.5	60.0	0.0	20.2	87.7	212.6	39.3
Maui: Kamaole: T#301: CPs=134	108.3	41.7	8.9	0.0	158.4	50.5	153.2	27.7	45.2	183.7	178.0	179.1	200.0	99.0	99.0	200.0
Maui: Kapalua: T#294: CPs=223	107.7	35.0	4.9	0.0	204.8	99.7	65.0	39.2	35.2	175.0	325.0	1.8	134.8	198.0	189.1	108.7
Maui: Keawakapu: T#306: CPs=90	107.2	53.6	0.0	0.0	180.7	30.2	150.7	22.0	27.3	214.5	260.1	13.3	195.3	129.8	129.8	200.0
Maui: Launiupoko: T#302: CPs=78	100.9	51.9	70.5	26.9	159.8	97.1	133.0	99.8	92.2	157.0	47.3	0.0	27.2	74.9	275.5	200.0
Maui: Honokahua: T#299: CPs=85	90.5	48.5	69.3	17.6	206.4	92.4	63.3	47.4	47.1	222.1	61.1	2.4	114.9	159.6	107.2	98.0
Maui: Wailea: T#307: CPs=659	90.5	51.1	5.5	0.0	80.8	75.3	136.2	29.2	20.7	65.8	352.3	0.3	139.4	99.3	101.6	199.5
Maui: North Wailuku: T#319: CPs=69	88.2	47.1	144.8	0.0	222.9	124.0	100.3	59.9	31.4	291.6	107.4	0.0	17.6	99.0	23.0	54.0
Maui: Waihee-Waikapu: T#322: CPs=590	81.9	27.5	1.0	59.5	90.5	97.7	81.0	100.1	68.8	104.8	226.9	0.0	55.2	133.6	105.2	76.2
Maui: Honokowai: T#293: CPs=62	78.9	48.8	19.4	0.0	109.0	33.6	108.6	59.1	28.4	102.8	112.7	41.9	197.0	95.8	60.7	165.6
Maui: Kula: T#325: CPs=2268	76.8	51.0	0.0	6.2	11.6	69.1	83.3	40.7	26.2	8.5	165.6	87.6	171.1	101.8	130.3	199.6
Maui: Hana: T#316: CPs=537	74.9	54.2	0.7	2.2	208.0	69.2	34.3	75.7	74.9		121.2	25.3	48.0	206.3	102.1	25.9
Maui: West Kahului: T#315: CPs=60	74.8	41.9	1.6	142.5	72.1	18.7	109.6	93.0	53.4	167.5	100.4	0.0	73.4	99.0	92.4	57.1
Maui: Hali'imaile: T#309: CPs=1146	72.6	26.5	0.0	3.9	15.7	69.1	47.8	71.7	30.1	15.3	359.3	72.9	70.5	49.5	219.5	37.4
Maui: South Wailuku: T#321: CPs=281	71.3	35.4	0.0	190.0	40.8	65.5	70.2	142.7	26.4	50.7	125.6	0.0	79.9	99.0	82.1	60.7
Maui: Southeast Kahului: T#317: CPs=31	70.6	42.9	0.0	121.0	44.9	13.2	117.5	95.8	50.8	135.6	93.8	0.0	66.7	99.0	121.7	56.5
Maui: East Central Wailuku: T#320: CPs=64	70.3	26.2	0.0	0.0	84.7	85.6	97.5	59.3	36.2	142.2	231.8	0.0	15.3	99.0	120.7	55.9
Maui: Pukalani: T#323: CPs=1492	68.5	24.4	0.0	0.2	14.4	57.4	63.0	32.6	57.0	16.1	337.3	26.9	84.8	73.0	145.7	94.8
Maui: Makawao: T#304: CPs=891	64.3	29.9	0.0	1.9	13.8	60.0	40.7	85.3	28.9	12.3	293.5	6.1	53.0	71.2	188.1	79.8
Maui: Ha'iku: T#311: CPs=1413	64.0	44.4	0.0	55.8	46.3	102.6	37.8	102.2	100.2	36.2	182.2	21.1	55.7	85.3	70.3	20.4
Maui: Huelo: T#310: CPs=466	62.2	35.4	0.0	48.3	76.1	116.9	28.6	57.8	126.2	35.3	91.2	24.0	51.6	152.6	68.2	21.5

Figure A4: *Pivot table showing census-tract based priority scores, (leftmost column) and individual risk factor scores, which were averaged to calculate the overall priority score of each census tract for Maui. (Updated 2022)*

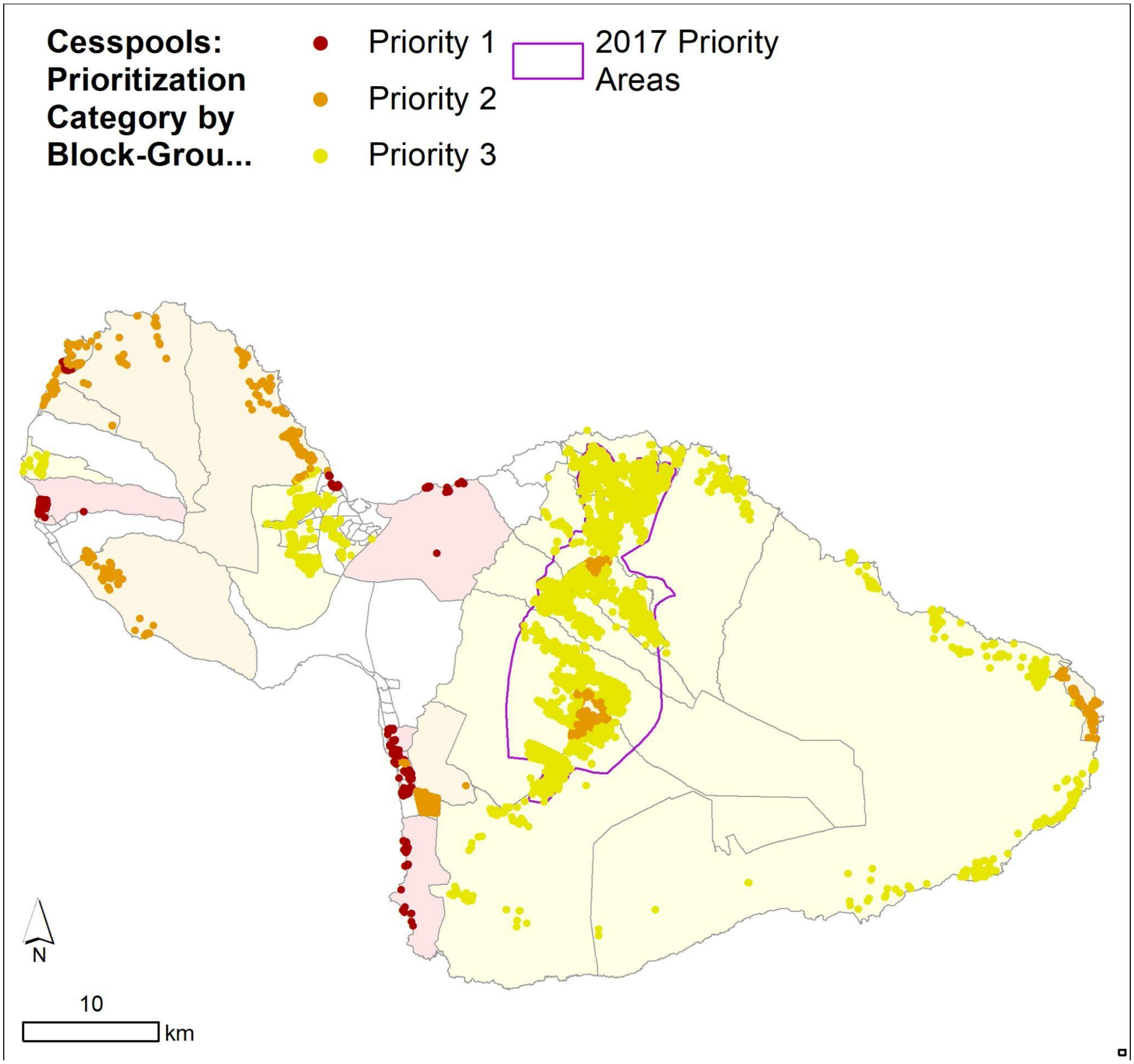


Figure A5: *Maui cesspools (dots) colored by prioritization category, arranged by census block-groups. Block-groups are shown as lightly colored areas where the block-group contains >20 cesspools. White areas signify the block-group contains <20 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

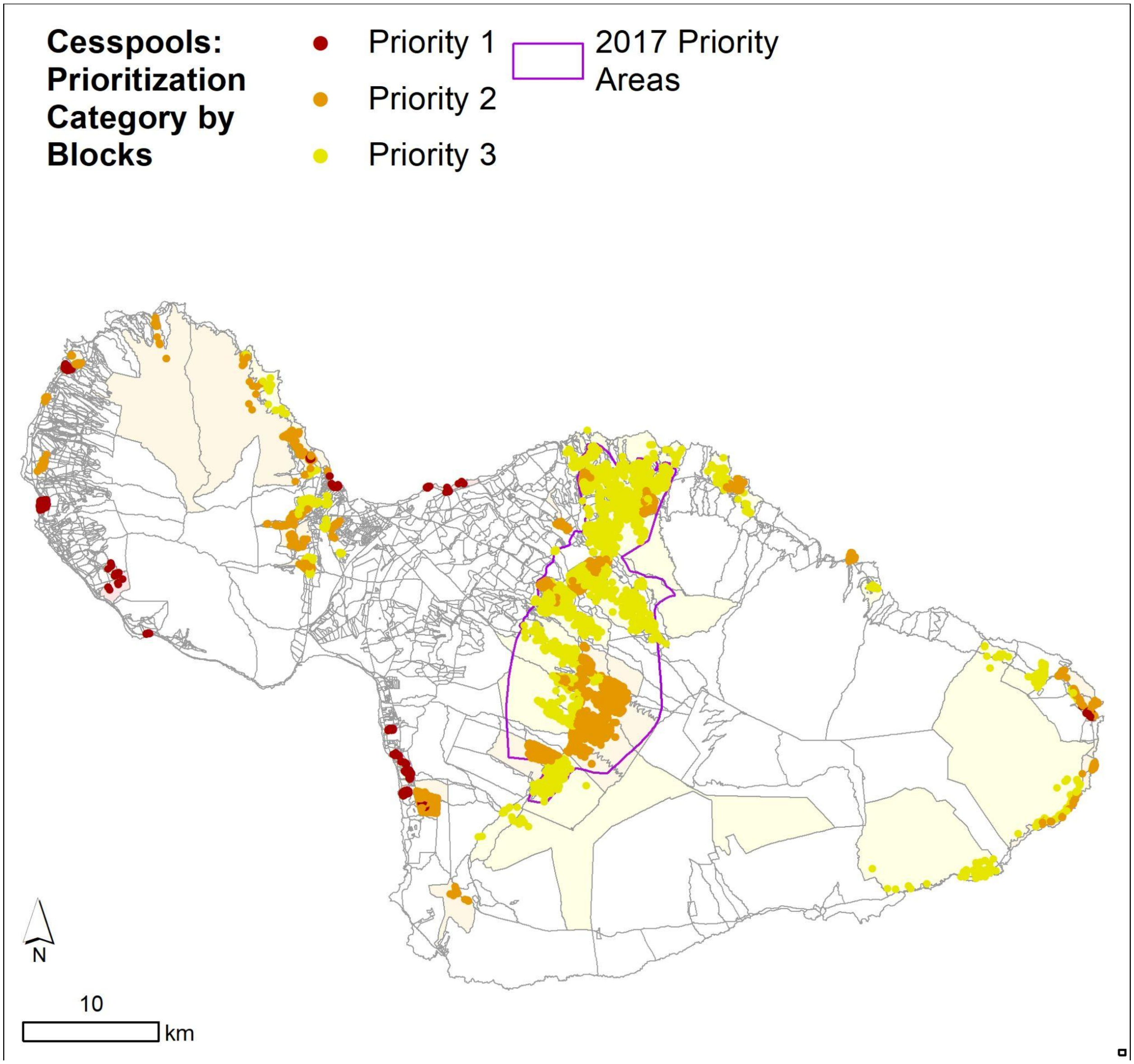


Figure A6: *Maui cesspools (dots) colored by prioritization category, arranged by census blocks. Blocks are shown as lightly colored areas where the block contains >10 cesspools. White areas signify the block contains <10 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

Additional Results: Hawaiʻi Island

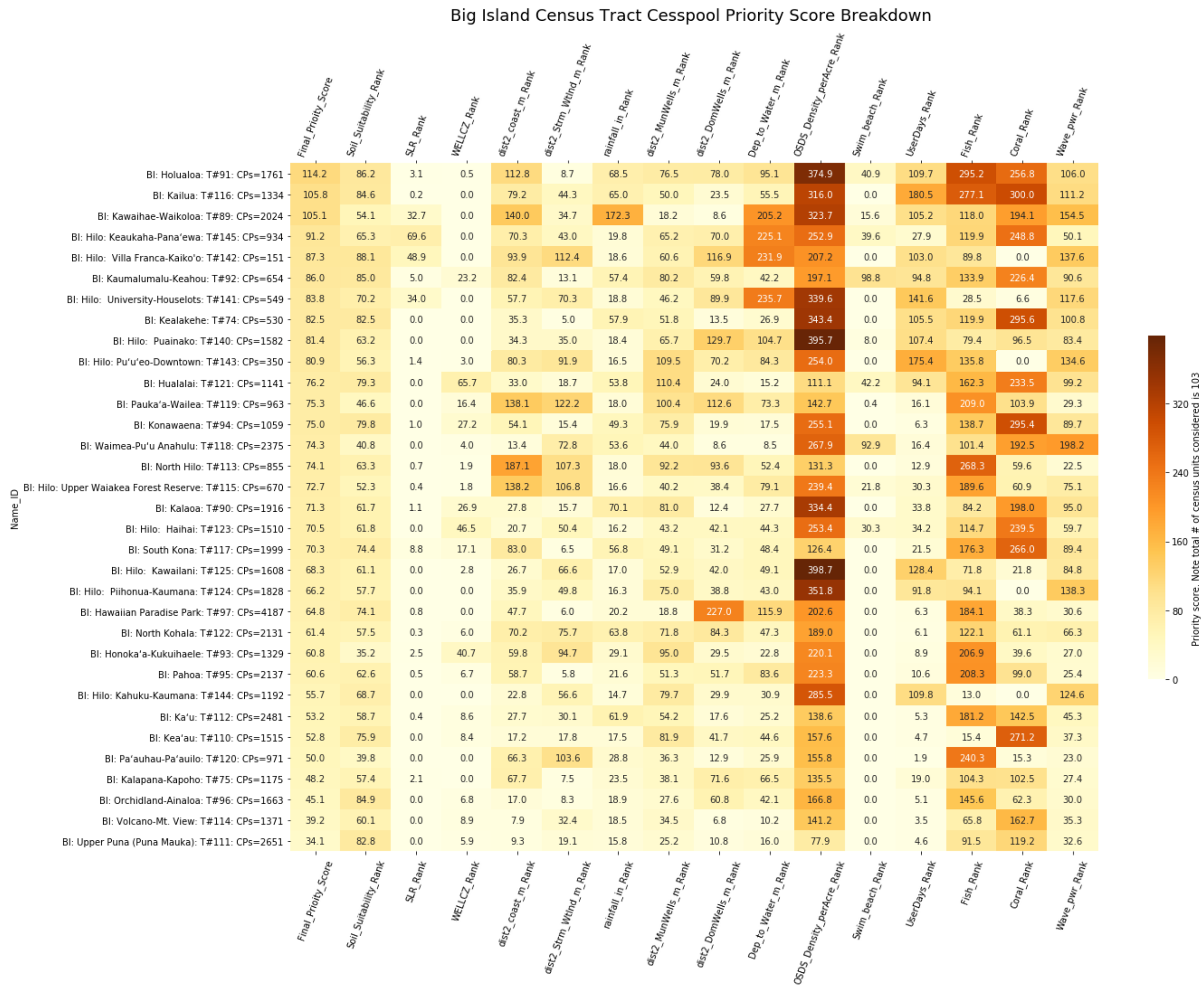


Figure A7: *Pivot table showing census-tract based priority scores, (leftmost column) and individual risk factor scores, which were averaged to calculate the overall priority score of each census tract for Hawaiʻi Island. (Updated 2022)*

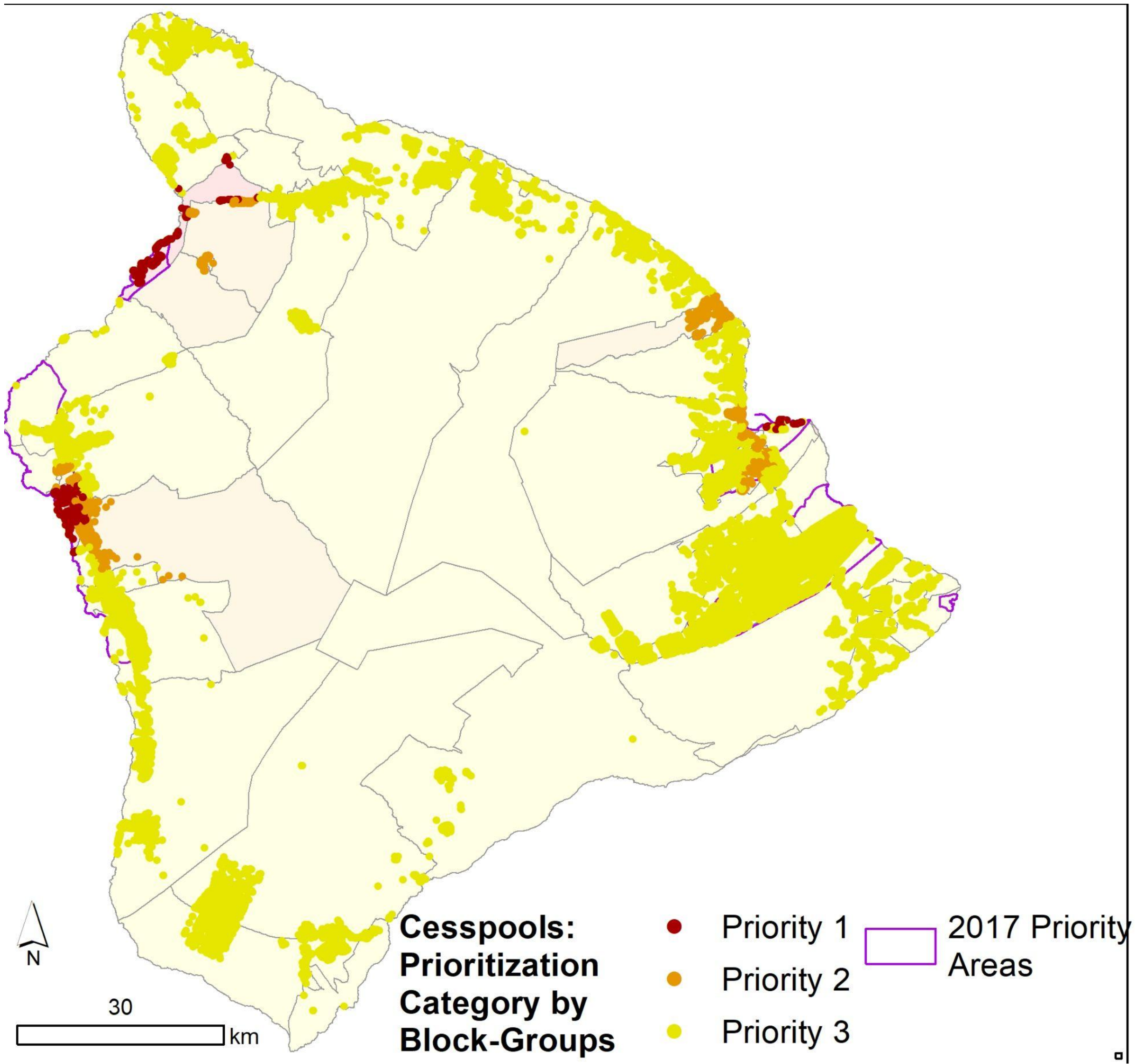


Figure A8: *Hawai'i Island cesspools (dots) colored by prioritization category, arranged by census block-groups. Block-groups are shown as lightly colored areas where the block-group contains >20 cesspools. White areas signify the block-group contains <20 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

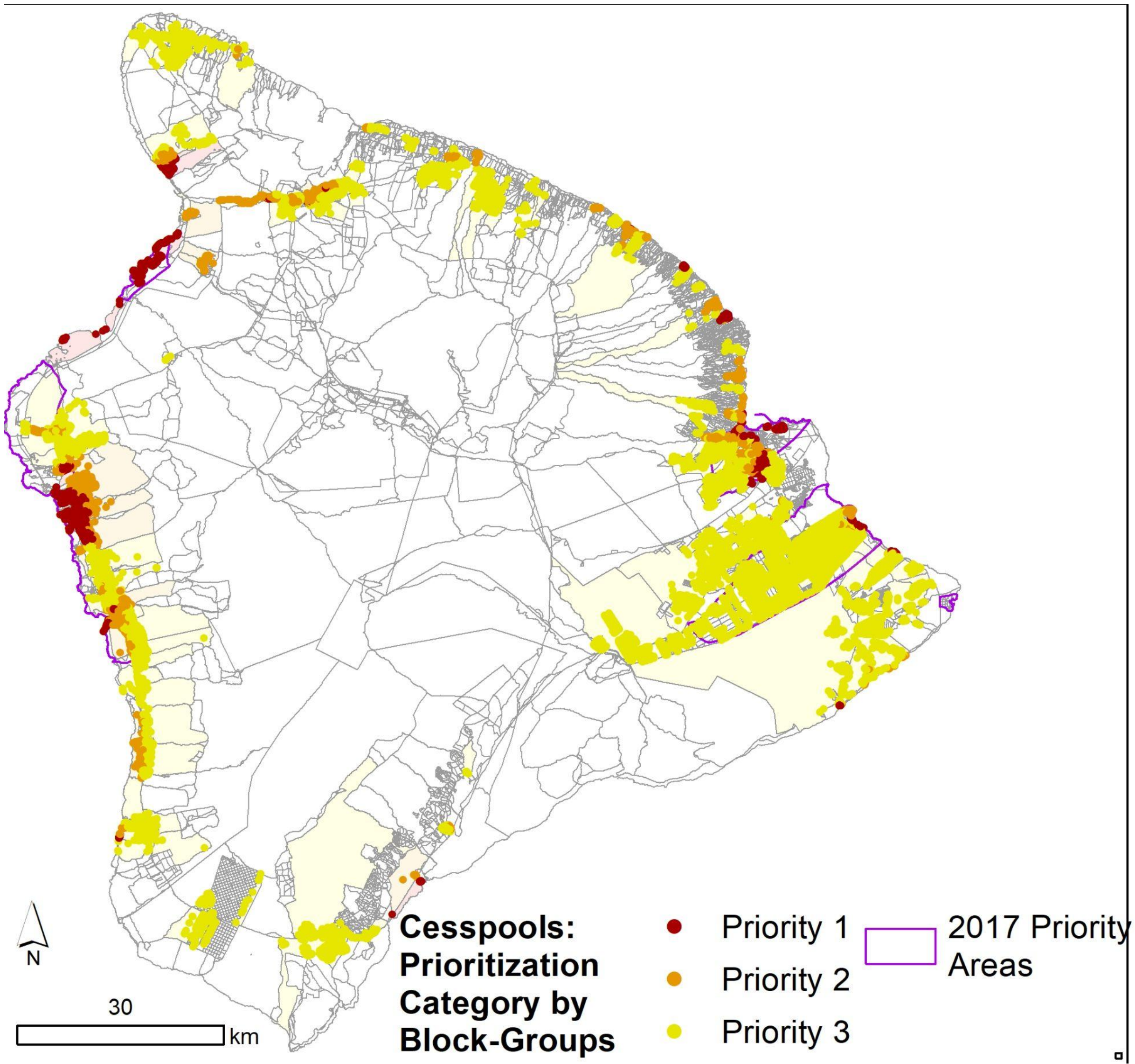


Figure A9: *Hawai'i Island cesspools (dots) colored by prioritization category, arranged by census blocks. Blocks are shown as lightly colored areas where the block contains >10 cesspools. White areas signify the block contains <10 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas. (Updated 2022)*

Additional Results: Kauaʻi

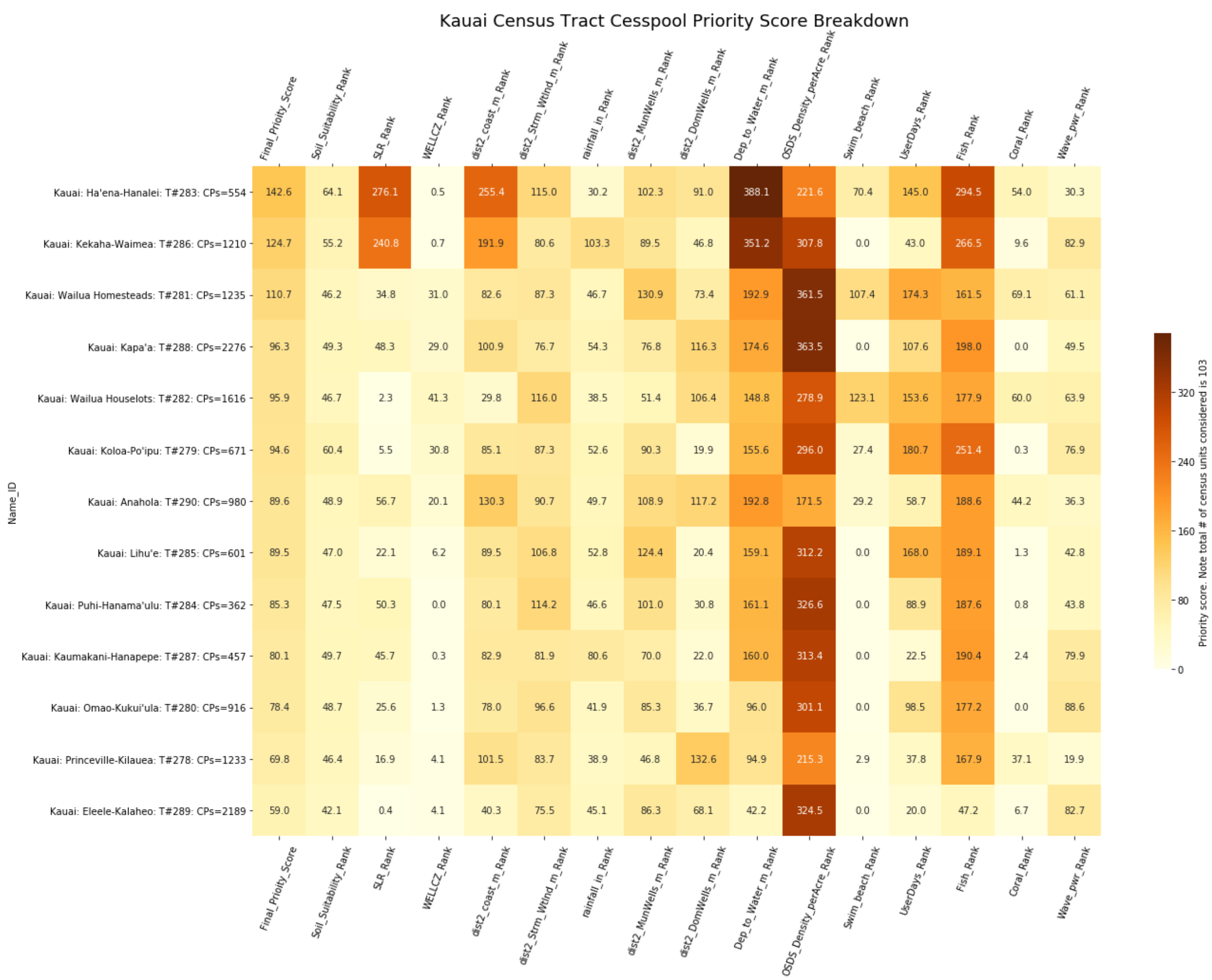


Figure A10: *Pivot table showing census-tract based priority scores, (leftmost column) and individual risk factor scores, which were averaged to calculate the overall priority score of each census tract for Kauaʻi. (Updated 2022)*

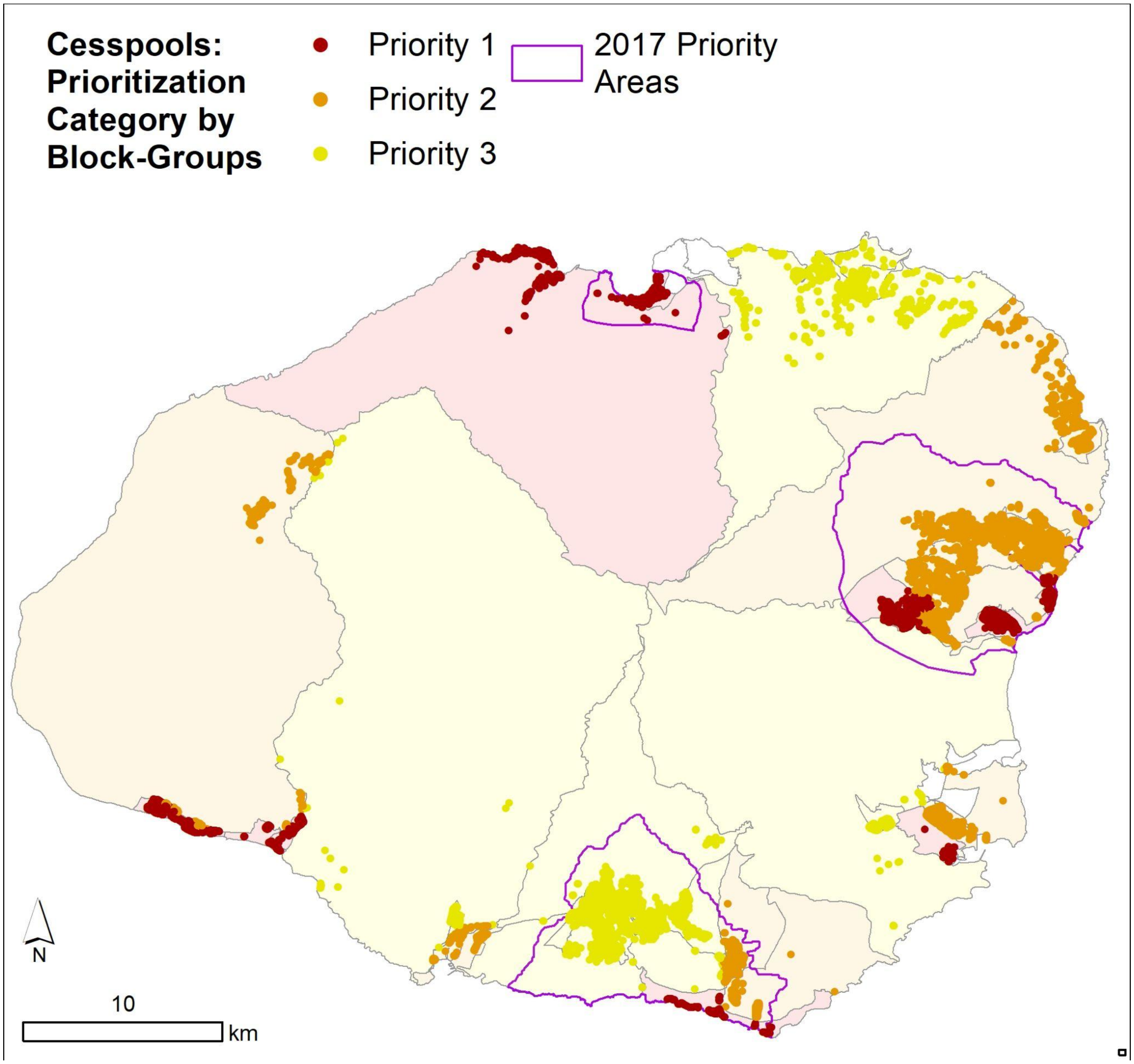


Figure A11: *Kaua'i cesspools (dots) colored by prioritization category, arranged by census block-groups. Block-groups are shown as lightly colored areas where the block-group contains >20 cesspools. White areas signify the block-group contains <20 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas.* (Updated 2022)

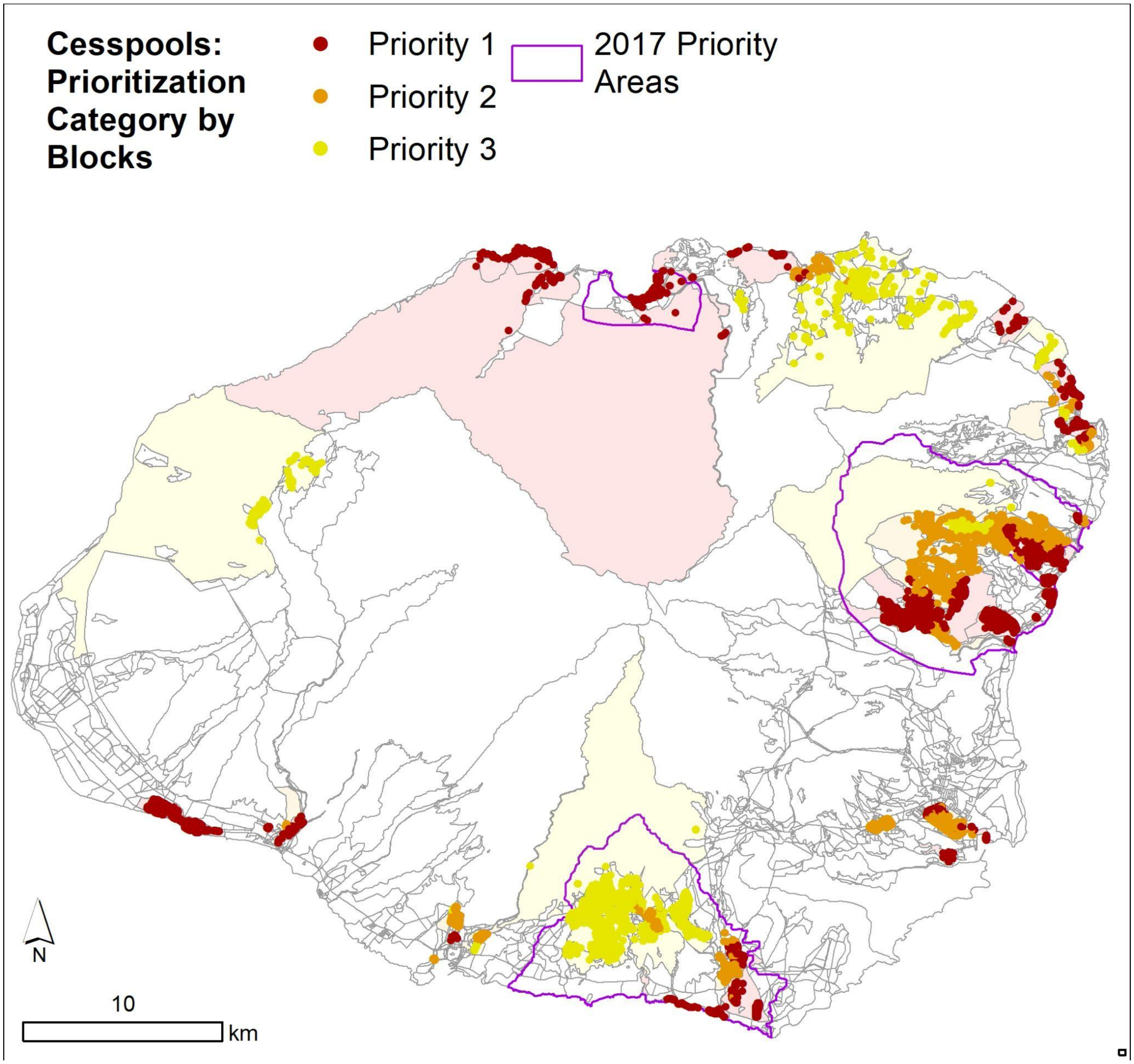


Figure A12: *Kaua'i cesspools (dots) colored by prioritization category, arranged by census blocks. Blocks are shown as lightly colored areas where the block contains >10 cesspools. White areas signify the block contains <10 cesspools (not assessed by the HCPT). Purple boundary indicates previous 2017 priority upgrade areas.* (Updated 2022)

Additional Results: Statewide

Figure A13 (full page) below provides a pivot table consisting of all 103 census tracts.

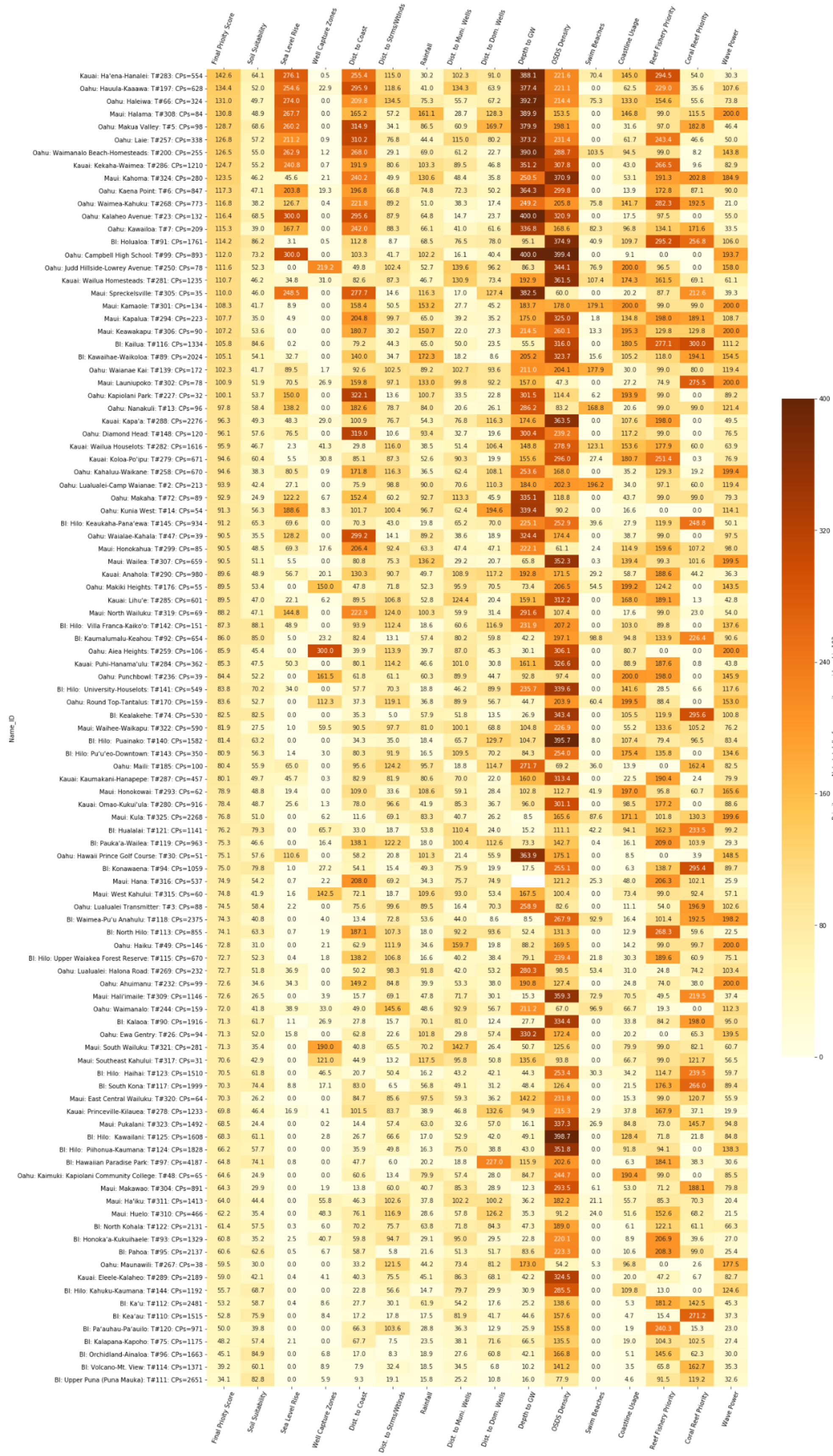

Final Priority Score
Soil Suitability
Sea Level Rise
Well Capture Zones
Dist. to Coast
Dist. to Strms/Wtlnds
Rainfall
Dist. to Muni. Wells
Dist. to Dom. Wells
Depth to GW
OSDS Density
Swim Beaches
Coastline Usage
Reef Fishery Priority
Coral Reef Priority
Wave Power
Name_ID
Priority score. Note total # of census units considered is 103
0
80
160
240
320
400

Figure A13. *Pivot table showing statewide census-tract based priority scores, (leftmost column) and individual risk factor scores, which were averaged to calculate the overall priority score of each census tract.* (Updated 2022)

Comparative Analysis with 2017 Priority Areas

To indicate where new priority areas from this work overlap with 2017 priority areas, additional information was appended to the prioritization by adding a + sign and differing darker color categories (Fig. A14). This overlap was defined as an area with greater than 50% of its cesspools falling within a 2017 priority zone. The comparative analysis for all Priority Categories is defined for each census unit as:

1. Priority Level 1 (+): The top 25% of the Census Unit Priority Scores that also have 50% or more of their cesspool units falling within a 2017 priority zone.
2. Priority Level 1: The top 25% of the Census Unit Priority Scores that do not have 50% or more of their cesspool units falling within a 2017 priority zone.
3. Priority Level 2 (+): The middle 25% (50%-25%) of the Census Unit Priority Scores that also have 50% or more of their cesspool units falling within a 2017 priority zone.
4. Priority Level 2: The middle 40% (50%-25%) of the Census Unit Priority Scores that do not have 50% or more of their cesspool units falling within a 2017 priority zone.
5. Priority Level 3 (+): The bottom 50% of the Census Unit Priority Scores that do have 50% or more of their cesspool units falling within a 2017 priority zone.
6. Priority Level 3: The bottom 50% of the Census Unit Priority Scores that do have 50% or more of their cesspool units falling within a 2017 priority zone.

While these categories are not used in the primary results, the tool does make them available should they be useful for future prioritization or management purposes.

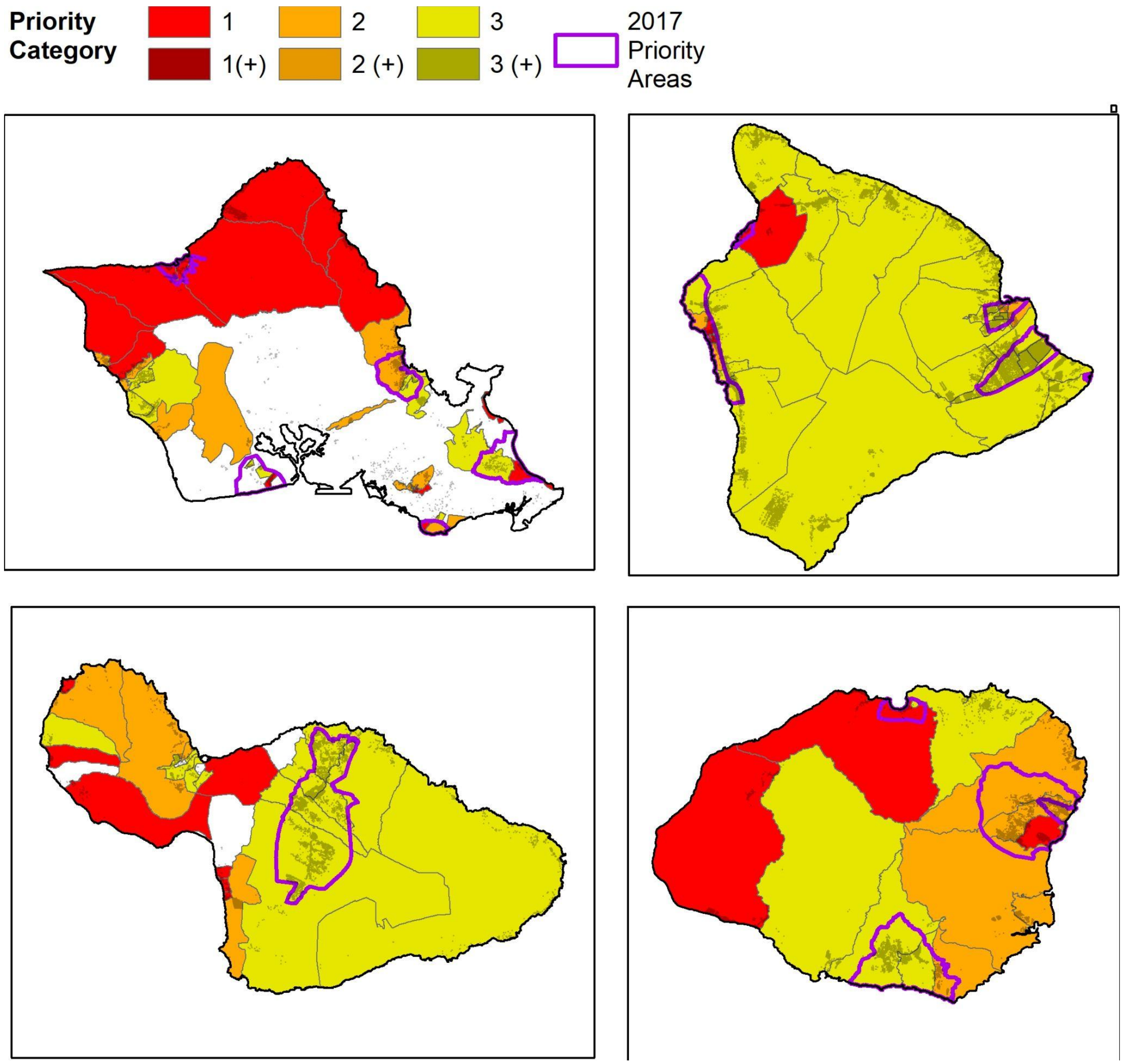


Figure A14: *Statewide prioritization at the census tract level showing added data from comparative analysis with 2017 Priority Areas. This data is for informational purposes and not used in the final results of the HCPT. (Updated 2022)*

Appendix B

Sensitivity Analysis of Priorities

The final Census Unit Aggregated Prioritization Score is derived from a simple average of all of the risk-factor (Input Section) prioritization scores that go into the analysis. This method of calculation rests on the implicit assumption that each factor is just as important as all of the other factors. However, in reality, each factor likely has a different degree of importance to different stakeholders, based on their overall objectives. While the HCPT provides the ability to apply weights to each factor in order to change the relative importance of each, the actual determination of appropriate weights is no simple matter. This is complicated by the fact that there is not a single end goal for cesspool upgrades. For example, optimizing the prioritization for human health factors (e.g. reducing contamination to drinking water wells or reducing pathogens at beaches) may sacrifice benefits to ecological systems such as coral and fish. Negative effects from cesspools manifest through multiple different hazard outcomes, including but not limited to drinking water quality degradation, coastal water quality impacts, human exposures to pathogens, and discharge of contaminants of emerging concern. The HCPT considers all of these hazard outcomes through a lumped approach. In reality, all of these outcomes are interconnected as human health is ultimately dependent on maintaining healthy ecosystems.

To explore how assigning different degrees of importance to different factors may skew outcomes of statewide prioritization, a sensitivity analysis was conducted. The sensitivity analysis compared three different scenarios where different weights were assigned to each risk factor, based on a hypothetical conceptual model of how different priorities might be expressed through the adjustment of weights to different factors.

Table B1 presents the different weights used to generate results for the sensitivity testing. It should be noted that weights applied in these scenarios are to be considered as examples only and do not constitute an actual prioritization process.

Table B1. *Example sensitivity testing scenario weights.*

Risk Factor	Base Scenario	Ecological Scenario	Human Health Scenario
Distance to Coastline (m)	1	3	1
Distance to Streams+Wetlands (m)	1	3	1
Distance to Municipal Wells (m)	1	1	4
Distance to Domestic Wells (m)	1	1	2
Well capture zones	1	1	3
Depth to Groundwater (m)	1	2	2
Cesspool Density (Units per Acre)	1	2	2
Sea Level Rise	1	2	2
Soil Suitability	1	2	2
Rainfall (in.)	1	1	1
Coastline Usage	1	1	3
Coral Reef Priority	1	4	1
Reef Fishery Priority	1	2	1
Swimming Beaches	1	1	3
Ocean Circulation(wave energy)	1	3	2

Figure B1 below shows the sensitivity test results graphically, whereas each census tract is represented by a row, labeled by the tract name, ID number, and the number of cesspools on the inventory falling within its borders. Each column is the final priority rank (where tracts are ranked based on their final priority scores) of the tract within each sensitivity test scenario. The heatmap is sorted by the base scenario rank with the most impacted tracts at the top of the figure. Note the figure is broken into two halves to fit the page.

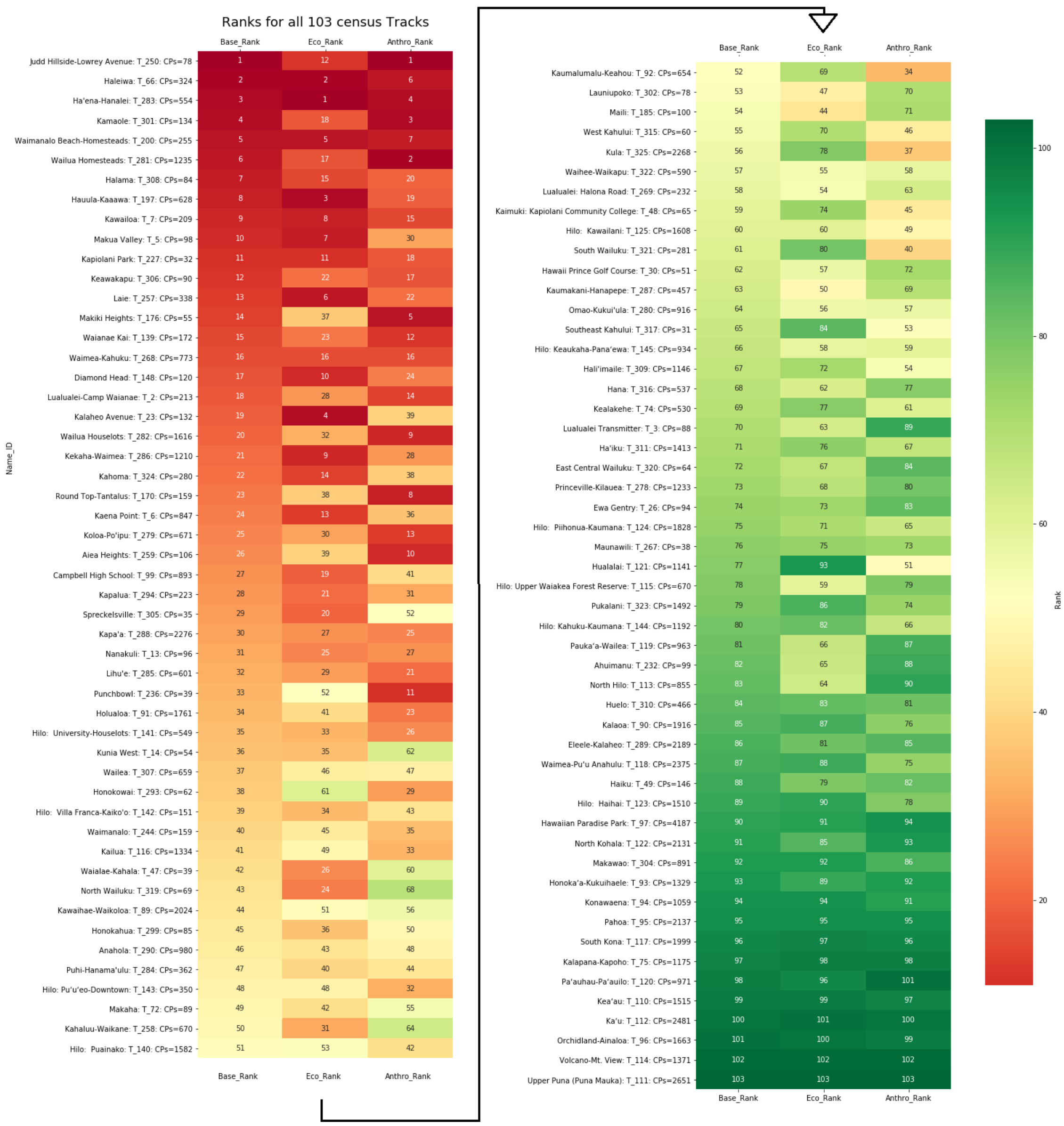


Figure B1. *Results of the sensitivity analysis, where each column represents how census tracts are prioritized (via a statewide ranking) for each of the three scenarios. The leftmost being the base scenario where all weights are equal to one, the middle column represents the Ecological Scenario and the rightmost represents the human health scenario.*

To quantify the difference between the sensitivity test scenarios numerically, the deviation from the base scenario was calculated for each tract by simply subtracting the rank of the tract in the test scenario by its rank in the base scenario and taking the absolute value of the result. This metric shows how far up or down the ranking an individual track will move given the changes in the risk-factor weights. Relevant statistics are compiled in Table B2 below. These statistics indicate that the average expected change in ranking if the risk factor weights were modified to the extent they were in this test, would be on the average order of 6 to 9 places, though it could change up to 26 places in the maximum case. Overall, considering the rankings cover 103 census tracts, this translates into an 'uncertainty' of less than 10% on the final results, thereby lending greater confidence to the final priority rankings (using the base scenario) presented in this report.

Table B2. *Statistical table describing the deviations in ranking values of individual census tracts between the Base Scenario and the other test scenarios. Higher mean or median (50th percentile) deviations indicate that the test scenario, on average, yields a prioritization result that has a higher degree of difference when compared to the base scenario.*

Statistics for Deviations in Ranks	Ecological Scenario Deviations	Human Health Scenario Deviations
Mean	6.93	8.35
Standard Dev.	6.25	6.37
Min	0	0
25th percentile	1	3
50th percentile	5	8
75th percentile	11	12
Max	25	26

Appendix C

Risk-Factor Weighting Workshops and Addendum

After the publication of the 2021 Hawaiʻi Cesspool Hazard Assessment & Prioritization Tool Report & Technical Appendices an update was performed in mid-2022 to better represent the disparity in importance of each of the input risk-factors. All figures and tabular results in this 2022 Updated version of the Hawaiʻi Cesspool Hazard Assessment & Prioritization Tool Report & Technical Appendices reflect the revision of the tool and present results generated using weights derived from the methodology described in the addendum below, the Hawaiʻi Cesspool Hazard Assessment & Prioritization Tool: Risk-Factor Assessment Survey and Workshops: Addendum to 2021 Report & Technical Appendices, June 2022, by Melanie Lander, Michael Mezzacapo, and Christopher Shuler.

Hawaiʻi Cesspool Hazard Assessment & Prioritization Tool

Risk-Factor Assessment Survey and Workshops

Addendum to 2021 Report & Technical Appendices

June 2022

Prepared For:

State of Hawaiʻi Department of Health Wastewater Branch
State of Hawaiʻi Cesspool Conversion Working Group

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This paper was primarily funded by a grant from the Hawaii Department of Health Wastewater Branch, and was also funded in part by a grant/cooperative agreement from the National Oceanic and Atmospheric Administration, Project A/AS-1, which is sponsored by the University of Hawaii Sea Grant College Program, SOEST, under Institutional Grant No. NA18OAR4170076 from NOAA Office of Sea Grant, Department of Commerce. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its subagencies. UNIHI-SEAGRANT-TT-21-06.

Table of Contents

1. Project Purpose and Background

This document describes ongoing efforts to assist the cesspool conversion process since the release of the publication, the ‘Hawai‘i Cesspool Hazard Assessment & Prioritization Tool Report & Technical Appendices’ in August 2021. In particular, this report addendum provides updates to the iterative cesspool prioritization methodology and expert opinion workshops held in early 2022. The prioritization of cesspools presents a useful method to quantify their relative impact on human and environmental health. Prioritization will also inform timetables recommended by the State of Hawai‘i Cesspool Conversion Working Group (CCWG) for conversion to more advanced forms of wastewater treatment. This work was undertaken on behalf of the State of Hawai‘i Department of Health (DOH) Wastewater Branch to inform ongoing DOH and CCWG planning processes for statewide cesspool conversion plan development.

In 2021, the ‘Hawai‘i Cesspool Hazard Assessment & Prioritization Tool Report & Technical Appendices’ was created to provide the DOH and CCWG with a comprehensive and data driven method to prioritize which cesspools likely have the most impact on human and environmental health. The report included consideration of fifteen risk-factors used to assess each geographic area’s vulnerability to contamination from cesspools. The factors were intended to be used to inform cesspool conversion prioritization and onsite wastewater planning throughout the state of Hawai‘i.

These factors included:

1. Distance to municipal drinking water wells;
2. Distance to domestic drinking water wells;
3. Well capture zones
4. Distance to streams and wetlands;
5. Distance to coastline;
6. Sea level rise zones;
7. Precipitation;
8. Depth to groundwater;
9. Soil characteristics;
10. Cesspool density;
11. Coral cover;
12. Fish biomass/recovery potential;
13. Beach user-days;
14. Proximity to lifeguarded beach; and
15. Coastal ocean circulation proxy

This information and associated data were included in a geographic information system (GIS) tool titled: the Hawai‘i Cesspool Prioritization Tool (HCPT), accessible through http://hawaiicesspooltool.org. The 2021 version of the HCPT weighted each of the fifteen risk factors equally in its prioritization calculation.

In 2022, the DOH directed a team from the University of Hawai‘i (UH) Sea Grant College Program (Hawai‘i Sea Grant), UH Water Resources Research Center, and One World One Water, LLC to refine the HCPT structure by developing and implementing an expert-driven methodology for weighting of the fifteen risk-factors. Specifically, the project team sought to answer these questions:

- Does weighting the fifteen risk-factors equally reflect the best available knowledge of subject matter experts relative to the risk of cesspool contamination?
- If not, which of the fifteen risk-factors are most critical to consider in the cesspool conversion prioritization process?
- How does an expert-informed weighting process change the priority rankings in each of the geographic areas outlined by the 2021 report (equal weights)?

2. Process and Methodology

a. Participants

The end goal of the updated weighting process was to synthesize contributions from a panel of experts into fifteen numeric weighting factors corresponding to each of the risk-factors used in the HCPT. The process was initiated by identifying subject matter areas related to the risk-factors used in the tool. Experts in each subject-matter area from Hawaiʻi, the Pacific, and the continental United States were identified by the project team and the DOH through research and personal recommendations. Invitees were contacted either by email or phone and briefed on the project background and purpose, and invited to participate in the expert weighting exercise.

The participant areas of expertise included:

DOH Regulatory and Wastewater Engineering
Coral Reef Ecosystems
Wells, Groundwater, and Drinking Water
Society and Economics
Surface Water, Aquatic Resources, Wildlife
Wastewater Engineering and Soils
Tourism and Recreation
Oceanography and Microbiology
Coastal Geochemistry and Water Quality
Native Hawaiian Affairs and Water Law
Coastal Biology and Limu
Center for Water Resource Management
Water Quality and Sewage Pollution
Public Drinking Water
Coral Reefs and Coastal Processes
Law, Policy, and Planning
State Coastal Planning
UH Environmental Science Students

b. Workshops, Survey, and Analysis

Two virtual workshops were held on the Zoom virtual meeting platform, and participants were asked to independently complete a survey during the interval between the workshop events. The first workshop was held on Wednesday, March 2nd, 2022 and lasted for one hour. Workshop 1 focused on providing background and context to attendees, as well as explaining the survey, which was used to collect quantitative and qualitative information from participants. Following Workshop 1, the 2021 ʻHawaiʻi Cesspool Hazard Assessment & Prioritization Tool Report & Technical Appendicesʼ and the website for the online HCPT were shared with participants, along with the detailed instructions about the online survey which were shared orally during Workshop 1.

The survey consisted of thirty questions. For each of the fifteen risk-factors, the survey asked for users to assign a weight from 1-5 for each factor.

The Scoring Rubric was defined as:

Weight of (1) Baseline: Factor is important, but not exceptionally.

Weight of (2) Double weight: Factor is more important than baseline.

Weight of (3) Triple weight: Factor is very important.

Weight of (4) Quadruple weight: Factor is one of the most important factors of all.

Weight of (5) Extremely important: reserved for the single or few factors that are the primary drivers of impact.

Users were then asked to provide a brief explanation of why they weighed the factor as they did, and to share references and other relevant information that informed their decisions. Participants were also asked if they wished to share their name and affiliation within the addendum report. This choice was optional so participants could speak freely and openly.

Following the survey period (March 2nd-23rd, 2022) and preceding the second workshop, the project team processed the survey results in order to share them with the participants and to facilitate discussion and feedback during the second workshop.

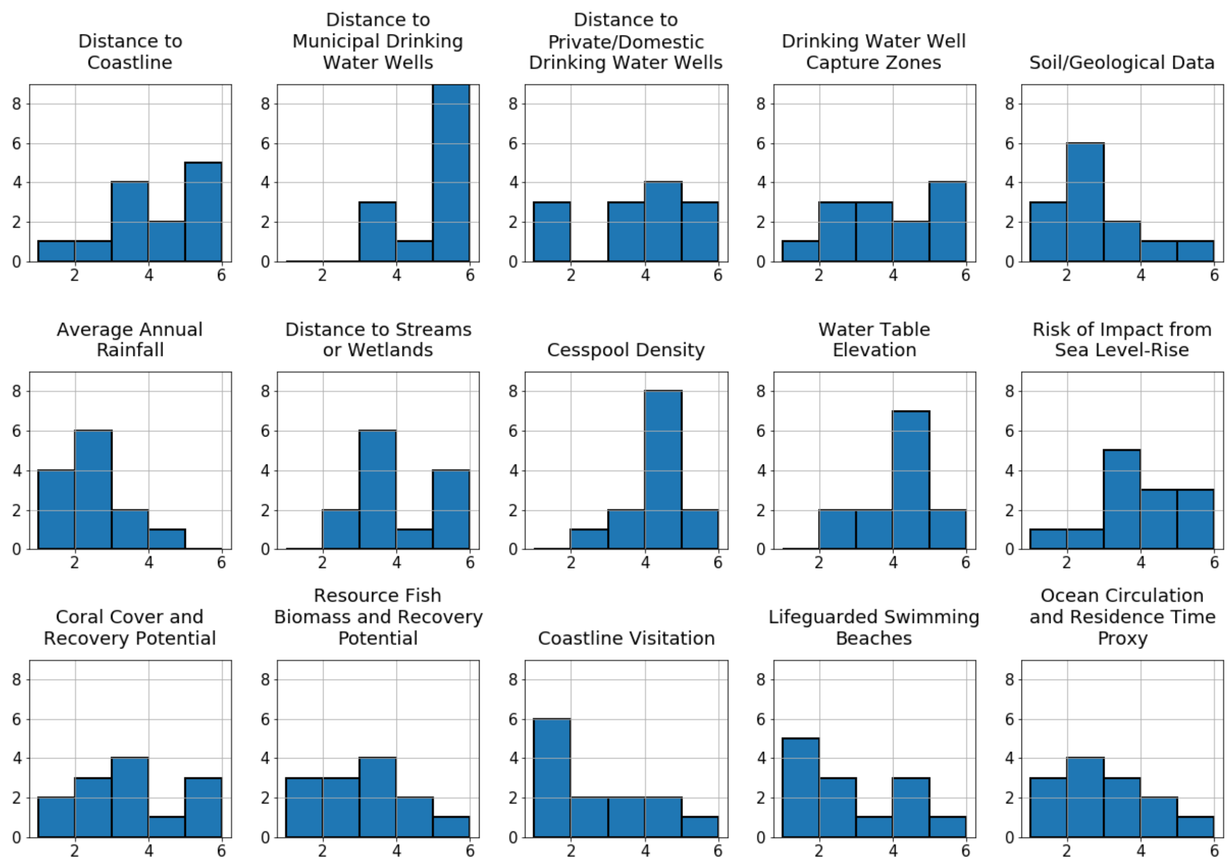
The second workshop was held on Wednesday, March 30th, 2022 and lasted two hours. The primary focus of Workshop 2 was communicating the results of the survey and analysis. The intent of the survey was to create a 'multiplication factor', or weight, for each of the fifteen risk-factors. Survey results were collected in a Google Form, which populated quantitative responses (weighted rankings) into a Google spreadsheet. Pandas, the Python analysis library, was used for the quantitative analysis of the results.

Raw Data from Survey:

Respondent Number	Distance to Coastline	Distance to Municipal Drinking Water Wells	Distance to Private/ Domestic Drinking Water Wells	Drinking Water Well Capture Zones	Soil/ Geological Data	Average Annual Rainfall	Distance to Streams or Wetlands	Cesspool Density	Water Table Elevation	Risk of Impact from Sea Level-Rise	Coral Cover and Recovery Potential	Resource Fish Biomass and Recovery Potential	Coastline Visitation	Lifeguarded Swimming Beaches	Ocean Circulation and Residence Time Proxy
0	5	5	3	3	4	4	5	4	4	3	3	3	4	4	3
1	1	5	4	4	5	2	3	4	4	3	3	3	3	3	2
2	4	5	5	5	2	1	3	4	4	3	1	1	1	1	1
3	2	5	4	5	2	3	2	4	2	3	3	3	3	2	4
4	5	5	3	5	3	3	5	5	4	5	3	3	1	2	3
5	3	3	3	2	2	2	3	4	3	4	2	1	1	1	2
6	3	5	1	4	1	2	5	3	5	5	5	5	5	5	4
7	5	5	5	3	2	2	3	4	3	4	4	4	4	4	2
8	3	5	5	2	3	2	3	4	4	1	2	2	2	2	1
9	4	5	4	5	2	2	5	3	4	3	5	4	2	4	5
10	3	3	4	3	1	1	2	5	4	2	2	2	1	1	3
11	5	3	1	2	2	1	3	2	2	4	5	2	1	1	2
12	5	4	1	1	1	1	4	4	5	5	1	1	1	1	1

Histograms were used and presented in the workshop to display the spectrum of weights assigned by the group to each of the fifteen risk factors. Histograms are useful in this context because they not only show which factors scored the 'highest' (higher weights being equivalent to a greater level of importance in prioritization considerations), but also indicate the spread of participants' rankings, which is quantified as the standard deviation of each risk-factor's results. This spread indicated the level of consensus among respondents, with a higher standard deviation equating to a greater difference of opinion among respondents and a lower standard deviation indicating better consensus.

Histograms:



It was necessary to combine each of the participants' responses into a single weight for each factor. However, there are many mathematical ways to achieve this result and each has unique advantages and disadvantages. Therefore, a number of aggregation techniques were explored. These included basic statistical metrics, specifically the mean and median of each distribution, as well as a non-parametric calculation that counted the number of individual scores given to each factor (i.e. 4, '1's', 3 '2's', etc.), and used a separate weighting factor for each of the sums of scores. These "weighted weights" were then normalized into a single number (see https://github.com/cshuler/Act132_Cesspool_Prioritization for details). The different aggregation methods were presented to the participants of the second workshop and due to the similarity in the results of each, and the desire to communicate simply and effectively, it was agreed upon that the median value of each of the raw weights was the preferred method for calculating a single weight for each factor.

Quantitative analysis:

Factor	Mean	Median	Standard Deviation	Rank: 1	Rank: 2	Rank: 3	Rank: 4	Rank: 5	Weighted Weights
Distance to Municipal Drinking Water Wells	4.5	5	0.9	0	0	3	1	9	6.4
Distance to Coastline	3.7	4	1.3	1	1	4	2	5	4.6
Drinking Water Well Capture Zones	3.4	3	1.4	1	3	3	2	4	3.8
Distance to Streams or Wetlands	3.5	3	1.1	0	2	6	1	4	4
Distance to Private/Domestic Drinking Water Wells	3.3	4	1.5	3	0	3	4	3	4
Risk of Impact from Sea Level-Rise	3.5	3	1.2	1	1	5	3	3	4
Coral Cover and Recovery Potential	3	3	1.4	2	3	4	1	3	3
Cesspool Density	3.8	4	0.8	0	1	2	8	2	4.8
Water Table Elevation	3.7	4	0.9	0	2	2	7	2	4.4
Soil/Geological Data	2.3	2	1.2	3	6	2	1	1	1.4
Resource Fish Biomass and Recovery Potential	2.6	3	1.3	3	3	4	2	1	2.2
Coastline Visitation	2.2	2	1.4	6	2	2	2	1	1.8
Lifeguarded Swimming Beaches	2.4	2	1.4	5	3	1	3	1	2
Ocean Circulation	2.5	2	1.3	3	4	3	2	1	2
Average Annual Rainfall	2	2	0.9	4	6	2	1	0	0.8

c. Survey Outcomes

The weighting activity for each of the fifteen risk-factors resulted in fairly normal distributions for most parameters. Only *Distance to Municipal Drinking Water Wells* had a median score of '5'. This was the highest weighted ranking, indicating that the factor is 'Extremely important: reserved for the single or few factors that are the primary drivers of impact' and also had the second lowest standard deviation of all factors, which denotes concurrence among the survey respondents. Four factors scored as '4: *Quadruple weight: Factor is one of the most important factors of all'*. These factors included *Distance to Coastline*, *Distance to Private/Domestic Drinking Water Wells*, *Cesspool Density*, and *Water Table Elevation*. Four factors scored as '3: Triple weight: Factor is very important'. These factors included *Drinking Water Well Capture Zones*, *Distance to Streams or Wetlands*, *Risk of Impact from Sea Level Rise*, *Coral Cover and Recovery Potential*, and *Resource Fish Biomass and Recovery Potential*. Five factors scored as '2: Double weight: Factor is more important than baseline'. These factors included, *Soil/Ecological Data*, *Coastline Visitation*, *Lifeguarded Swimming Beaches*, *Ocean Circulation*, and *Average Annual Rainfall*. No factors scored as '1: Baseline: Factor is important, but not exceptionally'. The factors with the highest levels of concurrence (lowest standard deviation) were *Cesspool Density*, which ranked as a '4' and *Distance to Municipal Drinking Wells*, which ranked as a '5'.

Factor	Weight
Distance to Municipal Drinking Water Wells	5
Distance to Coastline	4
Distance to Private/Domestic Drinking Water Wells	4
Cesspool Density	4
Water Table Elevation	4
Drinking Water Well Capture Zone	3
Distance to Streams or Wetlands.	3
Risk of Impact from Sea Level Rise.	3
Coral Cover and Recovery Potential	3
Resource Fish Biomass and Recovery Potential	3
Soil/Ecological Data	2
Coastline Visitation	2
Lifeguarded Swimming Beaches	2
Ocean Circulation and Residence Time Proxy	2
Average Annual Rainfall	2

3. Limitations and Notable Feedback

The methods of gathering expert feedback included some limitations which should be noted to improve future iterations of this or similar processes, which are further elaborated in the following subsections.

a. Attendance

The workshops were held virtually to encourage the highest level of attendance possible during the COVID-19 pandemic and as recommended by local and national guidelines. Not all attendees of the first workshop elected to participate in the subsequent survey, nor did all initial attendees attend the second workshop. However, the number of participants and their representative spectrum of expertise was considered acceptable to continue with the weighting exercise. The survey results were processed and analyzed with the potential for future exercises to build upon the results if deemed appropriate. An alternative meeting structure could have requested participants to attend a full day 'seminar' during which the content of both workshops and the survey would have occurred during a single, though substantially longer, meeting. This approach would have capitalized on the 'captive audience' to ensure a high level of participation in the survey. However, due to the time commitment of such an event, which likely would have lasted 4-5 hours, it is unknown whether attendance would have actually increased with this format compared to the chosen format of multiple workshops held several weeks apart with the survey taken in between.

b. Areas of Expertise and the Survey Scoring Rubric

Attendees were invited to participate in the workshops so that they could provide their subject-matter knowledge and enhance the weighting process. In the 2021 iteration of the prioritization exercise all factors were considered equal. The 2022 workshops were intended to interrogate this approach and create a more rigorous methodology for weighting the factors based on a broader spectrum of expertise. However, no one can be an expert in all subject areas. In order to account for the fact that respondents may have ranked certain factors with a low weight because they felt less informed about those subject areas, a 'weighted weight' which ignored low ranks was added to the statistical analysis. Ultimately, it was determined that the three analysis options (mean, median, and 'weighted weights') produced comparable results.

c. Feedback on Data Sets

<u>i. Regional Variability</u>
Relating to the risk-factors 'Soils and Average Annual Rainfall':

The prioritization tool was designed for management decisions at the state level, and the fifteen data sets used as risk-factors were selected based on their statewide coverage. However, Hawaiʻi has certain regions with distinct characteristics. For instance, the hydrogeology of the Kona region of Hawaiʻi Island is markedly different from most other areas of the state in that water dissipates quickly from the surface into the subterranean environment. In this region, coastal water quality is greatly influenced by land-based contaminants. Similarly, preliminary research shared by the participants indicates great differences in wastewater as well as other indicators in Kona vs. Hilo, substantiating the potential role of rainwater in dilution of contaminants prior to entering coastal waters. In certain circumstances, 'outlier' areas of the state, in this case one of the driest and one of the wettest regions, may merit further consideration and scenario planning when developing prioritization and conversion timelines. It was also noted that peak rainfall, which can cause cesspool overflow, may be more descriptive in areas prone to intense precipitation, compared to average annual rainfall which is less likely to capture such events. Rather than a one-size-fits-all analysis, this tool can be considered as a foundational layer for statewide management and decision-making.

ii. Policy Gaps

Relating to the risk-factor 'Cesspool Density':
Since 2000, the United States Environmental Protection Agency (EPA) has banned large-capacity cesspools, which are generally defined as serving over twenty individuals. However, participants noted that not only are some large-capacity cesspools still in operation in Hawaiʻi, but certain high-density residential areas with active cesspools are contributing contaminants to the environment in a similar way to those of 'large capacity'. Yet, these cesspools are subject to the same state-level regulations as any other cesspool. This comment was made to highlight the enforcement gap between banned large-capacity cesspools and high-density operational cesspools, and to reinforce the participant's ranking of 'Cesspool Density' as a highly important factor for conversion consideration.

iii. Complications Along the Coast

Relating to the risk-factors 'Distance to Coastline' and 'Sea Level Rise Exposure':
Participants discussed the fact that many oceanfront homes are already experiencing visible tidal fluctuations in their cesspools. Though 'Distance to Coastline' is a straightforward indicator of the potential for land-sea connectivity, Hawaiʻi does have some coastal real estate located on bluffs, high above sea level. For this reason, 'Sea Level Rise Exposure' is likely to be a more appropriate indicator of cesspools located at or near current sea level, with both present-day or future potential for groundwater inundation and cesspool failure. Participants also noted the quandary of residential homes with cesspools and the most imminent risk of coastal erosion (i.e., the North Shore of Oahu) for whom cesspool replacement is threatened by large winter storms and swells. These homeowners may elect to wait 'until the last minute' (closer to 2050) to replace their

systems given the variability in erosion on a multi-decadal timescale, though those homes may be high-risk to human and environmental health given their extreme proximity to the ocean and high likelihood of total cesspool failure (i.e. system collapse).

iv. Redundancy

Relating to the risk-factors ‘Beach user-days’, ‘Proximity to lifeguarded beach’, ‘Distance to Coastline’, and ‘Sea Level Rise Exposure’:

Because the two factors ‘Distance to Coastline’ and ‘Sea Level Rise Exposure’ already have the potential to highlight those cesspools with the most direct impact on coastal areas, participants pointed out that the risk-factors ‘Beach user-days’ and ‘Proximity to lifeguarded beach’ may be duplicative. It can be noted that from a human health perspective, the risk-factors ‘Beach user-days’ and ‘Proximity to lifeguarded beach’ more readily highlight concentrations of human activity than ‘Distance to Coastline’, and ‘Sea Level Rise Exposure’. In particular, areas like Kula, Maui which are regarded as “up country” have a direct and hazardous impact on Kihei, Maui beaches, despite their distance from the coastline.

d. Feedback on Methodology

i. Socio-Economic Considerations

This prioritization exercise focuses primarily on the cesspool risk-factors impacting human and environmental health. This provides a foundation to build upon, and can be further enhanced through the use of socio-economic data. When U.S. Census tracts are overlain on the HCPT tool, attributes like median household income can provide further insight and decision-making information. For instance, the state could compare Priority 1 areas of the greatest potential for contamination to areas of the lowest median household income. The intersection of these two layers would illustrate possible recipient areas for grant funding to facilitate the conversion of active cesspools into more advanced forms of wastewater treatment.

ii. Survey Design

The survey asked participants to consider each of the fifteen risk-factors according to a scoring rubric, by assigning a weight from 1-5 for each factor. For the weights of 5 (Extremely important: reserved for the single or few factors that are the primary drivers of impact) and 4 (Quadruple weight: Factor is one of the most important factors of all), the scoring rubric suggested that survey taker limit the number of high weights that were assigned (i.e. ‘reserved for the single or few factors…). These instructions may have been interpreted differently by each participant. An alternative would have been to overtly limit the number of each ranking that could be assigned (i.e. allocating a single ‘5’, up to three ‘4’s, etc.).

To view the complete survey responses and feedback, please navigate to:
https://github.com/cshuler/Act132_Cesspool_Prioritization/blob/main/Workshop2_analysis/Workshop%202%20Data%20Analysis.ipynb

4. Prioritization Results

The HCPT prioritization method places each geographic area into three Prioritization Categories that include:

1. **Priority Level 1:** Greatest contamination hazard (map color of red).
2. **Priority Level 2:** Significant contamination hazard (map color of orange).
3. **Priority Level 3:** Pronounced contamination hazard (map color of yellow).

Under the 2021 equal weighting scenario, the total number of cesspools in the state categorized as Priority Level 1 was 13,885, with 13,482 and 54,058 as Priority Level 2 and Priority Level 3, respectively. Approximately 35%, 7%, 21%, and 37% of cesspools in the Priority Level 1 group are located on O‘ahu, Maui, Kaua‘i, and Hawai‘i Island, respectively.

Under the 2022 expert-informed weighting scenario, the total number of cesspools in the state categorized as Priority Level 1 was 13,821, with 12,367 and 55,237 as Priority Level 2 and Priority Level 3, respectively. Approximately 35%, 7%, 21%, and 37% of cesspools in the Priority Level 1 group are located on O‘ahu, Maui, Kaua‘i, and Hawai‘i Island, respectively.

Census tracts that changed as a result of the expert-informed weighting process included:

Island, Census Tract Number (Tract #), and Cesspool Count	Original Rank	New Workshop Rank
Kauai		
Kauai: Puhi-Hanama'ulu: Tract#284: Cesspool Count =362	3 (Low)	2 (Medium)
Oahu		
Oahu: Nanakuli: Tract#13: Cesspool Count =96	1 (High)	2 (Medium)
Oahu: Kapiolani Park: Tract#227: Cesspool Count =32	2 (Medium)	1 (High)
Maui		
Maui: Honokowai: Tract#293: Cesspool Count =62	2 (Medium)	3 (Low)
Maui: Waihee-Waikapu: Tract#322: Cesspool Count =590	3 (Low)	2 (Medium)
Maui: Kula: Tract#325: Cesspool Count =2268	2 (Medium)	3 (Low)
Hawai‘i Island		
BI: Hilo: University-Houselots: Tract#141: Cesspool Count =549	3 (Low)	2 (Medium)
BI: Hilo: Pu‘u‘eo-Downtown: Tract#143: Cesspool Count =350	2 (Medium)	3 (Low)

Overall, there were minimal differences between the HCPT's 2021 equal weighting scenario and the 2022 expert-informed version of the tool. Statewide, eight census tracts shifted in priority designation between the two methodological approaches. Of these eight census tracts, the shift in priority was limited to a single step; e.g. none of the census tracts went from high to low priority or low to high priority.

The relative similarity between the two versions of the tool serves to validate the overall robustness of the 2021 HCPT tool. In many locations, similarities can be attributed to the fact that the cesspools which ranked as the highest priority for conversion negatively impact multiple aspects of social and environmental health, and the weights of individual factors are less important than the sum of the many impacts on risk-factors in the high priority ranked areas. This outcome was also alluded to by a sensitivity test detailed in the 2021 report, where hypothetical weights were applied to each factor collectively within different weighting scenarios. The sensitivity test indicated the changes in prioritization under different weighting strategies were likely to show small differences. Nonetheless, despite the limited magnitude of change, the social-science based weighting exercise was extremely valuable for not only demonstrating the validity of the results, but also for improving the robustness of the tool's methodology, including expanding the dimensionality of the tool's input. This robustness is now demonstrated by way of incorporating the expert judgements of knowledgeable practitioners and scholars.

5. Next Steps

The results of this effort will be shared with the DOH Wastewater Branch to inform ongoing cesspool conversion prioritization efforts. This work and the HCPT is only one part of Hawaiʻi's cesspool conversion prioritization process, as numerous other datasets including social, financial, and water quality impacts will also be factored into the cesspool prioritization process.

6. Technical Contributors

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Drinking Water Wells and Groundwater	Robert Whittier
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Tourism and Recreation	N/A
Oceanography/Microbiology	Wished to remain anonymous
Coastal Geochemistry/Water Quality	Steven Colbert, Tracy Wiegner
Native Hawaiian Affairs/Water Law	Wished to remain anonymous
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Public Drinking Water	Wished to remain anonymous
Coral/Coastal Processes	Wished to remain anonymous
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