Development of a Method to Evaluate Decentralized Cluster Wastewater Systems as an Alternative for Cesspool Replacement

by

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Content

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Abstract

Throughout Hawai'i there are approximately 88,000 cesspools that release an estimated 53 million gallons per day (mgd) of wastewater into the environment and pose an environmental and public health risk. ACT 125 was passed by the state legislature in 2017 to ban all cesspools in the state by the year 2050. It is expected that cesspools will be replaced by onsite wastewater treatment (OSWT) and disposal systems located on individual properties or connection to sewers and offsite wastewater treatment facilities. In some cases, however, where several cesspools are in proximity, it may be feasible to construct small-scale, decentralized cluster wastewater systems for several homes on a neighborhood level. These systems will require wastewater collection, treatment, and disposal. This report provides a statewide study of potential neighborhoods/sites for these small-scale/cluster systems with an initial focus on priority areas, including planning level cost estimates. The method found in this report uses GIS and density-based analysis across Oahu, Maui, the Big Island, and Kauai to determine the overall feasibility of cluster systems in Hawaii, evaluate specific clusters in priority areas, and make cost comparisons between OSWT's and cluster systems. The results indicate that the replacement of clusters of cesspools in Hawai'i with decentralized wastewater systems is feasible. While cluster systems are more expensive than onsite systems regardless of the size of the cluster or the site conditions, the difference is smaller in areas that require nitrogen removal from OSWT's and in areas that contain more houses/cesspools. Lastly this study leads to the following recommendations for future work: 1) evaluate large clusters of cesspools for possible centralized or heavy-duty decentralized treatment systems; and 2) design a collection, treatment, and disposal system for a specific neighborhood.

Chapter 1: Introduction and Background

This chapter is taken almost in whole from *Technical Memorandum No.4: Evaluation of Decentralized Cluster Wastewater Systems (*Carollo Engineers, Inc. in association with the University of Hawaii, 2020*).* I worked on this report as an employee at Carollo Engineers and as a student at the University of Hawaii at Manoa.

According to the United States Environmental Protection Agency (US EPA), cesspools are underground excavations that receive sanitary wastewater from bathrooms, kitchens, and washers. *Figure 1.1* is a schematic diagram of a typical cesspool. The structure usually has an open bottom and perforated walls (unlined, except for geotextile fabric on the outside). Domestic wastewater flows into the structure and the solid waste collects at the bottom of the cesspool and the liquid waste flows out of the perforations. Cesspools are not designed to treat wastewater, but rather to separate solids from sanitary waste and allow liquid wastes to percolate into the soil strata and underlying groundwater aquifer as well as any hydraulically connected surface waters.

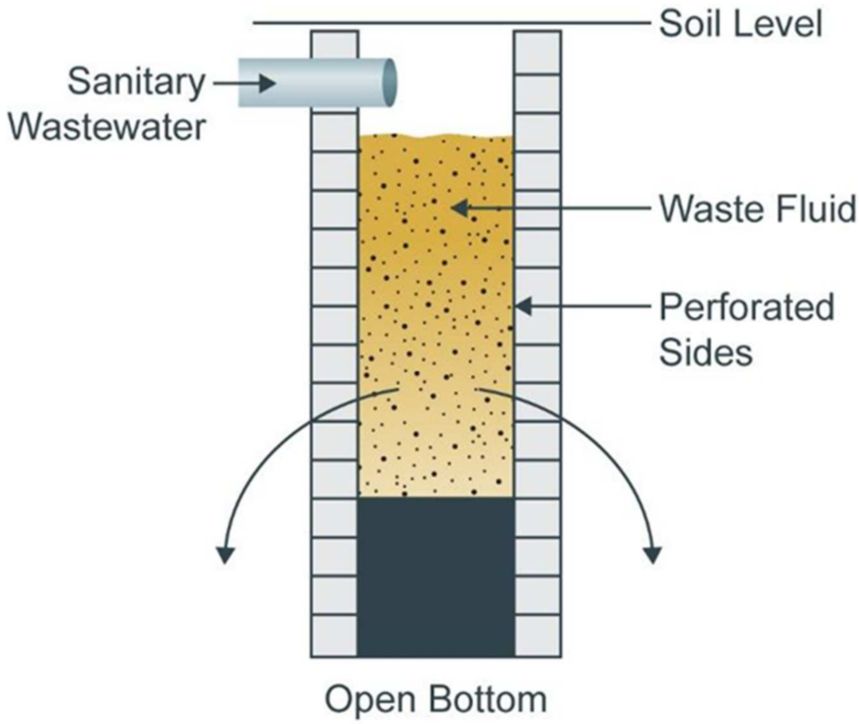

Figure 1.1 Cesspool Schematic

Throughout Hawaiʻi there are approximately 88,000 cesspools that release an estimated 53 million gallons per day (mgd) of wastewater into the environment. Most of these existing cesspools provide wastewater disposal for single-family residences, as opposed to large-capacity systems that serve multiple residences or commercial areas. Given that over 90 percent of the state's drinking water supplies are from groundwater sources, it was recognized that cesspools pose an environmental and public health risk. Subsequently, in 2017, the Hawaiʻi State Legislature passed Act 125, which states that by January 1, 2050 all cesspools in the state of Hawaiʻi, unless granted exemption, shall upgrade, or convert to a septic or aerobic treatment unit, or connect to a sewer system (ACT 125, 2017).

It is expected that cesspools will be replaced either by onsite wastewater treatment (OSWT) and disposal systems located on individual properties or connection to sewers and offsite wastewater treatment facilities. Connections to centralized sewers are feasible for some, but not all cesspools. Most cesspools are not located within a reasonable distance of an existing sewer system and expanding the centralized sewer system can be infeasible and cost prohibitive.

In some cases, however, where several cesspools are in proximity, it may be feasible to construct **small-scale, decentralized cluster wastewater systems** for several homes on a neighborhood level. These systems will require wastewater collection, treatment, and disposal.

This report provides a statewide study of potential neighborhoods/sites for these small-scale/cluster systems with an initial focus on priority areas, including planning level cost estimates. This study can help the state to evaluate and upgrade those cesspools deemed to pose the greatest risks to public health and the environment more rapidly. Furthermore, the information provided within this report can help to facilitate future studies and evaluations of decentralized cluster wastewater systems by licensed engineers. *Figure 1.2* shows the locations of the 88,000 cesspools and how they are spread across the Hawaiian Islands.

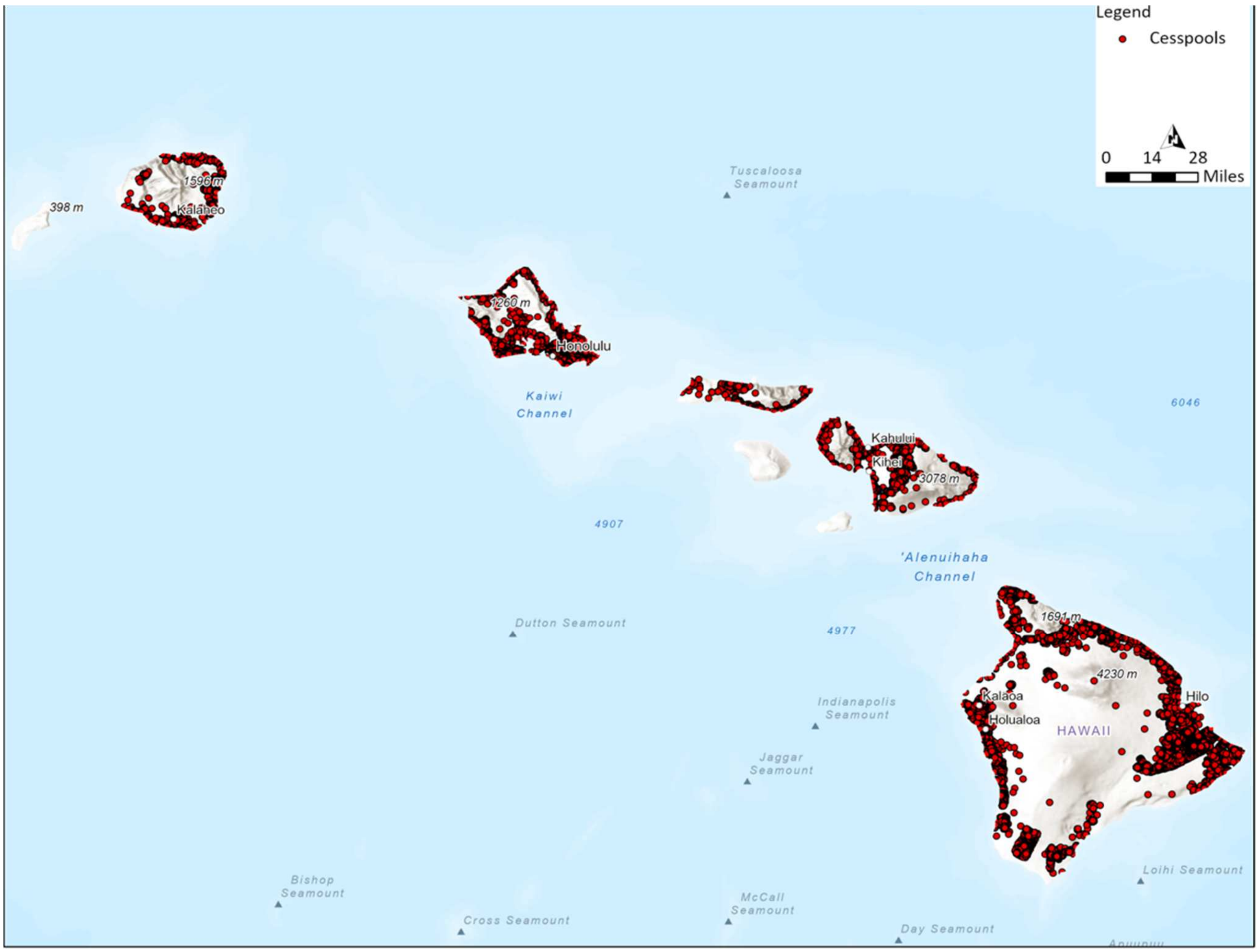

Figure 1.2 88,000 Cesspools Across the Hawaiian Islands

1.1 Decentralized Cluster Wastewater Systems and Key Assumptions

Decentralized cluster system components include collection, treatment, and disposal technologies, *Table 1.2* at the end of this chapter summarizes the technologies included as options in this report. Data and information for which were gathered from previous studies, technical literature, vendor websites, and other publicly available resources.

The cluster system technologies were evaluated by several criteria that can be grouped into the following categories:

- Benefits and challenges involved with implementation.
- Operation and maintenance (O&M) requirements.
- Land requirements for treatment and disposal systems.
- Construction, O&M, and 60-year life-cycle costs.

Decentralized cluster wastewater systems may make sense to convert several cesspools that have a high density, are within high priority areas, and where there is community support for this kind of a solution. The benefits of implementing cluster systems, where feasible include:

- **Potential for rapid conversions.** The use of cluster systems may allow the conversion of a greater number of cesspools at a single point in time. This could help to mitigate the public health and environmental risks in high priority areas in the near term.
- **Reducing the administrative oversight and enforcement burden on state/county agencies.** For the county/state, having all systems converted on an individual basis is a much larger task than having decentralized cluster systems. Just in terms of sheer numbers of permitted units, it could reduce the number by orders of magnitude (e.g., instead of 88,000 individual units: 880 to 8,800 cluster systems).
- **Reduce the burden on individual homeowners to hire engineers and contractors independently to design and construct onsite systems.** A coordinated, organized effort to evaluate a cluster system for a neighborhood would relieve the burden on individual homeowners to understand and determine their cesspool upgrade needs.
- **Ensure proper operations and ongoing maintenance of the systems by requiring a licensed wastewater operator.** Cluster systems are regulated and inspected by the State of Hawai‘ i Department of Health (DOH) Wastewater Branch (WWB) the same manner as existing wastewater treatment plants (WWTPs). The rules and procedures are already in place, including the requirement that state-licensed WWTP operators oversee the cluster systems. This is more likely to ensure that systems are inspected, operated, maintained, repaired, and function as required to meet the treatment and disposal regulations.
- **Potentially broaden the range of funding opportunities.** One of the hurdles in funding cesspool conversions is that many existing funding options require a conduit agency or intermediate party to manage and administer available grant or low interest loan funds to individual homeowners for cesspool conversions. Given that decentralized systems will need to be managed and operated by a third party, this also opens the door for more funding options. In addition, if water reuse is a disposal option for the decentralized system, there are additional funding opportunities that may apply. Water reuse is not allowed for onsite systems; thus, those funding opportunities would not be available.

The challenges to implementing cluster systems for cesspool conversions in Hawai’i include:

- **Need for neighborhood-level coordination.** One of the greatest hurdles to implementing decentralized solutions for cesspool conversions is that a group of homeowners would need to take the initiative to form an association or district to collect fees and procure various professional and construction-related services. To truly evaluate the feasibility of decentralized systems for certain neighborhoods, a licensed engineer needs to perform a site-specific analysis and develop costs for a recommended system (See *Section 3.3)*. Legislative measures may be necessary to facilitate neighborhood-level coordination especially if participation will be required of homeowners.

- **Cost.** A site-specific analysis is necessary to evaluate the feasibility and best overall system options for a neighborhood.
- **Need for skilled operators.** Licensed wastewater operations professionals would be required to operate and maintain the cluster system components in perpetuity.
- **Land/space requirement.** Decentralized systems would likely need to be constructed on newly acquired land and may require easements. These cluster systems would only be a viable option if the required land is available.

1.2 Potential Application of Decentralized Cluster Systems for Cesspool Conversions in High Priority Areas

The 2018 DOH Report to the Hawaii State Legislature prioritized existing cesspools into four categories:

- **Priority 1:** Significant risk of human health impacts, drinking water impacts, or draining to sensitive waters.
- **Priority 2:** Potential to Impact Drinking Water.
- **Priority 3:** Potential Impacts on Sensitive Waters.
- **Priority 4:** Impacts Not Identified.

The highest risk areas (Priority 1) should be addressed as soon as possible due to high public health and environmental risks.

The following risk factors were considered in formulating the priority categories:

- Density of cesspools in an area.
- Soil characteristics.
- Proximity to drinking water sources, streams, and shorelines.
- Other groundwater inputs including agriculture and injected wastewater.
- Physical characteristics of coastal waters that may compound the impacts of wastewater in bays and inlets.

Table 1.1 shows that Priority 1 areas include 8,140 cesspools which comprise approximately 9 percent of the 88,000 cesspools in Hawai‘ i. These priority categories and assignments were presented by the DOH WWB and the US EPA to the 2018 Hawai‘ i Legislature and they are subject to evaluation and possible revision. It is recommended that cesspools located in Priority 1 areas are upgraded with technologies that remove nitrogen and may also require disinfection (if near surface water). The costs for each OSWT and disposal system in the Priority 1 areas will likely be higher than other areas since a higher level of treatment is required.

Decentralized cluster systems may be a good option for Priority 1 & 2 upgrade areas to provide:

- Rapid, near-term conversions within areas deemed to have the greatest environmental risks.
- Reliable and appropriate level of treatment of wastewater prior to disposal.

Table 1.1 Initial Priority Upgrade Areas Established by DOH WWB (DOH, 2018)

Geographic Area	Priority Level Assigned	Number of Cesspools	Estimated Effluent Discharge (mgd)
Upcountry area of Maui	1	7,400	4.4
Kahalu u area of O ahu	1	740	0.44
Kea au area of Hawai i Island	2	9,300	4.9
Kapa a/Wailua area of Kaua i	2	2,900	2.2
Poipu/Kōloa area of Kaua i	2	3,600	2.6
Hilo Bay area of Hawai i Island	3	8,700	5.6
Coastal Kailua/Kona area of Hawai i Island	3	6,500	3.9
Puako area of Hawai i Island	3	150	0.60
Kapoho area of Hawai i Island	3	220	0.12
Hanalei Bay area of Kaua i	3	270	0.13
Diamond Head area of O ahu	3	240	0.17
Ewa area of O ahu	3	1,100	0.71
Waialua area of O ahu	3	1,080	0.75
Waimanalo area of O ahu	3	530	0.35
	Total Assigned	**42,730**	**26.87**
Hawai i Island Un-Assigned	NA	24,430	12.18
Kaua i Un-Assigned	NA	6,930	4.57
Maui Un-Assigned	NA	4,800	3.5
Oahu Un-Assigned	NA	7,610	5.08
Moloka i Un-Assigned	NA	1,400	0.80
	Total Un-Assigned	**45,170**	**26.13**
	Overall Totals	**87,900**	**53.0**

1.3 Regulation of Decentralized Cluster Wastewater Systems in Hawaiʻ i

Collection, treatment, and disposal systems are all regulated separately in Hawaiʻ i. Decentralized collection systems are regulated at the county level like centralized systems. These regulations include design standards, such as minimum slopes and diameters, materials, and depths[1].

Decentralized treatment systems are considered "treatment works" and thus, are regulated the same as centralized systems, such as those owned and operated by each of the counties, military facilities, and private sewer systems or districts. These regulations can be found in Hawaiʻ i Administrative Rules (HAR) HAR 11-62[2]. In addition, the City and County of Honolulu also has their own rules for treatment plant design[5].

HAR 11-62 also covers disposal via absorption and discharge to state waters. DOH has additional rules for water reuse[7] and for underground injection[8].

[1] Honolulu County's rules are contained here: http://www.honolulu.gov/rep/site/env/wwm_docs/DESIGN_STANDARDS_-_CHAPT_1_FINAL.pdf, http://www.honolulu.gov/rep/site/env/wwm_docs/DESIGN_STANDARDS_-_CHAPT_2_FINAL.pdf
[2] https://health.hawaii.gov/opppd/files/2015/06/11-62-Wastewater-Systems.pdf

Table 1.2 Summary of Benefits, Challenges, and Operation and Maintenance Requirements for Decentralized Cluster Systems (*Technical Memorandum No.4: Evaluation of Decentralized Cluster Wastewater Systems*. Carollo Engineers, Inc. in association with the University of Hawaii, 2020)

Technology(1)	Benefits	Challenges	Technology Status	Replace Interval (year)	O&M Effort(2)	O&M Requirements(3)
Collection System Options						
Gravity Sewers (GSs)	• Can handle grit and other solids, as well as large volumes of flow. • Does not require onsite treatment or storage of the household wastewater before it is discharged. • Little impact to homeowners and their properties. • Presents a viable option if there is an appropriate difference in elevation. • No electricity for pumping and no pump maintenance.	• Flat or large variations in terrain can increase costs. • Larger pipes compared to other collection system options. • Prone to clogging. • Manholes associated with gravity sewers are a potential source of inflow and infiltration. • Higher capital costs.	Most common, highly developed	60	L	• Inspect on a regular schedule, this can be accomplished via surface inspections of manholes, lowering hand-held camera or robotic CCTV. • Proactively flush accumulated debris and fats, oils, and grease (FOG). • Remove blockages and tree roots as required.
Liquid-Only Pressure Sewers	• Independent from land topography restrictions. • The septic tank retains most of the FOG and solids reducing clogging problems. • Septic tanks have storage capacity to operate during power outages. • Smaller pipes compared to conventional gravity sewers. • Can be installed at a shallow depth and do not require a minimum flow velocity or slope to function.	• Requires an onsite septic tank and pump on each property. • Grease and sludge must be pumped from each individual septic tank. • Anaerobic septic tanks can generate odors and methane gas. • Leaks pose a risk of wastewater exfiltration. • Pumps and filters must be maintained.	Highly developed	Pump - 20 Septic tank - 60 Piping - 60	M	• Provide/maintain electricity to each unit. • Inspect and clean filter on pump monthly. • Periodically remove accumulated sludge and scum from septic tank. • Remove any blockages in pressure pipe network.
Low-Pressure Sewers	• Small diameter piping, shallow, easily installed. • Independent from land topography restrictions. • No manholes required and no storm water infiltration. • Less clogging and subsequent O&M cleaning or flushing.	• Requires pump/vault installation on each property. • Requires an energy source for the grinder pumps. • Pumps must be maintained on each property.	Highly developed	Pump - 20 Piping - 60	M	• Provide/maintain electricity to each unit. • Inspect pump and chamber on a regular basis, remove any accumulated materials. • Inspect and maintain backflow preventers. • Remove any blockages in pressure pipe network.
Vacuum Sewers	• Small diameter piping, shallow, easily installed. • No manholes required and no storm water infiltration. • Closed system with no exfiltration or odors. • Flexible installations regardless of topography and water availability.	• Requires construction of vacuum equipment at each home. Requires land for central vacuum stations. • Economic feasibility depends on the number of homes served by the system (the more the better). • Requires energy to create the permanent vacuum. • Vacuum stations require regular O&M checks, typically higher O&M than gravity collection systems.	Uncommon, Highly developed	Pumps - 20 Equipment - 20 Piping - 60	H	• Provide/maintain electricity to each unit and vacuum station. • Regular pressure/vacuum testing. • Vacuum stations require regular O&M checks • Remove any blockages in pressure pipe network.

Technology[1]	Benefits	Challenges	Technology Status	Replace Interval (year)	O&M Effort[2]	O&M Requirements[3]
Treatment System Options						
Conventional Activated Sludge	• High BOD and nitrogen removal, high effluent quality, self-sustaining system. • Small land area requirement. • Free from fly and odor nuisance. • Can be modified to meet specific discharge limits.	• High electricity consumption and costly mechanical parts. • Requires skilled operation and maintenance. • Requires expert design and construction. • Bulking and biological surface foaming.	Most common, highly developed	30	M	• Monitoring of DO, pH, and MLSS. • Influent and effluent must be monitored, changing the parameters accordingly. • Regular cleaning of influent screens. • Regular sludge wasting and disposal. • Control of concentrations of sludge and oxygen levels in the aeration tanks. • Maintenance includes inspecting the aeration system and following manufacturer recommendations for maintenance of all equipment.
Extended Aeration Activated Sludge	• Systems consistently provide high quality effluent in terms of TSS, BOD, and ammonia levels. • Long HRT and complete mixing, minimal impact of a shock load or hydraulic surge. • Produces less sludge due to extended retention of biological solids in the aeration tank.	• Higher energy uses due to longer aeration time. • Larger footprint than CAS. • Less flexibility than CAS should regulations for effluent requirements change.	Most common, highly developed	30	M	• Monitoring of DO, pH, and MLSS. • Influent and effluent must be monitored, changing the parameters accordingly. • Regular cleaning of influent screens. • Regular sludge wasting and disposal. • Control of concentrations of sludge and oxygen levels in the aeration tanks. • Maintenance includes inspecting the aeration system and following manufacturer recommendations for maintenance of all equipment.
Membrane Bioreactor Activated Sludge	• Secondary clarifiers and tertiary filtration processes are eliminated, thereby reducing plant footprint. • High quality effluent.	• Membrane complexity and fouling. • Higher capital, operation, and energy costs. • Hydraulic flow peak capacity is limited to 1.8 times average flows and only for short periods.	Highly developed	30	M	• Maintenance includes chemical cleaning of membranes. • Monitoring of DO, pH, and MLSS. • Influent and effluent must be monitored, changing the parameters accordingly. • Regular cleaning of influent screens. • Regular sludge wasting and disposal. • Control of concentrations of sludge and oxygen levels in the aeration tanks. • Maintenance includes inspecting the aeration system and following manufacturer recommendations for maintenance of all equipment.
Textile Filter (Attached Growth Systems)	• Can operate at a range of organic and hydraulic loads. • Lower energy input than CAS. • Low sludge production.	• Requires expert design, construction, operation, and maintenance. • Some variations have larger footprints. • Risk of clogging, depending on pre and primary treatment.	Highly developed	30	L	• Monitoring of influent and effluent. • Maintenance of all equipment following manufacturer's recommendations. • Optimum dosing rates and flushing frequency are determined from the field operation. • The packing should also be kept moist which can be problematic at night or during power failures. • Regular cleaning of influent screens. • Regular sludge wasting and disposal. • The sludge that accumulates on the filter must be periodically washed away to prevent clogging and to keep the biofilm thin and aerobic.

Technology[1]	Benefits	Challenges	Technology Status	Replace Interval (year)	O&M Effort[2]	O&M Requirements[3]
Moving Bed Biofilm Reactor	• Efficient treatment, low HRT, flexibility to adapt to fluctuating hydraulic and organic loads. • Low Maintenance. • Very compact, due to the maximized surface area the media provide for biofilm growth.	• High-tech system. • Higher capital and operating costs. • Carriers can wash out of the system, necessitating supplemental additions.	Uncommon, Highly developed	30	H	• Monitoring of influent and effluent. • Maintenance of all equipment following manufacturer's recommendations. • Observation of media color and adjustment of air. • Monitoring and adjustment of dissolved air flotation units. • Regular cleaning of influent screens. • Regular sludge wasting and disposal. • Operators must take samples periodically and analyze them to ensure the bacteria on the carriers are still thriving.
Constructed Wetland	• Simple, easily operated natural system. • Inexpensive compared to other treatment options. • Requires little energy when the system operates with gravity flow.	• Large land requirement. • Not available as a package facility. • Vector and odor nuisances.	Uncommon, Highly developed	30	L	• Vector control to prevent population growth of insects and odor control. • Occasional maintenance of the vegetation promotes growth of desired vegetation and maintains hydraulic capacity. • Monitoring of influent and effluent.
Effluent Disposal Options						
Absorption Trench/Bed	• Common type of disposal system so there are many products available and experience with installation. • When deployed downstream from an aerobic treatment system, provides some treatment for BOD, TSS, and fecal coliform. • No power is required, and maintenance is generally not necessary. • Graveless dome systems require less gravel backfill and provide significant additional water storage volume.	• Cannot be used in terrain where natural slope is > 12 percent. • Cannot be used if groundwater is too close to the surface, minimum vertical separation of three feet from the bottom of the trench/bed. • Large land requirement. • Overloading, rainfall, or unsuitable soils may cause contaminants to spill out into the surroundings.	Most common, highly developed	60	N	• Normally none. • Some systems use a dosing pump - if present, it must be checked and cleaned. • Observation ports can be installed within the disposal area to check whether the water is percolating into the ground as expected.
High-Pressure Drip	• Reliable alternative for areas with low permeability, seasonal high-water tables, or severe slopes. • Ability to control dose/rest cycles allows for even spacing or dosing of effluent and facilitates wastewater infiltration by spreading it spatially and temporally. • Significant evapotranspiration is expected.	• Large dose tank is needed to accommodate timed dose delivery to the drip absorption area. • Power is required to run pumps, sensors, and controls. Some minimal regular maintenance is required. • Clogging of emitters can occur.	Highly developed	30	L	• Provide continuous electricity to small dosing pumps. • Typical inspections may include observing and reporting of the general condition of the system, water level in tanks, ponding around the system, clogging at pumps and filters, pump cycles, and readings of any meters. • Regular monitoring and maintenance of pump, filter and piping shall be performed.
Low Pressure Pipe	• Reliable alternative for areas with low permeability, seasonal high-water tables, and/or severe slopes. • Shallow and narrow trenches reduce site disturbance and land area requirement. • Ability to control dose/rest cycles allows for even spacing or dosing of effluent and facilitates wastewater infiltration by spreading it spatially and temporally.	• Limited storage capacity around laterals. • Possibility of wastewater accumulation in the trenches. • Potential for clogging and infiltration problems.	Highly developed	60	L	• Monitoring ponding at the bottom of trenches, readjusting operating pressure, and reducing flow to overloaded trenches. • Flushing manifold and lateral lines periodically.

Technology[1]	Benefits	Challenges	Technology Status	Replace Interval (year)	O&M Effort[2]	O&M Requirements[3]
Seepage Pit	• Simplest and most compact method to percolate water into the ground. • Viable options when land is insufficient for absorption beds or trenches, or the terrain is steep.	• Cannot provide additional treatment or evapotranspiration. • Must have adequate separation from groundwater (at least 3 ft).	Uncommon, unlikely to be approved	60	N	• Inspection and pumping every 2 to 4 years.
Water Reuse	• Helps reduce overall demand on potable water supply. • Utilized in landscaping, agricultural irrigation, and even toilet flushing.	• Often more expensive treatment is required to reach water quality requirements. • Strict rules and regulations to prevent potential environmental or health consequences.	Highly developed	60	H	• Extensive monitoring at the treatment facility is required; for R-1 water: continuous for NTU and fecal coliforms. • A water reuse plan is required for the reuse site, with monitoring and reporting. Signage is required at the site.
Evapotranspiration	• If an impermeable liner is included for a "zero-discharge" system, then 100 percent nitrogen removal is achieved. • Low cost, simple disposal system.	• Large surface areas are needed for year-round disposal. The size is controlled by a water balance based on rainfall and pan evaporation rates. • More effective in arid climates where evaporation rates are much higher than precipitation.	Uncommon, highly developed	60	L	• Provide continuous electricity to small dosing pumps. • Inspection of observation wells. • Trim vegetated area of ET system, replace plants as needed.
Injection Well	• Very simple system. • Little to no maintenance required.	• Limited applicable locations/siting. • Very difficult to obtain a permit.	Uncommon, unlikely to be approved	60	M	• Sampling and reporting.
Surface Water Discharge	• Simple system. • Effectively recycles water back into the environment. • Can augment stream flow.	• Potential negative impacts on natural bodies of water or drinking water. • NPDES permit required. Expensive monitoring and reporting required. • Very limited applicable locations/siting.	Uncommon, unlikely to be approved	60	M	• Sampling and reporting.

Notes:
(1) CAS = conventional activated sludge, LPP = low pressure pipe, ET = evapotranspiration.
(2) O&M = operations and maintenance, N = no maintenance, L = low maintenance, M = moderate maintenance, H = high maintenance.
(3) CCTV = closed circuit television, DO = dissolved oxygen, MLSS = mixed liquor suspended solids, BOD = biochemical oxygen demand, TSS = total suspended solids, HRT = hydraulic retention time, mg/L = milligrams per liter, mL = milliliter, NTU = Nephelometric Turbidity Units.

Chapter 2: Materials and Methods

2.1 Onsite Treatment and Cluster System Costs

The cost of a technology/facility/system is always a very important consideration. There are up-front capital costs for system construction followed by on-going, permanent, annual costs for operation and maintenance. These are normally combined in a net present worth analysis by the design engineer to determine life-cycle costs when making system comparisons.

2.1.1 Onsite Treatment Costs

The costs for on-site systems used in this study come from 81 cesspool replacements completed statewide between 2016 and 2019 that received approval for a tax rebate by the DOH WWB. 73 of these cesspool replacements were "Septic Tank + Absorption Disposal" and 8 were "Aerobic Treatment Unit + Absorption System". *Table 3.1* shows the data, including high and mean values for construction and 60-year life cycle costs.

2.1.2 Cluster System Costs

Cluster system costs in this study are adapted from WERF (2010). The WERF report provided costs in 2009 dollars for mainland USA. The WERF report contains construction, O&M, and 60-year life cycle costs (5.5% discount rate) for three different sizes of systems. Their construction costs include the on-property and off-property equipment and installation costs and 20% for contractor overhead and profit. It does not include engineering design costs. They estimated costs for 20, 40, and 200 homes with corresponding flows of 5,000, 10,000 and 50,000 gpd. Their flow per home assumption is 250 gpd/home which is one half of the value assumed in this study (500 gpd). For those systems which were included in the WERF report, their 2009 costs for construction and O&M were adjusted to 2020 dollars in Hawaii using a ratio of the RS Means Construction Cost Index - 239.1/180.1 = 1.328. The 60-yr net-present-worth life-cycle costs were recalculated using the adjusted costs, the replacement schedules, and a discount rate of 3.0%.

The WERF report did not include cost estimates for CW, MBR, MBBR, TF, and TXF. For constructed wetlands treatment (CW), it is assumed here that the costs should be like the cost of percolation-absorption disposal system with the addition of a synthetic liner system. The liner is assumed to add 5% to the construction cost of an absorption system to derive the CW cost in this report. For MBRs costs, it is assumed that MBRs are 50% greater construction cost due to all the additional equipment required for the membrane separation system. The operation of MBRs involves much more energy consumption due to addition of scour air for the membranes, this can double the O&M cost for MBRs compared to CAS. MBBRs are a type of activated sludge with small floating plastic media added to the aeration tank. The aeration tank must contain screens to retain the media and secondary solids separation (clarifiers, dissolved air flotation, etc.). A few of these systems are in operation in Hawaii that use dissolved air flotation for solids separation. The aeration tanks are smaller than CAS and EAAS so there is cost savings afforded, however, there are additional costs for the media and the filters. These costs could balance out, and thus, the costs for MBBR are assumed to be the same as CAS and EAAS in this report. Trickling filters are reported to cost approximately 38% less than CAS for construction and 52% less for O&M (Zahid, 2007). Older EPA fact sheet data indicate 50% lower capital and O&M costs than CAS. Thus, in this report, the values of 38% and 52% are used to derive the costs in *Table 3.3* for TFs. Textile trickling filters (TXF) are recirculating media filters that use textile instead of traditional sand media.

The basic components are the same and thus the WERF cost estimates for recirculating media filters were used in *Table 3.3*.

2.2 Method to Evaluate Decentralized Cluster Wastewater Systems as an Alternative for Cesspool Replacement Options

The following method is used to provide a statewide study of potential neighborhoods/sites for cluster systems with an initial focus on priority areas, including planning level cost estimates. This method can help the state to evaluate and upgrade those cesspools deemed to pose the greatest risks to public health and the environment more rapidly. Furthermore, the information provided from this method can help to facilitate studies and evaluations of decentralized cluster wastewater systems for replacing cesspools in Hawaii.

- **Start with total number of cesspools on a specific island.**
- **Perform density analysis of cesspools and cesspool clusters:**
    - Search for cesspool clusters that meet first density criteria of 3 acres.

The 3-acre density criteria entail that each cesspool in a specific cluster is within 204 ft of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 3 -acre area. Imagine a circle of 3-acres around each point (cesspool) in a cluster, from this, a search radius of 204 ft is derived to search for other points within that radius. The mathematical proof is below:

3 Acres X 43,650 ft^2/Acres =130,680 $ft^2 \rightarrow$ 130,680 $ft^2 = \pi R^2 \rightarrow$ R= **204ft**.

- Filter through different minimum sizes per cluster, for a smaller criterion of 3-acres, use minimum sizes of approximately 4, 10, 16, & 20.
- Determine the size of each cluster that is found by breaking down the results into the following size categories: 10-20,20-40, 40-60, 60-80, 80-100, and 100+.

Result from this step: Number of clusters and corresponding cesspools that meet 3-acre density criteria for minimum sizes of 4,10,16,& 20 cesspools along with the size breakdown for the clusters.

- Search for cesspool clusters that meet second density criteria of 6 acres.

The 6-acre density criteria entail that each cesspool in a specific cluster is within 288.5 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 6 -acre area. Imagine a circle of 6-acres around each point (cesspool) in a cluster, from this, a search radius of 288.5 ft is derived to search for other points within that radius. The mathematical proof is below:

Acres X 43,650 ft^2/Acres =261,900 $ft^2 \rightarrow$ 261,900 $ft^2 = \pi R^2 \rightarrow$ R= **288.5 ft**.

- Filter through different minimum sizes per cluster, for a medium criterion of 6-acres, use minimum sizes of approximately 12,16, & 20.
- Determine the size of each cluster that is found by breaking down the results into the following size categories: 10-20,20-40, 40-60, 60-80, 80-100, and 100+.

Result from this step: Number of clusters and corresponding cesspools that meet 6-acre density criteria for minimum sizes of 12,16,& 20 cesspools along with the size breakdown for the clusters.

- Search for cesspool clusters that meet last density criteria of 10 acres.

The 10-acre density criteria entail that each cesspool in a specific cluster is within 372 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 10 - acre area. Imagine a circle of 10-acres around each point (cesspool) in a cluster, from this, a search radius of 372 ft is derived to search for other points within that radius. The mathematical proof is below:

10 Acres X 43,650 ft^2/Acres =436,500 ft^2 → 436,500 ft^2= πR^2 → R= **372 ft**.

  - Filter through different minimum sizes per cluster, for a large criterion of 10-acres, use minimum sizes of approximately 12,24, and 32.
  - Determine the size of each cluster that is found by breaking down the results into the following size categories: 10-20,20-40, 40-60, 60-80, 80-100, and 100+.

Result from this step: Number of clusters and corresponding cesspools that meet 10-acre density criteria for minimum sizes of 12,24 ,& 20 cesspools along with the size breakdown for the clusters.

- **Overlay 3 different density search criteria onto one graph (3 acres, 6 acres, & 10 acres)**
  - Display the number of cesspools and clusters that meet the criteria for sizes of 10+ and for sizes of 10-100 for all three of the separate density criteria. For both size constraints, note the percentage of the results to that of the total population of cesspools on the island.

Result from this step: These statistics display how many cesspools on the island can be "clustered" and considered for decentralized treatment and the percentages help to put the numbers into context in terms of how feasible cluster systems are on that island.

- **Evaluate cesspool priority upgrade areas on the island, as defined by DOH.**
  - Map all priority upgrade areas on the island and tabulate basic information about each of them, such as what priority designation they have, how many cesspools they contain, and how much effluent they discharge.
  - Focus on priority 1 and 2 upgrade areas and take a more in depth look at the cesspools they contain and how they are clustered.
    - Choose one priority upgrade area per island and repeat the 3-acre and 10-acre density analysis for that specific area.
      - Determine how many cesspools and corresponding clusters in the area meet the density criteria and what percent of the total cesspools in the area it makes up.

Result from this step: "Focus clusters" from the priority upgrade area that can be further evaluated through cost comparisons.

- **For specific neighborhoods in priority areas, compare the costs of using onsite wastewater treatment technologies to that of using a decentralized cluster system.**
  - Out of the priority area density analysis from the previous step, choose a specific focus "cluster".
    - List basic information about this cluster such as how many cesspools it contains, how big the area is, and what the density index is (cesspools/acre).

- Compare the per household and overall costs of using onsite wastewater treatment technologies to that of using a decentralized cluster system.
  - Onsite treatment options include (see *Table 3.1*):
    - Septic tank + Absorption Disposal
    - ATU + Absorption Disposal
  - The cheapest decentralized treatment options include the following treatment trains (see *Table 3.2 & 3.3)*:
    - (**1A**): Liquid-Only Pressure Sewer (STEP) > Constructed Wetland (CW) > Absorption (ABS) / Evapotranspiration (ET)
    - (**2A**): Liquid-Only Pressure Sewer (STEP) > Textile Filter (TXF) > Absorption (ABS) / Evapotranspiration (ET)
    - (**2b**): Liquid-Only Pressure Sewer (STEP) > Textile Filter (TXF) > Drip Irrigation (DRIP)
    - (**4a)**: Liquid-Only Pressure Sewer (STEP) > Activated Sludge (CAS), (EEAS), (MBBR) > Absorption (ABS) / Evapotranspiration (ET)

Result from this step: The cost competitiveness or lack thereof of using a cluster system as opposed to onsite systems for a specific neighborhood in a priority upgrade area. This step helps to narrow in on what cluster system treatment trains are financially feasible for a specific neighborhood.

- **Repeat steps above for the remaining locations (Hawaiian Islands in this case) and choose different sized focus clusters while evaluating and comparing costs.**

Chapter 3: Results

3.1 Costs

Table 3.1 Life-Cycle Costs for Onsite Treatment and Disposal Systems (Adapted from *Technical Memorandum No. 3: Onsite Treatment Technologies Evaluation*. Carollo Engineers, Inc. in association with the University of Hawaii, 2020)

Onsite System Technology		Cost/Household ($)		
	Size	Construction	O&M	60-yr Lifecycle
Septic Tank + Absorption Disposal	Mean	22,000	400	33,000
	High	52,000	400	63,000
ATU + Absorption Disposal	Mean	29,000	1,200	74,000
	High	60,000	1,200	118,000

Table 3.1 shows the costs per household of using onsite treatment technologies to replace a cesspool. Technologies include "Septic Tank + Absorption Disposal" and "ATU + Absorption Disposal". See the *Materials and Methods(2.1)* section above to know where this cost information was derived from. The cost means will be used to compare the costs of using cluster systems in specific neighborhoods to the

costs of using onsite treatment systems in the same neighborhoods, see section *Comparing Costs to that of Onsite Wastewater Treatment Alternatives (3.3).*

Table 3.2 Ranking of Life-Cycle Costs for Decentralized Cluster Systems.(Adapted from *Technical Memorandum No.4: Evaluation of Decentralized Cluster Wastewater Systems. Carollo Engineers, Inc. in association with the University of Hawaii, 2020.)*

Cluster System Component		Lowest Cost Ranking (Based on 60-yr Life-Cycle Cost/Household)				
	Size (gpd)	1	2	3	4	5
Collection System Technology	5,000	Liquid-Only Pressure Sewer (STEP)	Low-Pressure Sewer (LPS) & Vacuum Sewer (VS) tie		Gravity Sewer (GS)	NA
	10,000	Liquid-Only Pressure Sewer (STEP)	Low-Pressure Sewer (LPS) & Vacuum Sewer (VS) tie		Gravity Sewer (GS)	NA
	50,000	Liquid-Only Pressure Sewer (STEP)	Low-Pressure Sewer (LPS) & Vacuum Sewer (VS) & Gravity Sewer (GS) tie			NA
Treatment System Technology	5,000	Constructed Wetland (CW)	Trickling Filter (TF) & Textile Filter (TXF) tie		Activated Sludge (CAS), (EEAS), (MBBR)	Membrane Bioreactor (MBR)
	10,000	Constructed Wetland (CW)	Trickling Filter (TF)	Textile Filter (TXF)	Activated Sludge (CAS), (EEAS), (MBBR)	Membrane Bioreactor (MBR)
	50,000	Trickling Filter (TF)	Constructed Wetland (CW)	Textile Filter (TXF)	Activated Sludge (CAS), (EEAS), (MBBR)	Membrane Bioreactor (MBR)
Disposal System Strategy	5,000, 10,000, 50,000	Absorption (ABS) & Evapotranspiration (ET) tie		Drip Irrigation (DRIP)	Spray Irrigation (SPRAY)	Low-Pressure Pipe (LPP)

Table 3.3 Comparison of Costs of Onsite Retrofits and Several Combinations of Cluster Systems. (Adapted from *Technical Memorandum No.4: Evaluation of Decentralized Cluster Wastewater Systems. Carollo Engineers, Inc. in association with the University of Hawaii, 2020.)*

Upgrade Option	Collection system	Treatment system	Disposal system	60-yr Life-Cycle Cost ($) [3% discount rate, 2020 dollars] Land Area Required (acres)		
				10 homes	20 homes	100 homes
Septic Onsite	NA	Septic	ABS	Median: 22,000-33,000 High: 52,000-63,000		
ATU Onsite	NA	ATU	ABS	Median: 61,000-62,000 High: 80,000-118,000		
1a	STEP	CW	ABS/ET	65,000-99,000 (0.5-0.8 ac)	65,000-97,000 (0.8-1.4 ac)	64,000-96,000 (2.8-5.6 ac)
1b	LPS/VS	CW	ABS/ET	90,000-133,000 (0.5-0.8 ac)	87,000-132,000 (0.8-1.4 ac)	87,000-130,000 (2.8-5.6 ac)
2a	STEP	TXF	ABS/ET	72,000-107,000 (0.35-0.75 ac)	73,000-110,000 (0.6-1.8 ac)	70,000-100,000 (2.1-7.9 ac)
2b	STEP	TXF	DRIP	76,000-113,000 (0.35-0.75 ac)	80,000-119,000 (0.6-1.8 ac)	71,000-106,000 (2.1-7.9 ac)
4a	STEP	CAS/ MBBR	ABS/ET	91,000-137,000 (0.25-0.6 ac)	83,000-123,000 (0.4-1.1 ac)	72,000-109,000 (1.3-4.2 ac)
4b	LPS/VS	CAS/ MBBR	ABS/ET	115,000-172,000 (0.25-0.6 ac)	105,000-158,000 (0.4-1.1 ac)	95,000-143,000 (1.3-4.2 ac)
4c	LPS/VS	CAS/ MBBR	DRIP	119,000-178,000 (0.25-0.6 ac)	111,000-167,000 (0.4-1.1 ac)	99,000-148,000 (1.3-4.2 ac)
4d	LPS/VS	MBR	DRIP	152,000-227,000 (0.35-0.75 ac)	138,000-206,000 (0.6-1.8 ac)	118,000-178,000 (2.1-7.9 ac)

Table 3.2 ranks the life cycle costs for decentralized cluster systems from least to most expensive. Choosing treatment systems is a very site-specific process but this table gives an overview of what some of the cheapest options are if a community is considering using a cluster system to replace their cesspools. For example, regardless of size, a Liquid-Only Pressure Sewer (STEP) system is the cheapest collection system option shown in the table. For treatment technologies, constructed wetlands is the cheapest option for 5,000 and 10,000 gpd flows and trickling filters is the cheapest option for 50,000 gpd flow.

In *Table 3.3*, these collection, treatment, and disposal technologies are grouped into treatment trains (1a-4d). Cost ranges are provided per household depending on the size of the community served (the amount of flow treated). Costs per household can range slightly depending on the size of the cluster system and the technologies used. See the *Materials and Methods(2.1)* section above to know where this cost information was derived from.

Reminder: *Table 1.2* provides a summary of all the technologies listed in *tables 3.1-3.3*.

3.2 GIS Clustering Analysis

3.2.1 Oahu

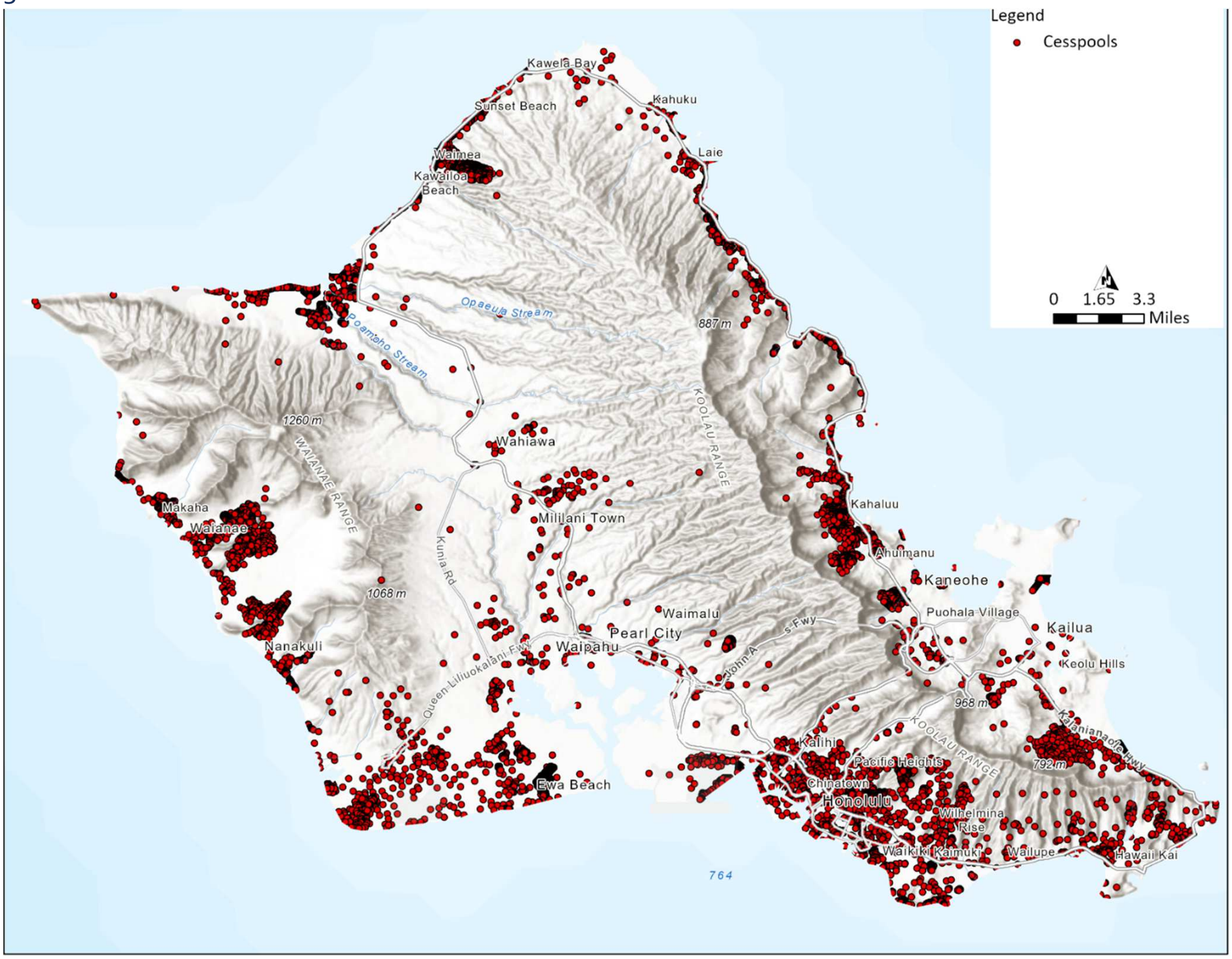

Figure 3.1 10,991 Total Cesspools on Oahu

Oahu, the most developed and densely populated Hawaiian island, hosts the third most cesspools in the chain. As shown in *Figure 3.1*, there are approximately 10,991 total cesspools on Oahu, mostly located along the coasts and in residential neighborhoods. Through the method laid out in the previous chapter (*Chapter 2: Materials and Methods)*, the following sections will analyze how cesspools are clustered across the island.

Density Criteria: 3 Acres (Search Radius of 204 ft.)

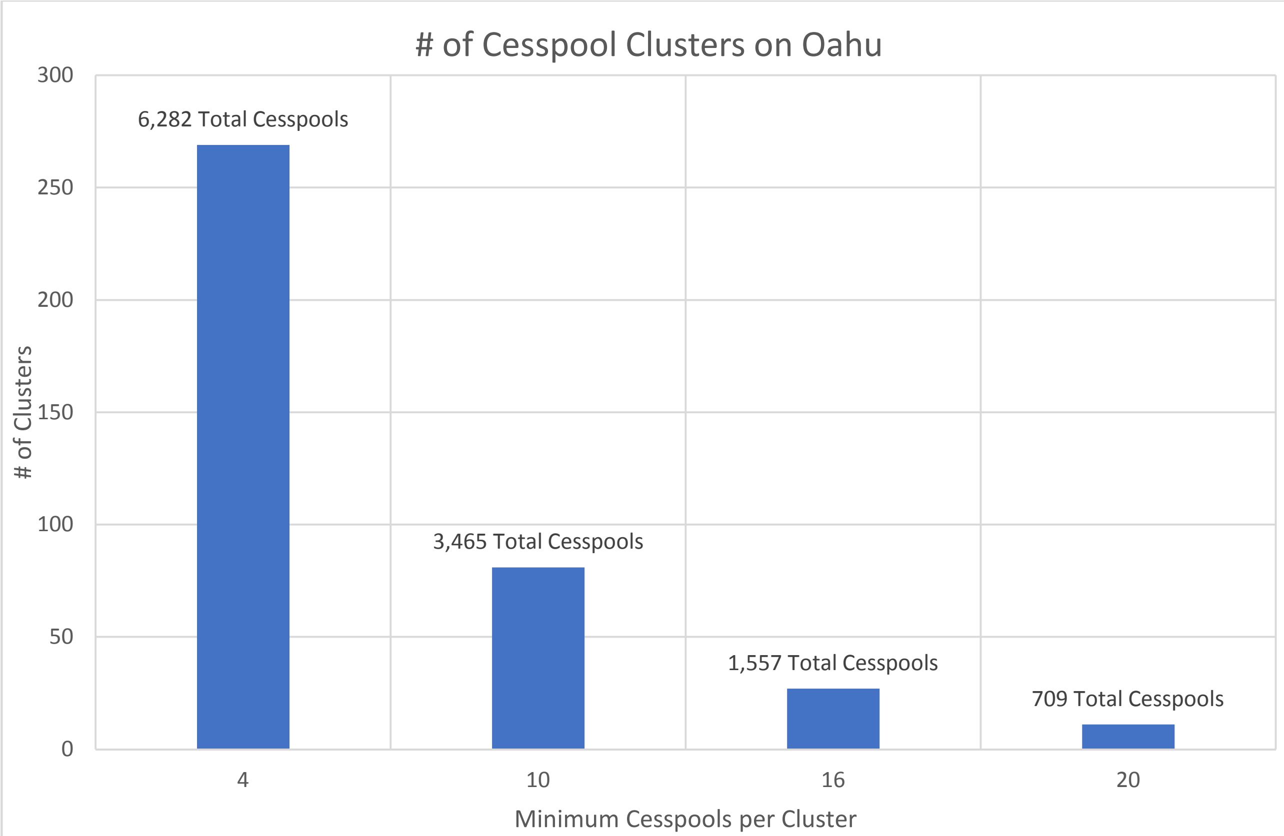

Figure 3.2 # of Clusters that Meet 3 Acre Density Criteria for Different Minimum Sizes of 4,10,16, & 20 Cesspools

Figure 3.2 shows the clusters of cesspools that meet 3-acre density criteria for different minimum sizes of 4,10,16,& 20 on the island of Oahu. The 3-acre density criteria entail that each cesspool in a specific cluster is within 204 ft of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 3 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 4 cesspools per cluster: 269 clusters hosting 6,282 cesspools.
- Minimum size of 10 cesspools per cluster: 76 clusters hosting 3,465 cesspools.
- Minimum size of 16 cesspools per cluster: 27 clusters hosting 1,557 cesspools.
- Minimum size of 20 cesspools per cluster: 11 clusters hosting 709 cesspools.

These results show that there are a lot of small clusters in the Island of Oahu, the total cesspools that meet the criteria is almost halved when you go from a minimum size of 4 to a minimum size of 10. It also shows that there are about 3,465 total cesspools that meet the 3-acre clustering criteria for a minimum size of 10 cesspools, which is approximately 32% of the total cesspools on the island. A minimum size of 10 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 32% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for decentralized treatment and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 32% to 20% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

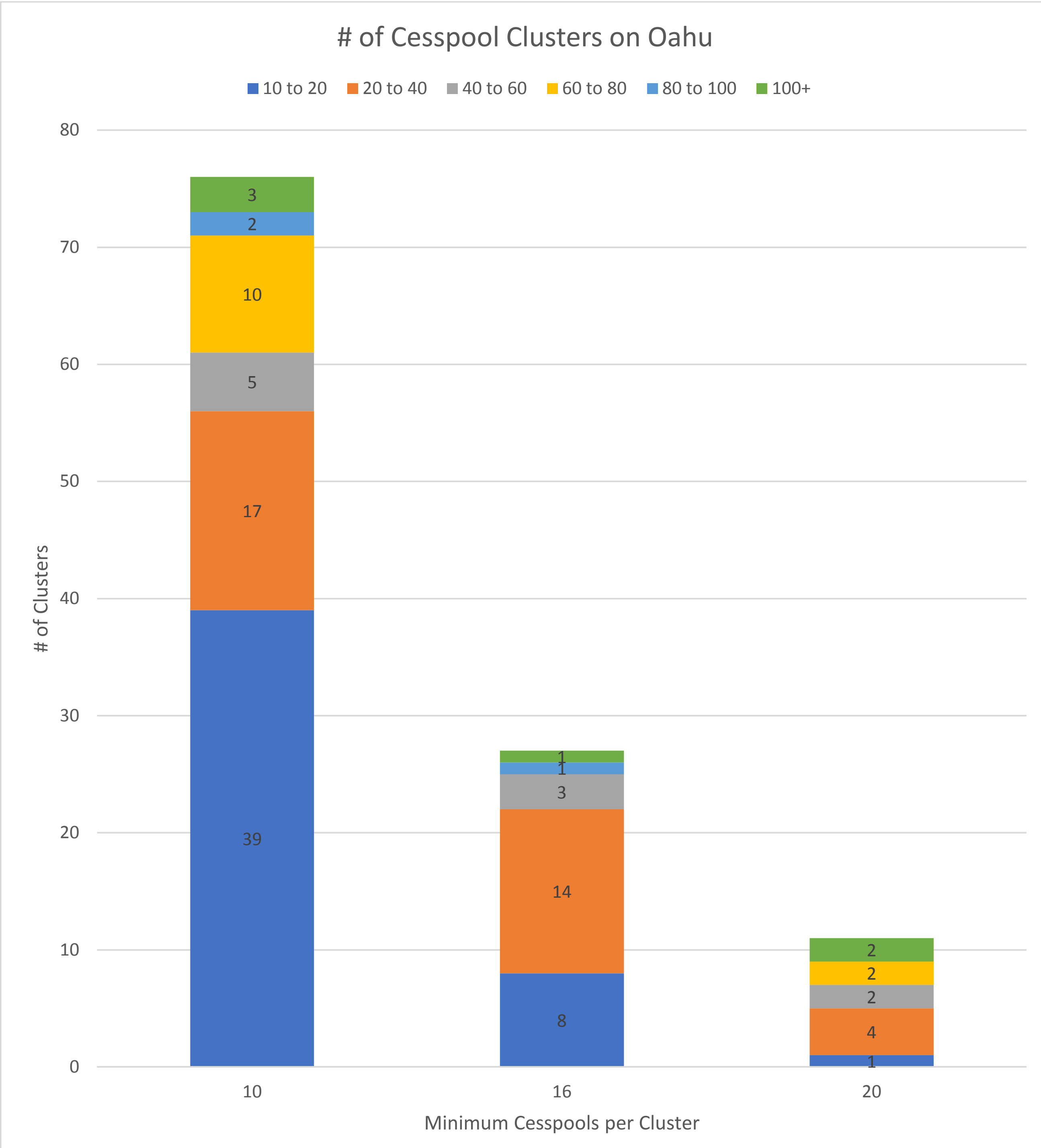

Figure 3.3 # of Clusters that meet the 3 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 3-acre density criteria, *Figure 3.3* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 76 clusters with a minimum size of 10 that meet the 3-acre density criteria, 73 are between 10-100 cesspools in size, 39 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Density Criteria: 6 Acres (Search Radius of 288.5 ft.)

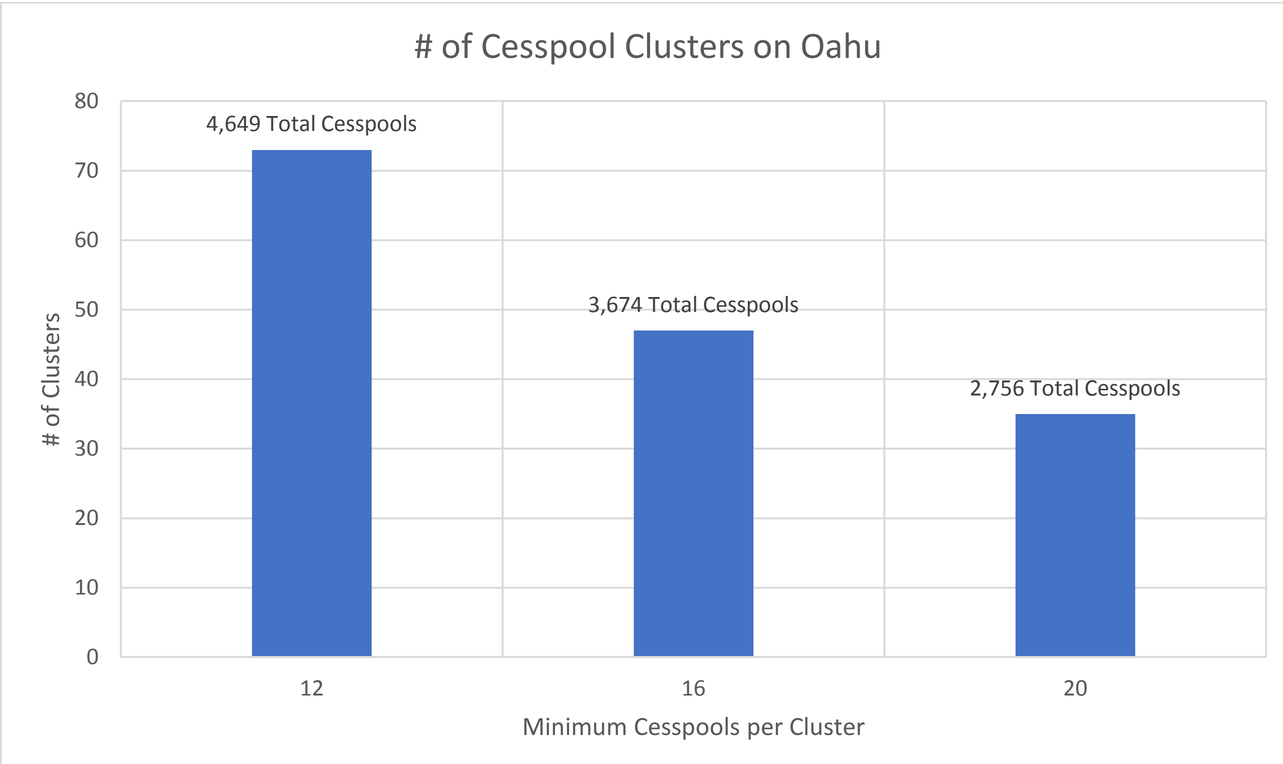

Figure 3.4 # of Clusters that Meet 6 Acre Density Criteria for Different Minimum Sizes of 12,16, & 20 Cesspools

Figure 3.4 shows the clusters of cesspools that meet 6-acre density criteria for different minimum sizes of 12,16,& 20 on the island of Oahu. The 6-acre density criteria entail that each cesspool in a specific cluster is within 288.5 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 6 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 12 cesspools per cluster: 73 clusters hosting 4,649 cesspools.
- Minimum size of 16 cesspools per cluster: 47 clusters hosting 3,674 cesspools.
- Minimum size of 20 cesspools per cluster: 35 clusters hosting 2,756 cesspools.

These results show that there are about 4,689 total cesspools that meet the 6-acre clustering criteria for a minimum size of 12 cesspools, which is approximately 43% of the total cesspools on the island. A minimum size of 12 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 43% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for cluster system implementation and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 43% to 18% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

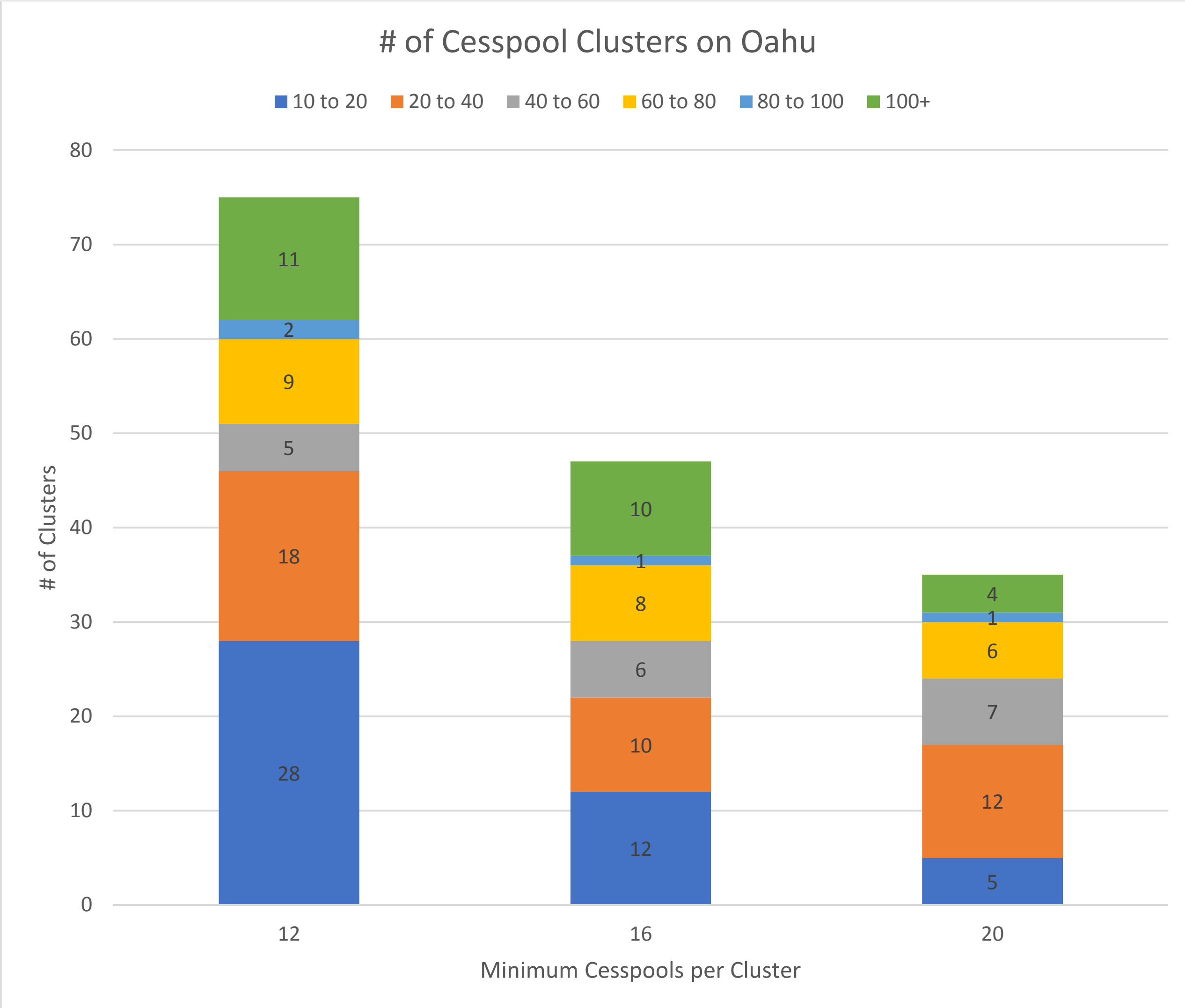

Figure 3.5 # of Clusters that meet the 6 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 6-acre density criteria, *Figure 3.5* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 73 clusters with a minimum size of 12 that meet the 6-acre density criteria, 62 are between 10-100 cesspools in size, 28 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Density Criteria: 10 Acres (Search Radius of 372 ft.)

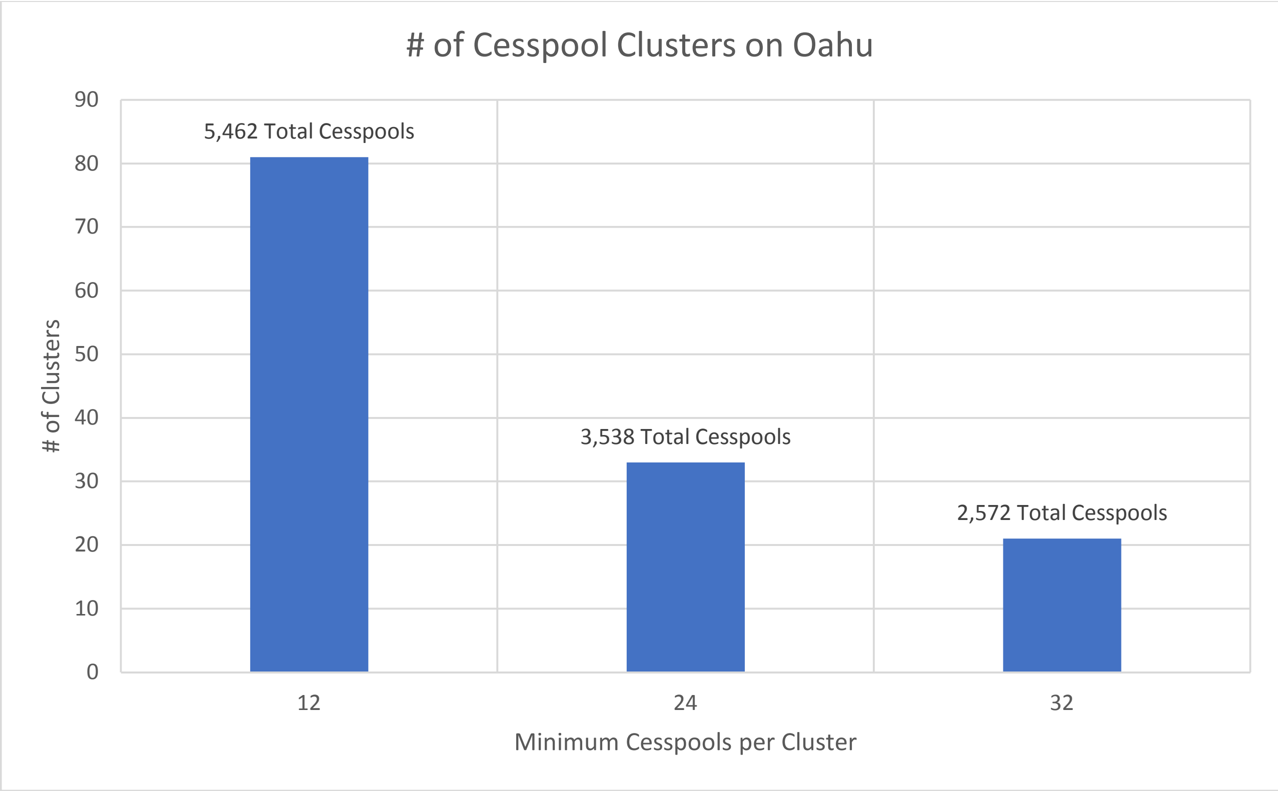

Figure 3.6 # of Clusters that Meet 10 Acre Density Criteria for Different Minimum Sizes of 12, 24, & 32 Cesspools

Figure 3.6 shows the clusters of cesspools that meet 10-acre density criteria for different minimum sizes of 12,24, & 32 on the island of Oahu. The 10-acre density criteria entail that each cesspool in a specific cluster is within 372 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 10 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 12 cesspools per cluster: 81 clusters hosting 5,462 cesspools.
- Minimum size of 24 cesspools per cluster: 33 clusters hosting 3,538 cesspools.
- Minimum size of 32 cesspools per cluster: 21 clusters hosting 2,572 cesspools.

These results show that there are about 5,462 total cesspools that meet the 10-acre clustering criteria for a minimum size of 12 cesspools, which is approximately 50% of the total cesspools on the island. A minimum size of 12 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 50% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for cluster system implementation and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 50% to 20% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

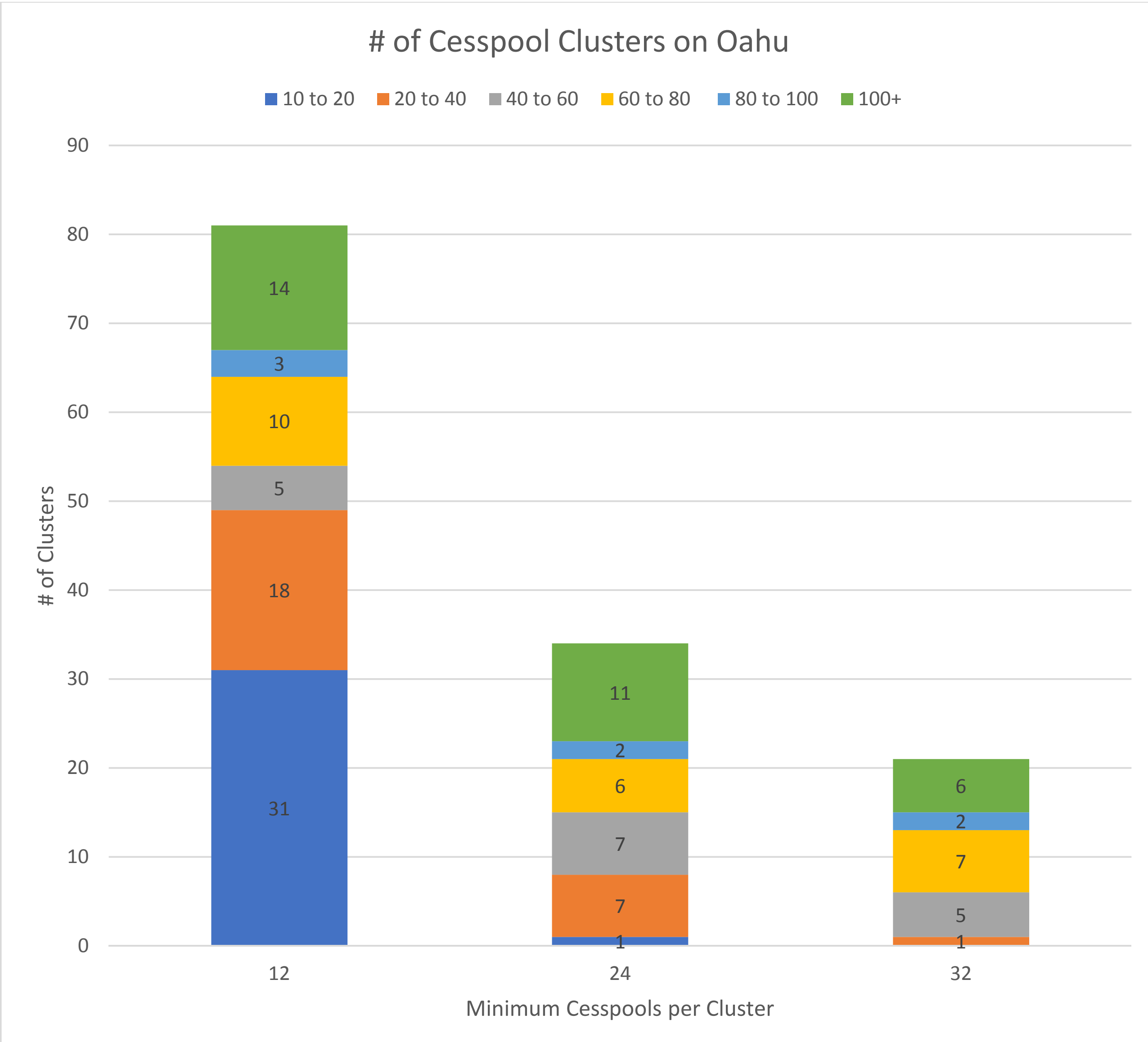

Figure 3.7 # of Clusters that meet the 10 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 10-acre density criteria, *Figure 3.7* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 81 clusters with a minimum size of 12 that meet the 10-acre density criteria, 67 are between 10-100 cesspools in size, 31 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Overview: A look at the Cluster Feasibility Density Analysis

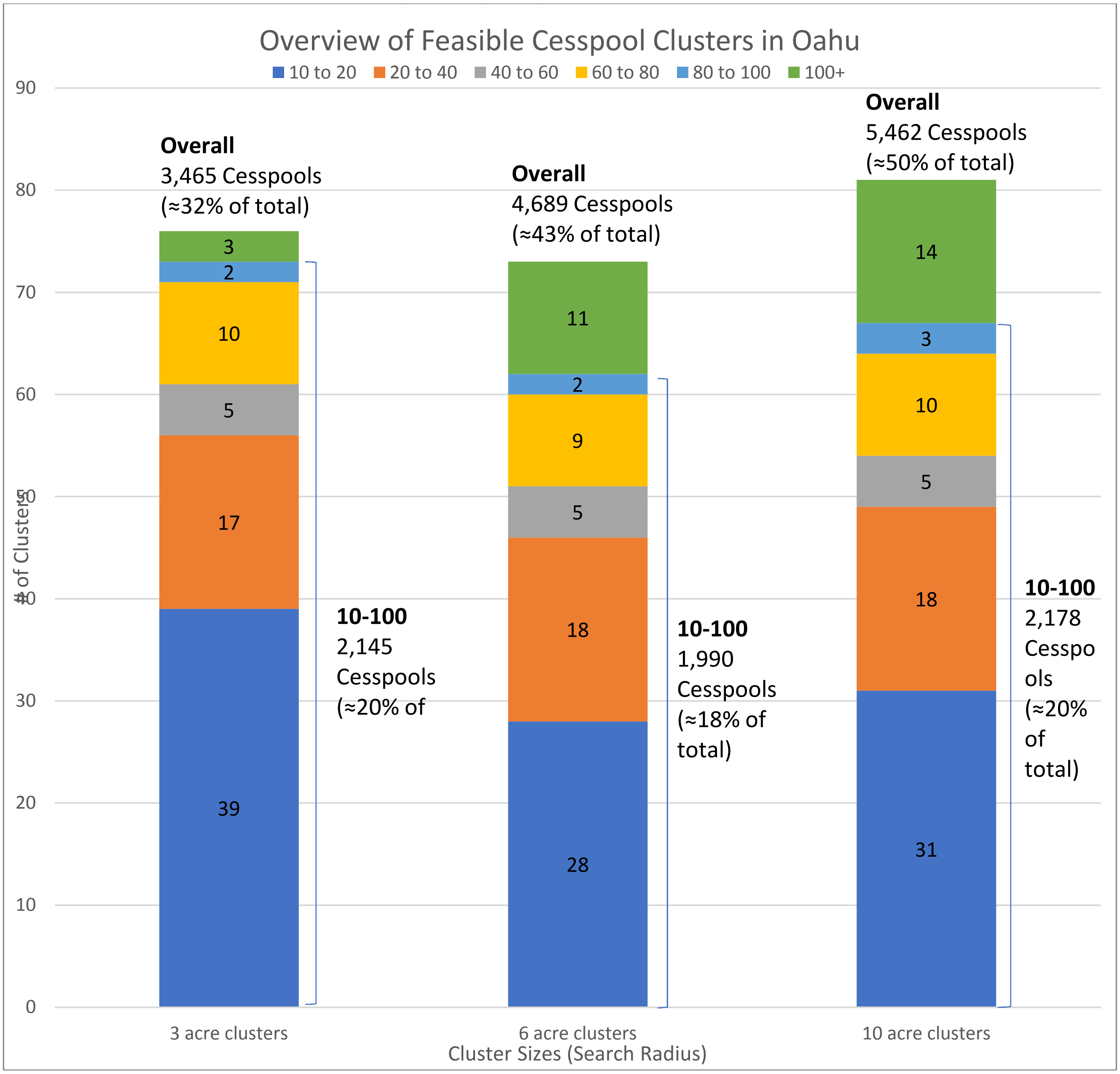

Figure 3.8 Overview of Feasible Cesspool Clusters in Oahu of size 10-100

Figure 3.8 shows an overview of the clusters of cesspools across the island of Oahu that meet a certain size feasibility constraint (10-100). The graph breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

The results are as follows:

- For 3-acre density criteria,
  - Overall: **76 clusters/neighborhoods**
    - 3,465 total cesspools (32% of total)

- Size 10-100: **73 clusters/neighborhoods**
    - 2,145 total cesspools (20% of total)
- For 6-acre density criteria,
  - Overall: **73 Clusters/neighborhoods**
    - 4,689 total cesspools (43% of total)
  - Size 10-100: **62 clusters/neighborhoods**
    - 1,990 total cesspools (18% of total)
- For 10-acre density criteria,
  - Overall: **81 clusters/neighborhoods**
    - 5,462 total cesspools (50% of total)
  - Size 10-100: **67 clusters/neighborhoods**
    - 2,178 total cesspools (20% of total)

These results provide an overview for cluster feasibility on the island of Oahu across different density criteria.

Oahu Focus Clusters & Priority Areas

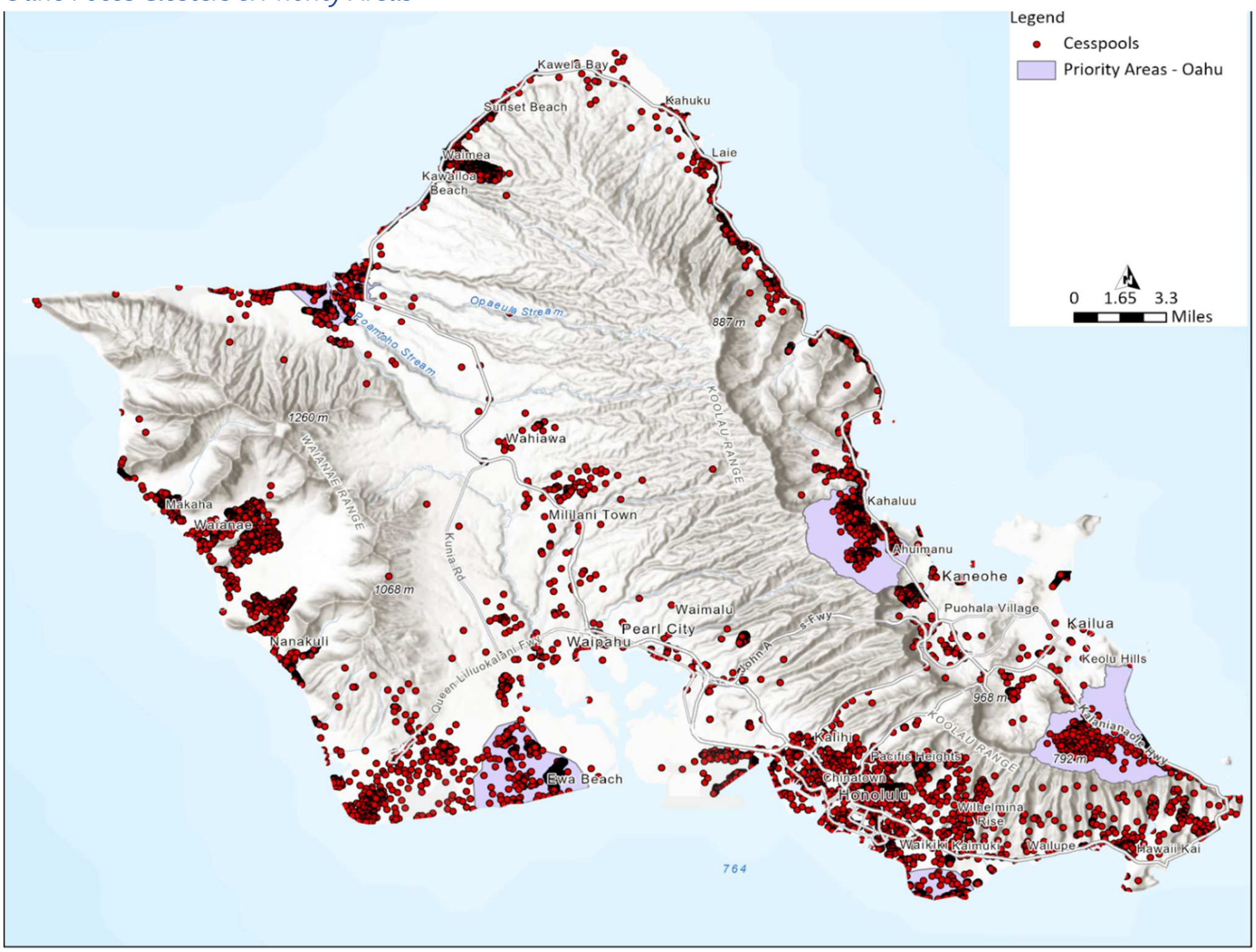

Figure 3.9 Priority Upgrade Areas in Oahu as Defined by DOH

Figure 3.9 shows the five priority areas on the Island of Oahu, outlined in *Table 3.4*. There are four priority-3 areas and one priority-1 area, as described by DOH (see section *1.3)*. The priority areas on Oahu host a total of 3,690 cesspools that discharge an estimated 2.42 mgd of effluent (DOH).

Table 3.4 Initial Oahu Priority Upgrade Areas Established by DOH WWB (DOH, 2018)

Geographic Area	Priority Level Assigned	Number of Cesspools	Estimated Effluent Discharge (mgd)
Kahaluʻu area of Oʻahu	1	740	0.44
ʻEwa area of Oʻahu	3	1,100	0.71
Waialua area of Oʻahu	3	1,080	0.75
Waimanalo area of Oʻahu	3	530	0.35
Diamond Head area of Oʻahu	3	240	0.17
	Total Assigned	**3,690**	**2.42**
Oahu Un-Assigned	NA	7,610	5.08
	Overall Totals	**11,060**	**7.33**

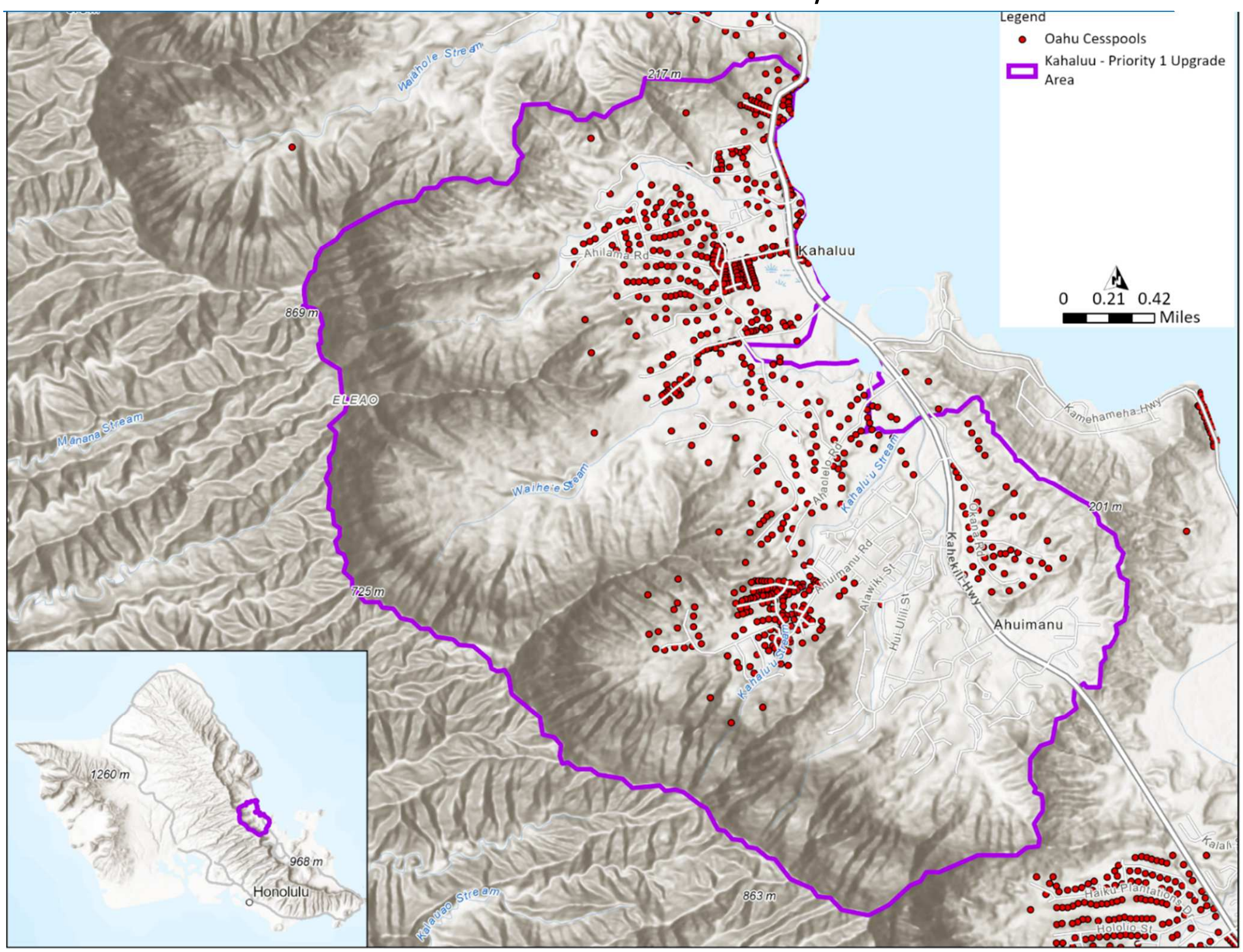

Figure 3.10 Kahaluu: Priority 1 Upgrade Area

Figure 3.10 shows the most important priority area on the island of Oahu. Located along the eastern coast of the island, Kahaluu is a priority-1 area as defined by DOH, the cesspools it contains pose a significant risk of human health impacts, drinking water impacts, or draining to sensitive waters. *Table 3.5* provides specific information to the area derived from DOH and GIS. There is not a high quantity of cesspools in the area (665), but, *Figure 3.10* shows that the cesspools are clustered around vulnerable bodies of water, particularly the Kahaluu Stream. The following sections will evaluate how cesspools are clustered in the area and if there are any feasible locations to implement decentralized cluster wastewater treatment systems.

Table 3.5 Kahaluu: Priority 1 Upgrade Area

From GIS:	From DOH:
• **665** of approximately 10,991 cesspools on Oahu are in this priority 1 area. • Density Index: 0.1237.	• 740 cesspools of 11,300 cesspools on Oahu are in this priority 1 area. • Approximately 5,736 acres. • Discharging .44 mgd. • Nitrogen Flux: 110 kg/d. • Phosphorus flux: 30 kg/d.

Kahaluu: Density Criteria: 3 acres (Search radius of 204 ft.).

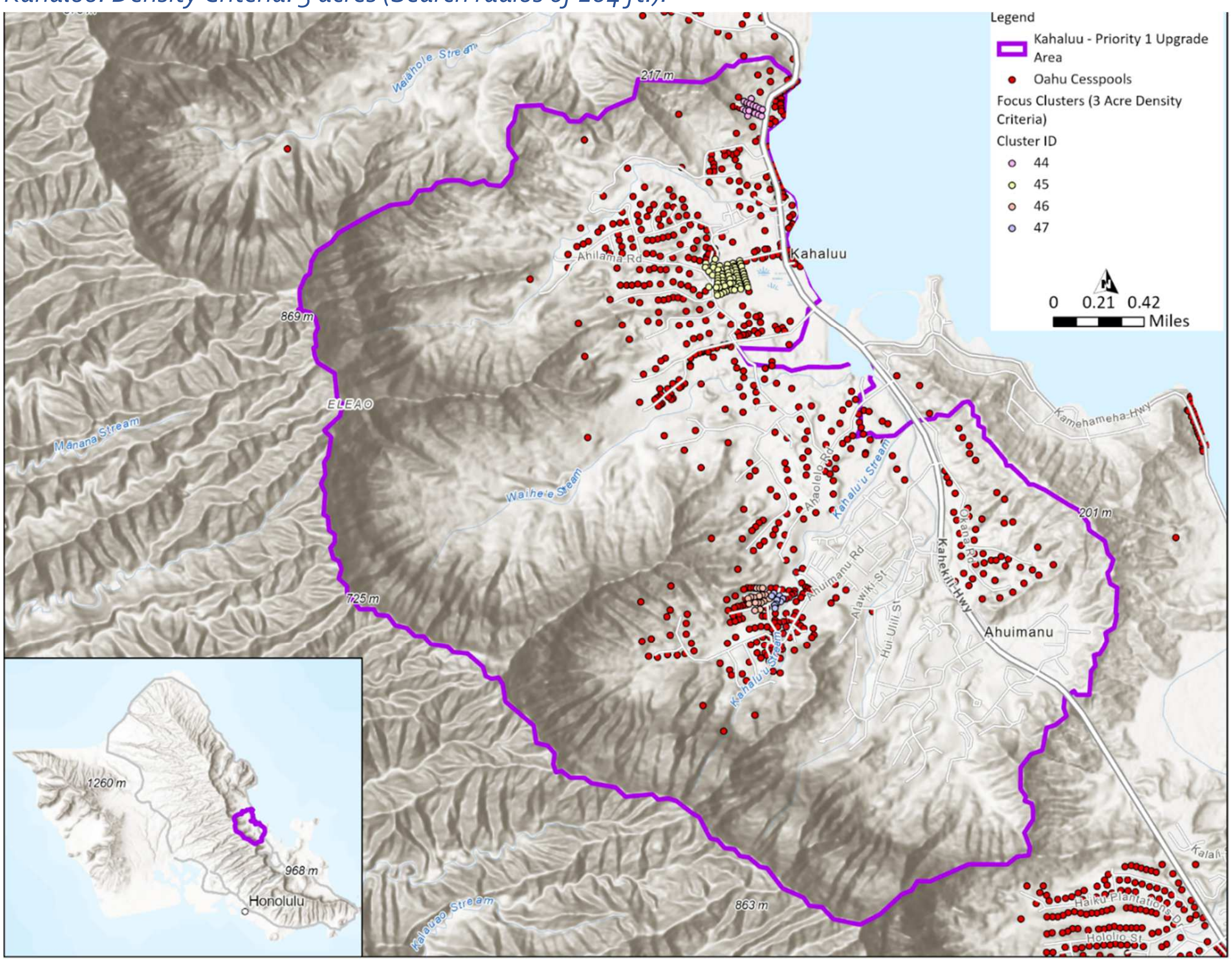

Figure 3.11 Kahaluu Focus Clusters (3 Acre Density Criteria)

Figure 3.11 shows the clusters of cesspools that meet 3-acre density criteria in Kahaluu. There are four focus clusters to analyze further for the 3-acre density criteria in this priority area. These clusters are referred to as "Kahaluu Focus Clusters (3-acre density criteria)", the sizes of which are shown in the chart below (*Figure 3.12).*

- 4 cesspool clusters make up 105 cesspools in this area that meet the density criteria.
    - 105 cesspools are approximately 16% of the total cesspools in Kahaluu.

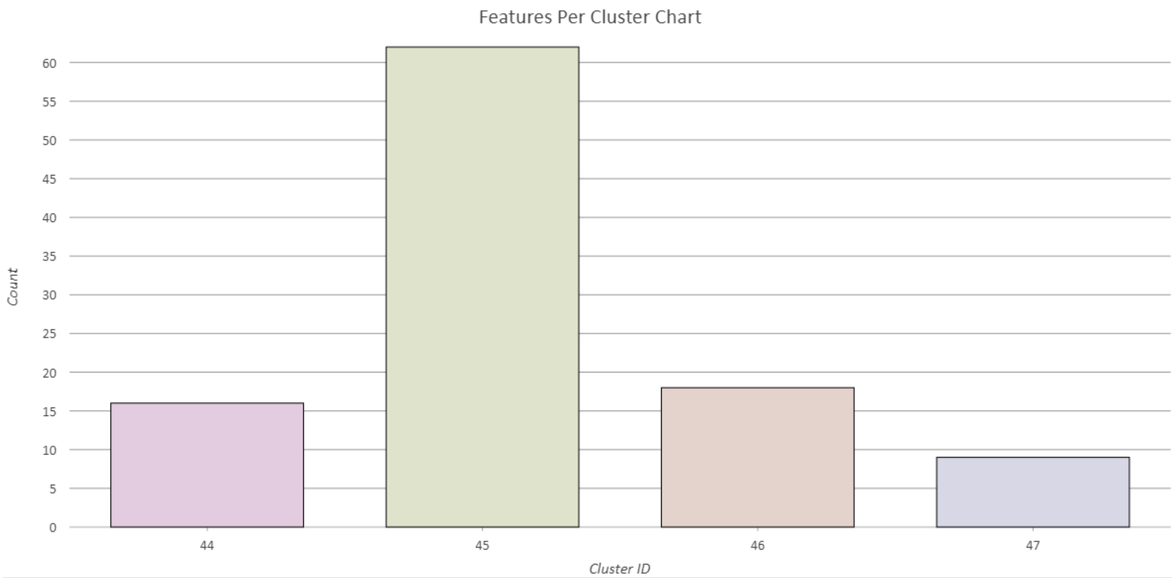

Figure 3.12 Kahaluu Focus Clusters (3 Acre Density Criteria): Features Per Cluster Chart

Kahaluu: Density Criteria: 10 acres (Search radius of 372 ft.).

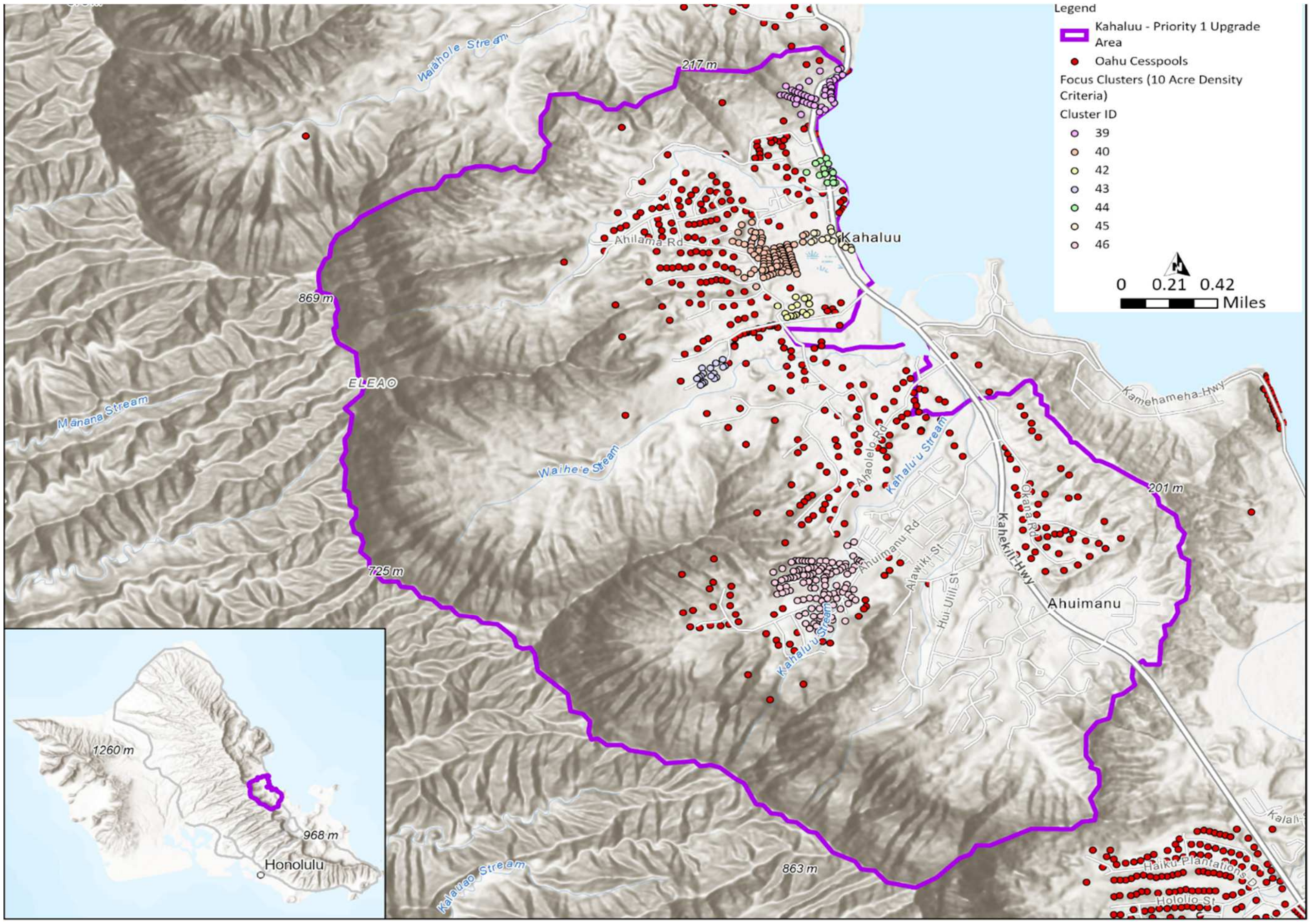

Figure 3.13 Kahaluu Focus Clusters (10 Acre Density Criteria)

Figure 3.13 shows the clusters of cesspools that meet 10-acre density criteria in Kahaluu. There are seven focus clusters to analyze further for the 10-acre density criteria in this priority area. These clusters are referred to as "Kahaluu Focus Clusters (10-acre density criteria)" and their sizes are shown in the chart below (*Figure 3.14).*

- 7 cesspool clusters make up 307 cesspools in this area that meet the density criteria.
  - 1307 cesspools are approximately 46% of the total cesspools in Kahaluu.

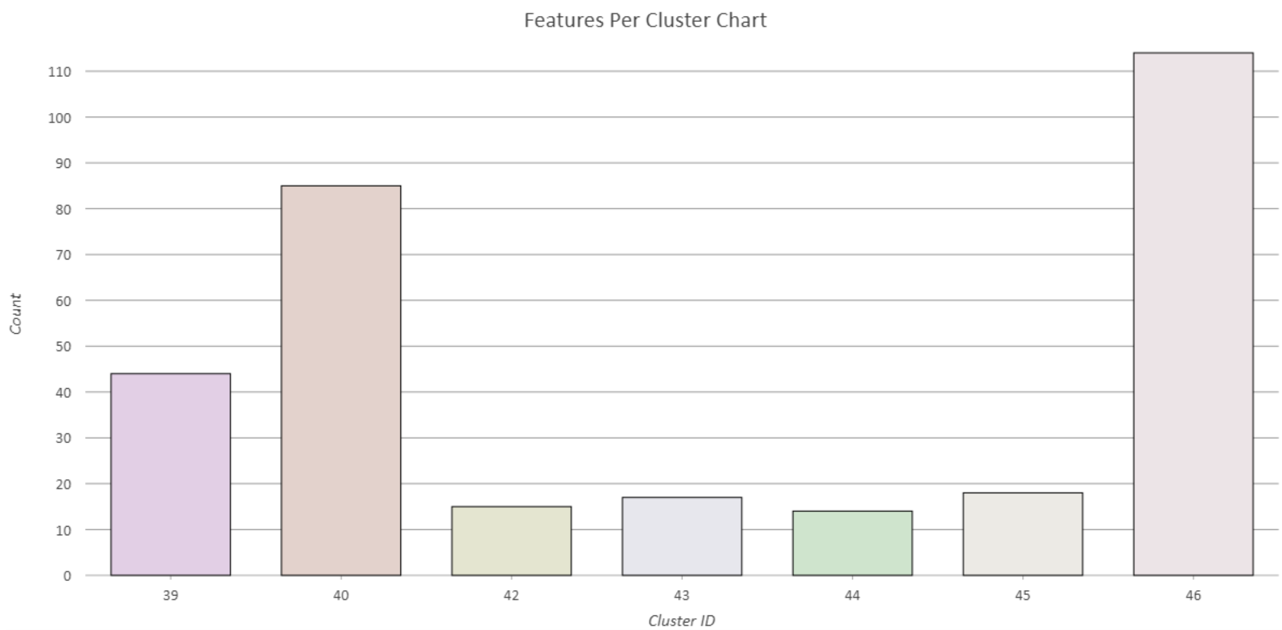

Figure 3.14 Kahaluu Focus Clusters (10 Acre Density Criteria): Features Per Cluster Chart

3.2.2 Maui

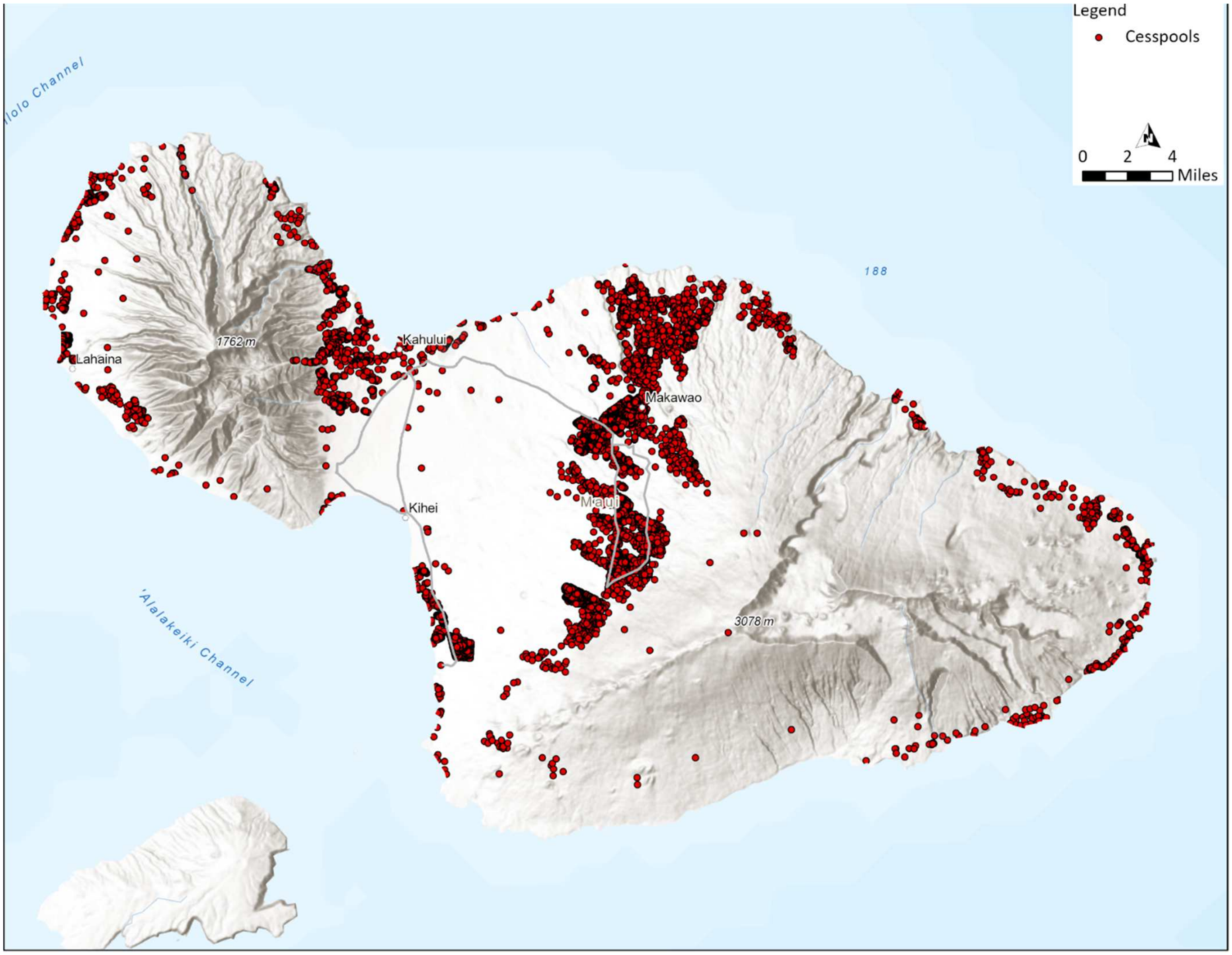

Figure 3.15 9,325 Total Cesspools on Maui

Maui, the third most populated Hawaiian island, hosts the fourth most cesspools in the chain. As shown in *Figure 3.15*, there are approximately 9,325 cesspools on Maui, mostly located in upcountry Maui. Through the method laid out in the previous chapter (*Chapter 2: Materials and Methods)*, the following sections will analyze how cesspools are clustered across the island.

Density Criteria: 3 Acres (Search Radius of 204 ft.)

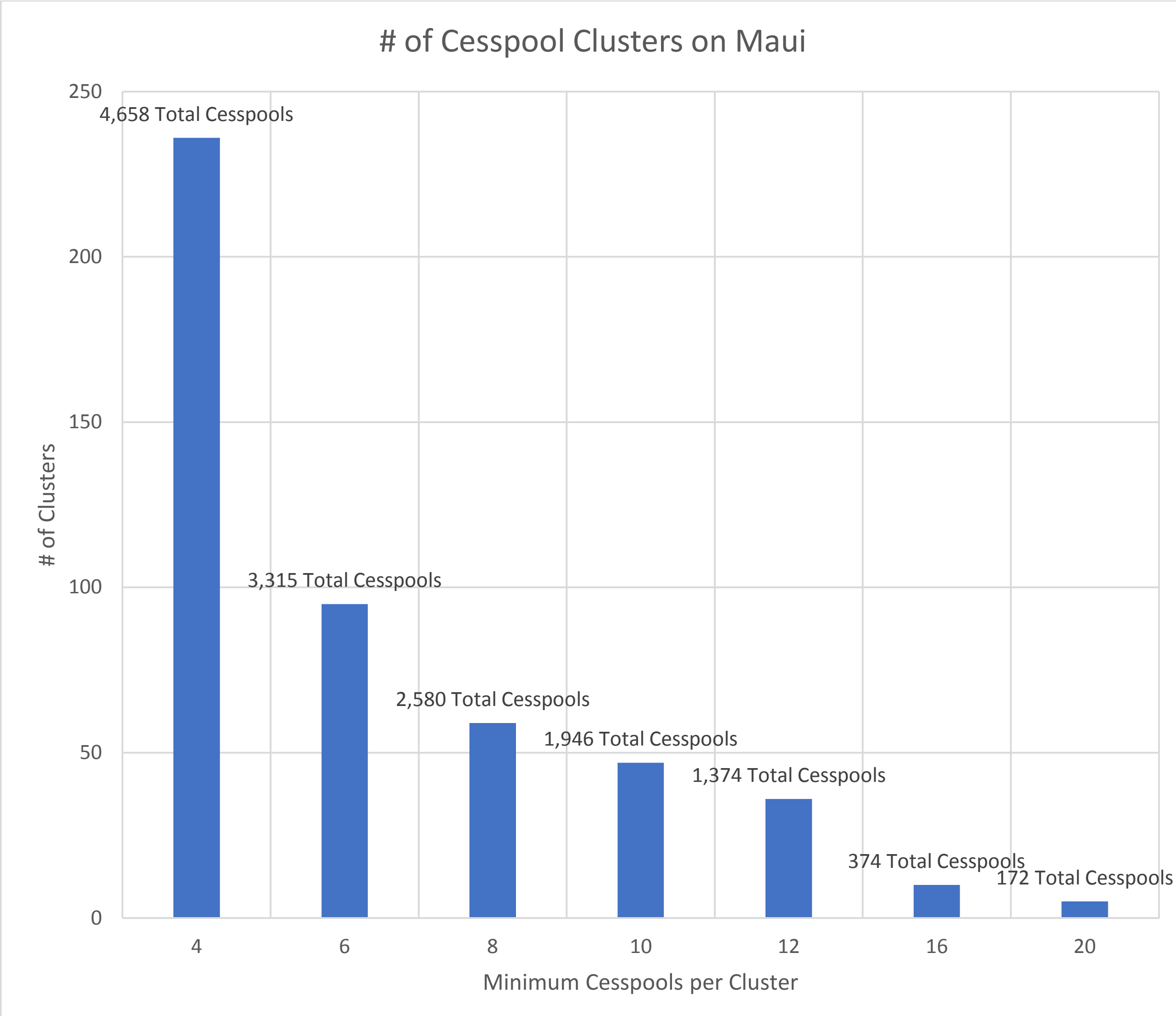

Figure 3.16 # of Clusters that Meet 3 Acre Density Criteria for Different Minimum Sizes of 4,6,8,10,12,16, & 20 Cesspools

Figure 3.16 shows the clusters of cesspools that meet 3-acre density criteria for different minimum sizes of 4,6,8,10,12,16, & 20 on the island of Maui. The 3-acre density criteria entail that each cesspool in a specific cluster is within 204 ft of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 3 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 4 cesspools per cluster: 236 clusters hosting 4,658 cesspools.
- Minimum size of 6 cesspools per cluster: 95 clusters hosting 3,315 cesspools.

- Minimum size of 8 cesspools per cluster: 59 clusters hosting 2,580 cesspools.
- Minimum size of 10 cesspools per cluster: 43 clusters hosting 1,946 cesspools.
- Minimum size of 12 cesspools per cluster: 35 clusters hosting 1,374 cesspools.
- Minimum size of 16 cesspools per cluster: 10 clusters hosting 374 cesspools.
- Minimum size of 20 cesspools per cluster: 5 clusters hosting 172 cesspools.

These results show that there are a lot of small clusters in the Island of Maui, the number of clusters that meet the criteria is more than halved when you go from a minimum size of 4 to a minimum size of 6. It also shows that there are about 1,946 total cesspools that meet the 3-acre clustering criteria for a minimum size of 10 cesspools, which is approximately 21% of the total cesspools on the island. A minimum size of 10 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 21% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for decentralized treatment and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 21% to 12% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

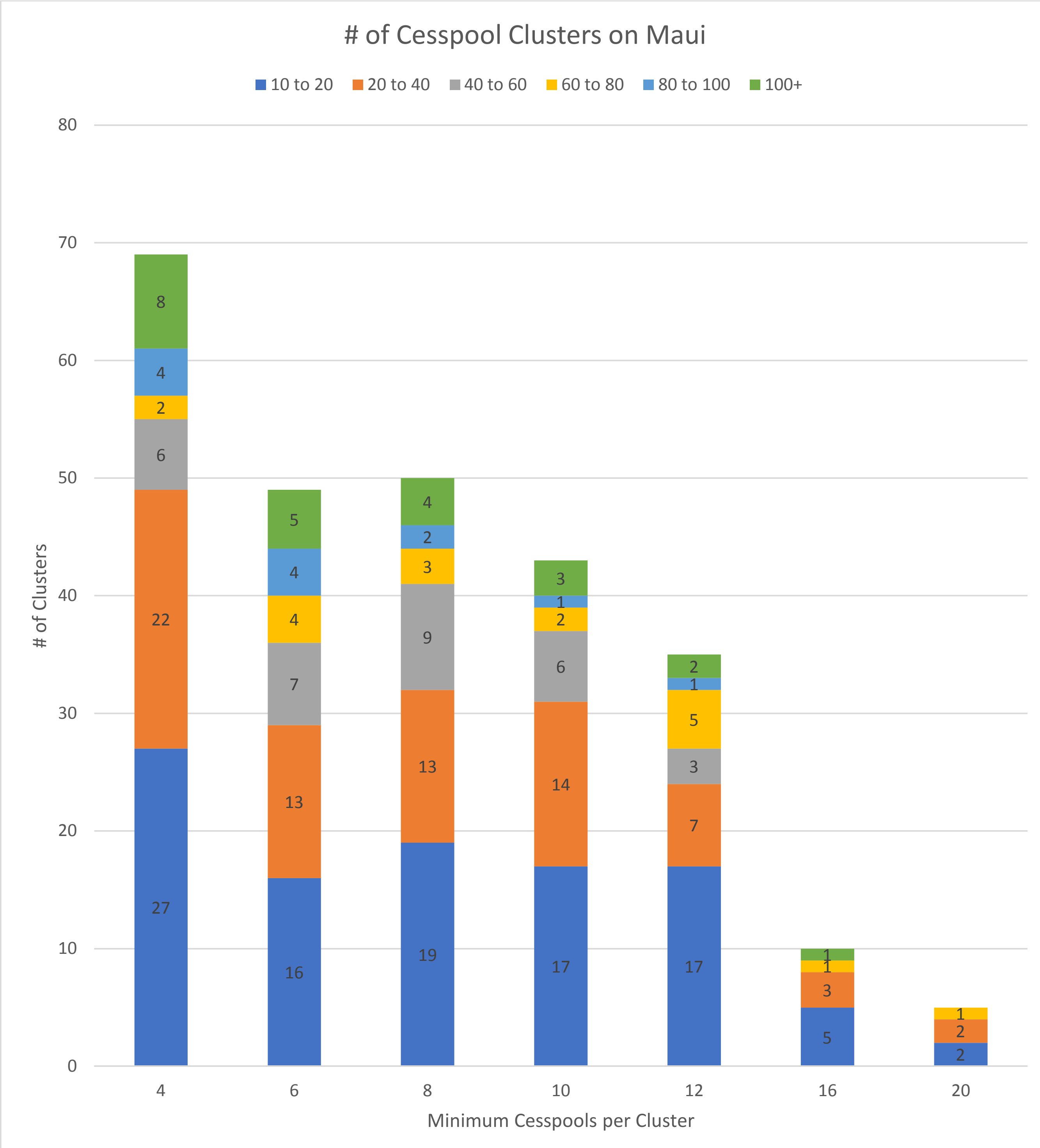

Figure 3.17 # of Clusters that meet the 3 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 3-acre density criteria, *Figure 3.17* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 43 clusters with a minimum size of 10 that meet the 3-acre density criteria, 40 are between 10-100 cesspools in size, 17 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Density Criteria: 6 Acres (Search Radius of 288.5 ft.)

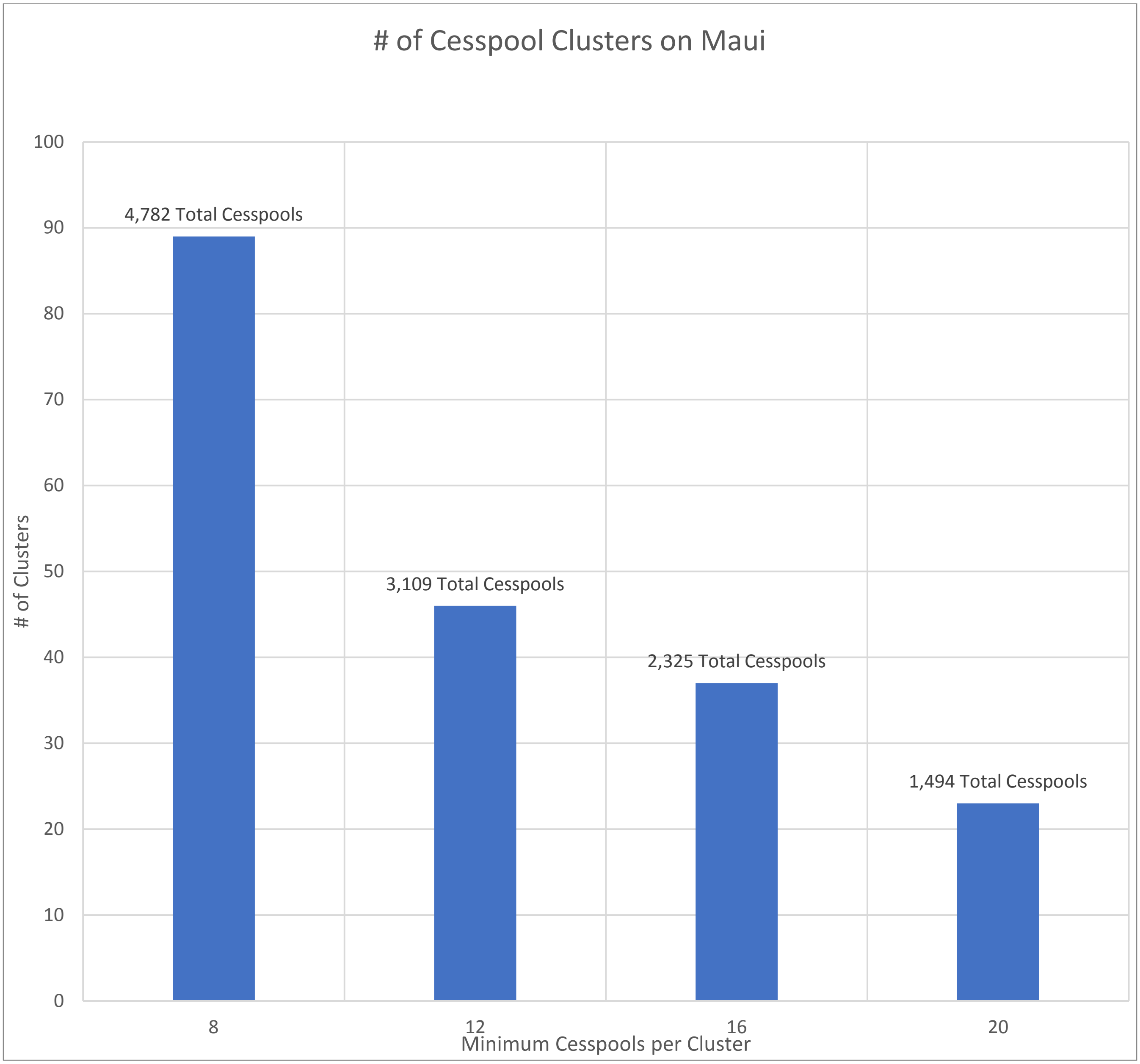

Figure 3.18 # of Clusters that Meet 6 Acre Density Criteria for Different Minimum Sizes of 8,12,16, & 20 Cesspools

Figure 3.18 shows the clusters of cesspools that meet 6-acre density criteria for different minimum sizes of 8,12,16,& 20 on the island of Maui. The 6-acre density criteria entail that each cesspool in a specific cluster is within 288.5 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 6 -acre area.

The “minimum cesspools per cluster” on the x axis shows different size requirements that needed to be met and the “# of Clusters” on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 8 cesspools per cluster: 89 clusters hosting 4,782 cesspools.
- Minimum size of 12 cesspools per cluster: 46 clusters hosting 3,109 cesspools.
- Minimum size of 16 cesspools per cluster: 37 clusters hosting 2,325 cesspools.
- Minimum size of 20 cesspools per cluster: 23 clusters hosting 1,494 cesspools.

These results show that there are about 3,109 total cesspools that meet the 6-acre clustering criteria for a minimum size of 12 cesspools, which is approximately 33% of the total cesspools on the island. A minimum size of 12 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 33% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for cluster system implementation and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 33% to 17% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

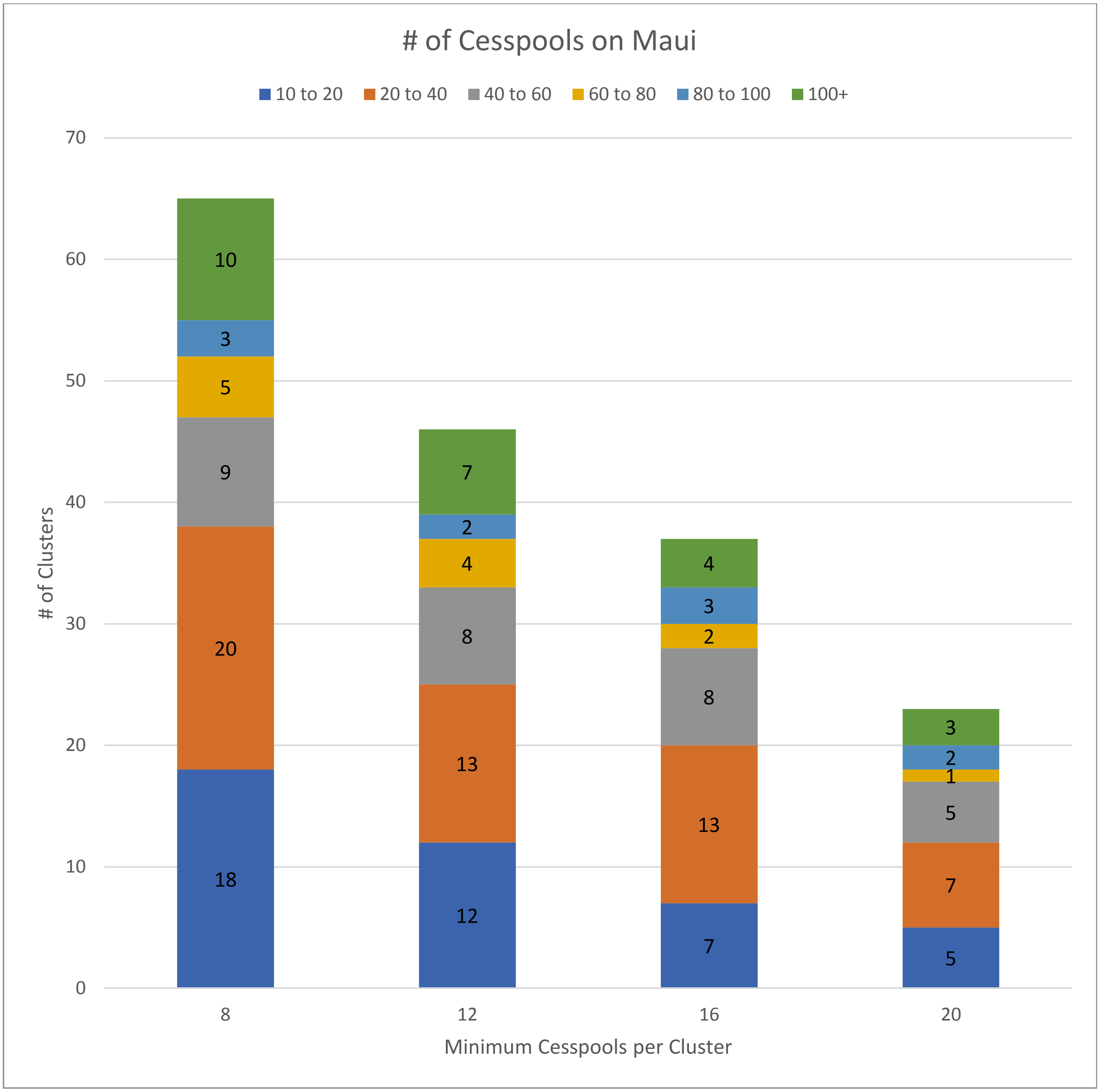

Figure 3.19 # of Clusters that meet the 6 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 6-acre density criteria, *Figure 3.19* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100 and 100+.

For example, of the 46 clusters with a minimum size of 12 that meet the 6-acre density criteria, 39 are between 10-100 cesspools in size, 12 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Density Criteria: 10 Acres (Search Radius of 372 ft.)

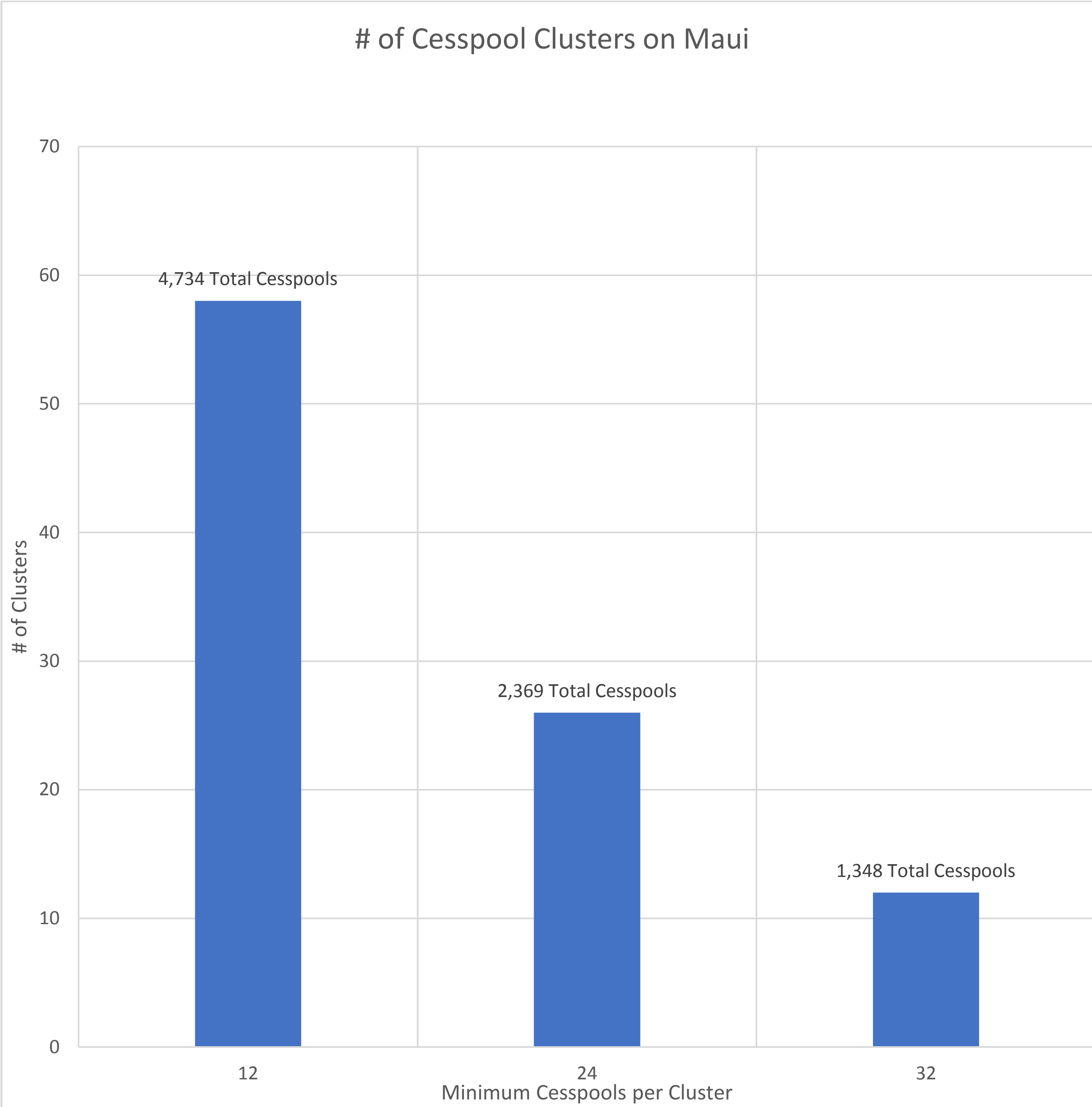

Figure 3.20 # of Clusters that Meet 10 Acre Density Criteria for Different Minimum Sizes of 12, 24, & 32 Cesspools

Figure 3.20 shows the clusters of cesspools that meet 10-acre density criteria for different minimum sizes of 12, 24, & 32 on the island of Maui. The 10-acre density criteria entail that each cesspool in a specific cluster is within 372 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 10 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 12 cesspools per cluster: 56 clusters hosting 4,743 cesspools.
- Minimum size of 24 cesspools per cluster: 26 clusters hosting 2,369 cesspools.
- Minimum size of 32 cesspools per cluster: 12 clusters hosting 1,348 cesspools.

These results show that there are about 4,743 total cesspools that meet the 10-acre clustering criteria for a minimum size of 12 cesspools, which is approximately 51% of the total cesspools on the island. A minimum size of 12 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 51% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for cluster system implementation and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 51% to 16% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

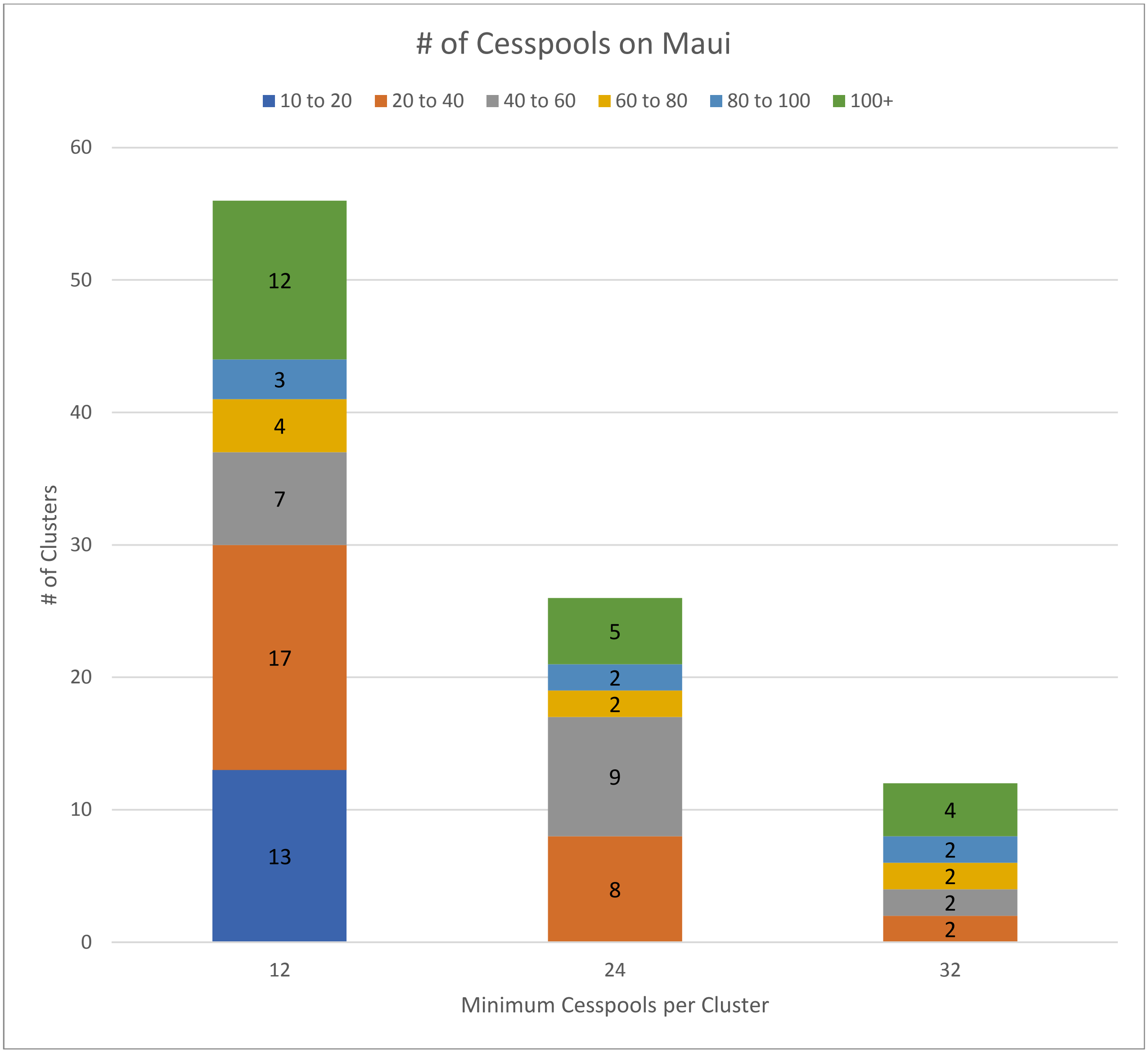

Figure 3.21 # of Clusters that meet the 10 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 10-acre density criteria, *Figure 3.21* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 56 clusters with a minimum size of 12 that meet the 10-acre density criteria, 44 are between 10-100 cesspools in size, 13 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Overview: A look at the Cluster Feasibility Density Analysis

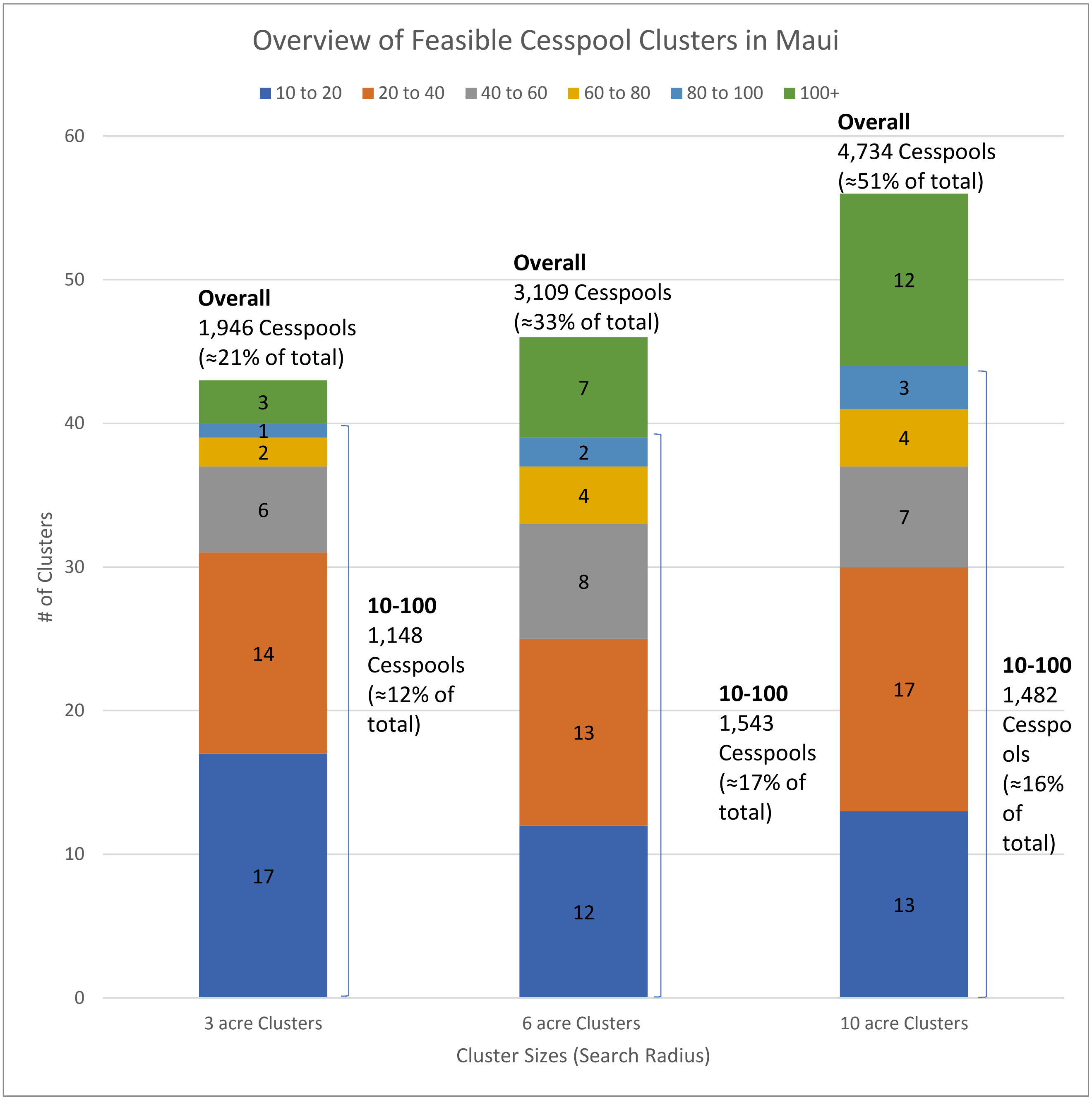

Figure 3.22 Overview of Feasible Cesspool Clusters in Maui of size 10-100

Figure 3.22 shows an overview of the clusters of cesspools across the island of Maui that meet a certain size feasibility constraint (10-100). The graph breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

The results are as follows:

- For 3-acre density criteria,

    - Overall: **43 clusters/neighborhoods**
        - 1,946 total cesspools (21% of total)
    - Size 10-100: **40 clusters/neighborhoods**
        - 1,148 total cesspools (12% of total)
- For 6-acre density criteria,
    - Overall: **46 Clusters/neighborhoods**
        - 3,109 total cesspools (33% of total)
    - Size 10-100: **39 clusters/neighborhoods**
        - 1,543 total cesspools (17% of total)
- For 10-acre density criteria,
    - Overall: **56 clusters/neighborhoods**
        - 4,734 total cesspools (51% of total)
    - Size 10-100: **44 clusters/neighborhoods**
        - 1,482 total cesspools (16% of total)

These results provide an overview for cluster feasibility on the island of Maui across different density criteria.

Maui Focus Clusters & Priority Areas

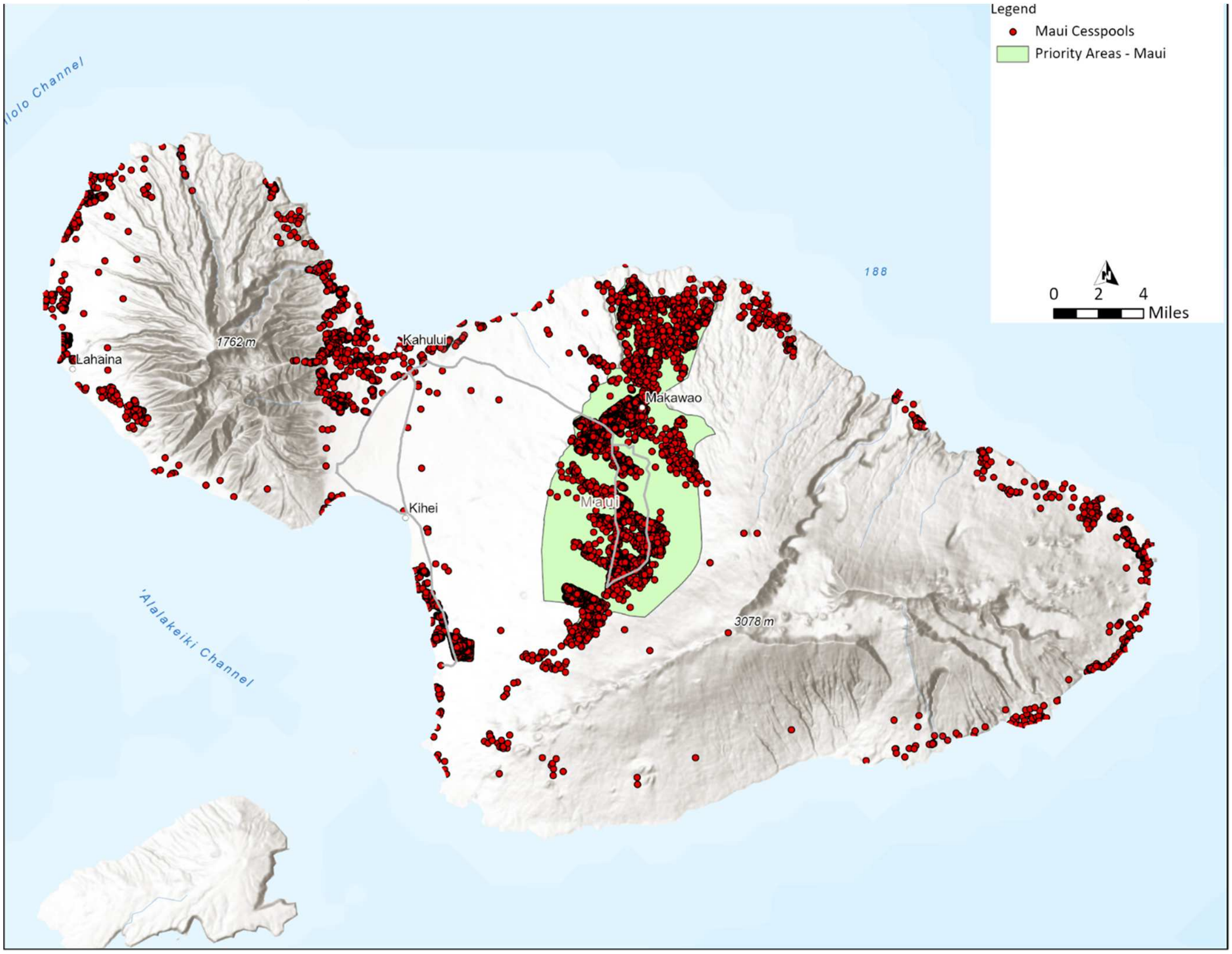

Figure 3.23 Priority Upgrade Areas in Maui as Defined by DOH

Figure 3.23 shows the single priority area on the Island of Maui, outlined in *Table 3.4.* The area in green is called Upcountry Maui and it is a priority-1 area, as defined by DOH (see section *1.3)* . Upcountry Maui hosts a total of 7,400 cesspools that discharge an estimated 4.4 mgd of effluent (DOH).

Table 3.6 Initial Maui Priority Upgrade Areas Established by DOH WWB (DOH, 2018)

Geographic Area	Priority Level Assigned	Number of Cesspools	Estimated Effluent Discharge (mgd)
Upcountry area of Maui	1	7,400	4.4
	Total Assigned	**7,400**	**4.4**
Maui Un-Assigned	NA	4,800	3.5
	Totals	**12,200**	**7.9**

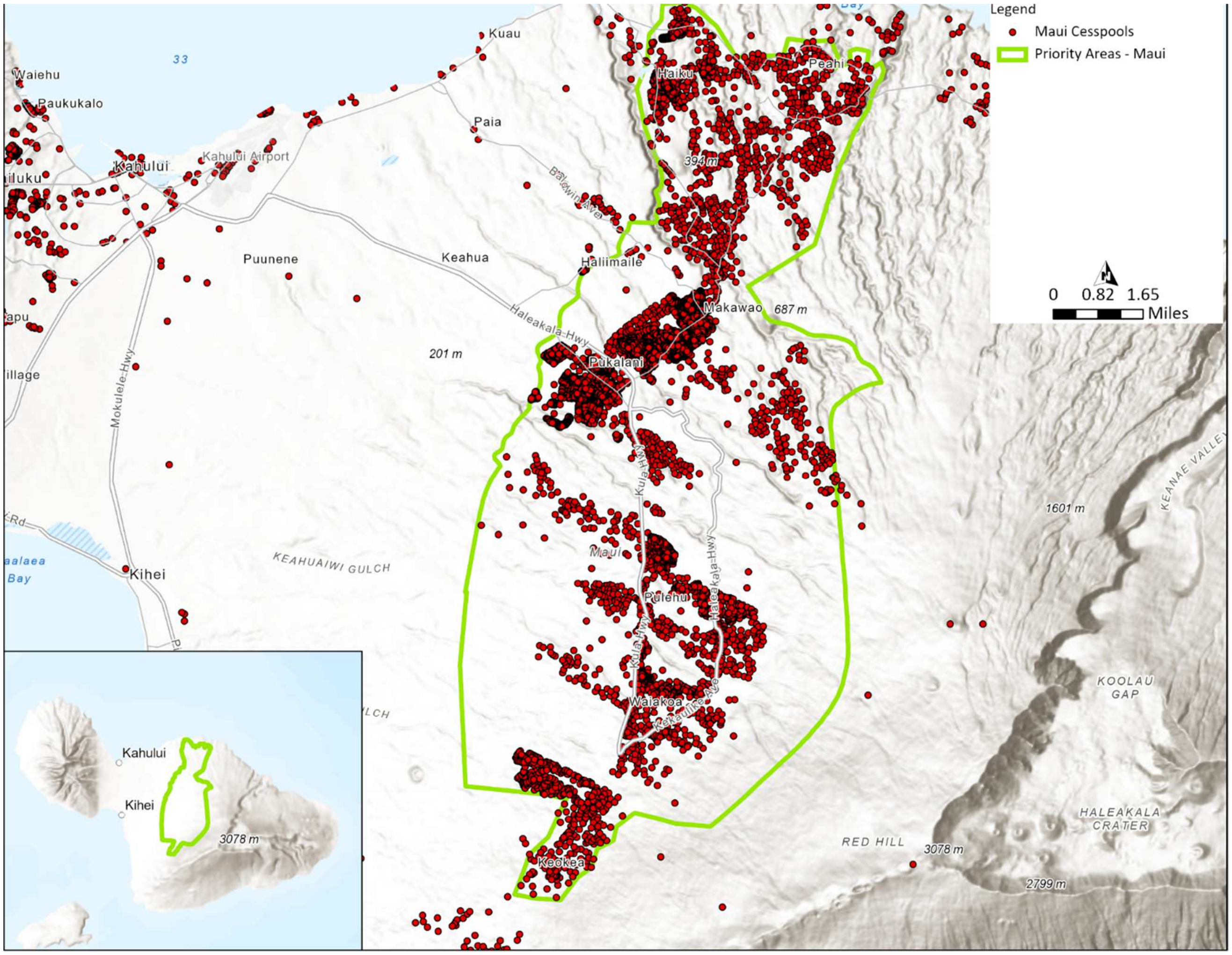

Figure 3.24 Upcountry Maui: Priority 1 Upgrade Area

Figure 3.24 focuses in on Upcountry Maui, a priority-1 area as defined by DOH, the cesspools it contains pose a significant risk of human health impacts, drinking water impacts, or draining to sensitive waters. *Table 3.7* provides specific information to the area derived from DOH and GIS. Approximately 60 % of the total cesspools on Maui are found in this area and *Figure 3.24* shows how densely populated it is. The following sections will evaluate how cesspools are clustered in the area and if there are any feasible locations to implement decentralized cluster wastewater treatment systems.

Table 3.7 Upcountry Maui: Priority 1 Upgrade Area

From GIS:	From DOH:
• **5,682** of approximately 9,325 cesspools on Maui are in this priority 1 area. • Density Index: 0.1272.	• 7,400 cesspools of 12,200 cesspools on Maui are in this priority 1 area. • Approximately 46,080 acres. • Discharging 4.4 mgd. • Nitrogen Flux: 980 kg/d. • Phosphorus flux: 280 kg/d.

Upcountry Maui: Density Criteria: 3 acres (Search radius of 204 ft.).

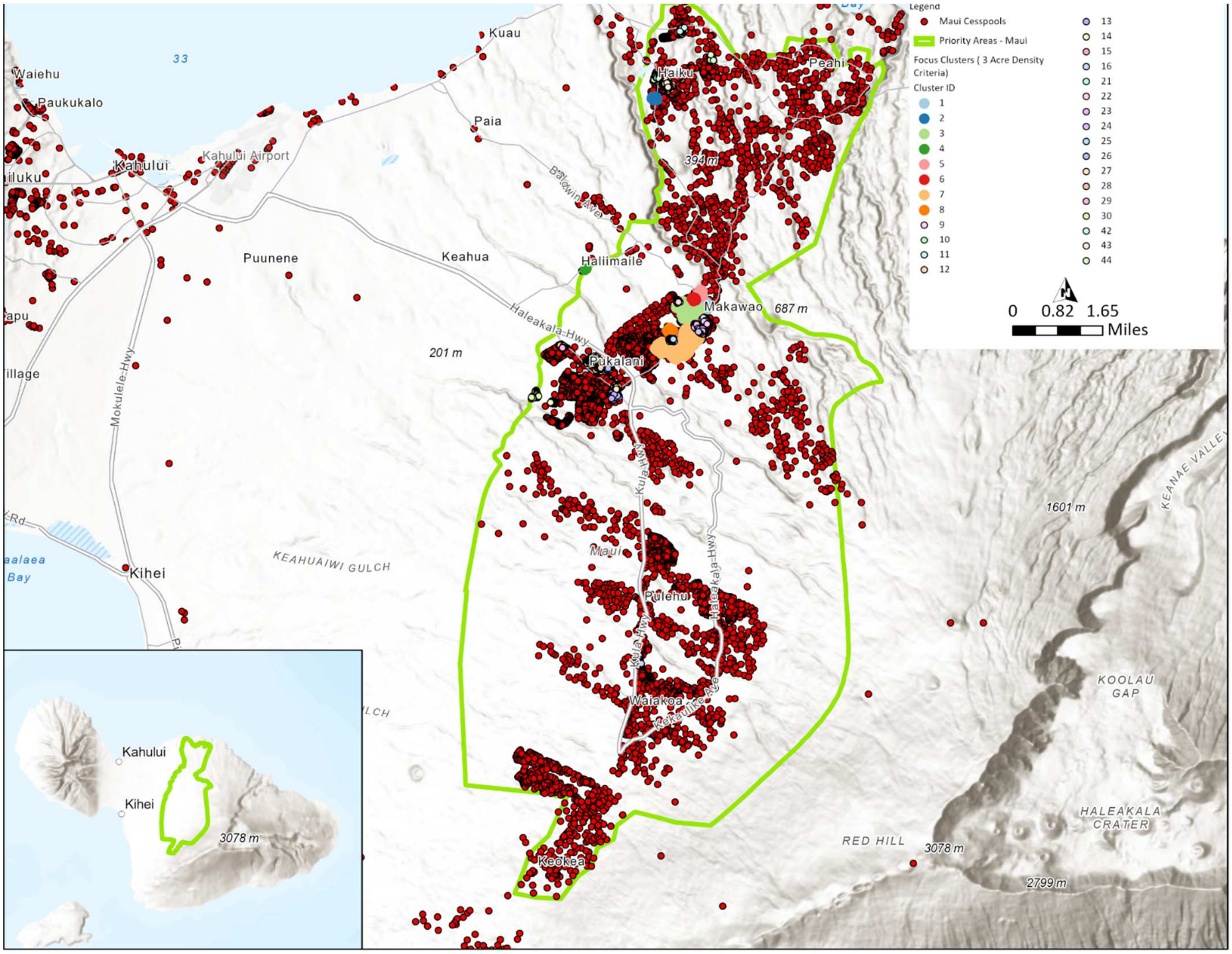

Figure 3.25 Upcountry Maui Focus Clusters (3 Acre Density Criteria)

Figure 3.25 shows the clusters of cesspools that meet 3-acre density criteria in Upcountry Maui. There are 29 focus clusters that could be analyzed further for the 3-acre density criteria in this priority area. These clusters are referred to as "Upcountry Maui Focus Clusters (3-acre density criteria)", the sizes of which are shown in the chart below (*Figure 3.26).*

- 29 cesspool clusters make up 1,196 cesspools in this area that meet the density criteria.
    - 1,196 cesspools are approximately 21% of the cesspools in Upcountry Maui.

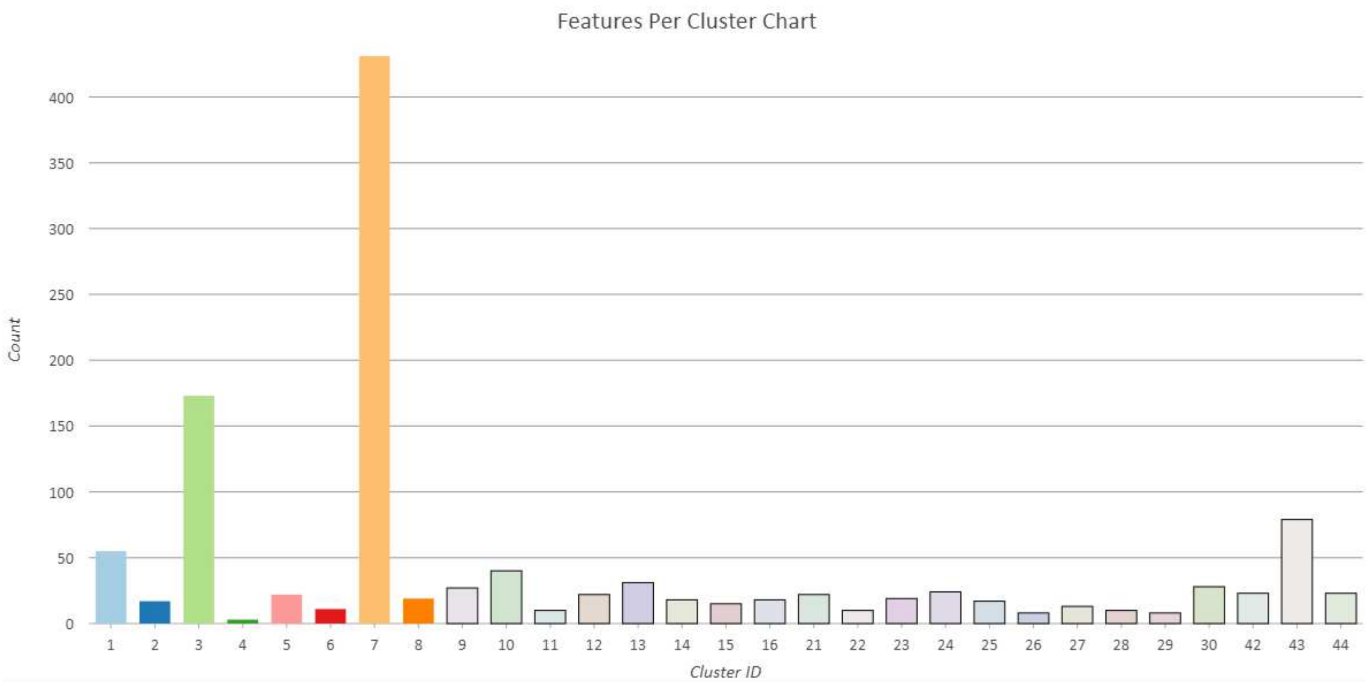

Figure 3.26 Upcountry Maui Focus Clusters (3 Acre Density Criteria): Features Per Cluster Chart

Upcountry Maui: Density Criteria: 10 acres (Search radius of 372 ft.).

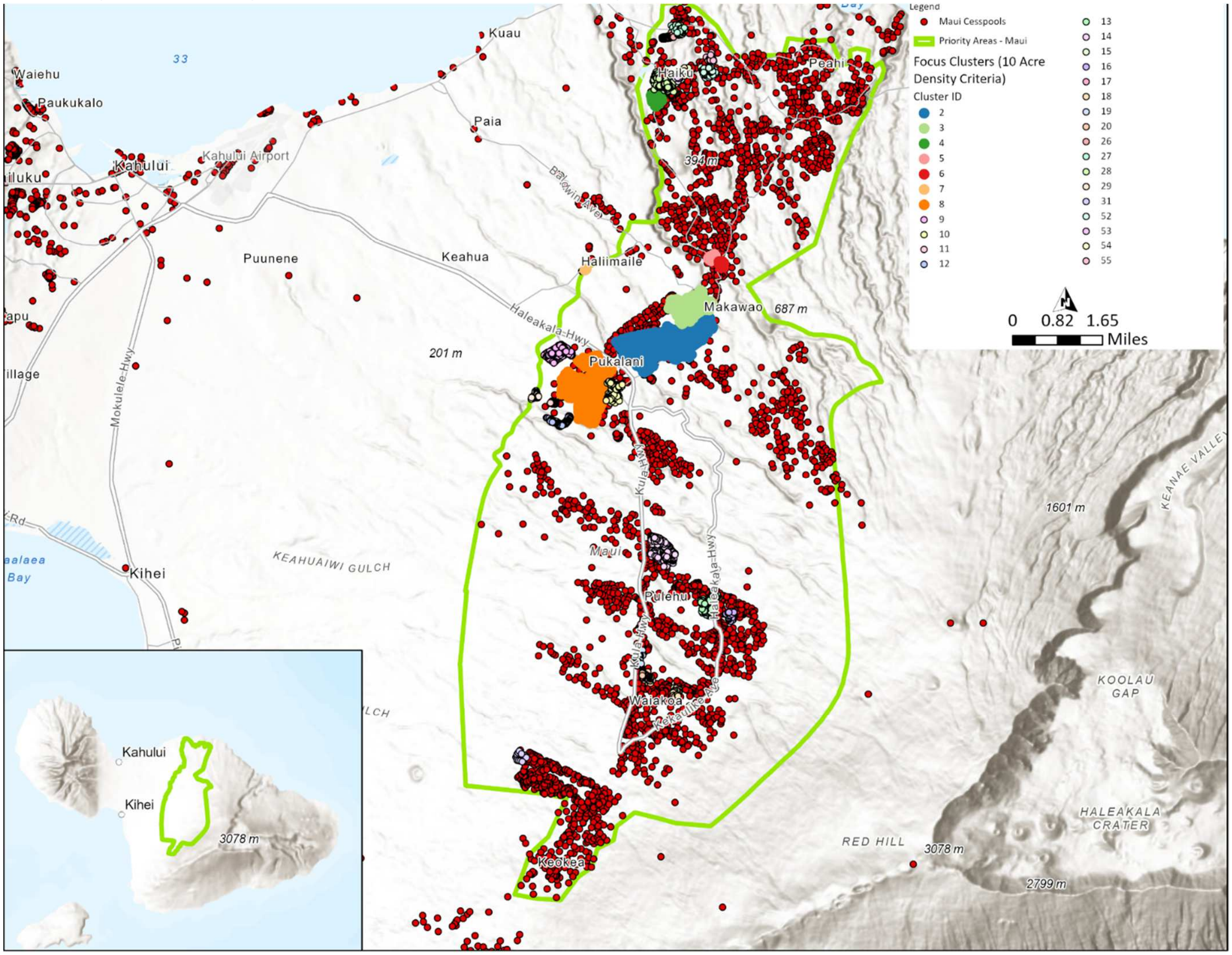

Figure 3.27 Upcountry Maui Focus Clusters (10 Acre Density Criteria)

Figure 3.27 shows the clusters of cesspools that meet 10-acre density criteria in Upcountry Maui. There are 29 focus clusters that could be analyzed further for the 10-acre density criteria in this priority area. These clusters are referred to as "Upcountry Maui Focus Clusters (10-acre density criteria)", the sizes of which are shown in the chart below (*Figure 3.28).*

- 26 cesspool clusters make up 3,004 cesspools in this area that meet the density criteria.
  - 3,004 cesspools are approximately 53% of the cesspools in Upcountry Maui.

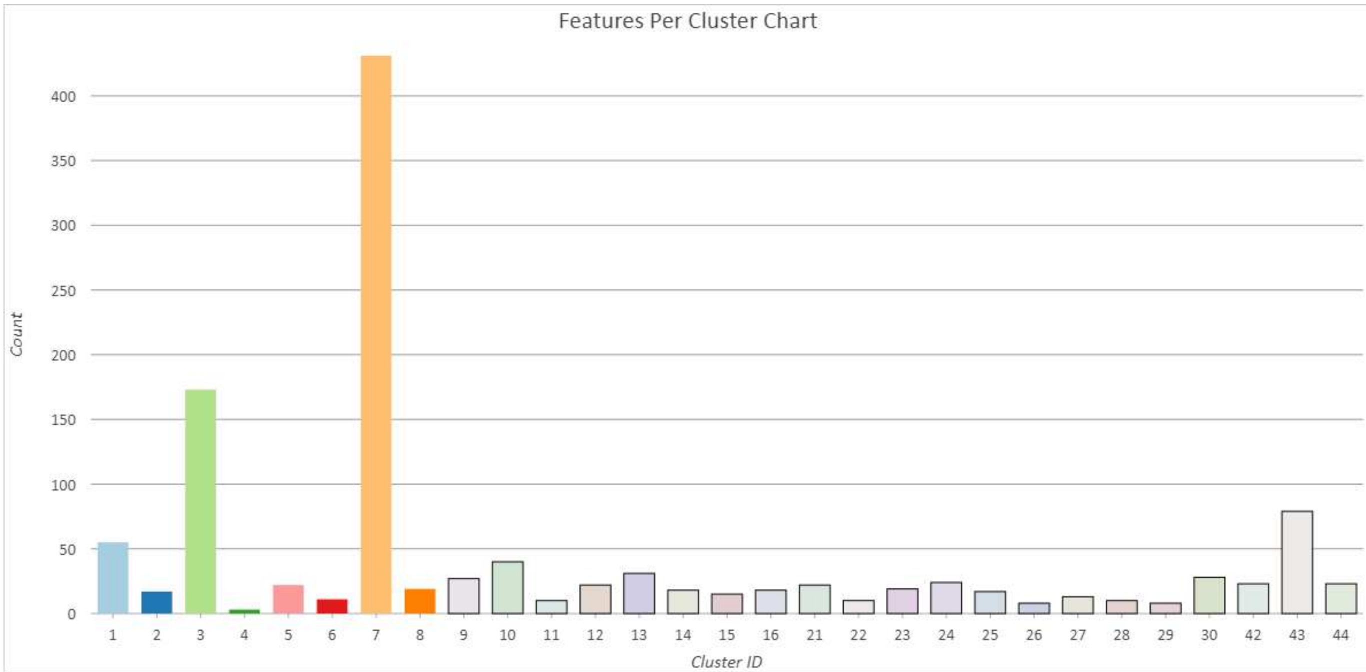

Figure 3.28 Upcountry Maui Focus Clusters (10 Acre Density Criteria): Features Per Cluster Chart

3.2.3 Big Island

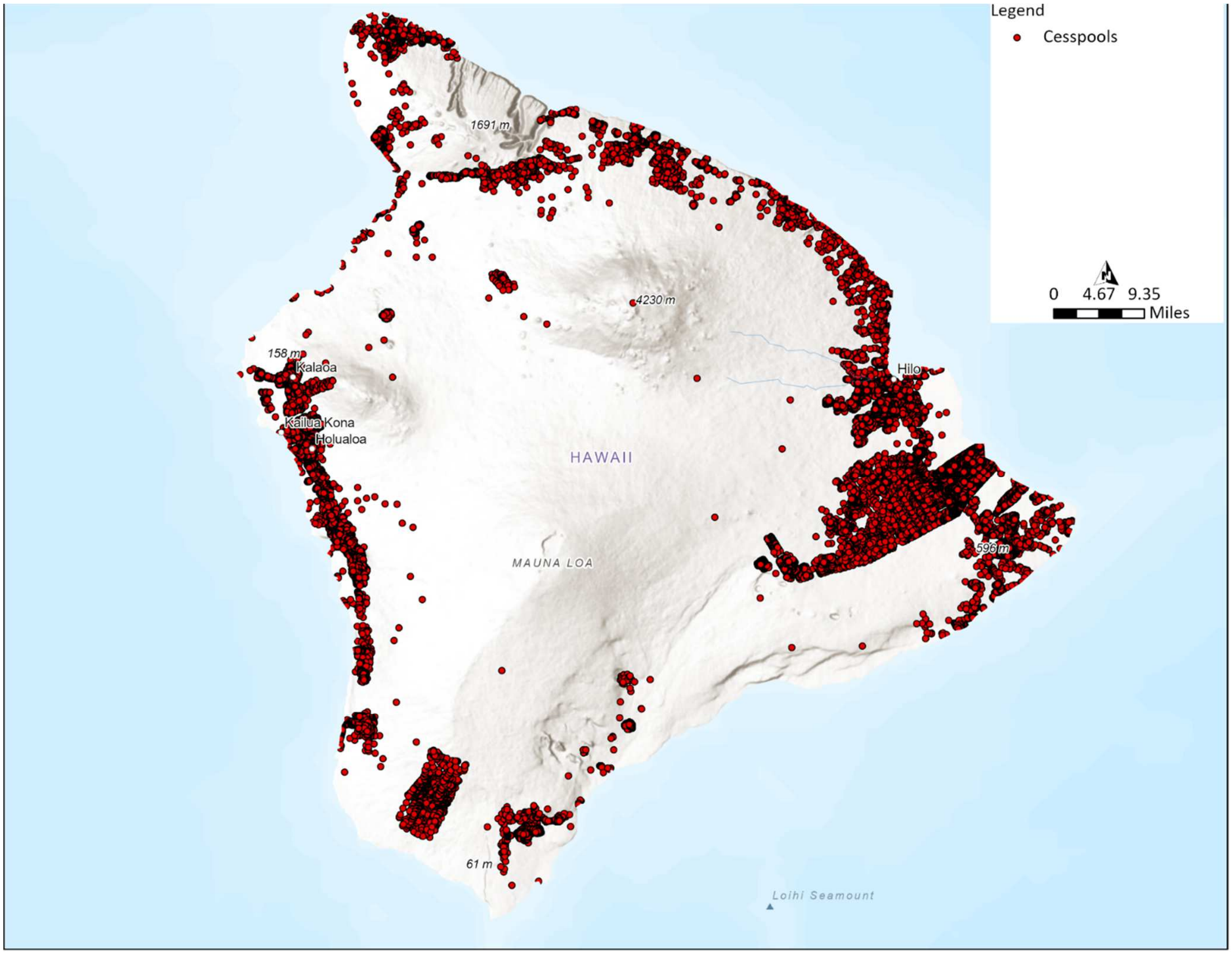

Figure 3.29 45,819 Total Cesspools on Big Island

The Big Island (Hawaii) is the biggest and second most populated Hawaiian island, it also hosts the most cesspools in the chain, by far. As shown in *Figure 3.29*, there are approximately 45,819 cesspools on Big Island, more than all the other islands combined. Like the other islands, most of the cesspools are located along the coasts and in residential neighborhoods. Through the method laid out in the previous chapter (*Chapter 2: Materials and Methods)*, the following sections will analyze how cesspools are clustered across the island.

Density Criteria: 3 Acres (Search Radius of 204 ft.)

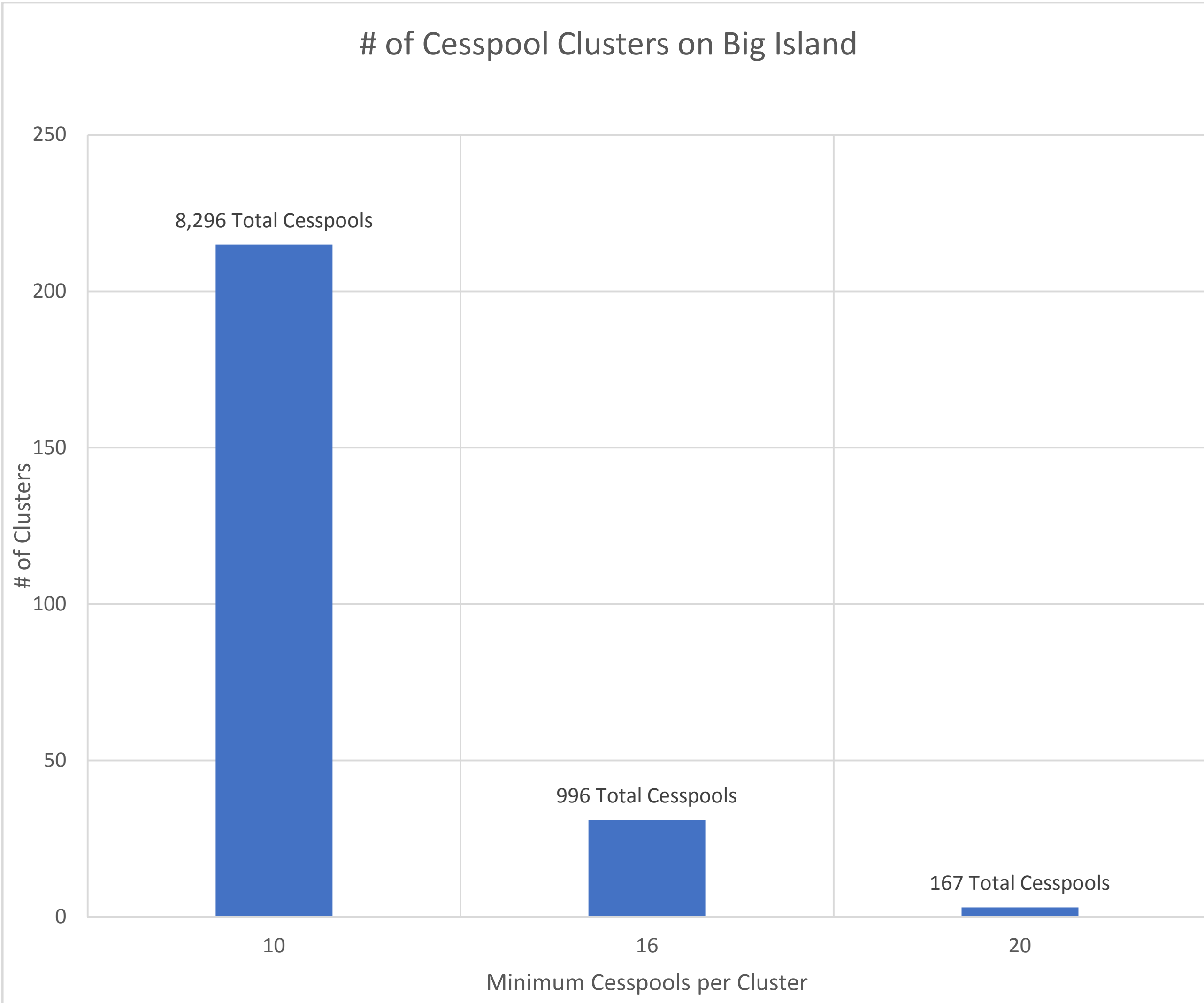

Figure 3.30 # of Clusters that Meet 3 Acre Density Criteria for Different Minimum Sizes of 10,16, & 20 Cesspools

Figure 3.30 shows the clusters of cesspools that meet 3-acre density criteria for different minimum sizes of 10,16, & 20 on the Big Island. The 3-acre density criteria entail that each cesspool in a specific cluster is within 204 ft of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 3 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 10 cesspools per cluster: 215 clusters hosting 8,296 cesspools.
- Minimum size of 16 cesspools per cluster: 31 clusters hosting 996 cesspools.
- Minimum size of 20 cesspools per cluster: 3 clusters hosting 167 cesspools.

These results show that there are a lot of small clusters in the Big Island , the number of cesspools that meet the criteria goes way down when you go from a minimum size of 10 to a minimum size of 16. It also shows that there are about 8,296 total cesspools that meet the 3-acre clustering criteria for a minimum size of 10 cesspools, which is approximately 18% of the total cesspools on the island. A minimum size of 10 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 18% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for decentralized treatment and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 18% to 13% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

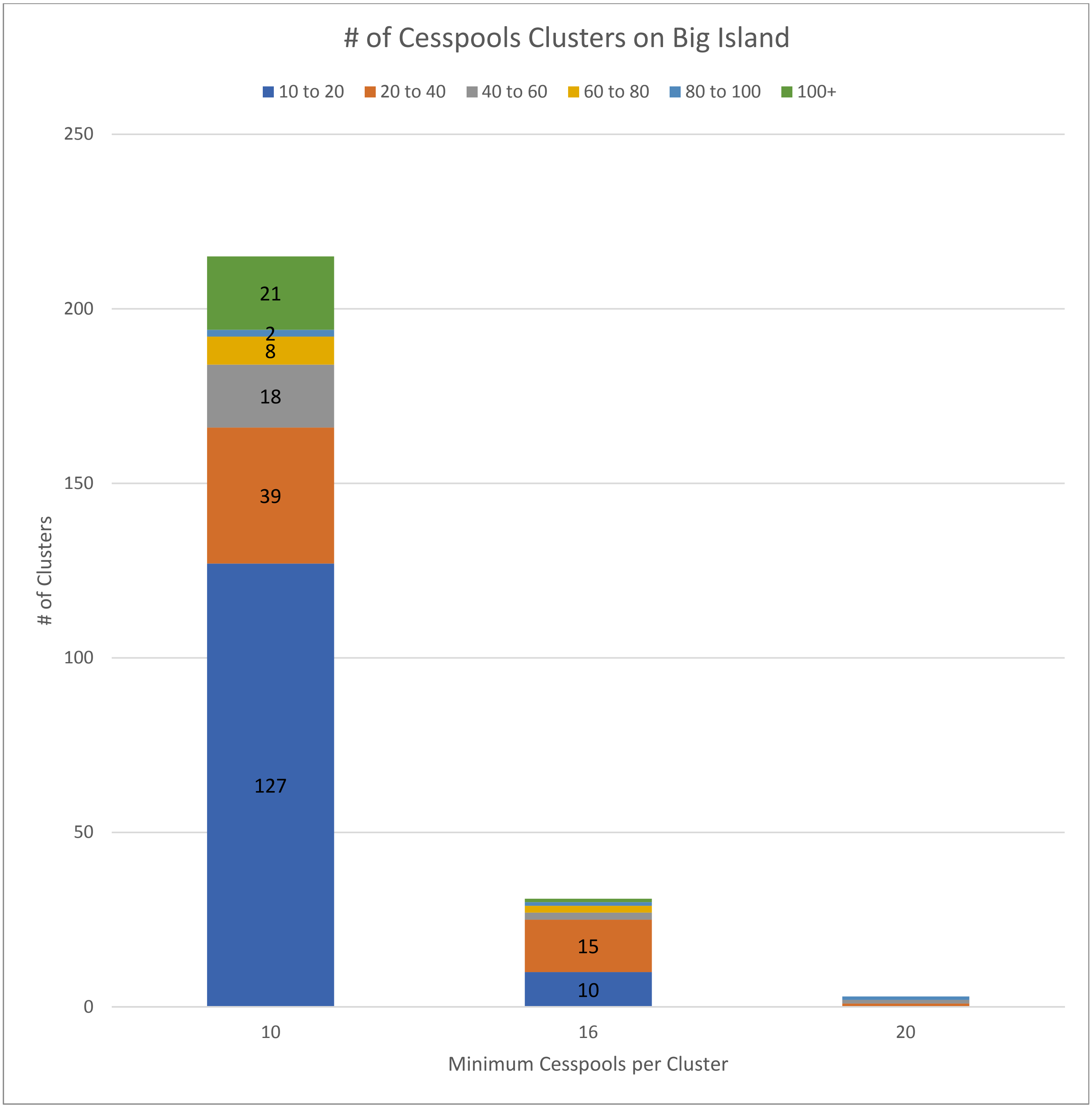

Figure 3.31 # of Clusters that meet the 3 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 3-acre density criteria, *Figure 3.31* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 215 clusters with a minimum size of 10 that meet the 3-acre density criteria, 194 are between 10-100 cesspools in size, 127 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Density Criteria: 6 Acres (Search Radius of 288.5 ft.)

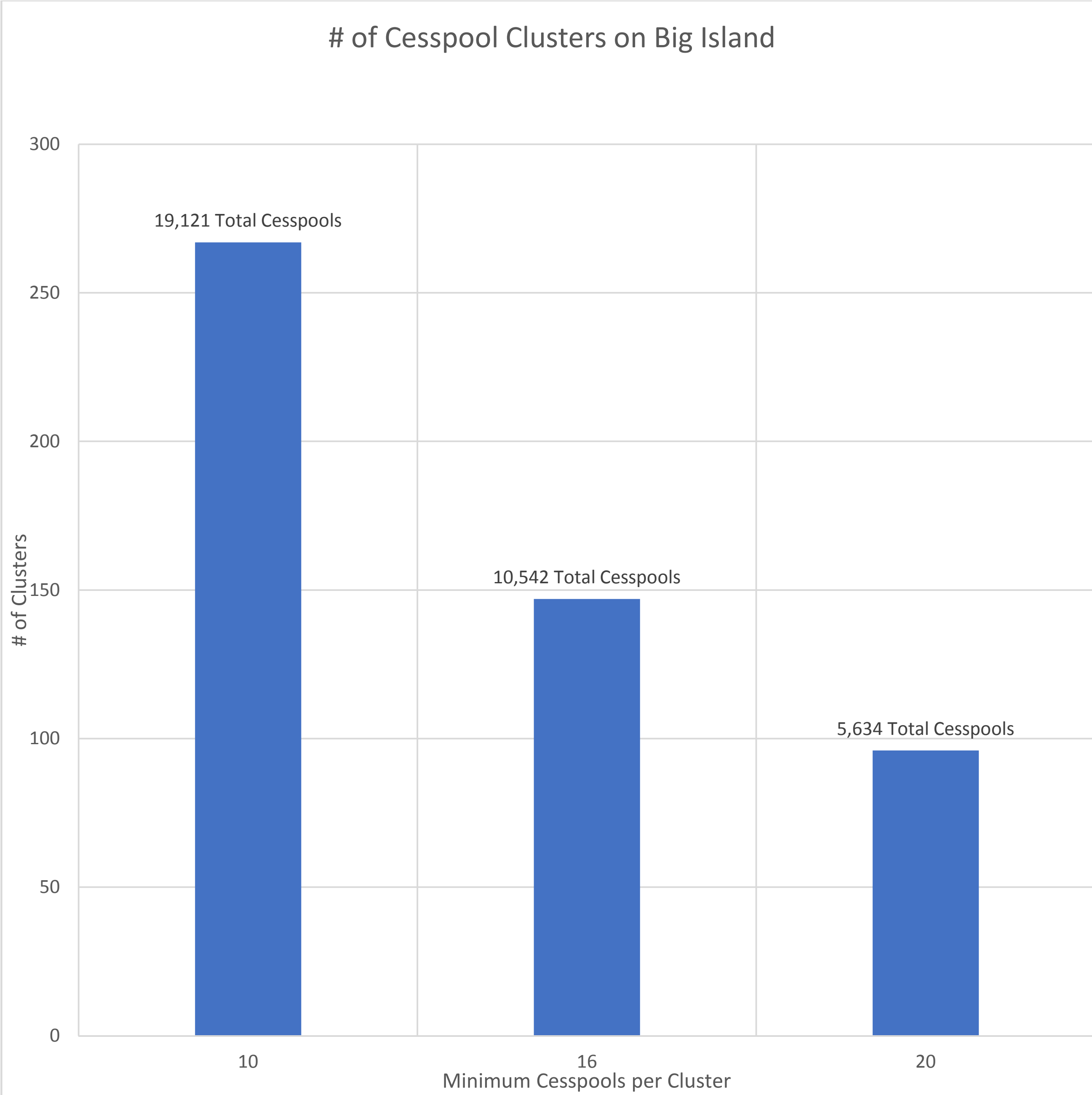

Figure 3.32 # of Clusters that Meet 6 Acre Density Criteria for Different Minimum Sizes of 10,16, & 20 Cesspools

Figure 3.32 shows the clusters of cesspools that meet 6-acre density criteria for different minimum sizes of 10,16,& 20 on the Big Island. The 6-acre density criteria entail that each cesspool in a specific cluster is within 288.5 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 6 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 10 cesspools per cluster: 267 clusters hosting 19,121 cesspools.
- Minimum size of 16 cesspools per cluster: 147 clusters hosting 10,542 cesspools.
- Minimum size of 20 cesspools per cluster: 96 clusters hosting 5,634 cesspools.

These results show that there are about 19,121 total cesspools that meet the 6-acre clustering criteria for a minimum size of 10 cesspools, which is approximately 42% of the total cesspools on the island. A minimum size of 10 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 42% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for cluster system implementation and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 42% to 13% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

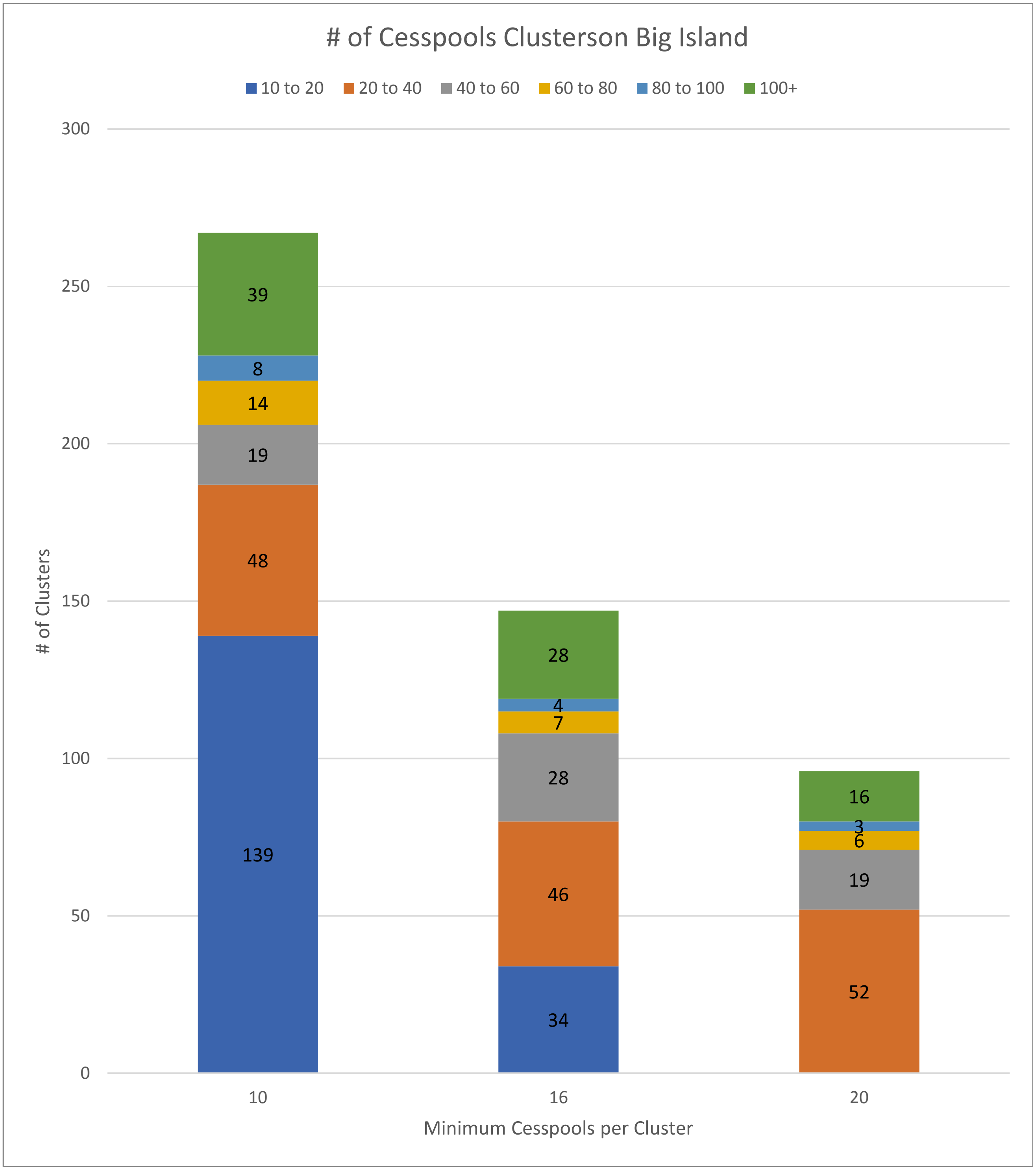

Figure 3.33 # of Clusters that meet the 6 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 6-acre density criteria, *Figure 3.19* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 267 clusters with a minimum size of 10 that meet the 6-acre density criteria, 228 are between 10-100 cesspools in size, 139 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Density Criteria: 10 Acres (Search Radius of 372 ft.)

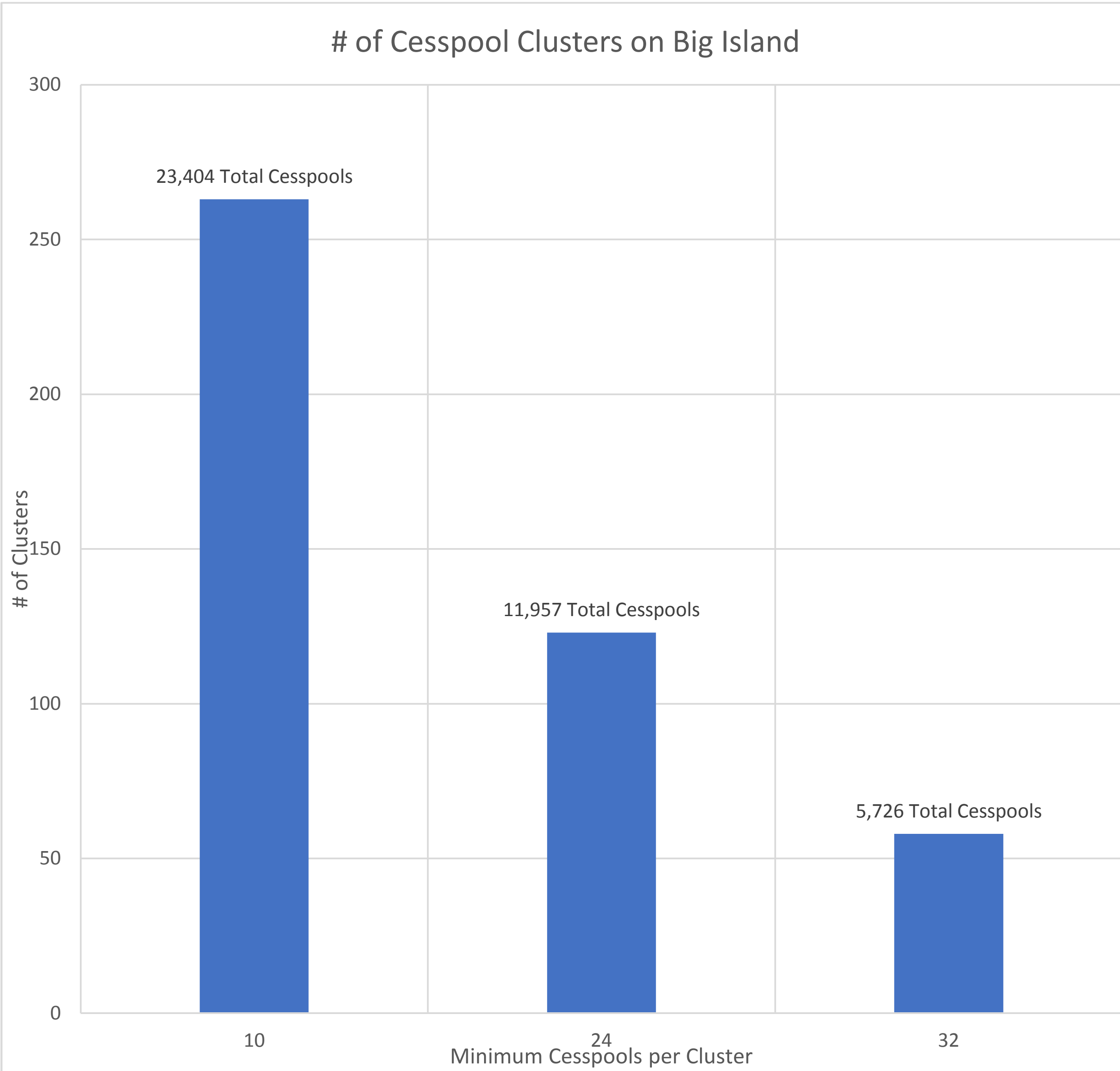

Figure 3.34 # of Clusters that Meet 10 Acre Density Criteria for Different Minimum Sizes of 10,24, & 32 Cesspools

Figure 3.34 shows the clusters of cesspools that meet 10-acre density criteria for different minimum sizes of 10, 24, & 32 on the Big Island. The 10-acre density criteria entail that each cesspool in a specific cluster is within 372 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 10 -acre area.

The “minimum cesspools per cluster” on the x axis shows different size requirements that needed to be met and the “# of Clusters” on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 10 cesspools per cluster: 263 clusters hosting 23,404 cesspools.
- Minimum size of 24 cesspools per cluster: 123 clusters hosting 11,957 cesspools.
- Minimum size of 32 cesspools per cluster: 58 clusters hosting 5,726 cesspools.

These results show that there are about 23,404 total cesspools that meet the 10-acre clustering criteria for a minimum size of 10 cesspools, which is approximately 51% of the total cesspools on the island. A minimum size of 10 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 51% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for cluster system implementation and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 51% to 13% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

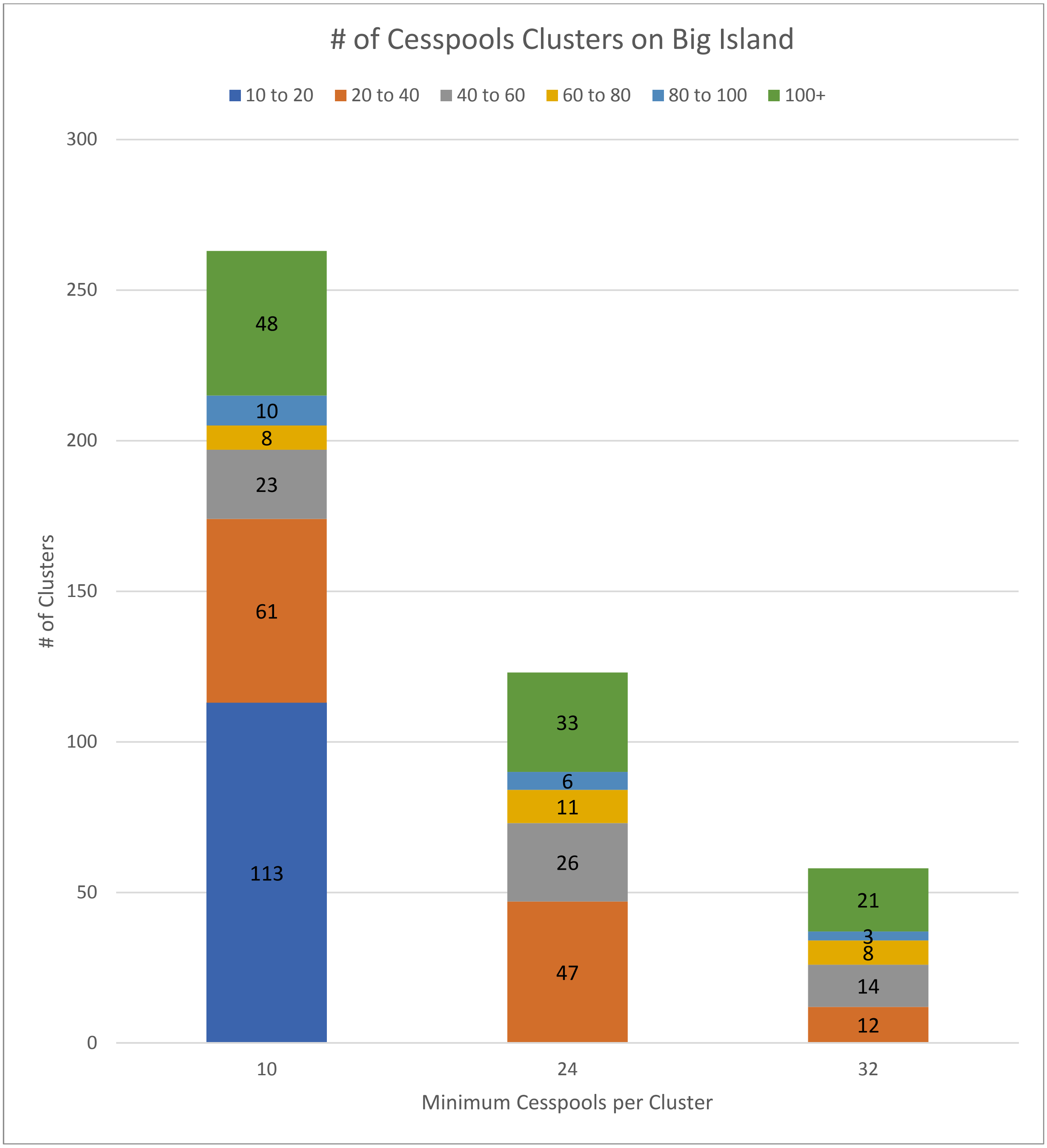

Figure 3.35 # of Clusters that meet the 10 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 10-acre density criteria, *Figure 3.35* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100 and 100+.

For example, of the 263 clusters with a minimum size of 10 that meet the 10-acre density criteria, 215 are between 10-100 cesspools in size, 113 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Overview: A look at the Cluster Feasibility Density Analysis

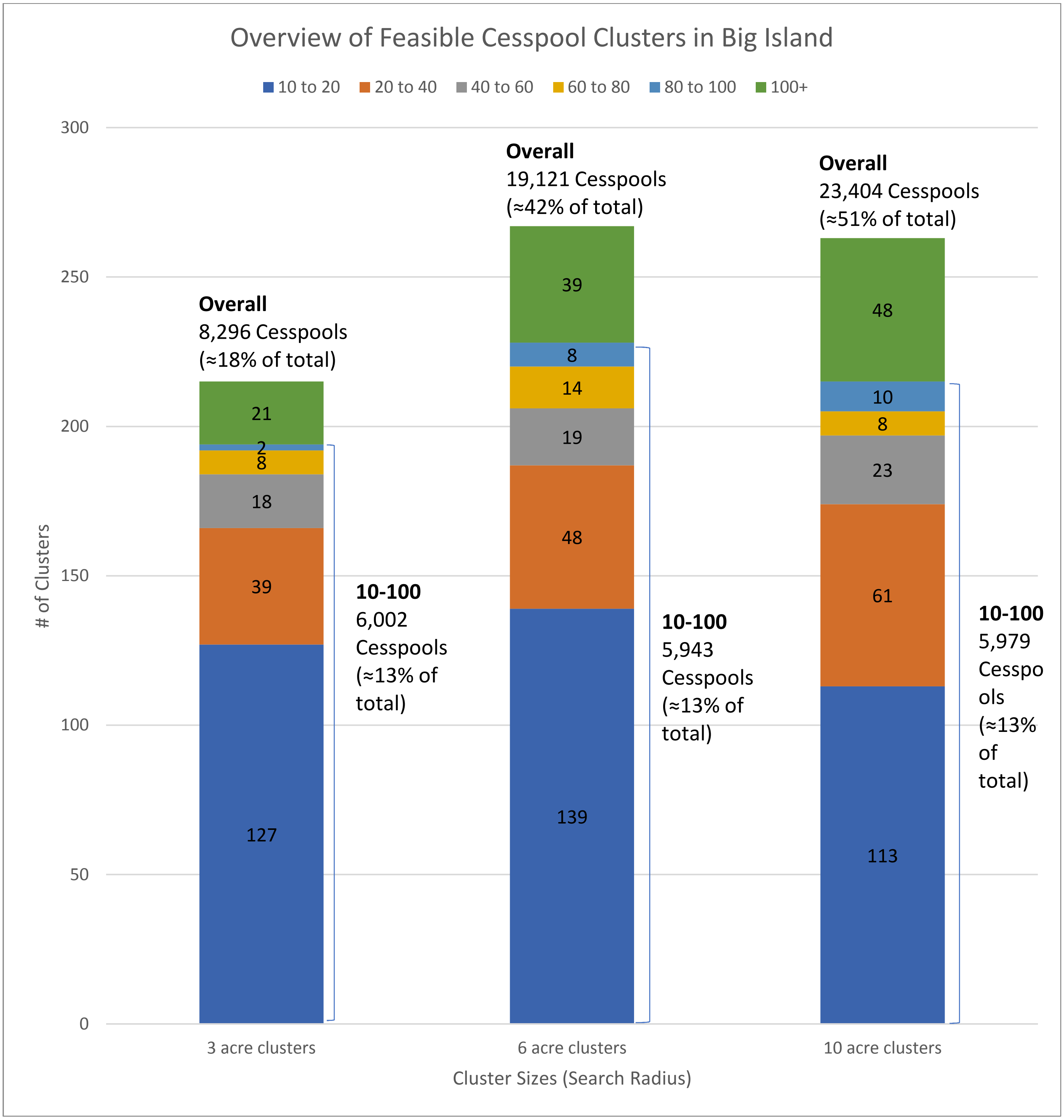

Figure 3.36 Overview of Feasible Cesspool Clusters in the Big Island of size 10-100

Figure 3.36 shows an overview of the clusters of cesspools across the Big Island that meet a certain size feasibility constraint (10-100). The graph breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

The results are as follows:

- For 3-acre density criteria,
    - Overall: **215 clusters/neighborhoods**
        - 8,296 total cesspools (18% of total)
    - Size 10-100: **194 clusters/neighborhoods**
        - 6,002 total cesspools (13% of total)
- For 6-acre density criteria,
    - Overall: **267 Clusters/neighborhoods**
        - 19,121 total cesspools (42% of total)
    - Size 10-100: **228 clusters/neighborhoods**
        - 5,943 total cesspools (13% of total)
- For 10-acre density criteria,
    - Overall: **263 clusters/neighborhoods**
        - 23,404 total cesspools (51% of total)
    - Size 10-100: **215 clusters/neighborhoods**
        - 5,979 total cesspools (13% of total)

These results provide an overview for cluster feasibility on the Big Island across different density criteria.

Big Island Focus Clusters & Priority Areas

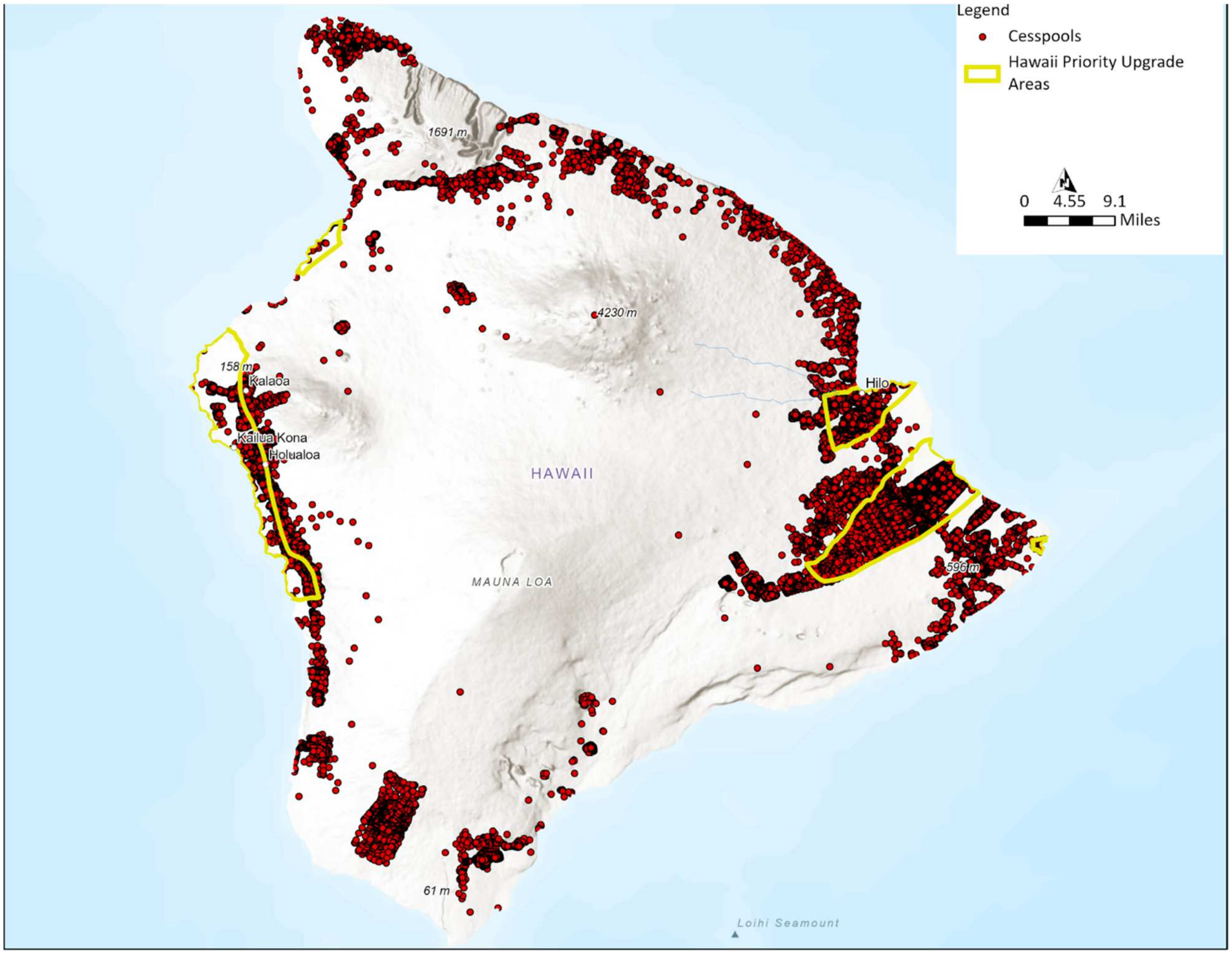

Figure 3.37 Priority Upgrade Areas in Big Island as Defined by DOH

Figure 3.37 shows the five priority areas on the Big Island, outlined in *Table 3.8.* There are four priority-3 areas and one priority-2 area, as described by DOH (see section *1.3)*. The priority areas on the Big Island host a total of 24,870 cesspools that discharge an estimated 15.12 mgd of effluent (DOH).

Table 3.8 Initial Big Island Priority Upgrade Areas Established by DOH WWB (DOH, 2018)

Geographic Area	Priority Level Assigned	Number of Cesspools	Estimated Effluent Discharge (mgd)
Keaʻau area of Hawaiʻi Island	2	9,300	4.9
Hilo Bay area of Hawaiʻi Island	3	8,700	5.6
Coastal Kailua/Kona area of Hawaiʻi Island	3	6,500	3.9
Puako area of Hawaiʻi Island	3	150	0.60
Kapoho area of Hawaiʻi Island	3	220	0.12
	Total Assigned	**24,870**	**15.12**
Hawaiʻi Island Un-Assigned	NA	24,430	12.18
	Overall Totals	**49,300**	**27.3**

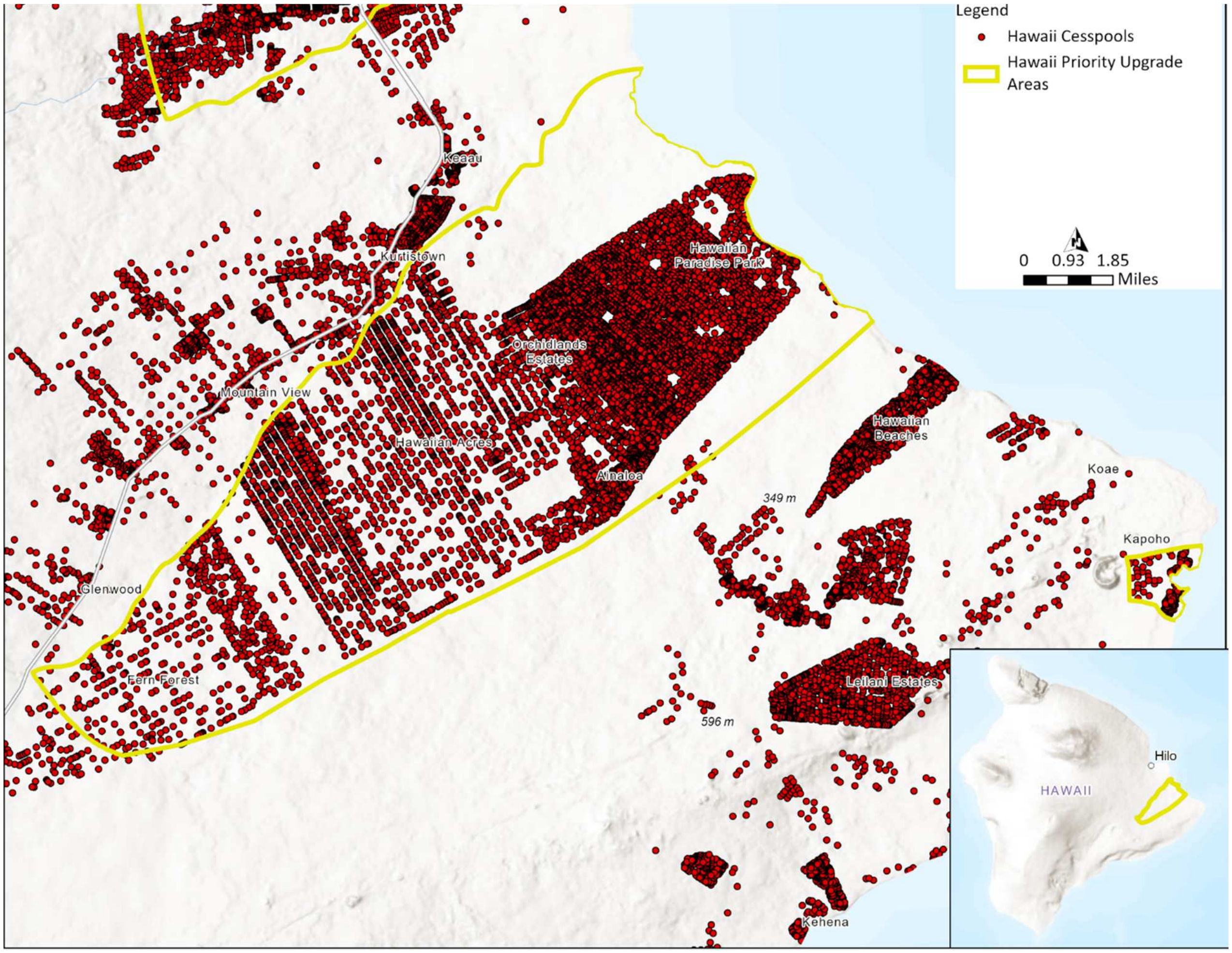

Figure 3.38 Kea'au: Priority 2 Upgrade Area

Figure 3.38 focuses in on Kea'au, a priority-2 area as defined by DOH, the cesspools it contains pose potential impacts to drinking water supply. *Table 3.9* provides specific information to the area derived from DOH and GIS. Approximately 18 % of the total cesspools on the Big Island are found in this area and *Figure 3.24* shows how densely populated it is. The following sections will evaluate how cesspools are clustered in the area and if there are any feasible locations to implement decentralized cluster wastewater treatment systems.

Table 3.9 Kea'au: Priority 2 Upgrade Area

From GIS:	From DOH:
• **7,805** of approximately 45,819 cesspools on Big Island are in this priority 2 area. • Density Index: .134	• 9,300 Cesspools of 49,300 cesspools on Big Island are in this priority 2 area. • Approximately 58,240 Acres. • Discharging 4.9 mgd. • Nitrogen Flux: 970 kg/d. • Phosphorus flux: 270 kg/d.

Kea'au: Density Criteria: 3 acres (Search radius of 204 ft.).

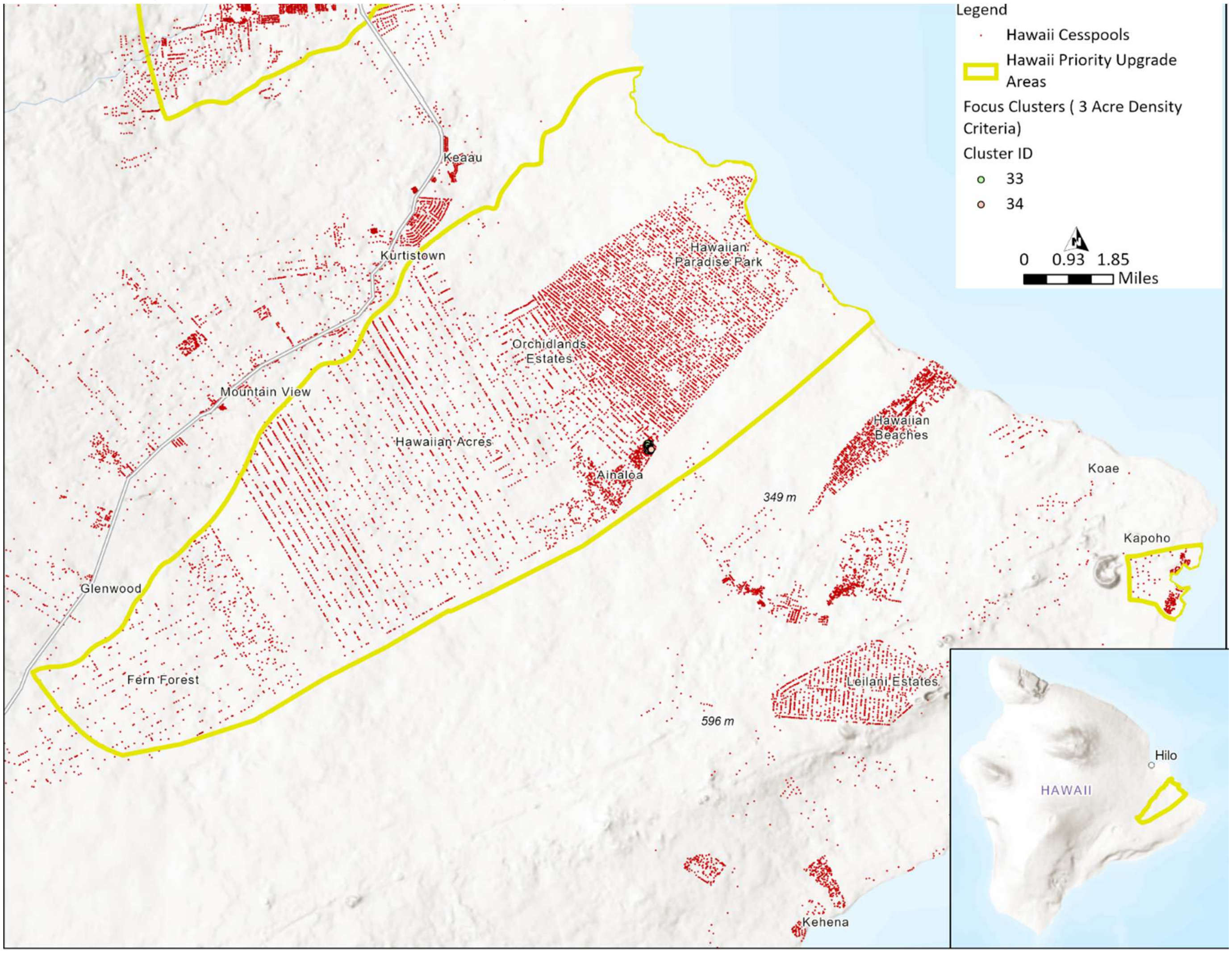

Figure 3.39 Kea'au Focus Clusters (3 Acre Density Criteria)

Figure 3.39 shows the clusters of cesspools that meet 3-acre density criteria in Kea'au. There are 2 focus clusters that could be analyzed further for the 3-acre density criteria in this priority area. These clusters are referred to as "Kea'au Focus Clusters (3-acre density criteria)", the sizes of which are shown in the chart below (*Figure 3.40).*

- 2 cesspool clusters make up 22 cesspools in this area that meet the density criteria.
    - 22 cesspools are approximately 0.3% of the cesspools in Kea'au.

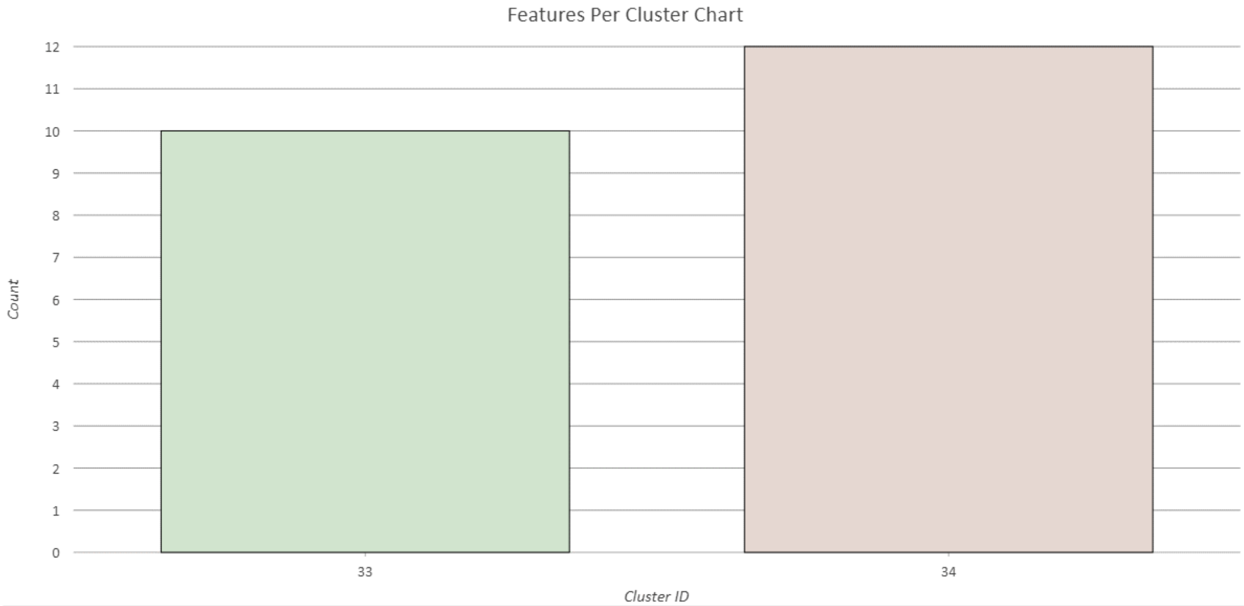

Figure 3.40 Kea'au Focus Clusters (3 Acre Density Criteria): Features Per Cluster Chart

Kea'au: Density Criteria: 10 acres (Search radius of 372 ft.).

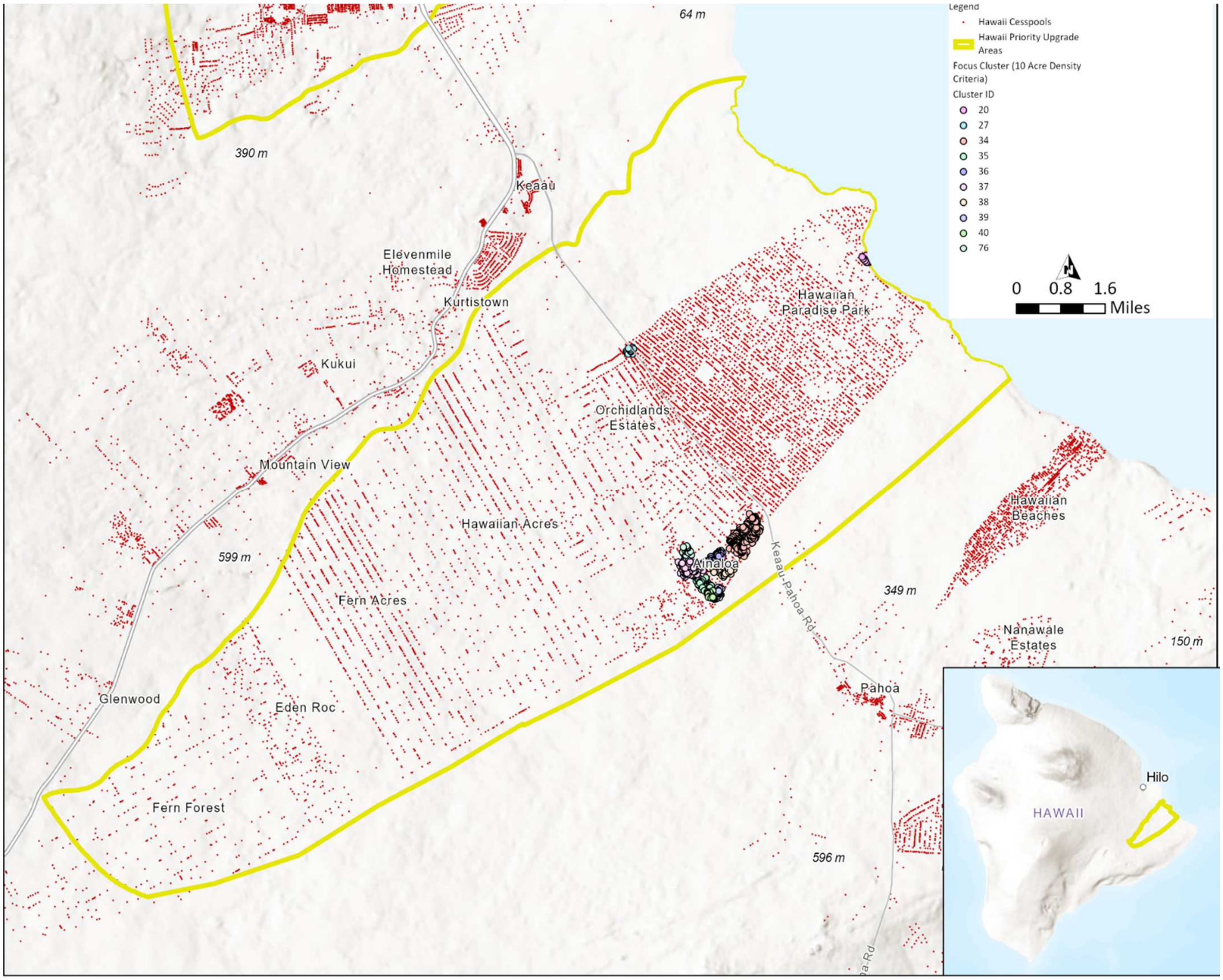

Figure 3.41 Kea'au Focus Clusters (10 Acre Density Criteria)

Figure 3.41 shows the clusters of cesspools that meet 10-acre density criteria in Kea'au. There are 10 focus clusters that could be analyzed further for the 10-acre density criteria in this priority area. These clusters are referred to as "Kea'au Focus Clusters (10-acre density criteria)", the sizes of which are shown in the chart below (*Figure 3.42).*

- 10 cesspool clusters make up 479 cesspools in this area that meet the density criteria.
  - 479 cesspools are approximately 6% of the total cesspools in Kea'au.

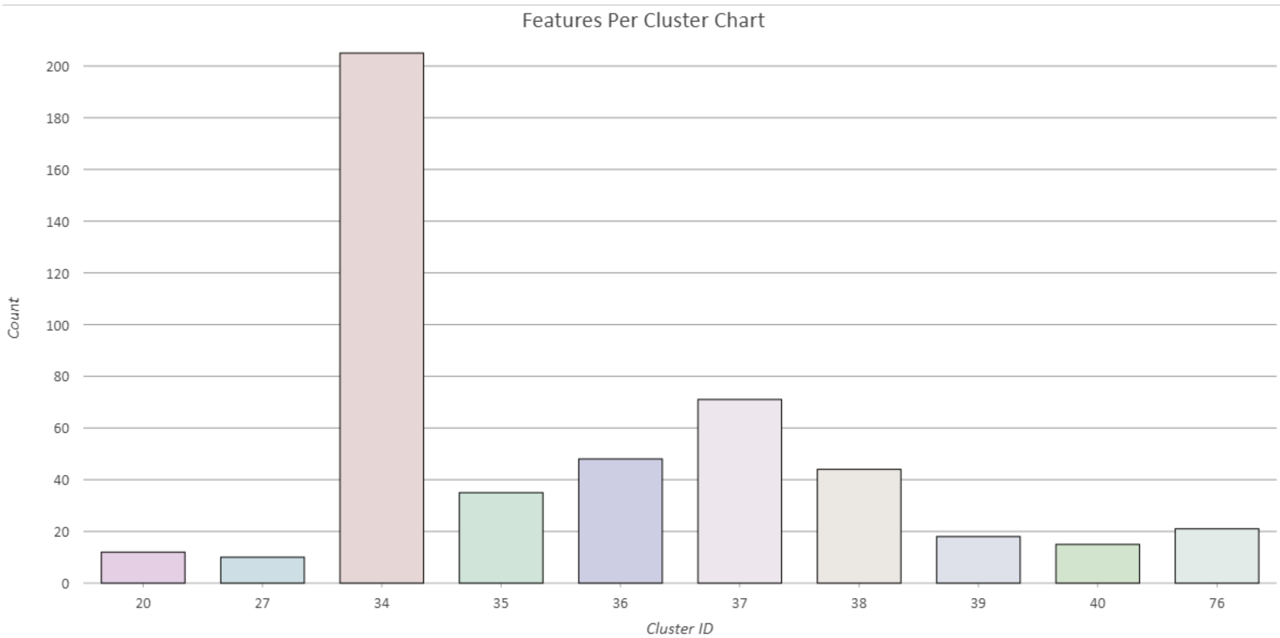

Figure 3.42 Kea'au Focus Clusters (10 Acre Density Criteria): Features Per Cluster Chart

3.2.4 Kauai

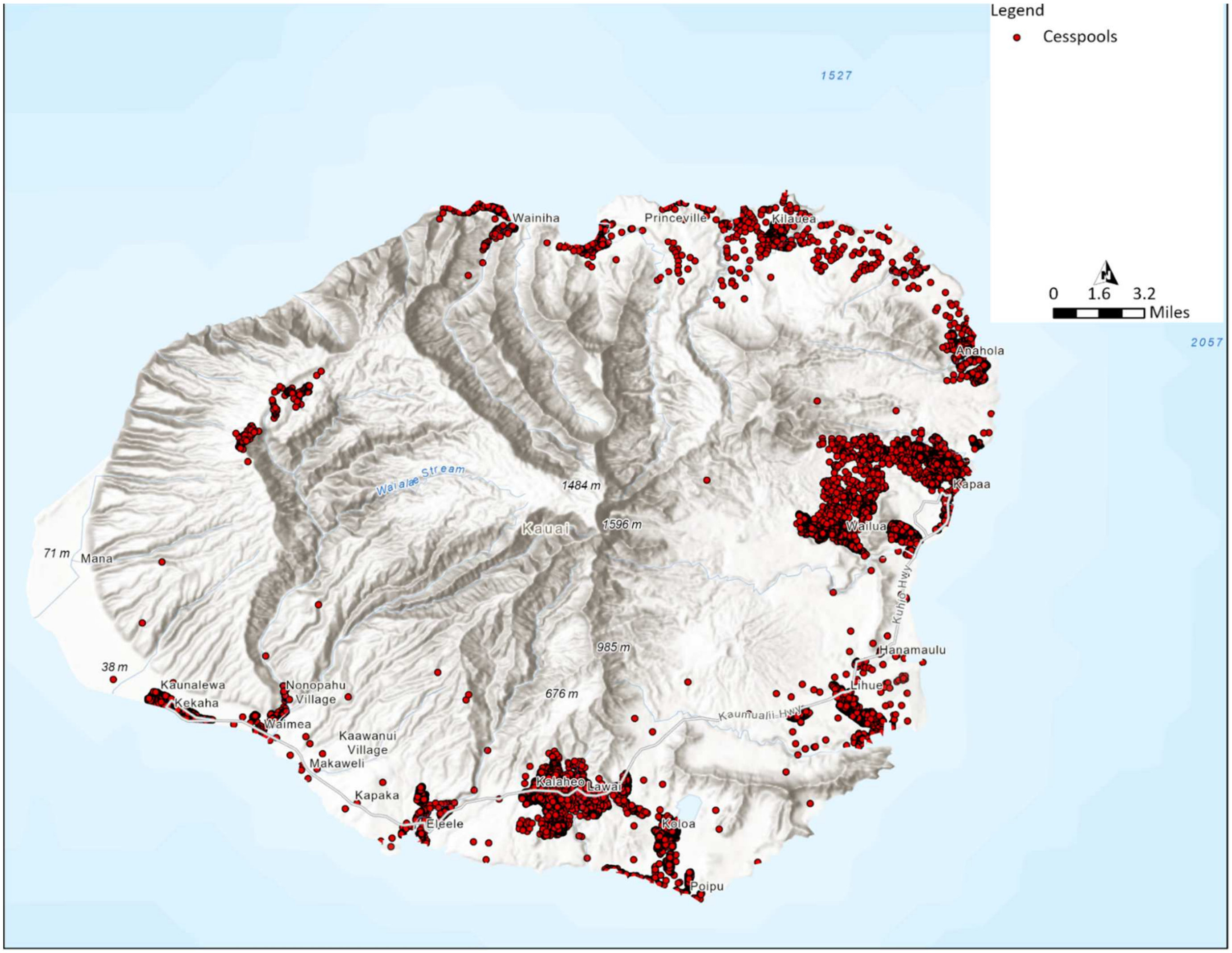

Figure 3.43 11,783 Total Cesspools on Kauai

Kauai plays host to the second highest population of cesspools among the Hawaiian Islands, although its quantity is very close to both Oahu and Maui. As shown in *Figure 3.29*, there are approximately 11,783 cesspools on Kauai. Like the other islands, most of the cesspools are located along the coasts and in residential neighborhoods. Through the method laid out in the previous chapter (*Chapter 2: Materials and Methods)*, the following sections will analyze how cesspools are clustered across the island.

Density Criteria: 3 Acres (Search Radius of 204 ft.)

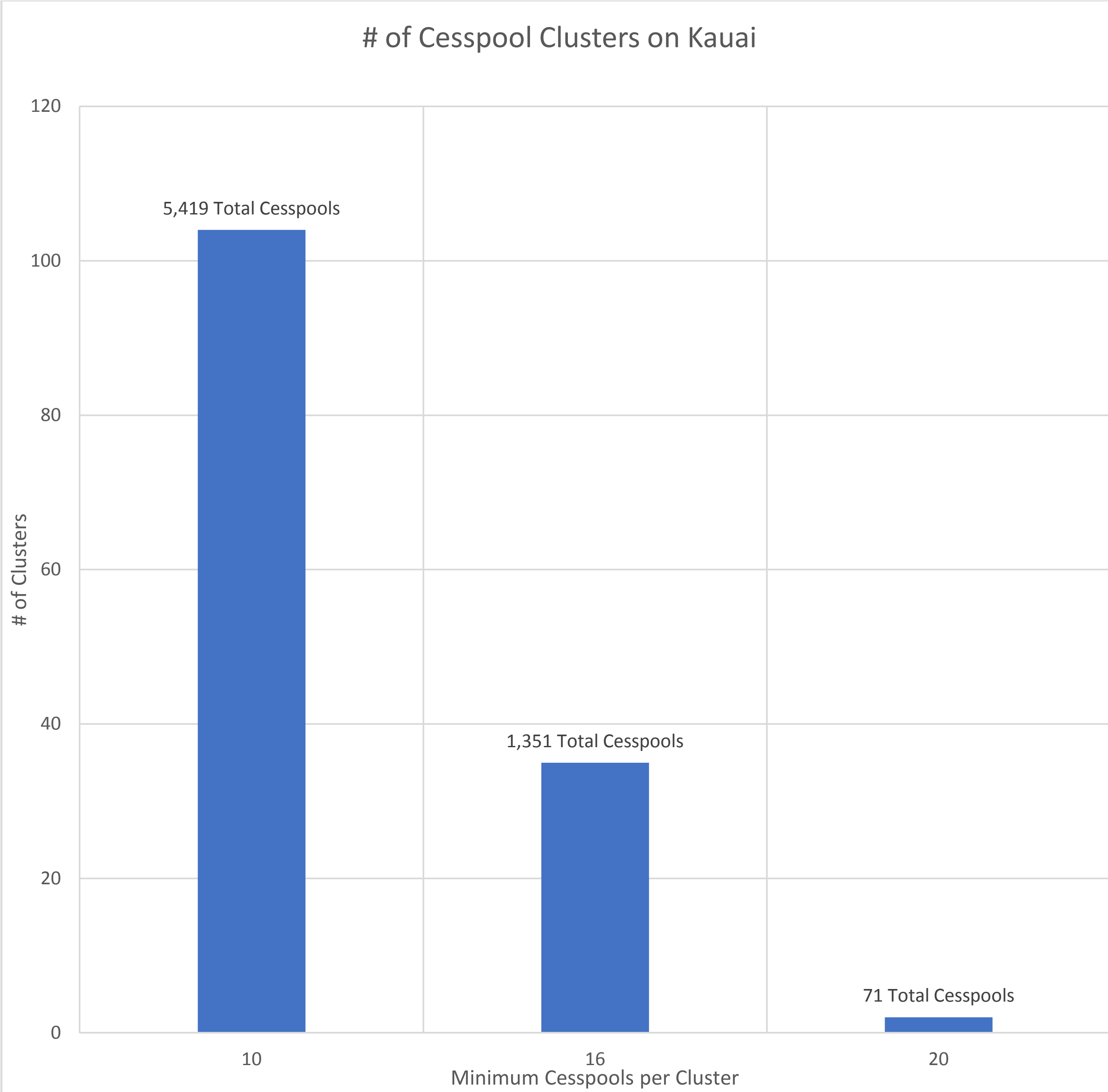

Figure 3.44 # of Clusters that Meet 3 Acre Density Criteria for Different Minimum Sizes of 10,16, & 20 Cesspools

Figure 3.44 shows the clusters of cesspools that meet 3-acre density criteria for different minimum sizes of 10,16, & 20 on Kauai. The 3-acre density criteria entail that each cesspool in a specific cluster is within 204 ft of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 3 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 10 cesspools per cluster: 104 clusters hosting 5,419 cesspools.
- Minimum size of 16 cesspools per cluster: 35 clusters hosting 1,351 cesspools.
- Minimum size of 20 cesspools per cluster: 2 clusters hosting 71 cesspools.

These results show that there are a lot of small clusters on Kauai , the number of cesspools that meet the criteria goes way down when you go from a minimum size of 10 to a minimum size of 16. It also shows that there are about 5,419 total cesspools that meet the 3-acre clustering criteria for a minimum size of 10 cesspools, which is approximately 46% of the total cesspools on the island. A minimum size of 10 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 46% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for decentralized treatment and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 46% to 17% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

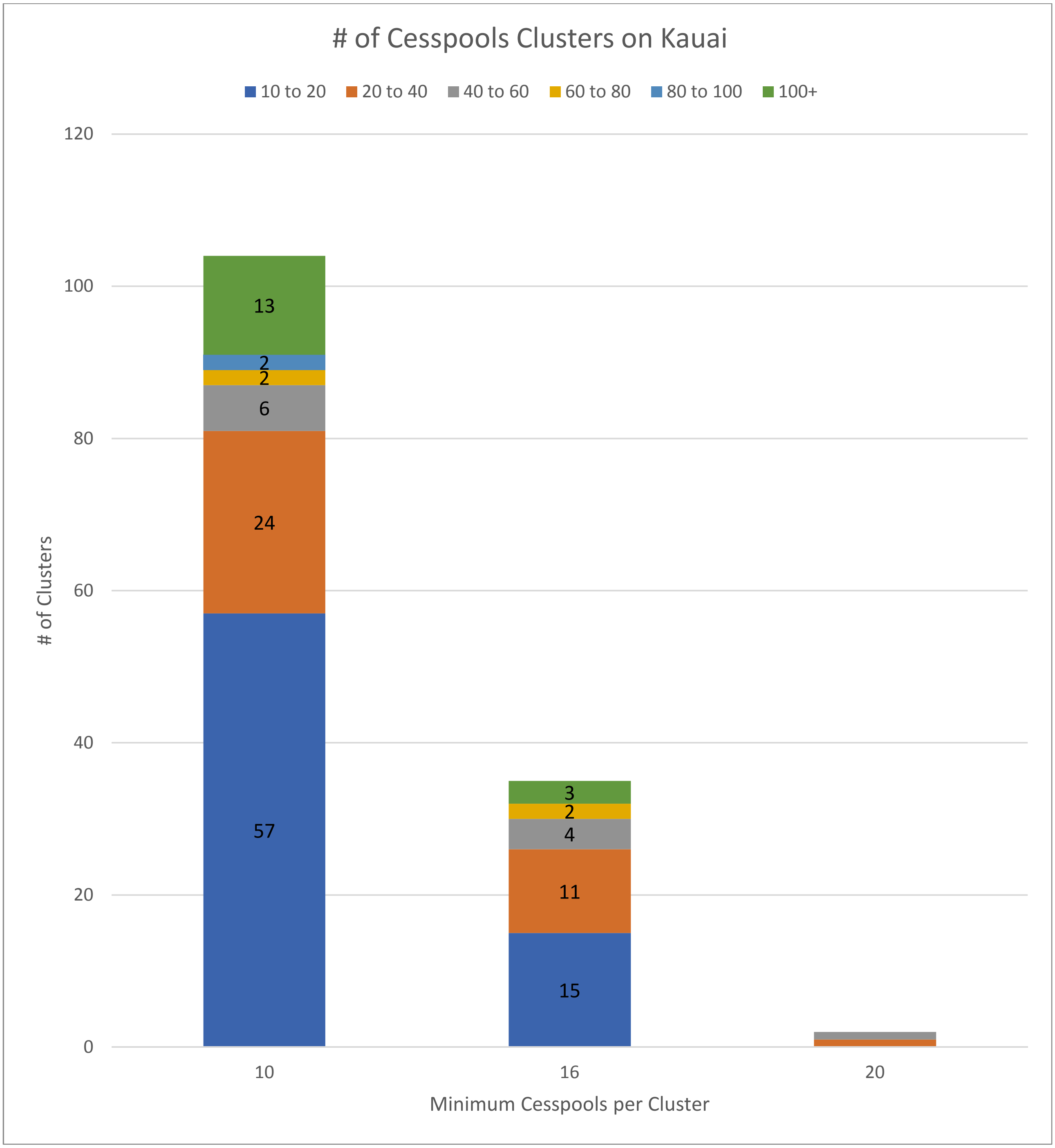

Figure 3.45 # of Clusters that meet the 3 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 3-acre density criteria, *Figure 3.45* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 104 clusters with a minimum size of 10 that meet the 3-acre density criteria, 91 are between 10-100 cesspools in size, 57 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Density Criteria: 6 Acres (Search Radius of 288.5 ft.)

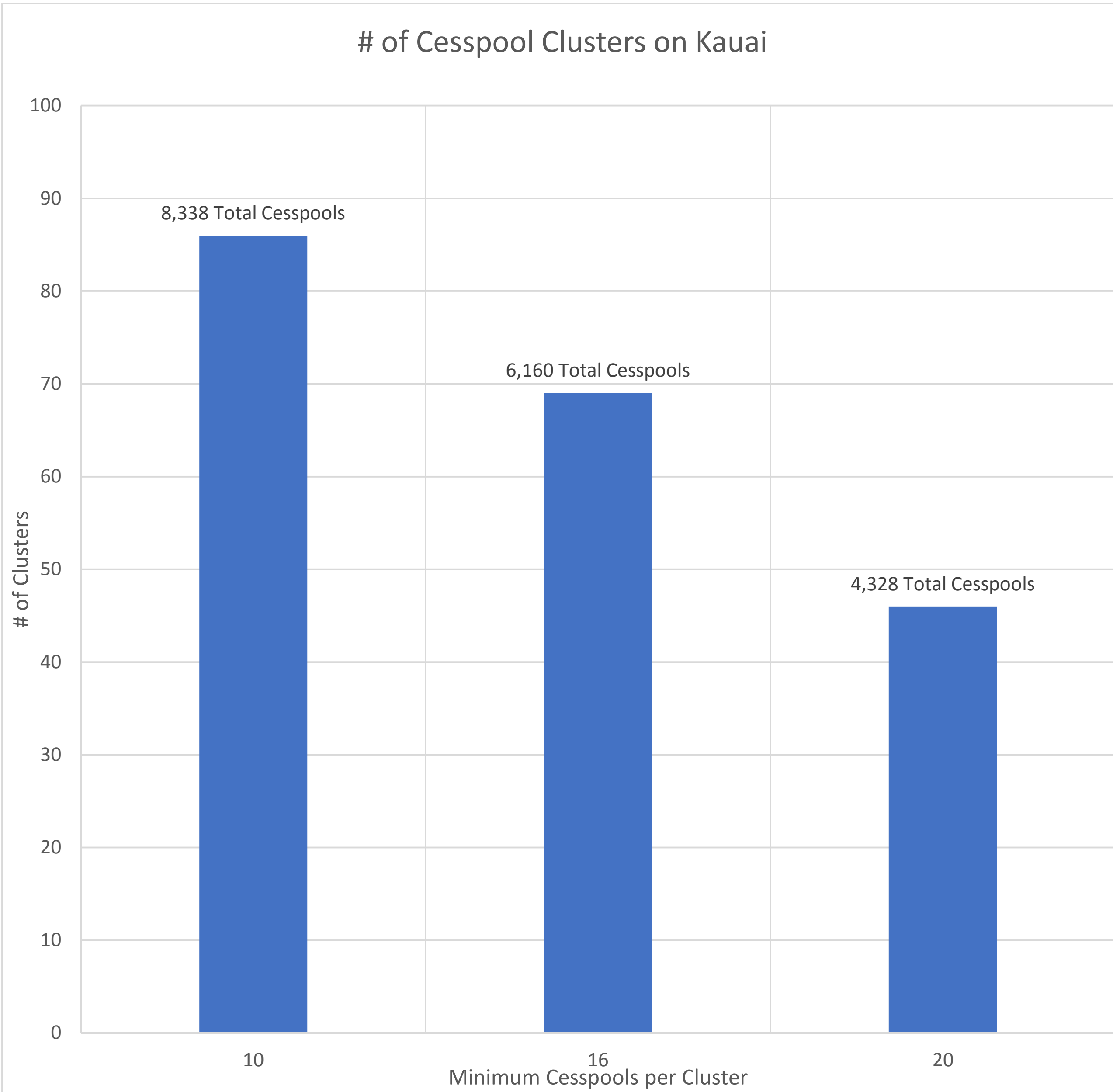

Figure 3.46 # of Clusters that Meet 6 Acre Density Criteria for Different Minimum Sizes of 10,16, & 20 Cesspools

Figure 3.46 shows the clusters of cesspools that meet 6-acre density criteria for different minimum sizes of 10,16,& 20 on Kauai. The 6-acre density criteria entail that each cesspool in a specific cluster is within 288.5 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 6 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 10 cesspools per cluster: 86 clusters hosting 8,338 cesspools.
- Minimum size of 16 cesspools per cluster: 69 clusters hosting 6,160 cesspools.
- Minimum size of 20 cesspools per cluster: 46 clusters hosting 4,328 cesspools.

These results show that there are about 8,338 total cesspools that meet the 6-acre clustering criteria for a minimum size of 10 cesspools, which is approximately 71% of the total cesspools on the island. A minimum size of 10 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 71% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for cluster system implementation and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 71% to 17% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

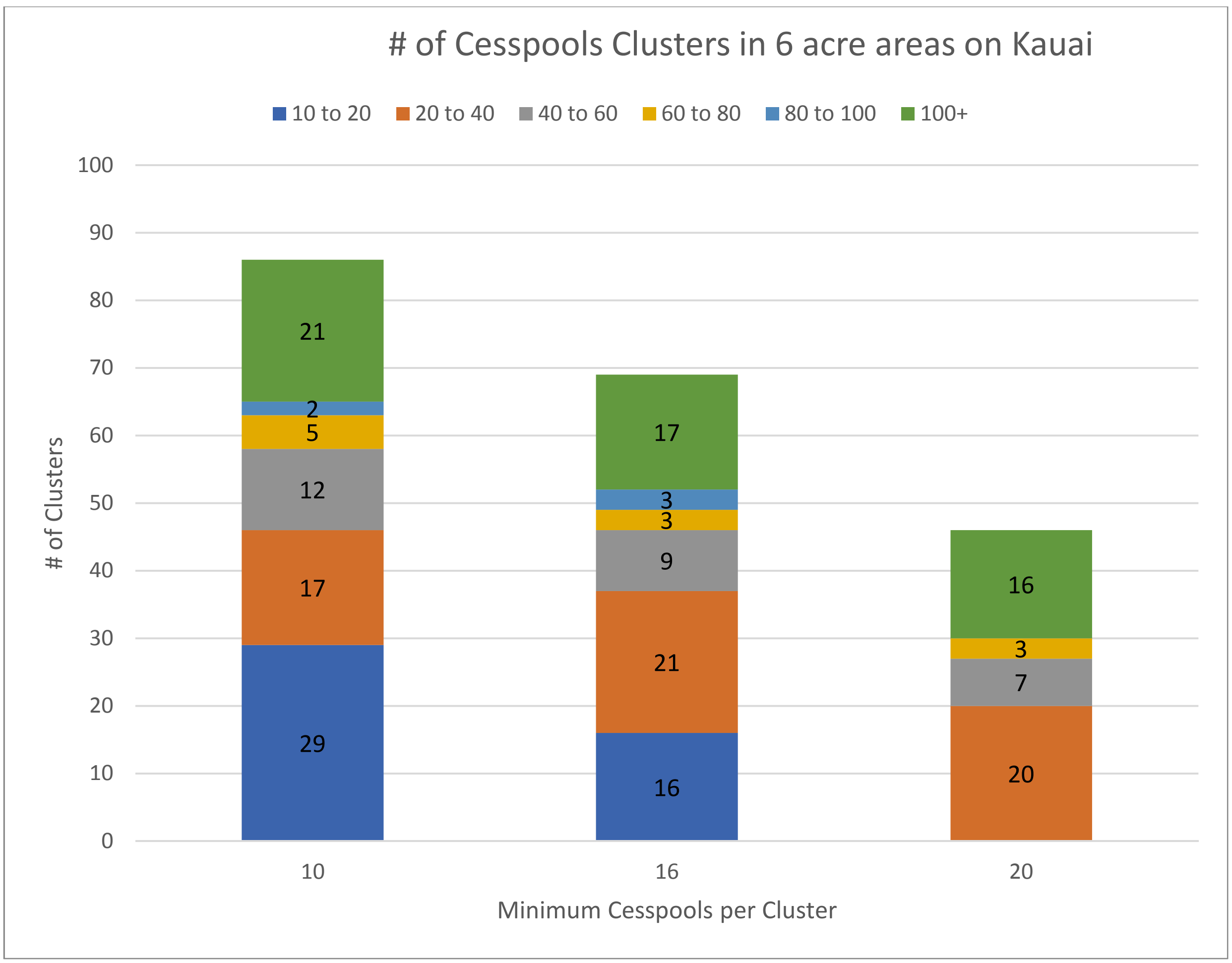

Figure 3.47 # of Clusters that meet the 6 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 6-acre density criteria, *Figure 3.47* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

For example, of the 86 clusters with a minimum size of 10 that meet the 6-acre density criteria, 65 are between 10-100 cesspools in size, 29 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Density Criteria: 10 Acres (Search Radius of 372 ft.)

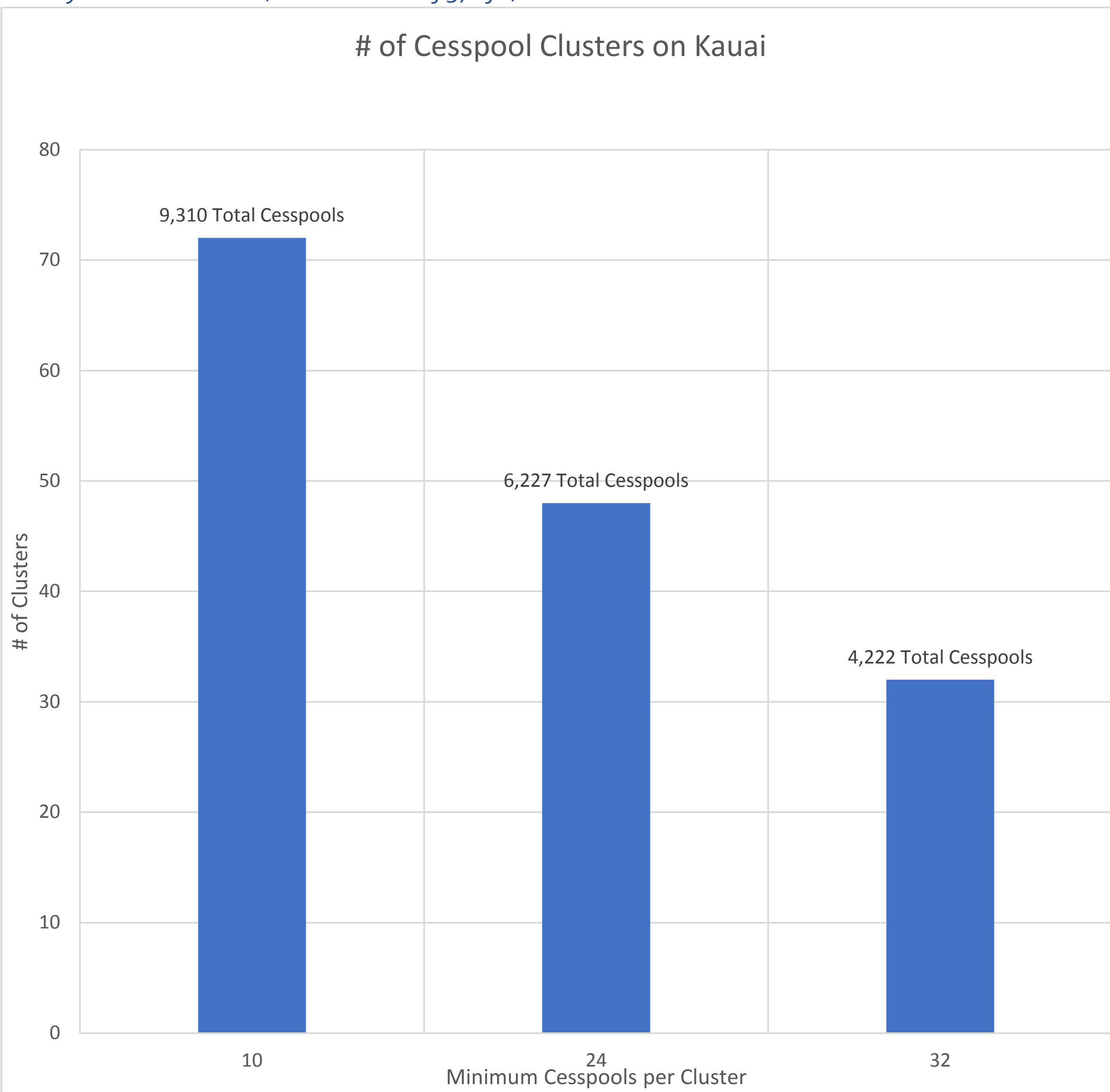

Figure 3.48 # of Clusters that Meet 10 Acre Density Criteria for Different Minimum Sizes of 10,24, & 32 Cesspools

Figure 3.48 shows the clusters of cesspools that meet 10-acre density criteria for different minimum sizes of 10, 24, & 32 on Kauai. The 10-acre density criteria entail that each cesspool in a specific cluster is within 372 ft. of another cesspool in the same cluster. It does not mean that all the cesspools in the cluster are within a single 10 -acre area.

The "minimum cesspools per cluster" on the x axis shows different size requirements that needed to be met and the "# of Clusters" on the y-axis simply shows the # of clusters that met the criteria.

The graph shows the following results:

- Minimum size of 10 cesspools per cluster: 72 clusters hosting 9,310 cesspools.
- Minimum size of 24 cesspools per cluster: 48 clusters hosting 6,227 cesspools.
- Minimum size of 32 cesspools per cluster: 32 clusters hosting 4,222 cesspools.

These results show that there are about 9,310 total cesspools that meet the 10-acre clustering criteria for a minimum size of 10 cesspools, which is approximately 79% of the total cesspools on the island. A minimum size of 10 is a good lower boundary to look at when considering decentralized cluster system implementation. Thus, approximately 79% of cesspools on the island can be looked at for possible cluster systems based on this criterion, keep in mind that some of these clusters may be too big for cluster system implementation and thus would need to be looked at separately for possible centralized treatment. While only looking at more feasible clusters of size 10-100, the percentage drops from 79% to 17% (see *Overview: A look at the Cluster Feasibility Density Analysis).*

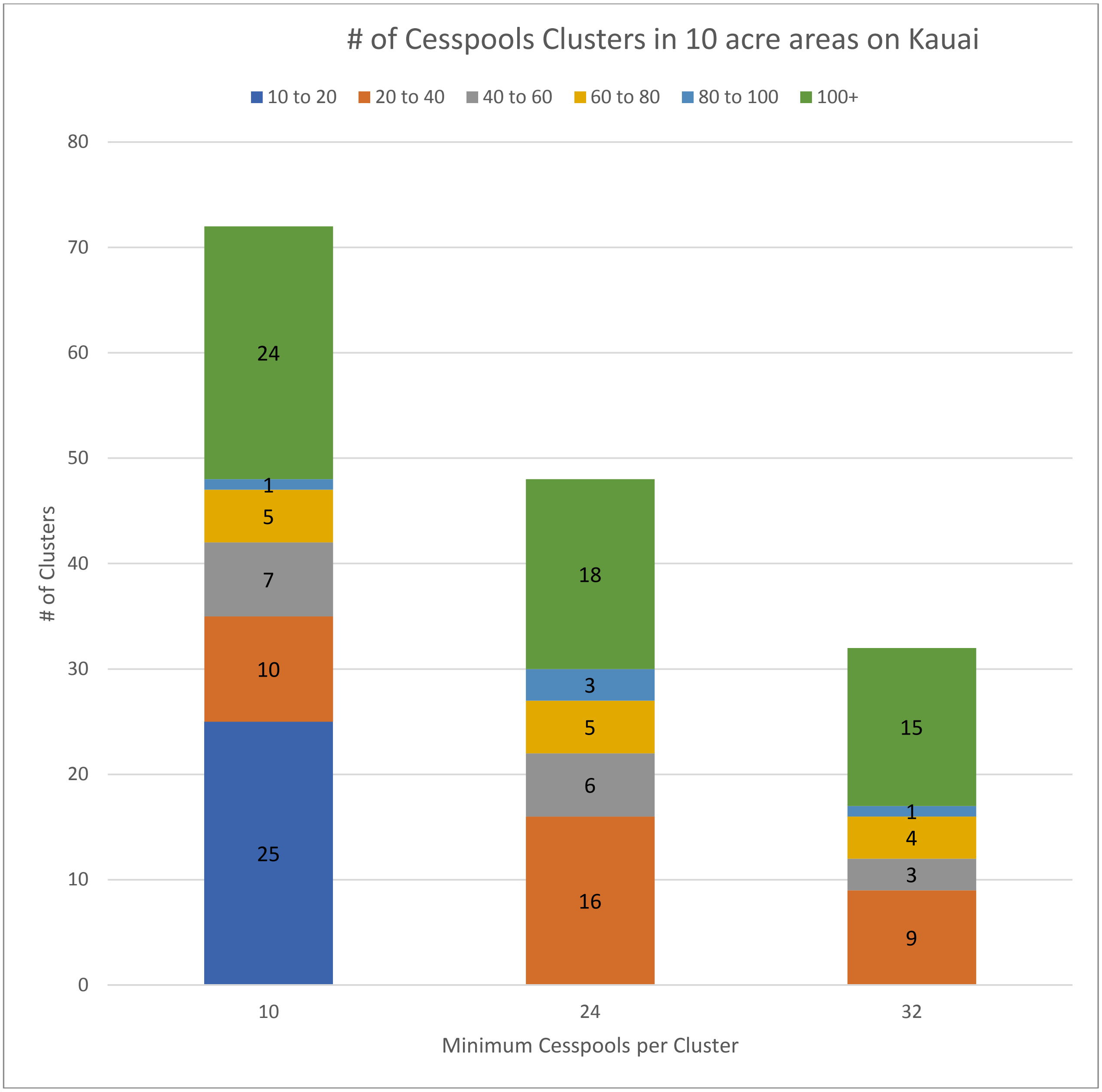

Figure 3.49 # of Clusters that meet the 10 Acre Density Criteria for Sizes of 10 to 100 Cesspools

While still looking at 10-acre density criteria, *Figure 3.49* focuses on specific sizes of cesspools that would be most feasible for decentralized wastewater treatment system implementation. 10 to 100 households per cluster system is not a strict size requirement but it is a good baseline size to look at. The graph also breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, and 80-100.

For example, of the 72 clusters with a minimum size of 10 that meet the 10-acre density criteria, 48 are between 10-100 cesspools in size, 25 are between 10-20 in size, and so forth. This helps in determining how many potential sites/neighborhoods can be analyzed and considered further.

Overview: A look at the Cluster Feasibility Density Analysis

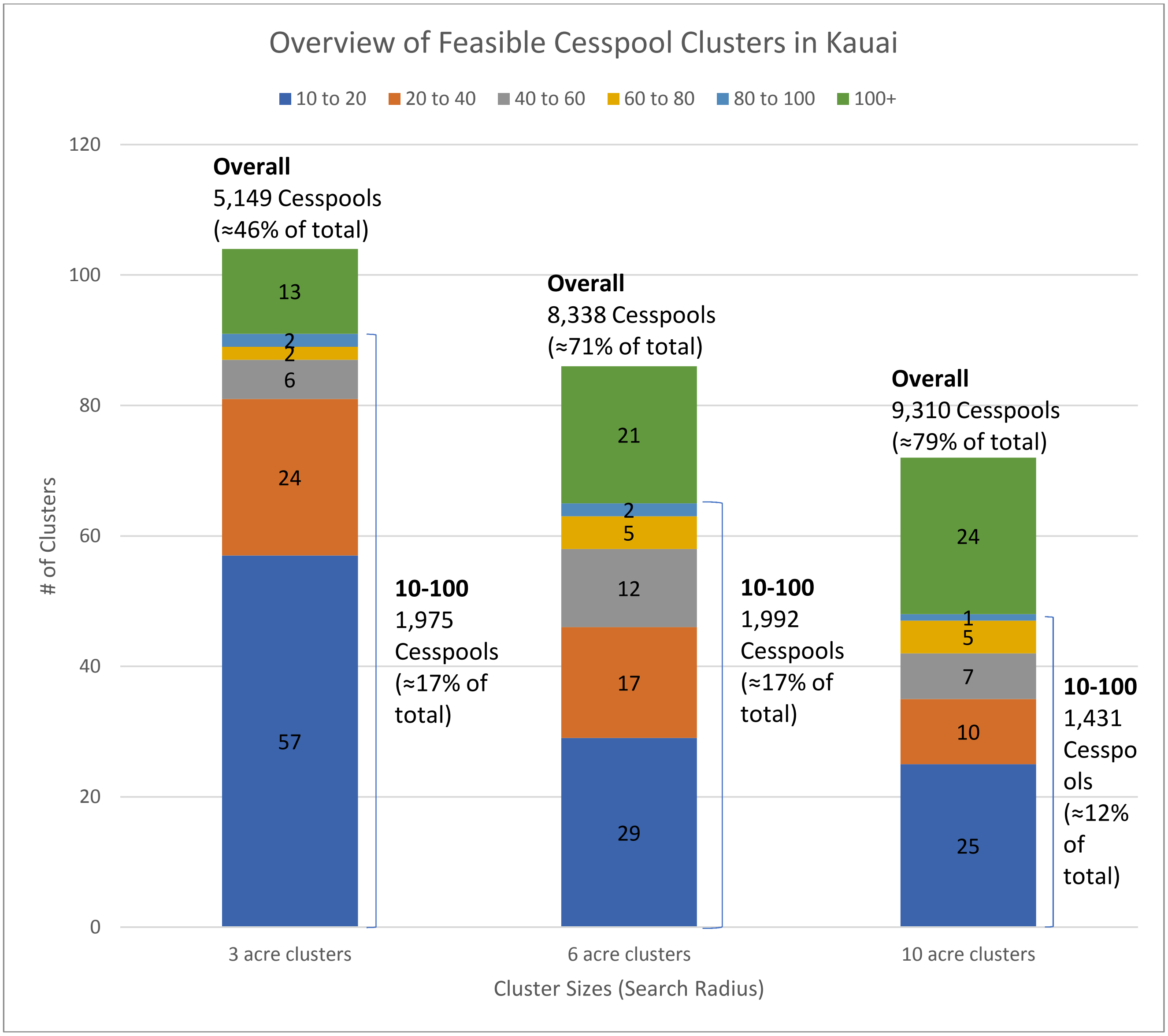

Figure 3.50 Overview of Feasible Cesspool Clusters in Kauai of size 10-100

Figure 3.50 shows an overview of the clusters of cesspools across Kauai that meet a certain size feasibility constraint (10-100). The graph breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100+.

The results are as follows:

- For 3-acre density criteria,
  - Overall: **104 clusters/neighborhoods**
    - 5,149 total cesspools (46% of total)
  - Size 10-100: **91 clusters/neighborhoods**

- 1,975 total cesspools (17% of total)

- For 6-acre density criteria,
    - Overall: **86 Clusters/neighborhoods**
        - 8,338 total cesspools (71% of total)
    - Size 10-100: **65 clusters/neighborhoods**
        - 1,992 total cesspools (17% of total)
- For 10-acre density criteria,
    - Overall: **72 clusters/neighborhoods**
        - 9,310 total cesspools (79% of total)
    - Size 10-100: **48 clusters/neighborhoods**
        - 1,431 total cesspools (12% of total)

These results provide an overview for cluster feasibility on the island of Kauai across different density criteria.

Kauai Focus Clusters & Priority Areas

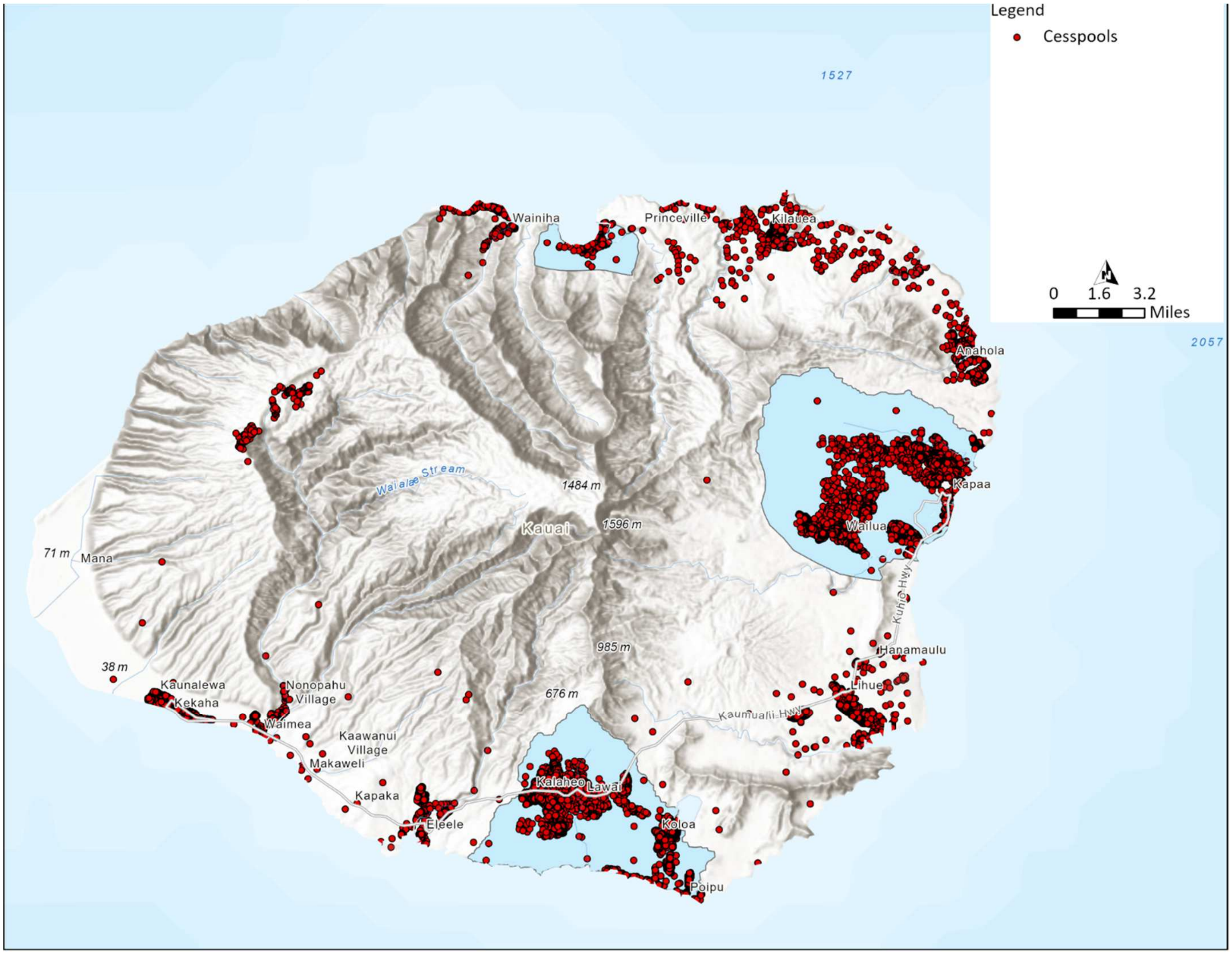

Figure 3.51 Priority Upgrade Areas in Big Kauai as Defined by DOH

Figure 3.51 shows the three priority areas on the Big Island, outlined in *Table 3.8.* There is one priority-3 area and two priority-2 areas, as described by DOH (see section *1.3*). The priority areas on Kauai host a total of 6,770 cesspools that discharge an estimated 4.93 mgd of effluent (DOH).

Table 3.10 Initial Kauai Priority Upgrade Areas Established by DOH WWB (DOH, 2018)

Geographic Area	Priority Level Assigned	Number of Cesspools	Estimated Effluent Discharge (mgd)
Kapaʻa/Wailua area of Kauaʻi	2	2,900	2.2
Poipu/Kōloa area of Kauaʻi	2	3,600	2.6
Hanalei Bay area of Kauaʻi	3	270	0.13
	Total Assigned	**6,770**	**4.93**
Kauaʻi Un-Assigned	NA	6,930	4.57
	Overall Totals	**13,700**	**9.5**

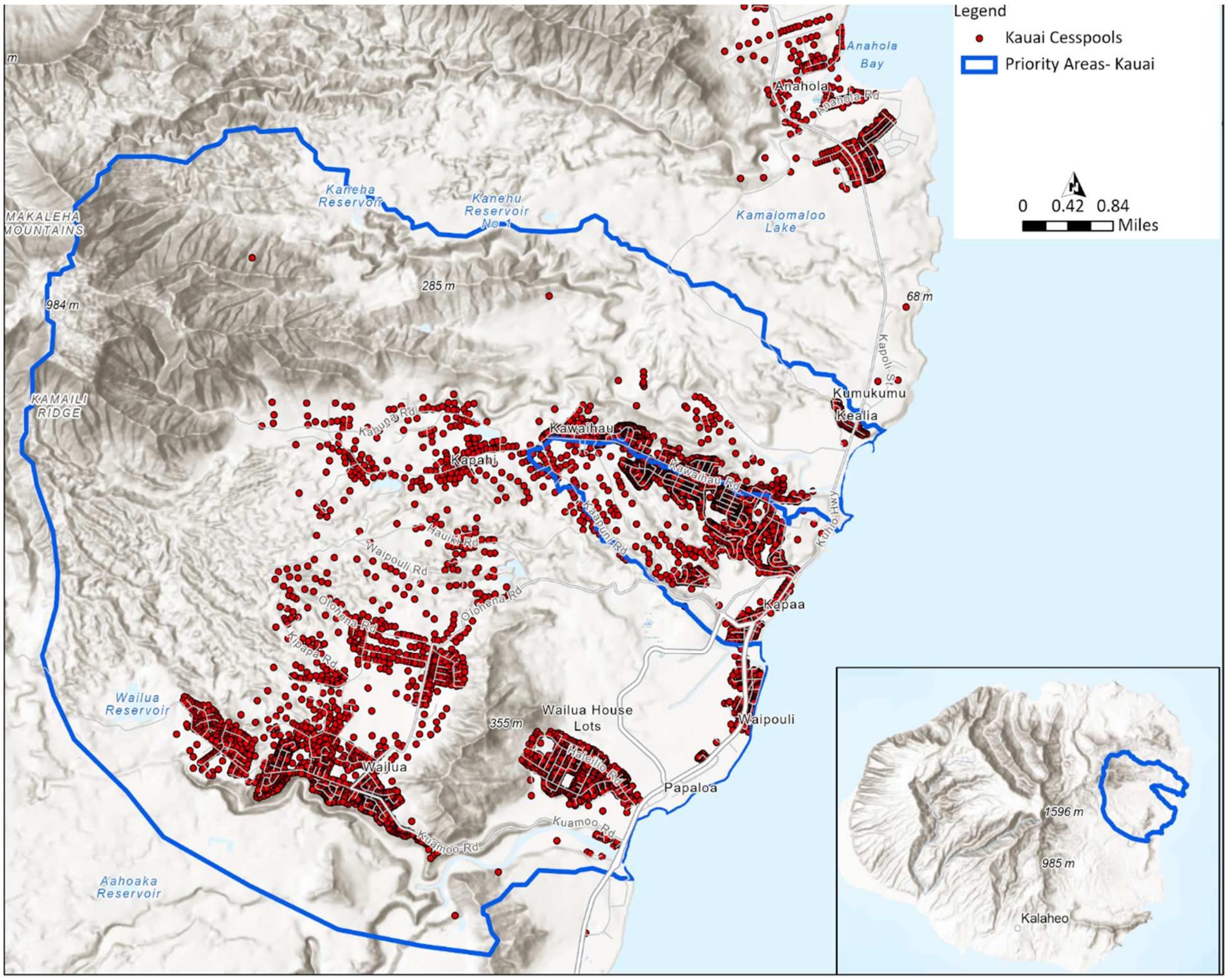

Figure 3.52 Kapaa/Wailua: Priority 2 Upgrade Area

Figure 3.52 focuses in on Kapaa/Wailua, a priority-2 area as defined by DOH, the cesspools it contains pose potential impacts to drinking water supply. *Table 3.11* provides specific information to the area derived from DOH and GIS. Approximately 25 % of the total cesspools on Kauai are found in this area and *Figure 3.24* shows how densely populated it is. The following sections will evaluate how cesspools are clustered in the area and if there are any feasible locations to implement decentralized cluster wastewater treatment systems.

Table 3.11 Kapaa/Wailua: Priority 2 Upgrade Area

From GIS:	From DOH:
• **3,118** of approximately 11,783 cesspools on Kauai are in this priority 2 area. • Density Index: 0.135	• 2,900 Cesspools of 13,700 cesspools on Kauai are in this priority 2 area. • Approximately 23,040 Acres. • Discharging 2.2 mgd. • Nitrogen Flux: 430 kg/d. • Phosphorus flux: 120 kg/d.

Kapaa/Wailua: Density Criteria: 3 acres (Search radius of 204 ft.).

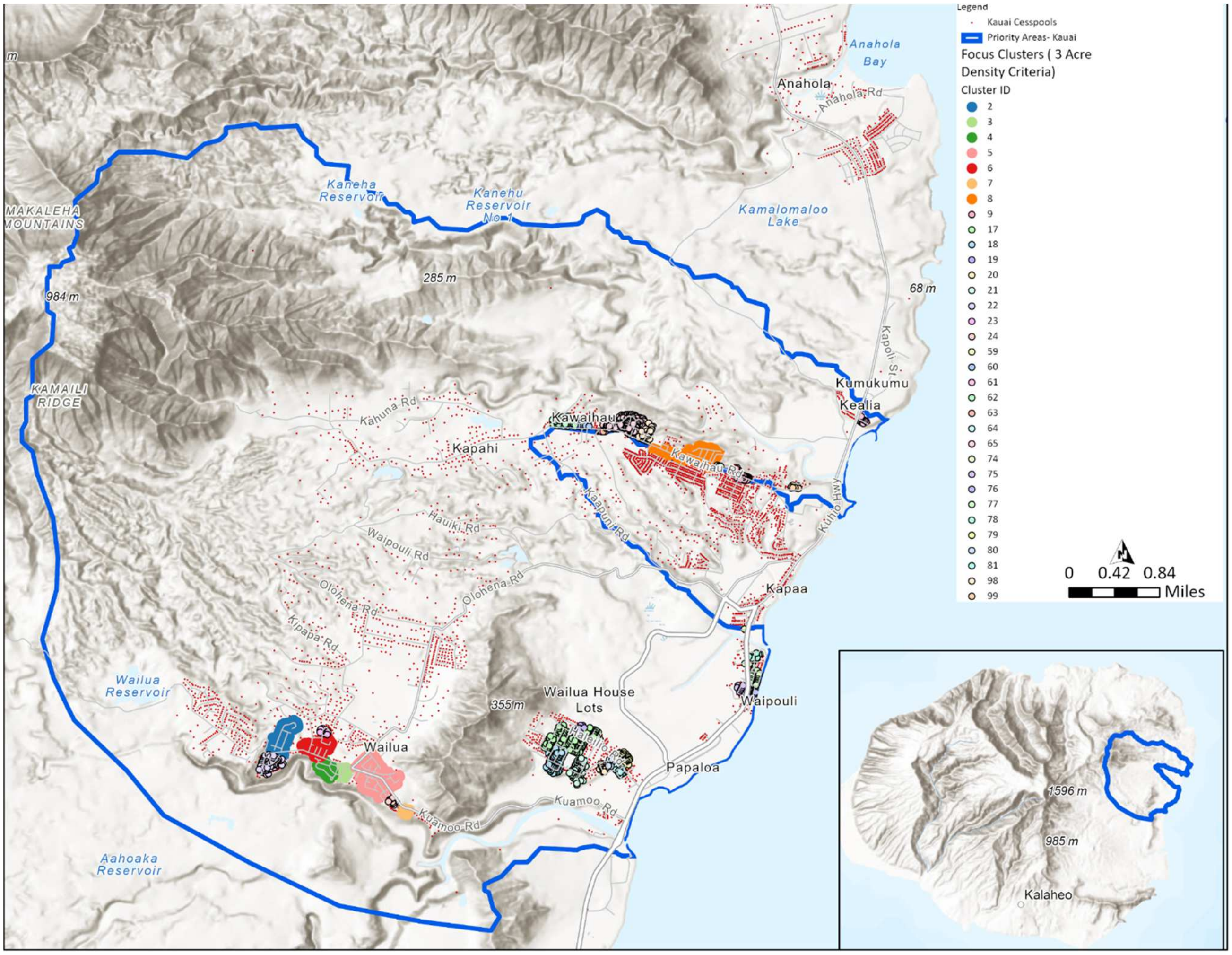

Figure 3.53 Kapaa/Wailua Focus Clusters (3 Acre Density Criteria)

Figure 3.53 shows the clusters of cesspools that meet 3-acre density criteria in Kapaa/Wailua. There are 33 focus clusters that could be analyzed further for the 3-acre density criteria in this priority area. These clusters are referred to as "Kapaa/Wailua Focus Clusters (3-acre density criteria)", the sizes of which are shown in the chart below (*Figure 3.54).*

- 33 cesspool clusters make up 1,334 cesspools in this area that meet the density criteria.
  - 1,334 cesspools are approximately 43% of the total in Kappa/Wailua.

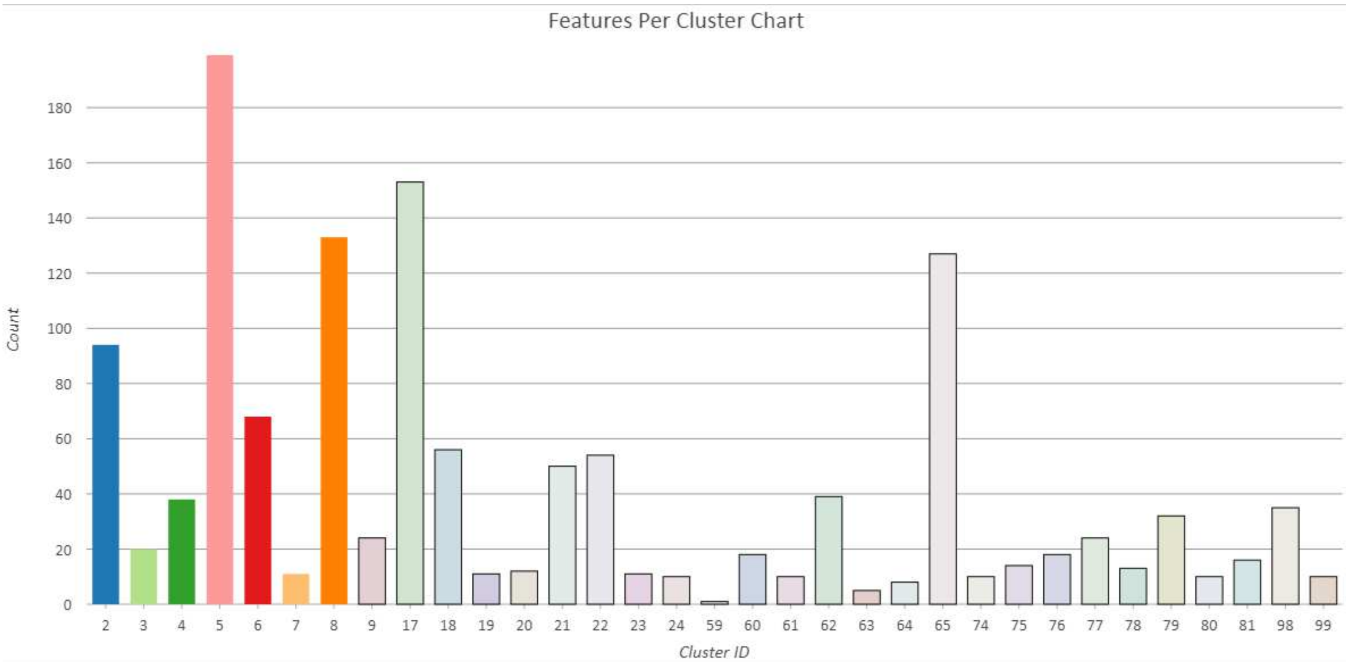

Figure 3.54 Kapaa/Wailua Focus Clusters (3 Acre Density Criteria): Features Per Cluster Chart

Kapaa/Wailua: Density Criteria: 10 acres (Search radius of 372 ft.).

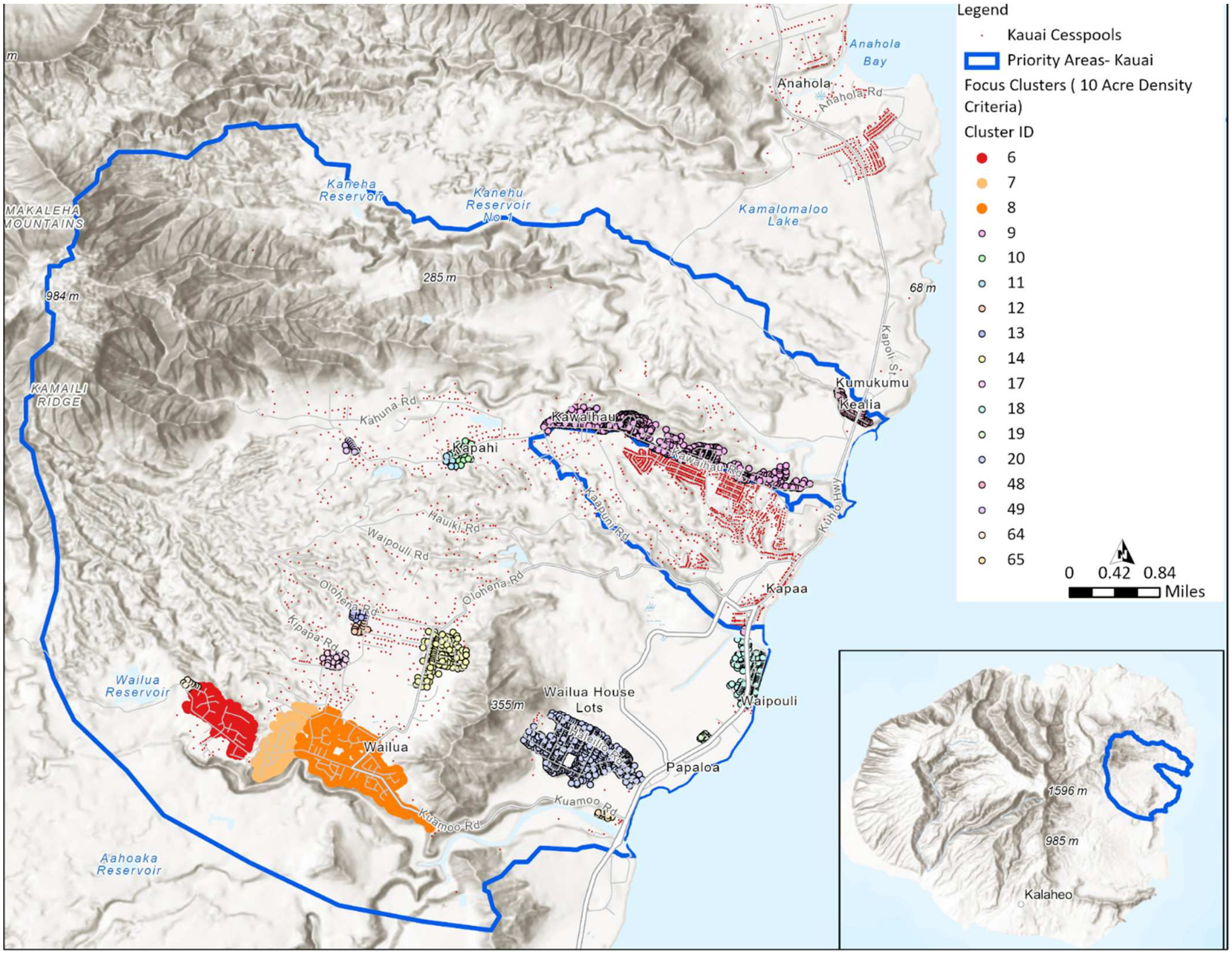

Figure 3.55 Kapaa/Wailua Focus Clusters (10 Acre Density Criteria)

Figure 3.55 shows the clusters of cesspools that meet 10-acre density criteria in Kapaa/Wailua. There are 17 focus clusters that could be analyzed further for the 10-acre density criteria in this priority area. These clusters are referred to as "Kapaa/Wailua Focus Clusters (10-acre density criteria)", the sizes of which are shown in the chart below (*Figure 3.56).*

- 17 cesspool clusters make up 2,437 cesspools in this area that meet the density criteria.
    - 2,437 cesspools are approximately 78% of the total in Kappa/Wailua.

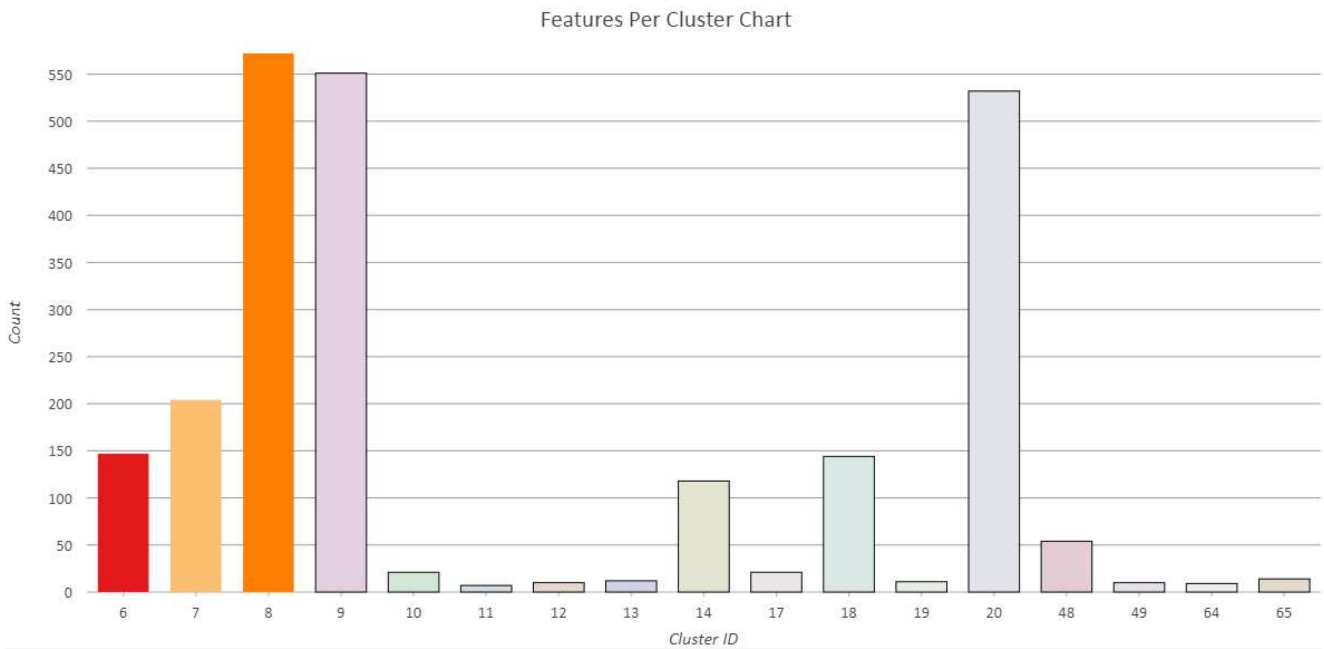

Figure 3.56 Kapaa/Wailua Focus Clusters (10 Acre Density Criteria): Features Per Cluster Chart

3.2.5 Molokai

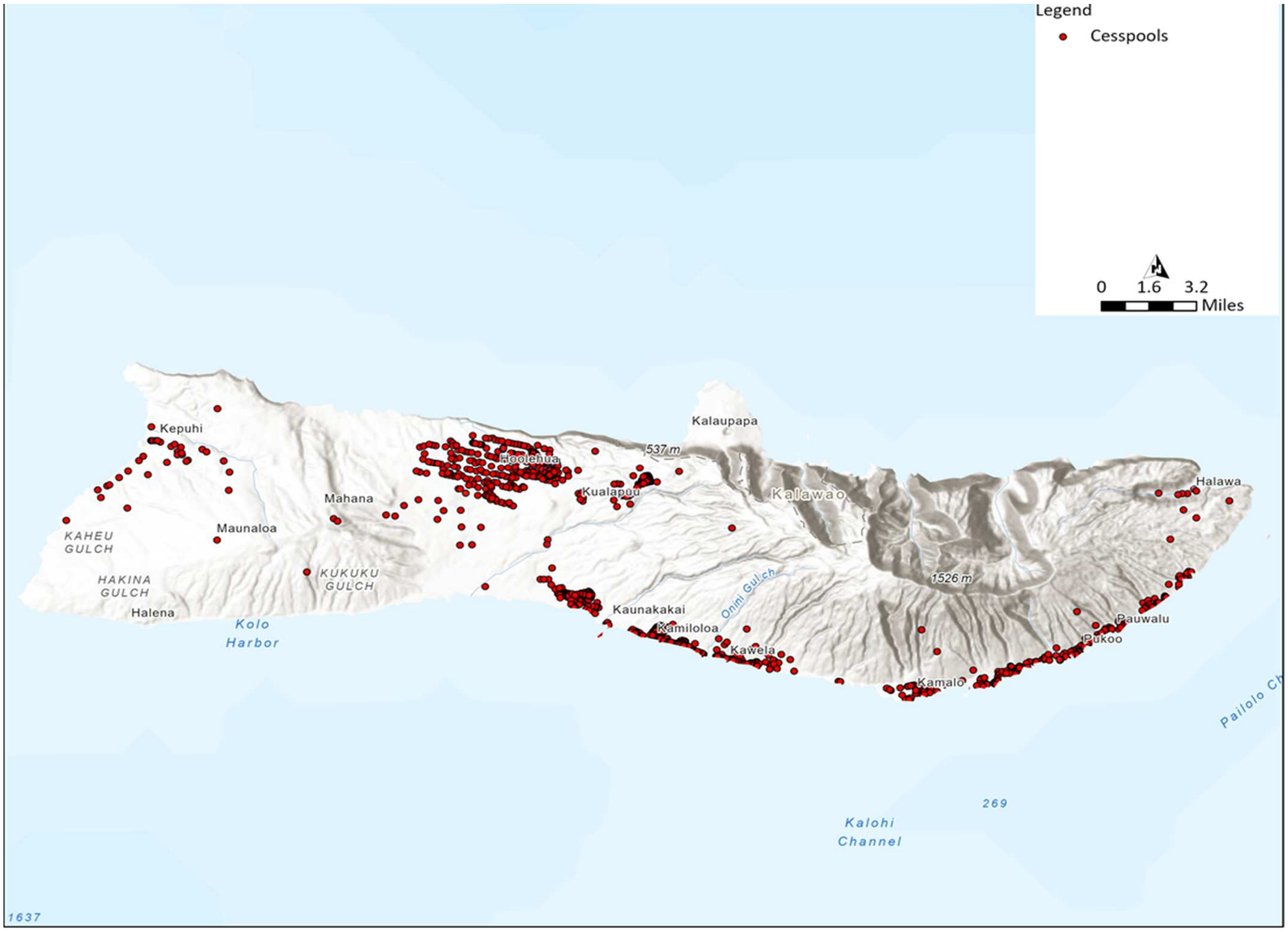

Figure 3.57 1,212 Total Cesspools on Molokai

Molokai plays host to the smallest population of cesspools among the Hawaiian Islands covered in this study. As shown in *Figure 3.29*, there are approximately 1,212 cesspools on Molokai. Like the other islands, most of the cesspools are located along the coasts and in residential neighborhoods. Through the method laid out in the previous chapter (*Chapter 2: Materials and Methods)*, the following sections will analyze how cesspools are clustered across the island.

Overview: A look at the Cluster Feasibility Density Analysis

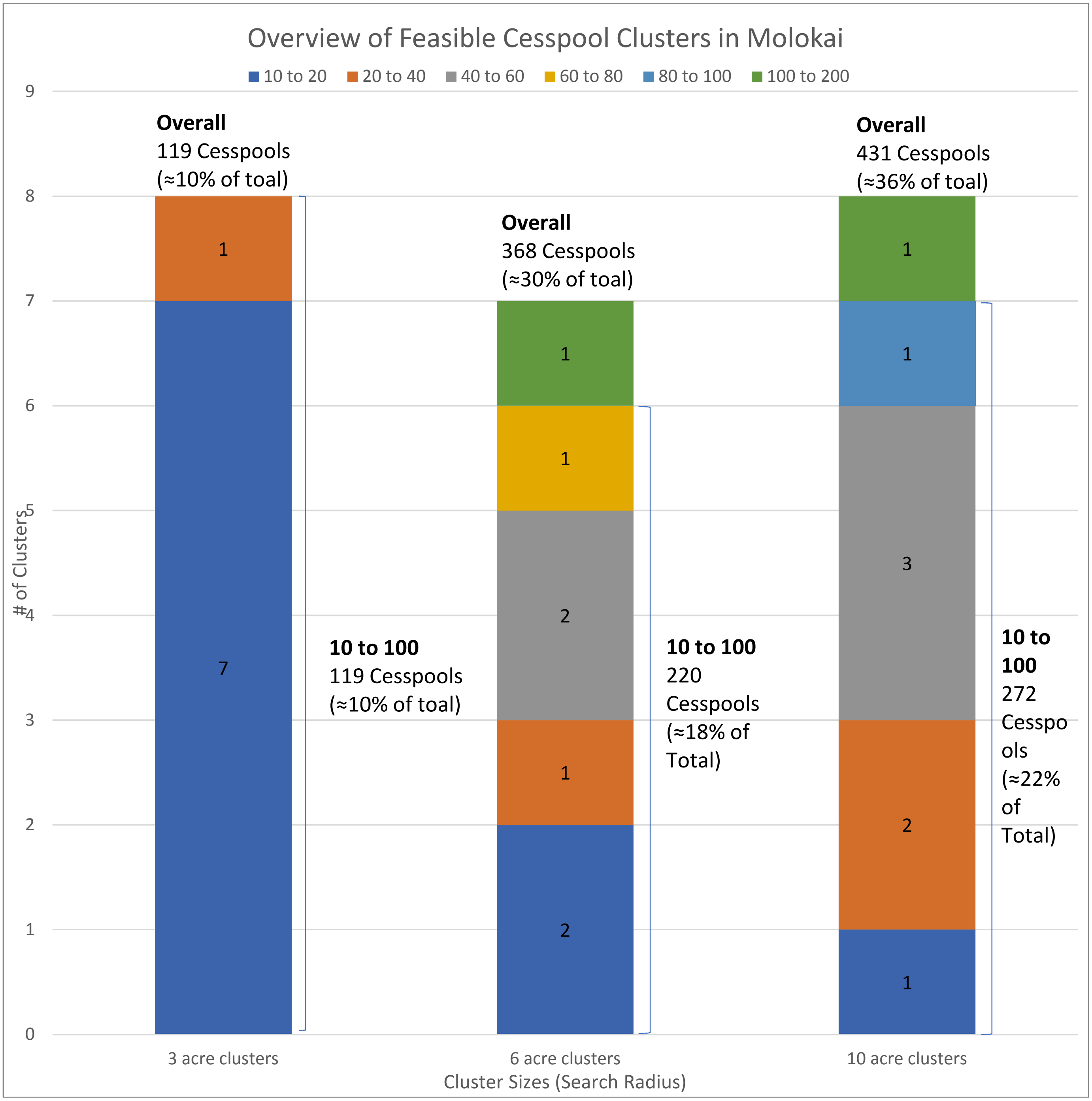

Figure 3.58 Overview of Feasible Cesspool Clusters in Molokai of size 10-100

Figure 3.58 shows an overview of the clusters of cesspools across Molokai. The graph breaks the sizes down into sub-categories: 10-20, 20-40, 40-60, 60-80, 80-100, and 100-200. The extra size category of 100-200 was included because there are no clusters above 200 in Molokai that meet any of the density criteria. Therefore, the graph above includes all the clusters found in the density analysis.

The results are as follows:

- For 3-acre density criteria,
  - Overall: **8 clusters/neighborhoods**
    - 119 total cesspools (10% of total)
  - Size 10-100: **8 clusters/neighborhoods**
    - 119 total cesspools (10% of total)
- For 6-acre density criteria,
  - Overall: **5 Clusters/neighborhoods**
    - 368 total cesspools (30% of total)
  - Size 10-100: **6 clusters/neighborhoods**
    - 220 total cesspools (18% of total)
- For 10-acre density criteria,
  - Overall: **7 clusters/neighborhoods**
    - 431 total cesspools (36% of total)
  - Size 10-100: **8 clusters/neighborhoods**
    - 272 total cesspools (22% of total)

These results provide an overview for cluster feasibility on the island of Molokai across different density criteria.

Maui Focus Clusters & Priority Areas

- There are no priority upgrade areas on Molokai as defined by DOH.

3.3 Comparing Costs to that of Onsite Wastewater Treatment Alternatives

3.3.1 Oahu Focus Cluster

Figure 3.59 Kahaluu Focus Cluster: ID 45

Kahaluu Focus Cluster: ID 45

- Approximately 70 Cesspools
- Approximately 25 Acres
- Density Index: Approximately 2.8

Figure 3.59 shows a specific focus cluster (ID:45) in the priority-1 area of Kahaluu, Oahu (see *Oahu Focus Clusters & Priority Areas* section) that has the potential for decentralized cluster system implementation. It makes sense to add the surrounding cesspools that do not technically meet the 3-acre density criteria but are close enough to include, therefore the cluster now has a size of approximately 70 cesspools.

Tables 3.12 and 3.13 compare the cost to this neighborhood of using individual onsite treatment options or a connected decentralized cluster treatment option. Since Kahaluu is a priority 1 area, nitrogen removal is required for onsite treatment, thus, "Septic Tank + Absorption Disposal" is not a viable alternative for the community in Kahaluu Focus Cluster: ID 45.

Comparing the costs of "ATU + Absorption Disposal" to that of the 4 treatment trains listed in *Table 3.13* shows that the financial decision for the community is very close. Treatment train 2a and 2b have cheaper capital costs but more expensive 60-year life cycle costs than the ATU onsite system. Treatment train 1a is the most cost comparative option when the 60-year life cycle is considered. It only costs approximately $6,000 more per household over the entire 60-year life span. This financial competitiveness along with the other benefits of cluster systems (see *section 1.1*) should make decentralized treatment a serious consideration for this community.

Table 3.12 Cost to Entire Neighborhood (Cluster) if Onsite Systems are Implemented (Adapted from *Technical Memorandum No. 3: Onsite Treatment Technologies Evaluation*. Carollo Engineers, Inc. in association with the University of Hawaii, 2020.)

Onsite	Construction (Capital)	60 Year Life Cycle
Septic Tank + Absorption Disposal (Not a viable option for this focus cluster)	**Avg: $1,540,000** **($22,000 per home)**	**Avg: $2,310,000** **(33,000 per home)**
ATU + Absorption Disposal	**Avg: $2,030,000** **(29,000 per home)**	**Avg: $ 5,180,000** **(74,000 per home)**

Table 3.13 Costs to Entire Neighborhood (Cluster) if a Decentralized Cluster System is Implemented. (Adapted from *Performance and Cost of Decentralized Unit Processes*. WERF,2010.)

Decentralized Cluster System	Construction (Capital)	60 Year Life Cycle
1a (STEP-CW-ABS/ET)	**Avg: $2,280,000** **(32,500 per home)**	**Avg: $5,610,000** **(80,000 per home)**
2a (STEP-TXF-ABS/ET)	**Avg: $1,980,000** **(28,000 per home)**	**Avg: $5,850,000** **(83,500 per home)**
2b (STEP-TXF-DRIP)	**Avg: $1,760,000** **(25,000 per home)**	**Avg: $6,170,000** **(88,000 per home)**
4a (STEP-CAS/MBR-ABS/ET)	**Avg: $2,130,000** **(30,000 per home)**	**Avg: $6,340,000** **(90,500 per home)**

3.3.2 Maui Focus Cluster

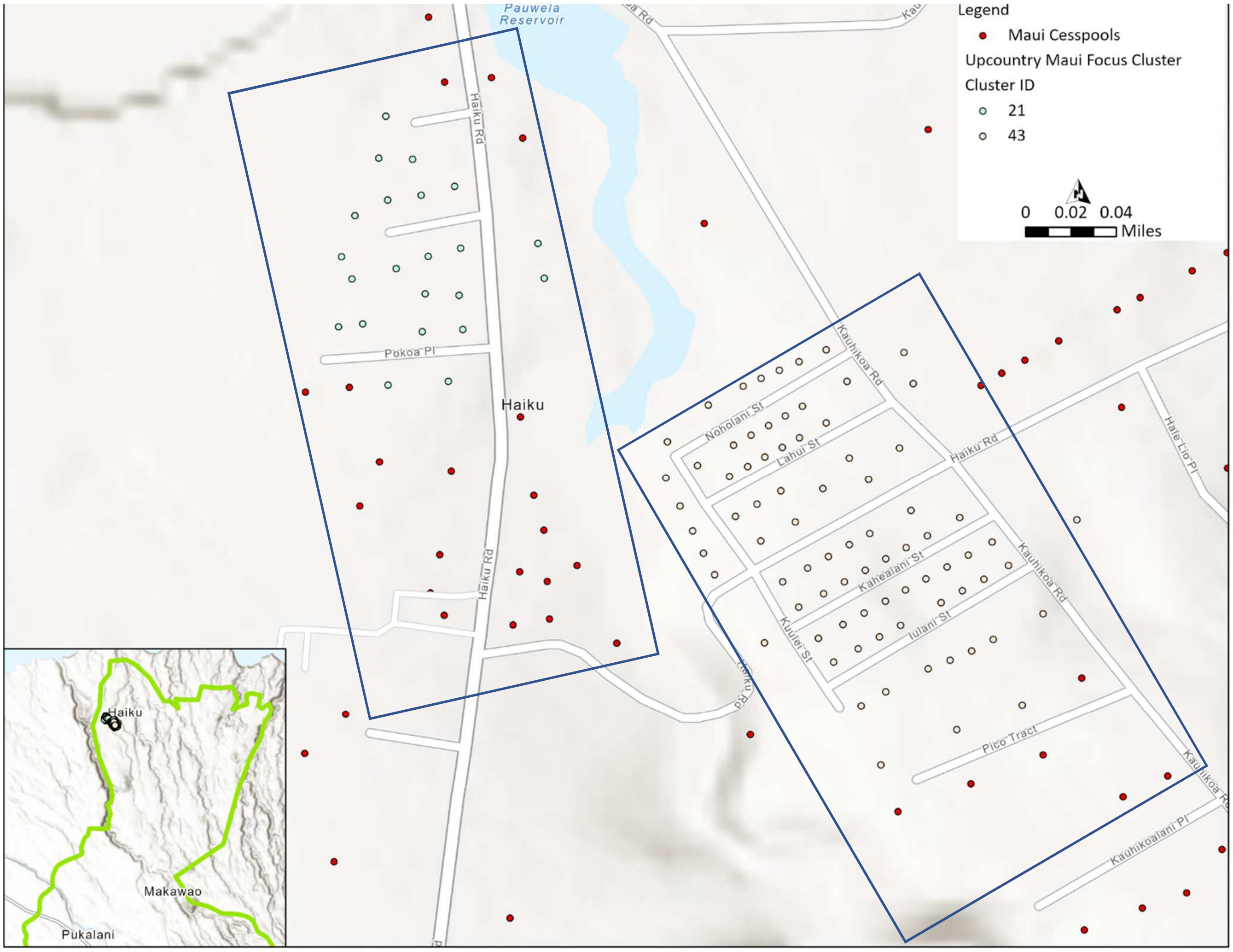

Figure 3.60 Upcountry Maui Focus Cluster: ID 21 & 43

Upcountry Maui Focus Cluster: Combine ID 21 & 43.

- Approximately 130 Cesspools
- Approximately 45 Acres
- Density Index: Approximately 2.9

Figure 3.60 shows a specific focus cluster (ID 21 & 43) in the priority-1 area of Upcountry Maui (see *Maui Focus Clusters & Priority Areas* section) that has the potential for decentralized cluster system implementation. It makes sense to add the surrounding cesspools that do not technically meet the 3-acre density criteria but are close enough to include, therefore the cluster now has a size of approximately 130 cesspools when combining ID 21 and 43.

Tables 3.14 and 3.15 compare the cost to this neighborhood of using individual onsite treatment options or a connected decentralized cluster treatment option. Since Upcountry Maui is a priority 1 area, nitrogen removal is required for onsite treatment, thus, "Septic Tank + Absorption Disposal" is not a viable alternative for the community in Upcountry Focus Cluster: ID 21 & 43.

Comparing the costs of "ATU + Absorption Disposal" to that of the 4 treatment trains listed in *Table 3.15* shows that the financial decision for the community is very close. Treatment train 2a and 2b have cheaper capital costs but more expensive 60-year life cycle costs than the ATU onsite system. Treatment train 1a is the most cost comparative option when the 60-year life cycle is considered. It only costs approximately $6,000 more per household over the entire 60-year life span. This financial competitiveness along with the other benefits of cluster systems (see *section 1.1*) should make decentralized treatment a serious consideration for this community.

Table 3.14 Cost to Entire Neighborhood (Cluster) if Onsite Systems are Implemented. (Adapted from *Technical Memorandum No. 3: Onsite Treatment Technologies Evaluation*. Carollo Engineers, Inc. in association with the University of Hawaii, 2020.)

Onsite	Construction (Capital)	60 Year Life Cycle
Septic Tank + Absorption Disposal (Not a viable option for this focus cluster)	**Avg: $2,860,000** **($22,000 per home)**	**Avg: $4,290,000** **(33,000 per home)**
ATU + Absorption Disposal	**Avg: $3,770,000** **(29,000 per home)**	**Avg: $ 9,620,000** **(74,000 per home)**

Table 3.15 Costs to Entire Neighborhood (Cluster) if a Decentralized Cluster System is Implemented. (Adapted from *Performance and Cost of Decentralized Unit Processes*. WERF,2010.)

Decentralized Cluster System	Construction (Capital)	60 Year Life Cycle
1a (STEP-CW-ABS/ET)	**Avg: $4,230,000** **(32,500 per home)**	**Avg: $10,410,000** **(80,000 per home)**
2a (STEP-TXF-ABS/ET)	**Avg: $3,690,000** **(28,000 per home)**	**Avg: $10,860,000** **(83,500 per home)**
2b (STEP-TXF-DRIP)	**Avg: $3,270,000** **(25,000 per home)**	**Avg: $11,460,000** **(88,000 per home)**
4a (STEP-CAS/MBR-ABS/ET)	**Avg: $3,950,000** **(30,000 per home)**	**Avg: $11,770,000** **(90,500 per home)**

3.3.3 Big Island Focus Cluster

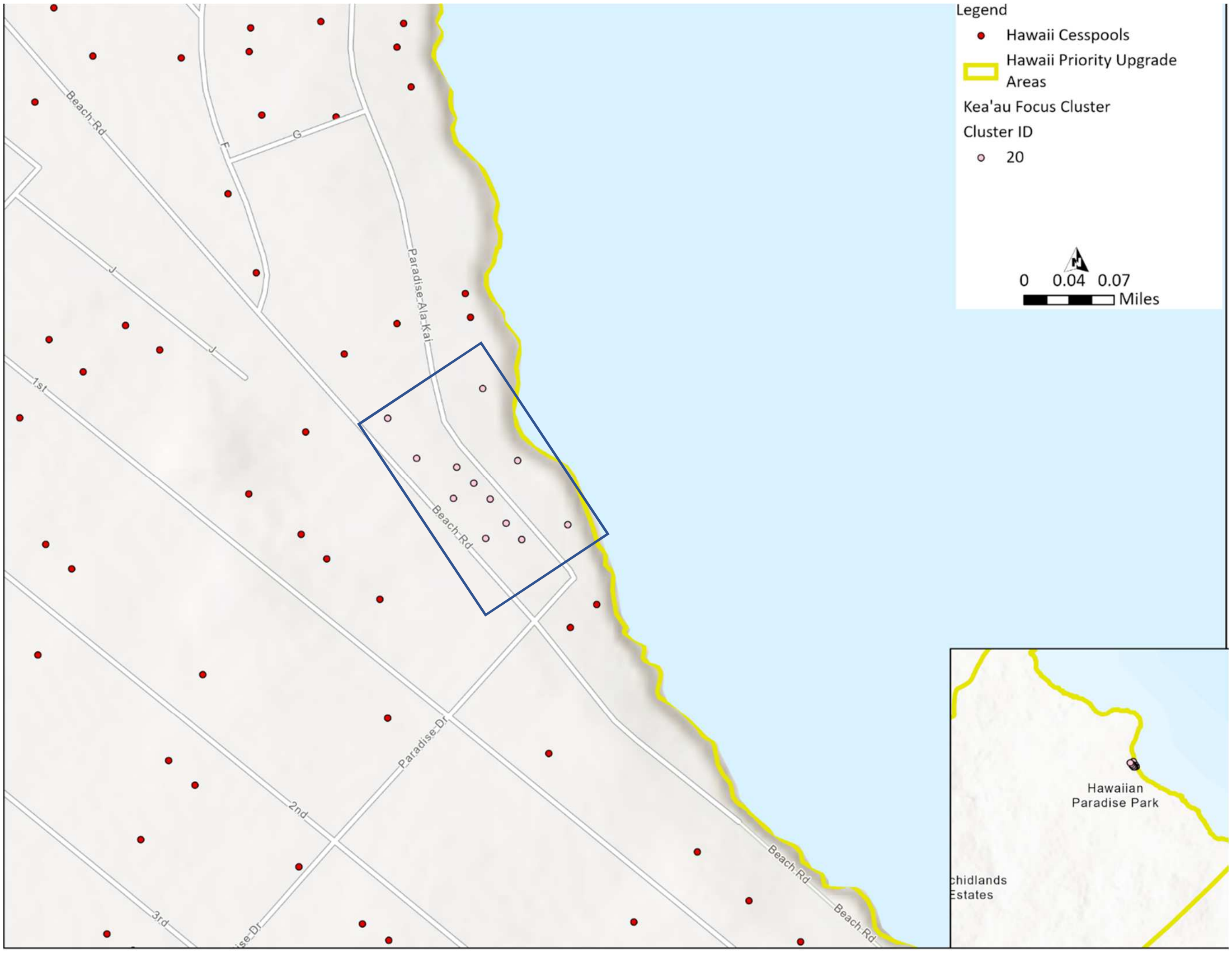

Figure 3.61 Kea'au Focus Cluster: ID 20

Kea'au Focus Cluster: ID 20

- Approximately 12 Cesspools
- Approximately 11 Acres
- Density Index: Approximately 1

Figure 3.61 shows a specific focus cluster (ID 20) in the priority-2 area of Kea'au, Hawaii (see *Big Island Focus Clusters & Priority Areas* section) that has the potential for decentralized cluster system implementation. The cluster is quite small and has a size of approximately 12 cesspools.

Tables 3.16 and 3.17 compare the cost to this neighborhood of using individual onsite treatment options or a connected decentralized cluster treatment option. Septic tanks are by far the cheapest option if allowed in this neighborhood. However, if nitrogen removal is required or preferred, "ATU + Absorption Disposal" costs should be compared to that of cluster system alternatives.

Comparing the costs of "ATU + Absorption Disposal" to that of the 4 treatment trains listed in *Table 3.17* shows that the financial decision for the community is very close. Treatment train 2a and 2b have cheaper or equal capital costs but more expensive 60-year life cycle costs than the ATU onsite system. Treatment train 1a is the most cost comparative option when the 60-year life cycle is considered. It only costs approximately $8,300 more per household over the entire 60-year life span, or $. This financial competitiveness along with the other benefits of cluster systems (see *section 1.1*) should make decentralized treatment a serious consideration for this community.

Table 3.16 Cost to Entire Neighborhood (Cluster) if Onsite Systems are Implemented. (Adapted from *Technical Memorandum No. 3: Onsite Treatment Technologies Evaluation*. Carollo Engineers, Inc. in association with the University of Hawaii, 2020.)

Onsite	Construction (Capital)	60 Year Life Cycle
Septic Tank + Absorption Disposal	**Avg: $260,000 (22,000 per home)**	**Avg: $390,000 (33,000 per home)**
ATU + Absorption Disposal	**Avg: $350,000 (29,000 per home)**	**Avg: $890,000 (74,000 per home)**

Table 3.17 Costs to Entire Neighborhood (Cluster) if a Decentralized Cluster System is Implemented. (Adapted from *Performance and Cost of Decentralized Unit Processes*. WERF,2010.)

Decentralized Cluster System	Construction (Capital)	60 Year Life Cycle
1a (STEP-CW-ABS/ET)	**Avg: $390,000 (32,500 per home)**	**Avg: $990,000 (82,500 per home)**
2a (STEP-TXF-ABS/ET)	**Avg: $340,000 (28,000 per home)**	**Avg: $1,100,000 (91,600 per home)**
2b (STEP-TXF-DRIP)	**Avg: $310,000 (26,000 per home)**	**Avg: $1,100,000 (91,600 per home)**
4a (STEP-CAS/MBR-ABS/ET)	**Avg: $480,000 (40,000 per home)**	**Avg: $1,400,000 (120,000 per home)**

3.3.4 Kauai Focus Cluster

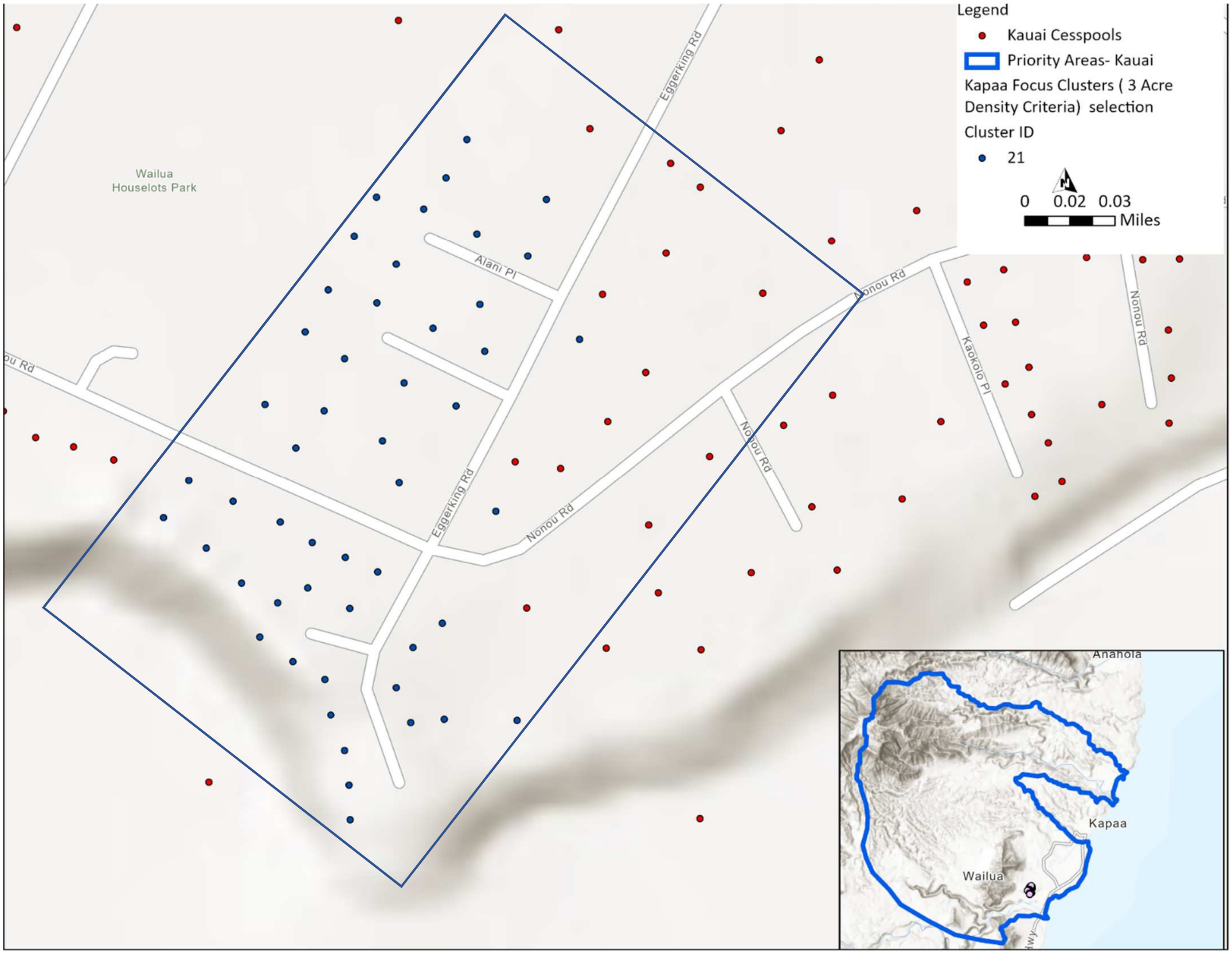

Figure 3.62 Kapaa/Wailua Focus Cluster: ID 21

Kapaa/Wailua Focus Cluster: ID 21

- Approximately 60 Cesspools
- Approximately 25 Acres
- Density Index: Approximately 2.4

Figure 3.62 shows a specific focus cluster (ID 21) in the priority-2 area of Kapaa/Wailua, Kauai (see *Kauai Focus Clusters & Priority Areas* section) that has the potential for decentralized cluster system implementation. It makes sense to add the surrounding cesspools that do not technically meet the 3-acre density criteria but are close enough to include, therefore the cluster now has a size of approximately 60 cesspools.

Tables 3.18 and 3.19 compare the cost to this neighborhood of using individual onsite treatment options or a connected decentralized cluster treatment option. Septic tanks are by far the cheapest option if allowed in this neighborhood. However, if nitrogen removal is required or preferred, “ATU + Absorption Disposal” costs should be compared to that of cluster system alternatives.

Comparing the costs of “ATU + Absorption Disposal” to that of the 4 treatment trains listed in *Table 3.18* shows that the financial decision for the community is very close. Treatment train 2a and 2b have cheaper or equal capital costs but more expensive 60-year life cycle costs than the ATU onsite system. Treatment train 1a is the most cost comparative option when the 60-year life cycle is considered. It only costs approximately $6,000 more per household over the entire 60-year life span. This financial competitiveness along with the other benefits of cluster systems (see *section 1.1*) should make decentralized treatment a serious consideration for this community.

Table 3.18 Cost to Entire Neighborhood (Cluster) if Onsite Systems are Implemented. (Adapted from *Technical Memorandum No. 3: Onsite Treatment Technologies Evaluation*. Carollo Engineers, Inc. in association with the University of Hawaii, 2020.)

Onsite	Construction (Capital)	60 Year Life Cycle
Septic Tank + Absorption Disposal	**Avg: $1,320,000 (22,00 per home)**	**Avg: $1,980,000 (33,000 per home)**
ATU + Absorption Disposal	**Avg: $1,740,000 (29,000 per home)**	**Avg: $4,440,000 (74,000 per home)**

Table 3.19 Cost to Entire Neighborhood (Cluster) if a Decentralized Cluster System is Implemented (Adapted from *Performance and Cost of Decentralized Unit Processes*. WERF,2010.)

Decentralized Cluster System	Construction (Capital)	60 Year Life Cycle
1a (STEP-CW-ABS/ET)	**Avg: $1,950,000 (32,500 per home)**	**Avg: $4,800,000 (80,000 per home)**
2a (STEP-TXF-ABS/ET)	**Avg: $1,700,000 (28,000 per home)**	**Avg: $5,000,000 (83,500 per home)**
2b (STEP-TXF-DRIP)	**Avg: $1,500,000 (25,000 per home)**	**Avg: $5,300,000 (88,000 per home)**
4a (STEP-CAS/MBR-ABS/ET)	**Avg: $1,800,000 (30,000 per home)**	**Avg: $5,400,000 (90,500 per home)**

Chapter 4: Conclusions and Recommendations

Analysis & Data Presented in this Study Allows the Following Conclusions:

- Decentralized wastewater treatment (cluster) systems replacing clusters of cesspools in Hawaii is **feasible**.
    - “Feasible” clusters of 10-100 cesspools make up approximately:
        - 18-20% of the cesspools on Oahu,
        - 12-17% of the cesspools on Maui,
        - 13% of the cesspools on the Big Island, and
        - 12-17% of the cesspools on Kauai.
    - Clusters of any size make up approximately:
        - 32-50% of the cesspools on Oahu,

        - 21-51% of the cesspools on Maui,
        - 18-51% of the cesspools on the Big Island, and
        - 46-79% of the cesspools on Kauai.
    - "Focus clusters" in priority areas make up approximately:
        - 16-46% of the total cesspools in Kahaluu, Oahu,
        - 21-53% of the total cesspools in Upcountry Maui,
        - 0.3-6% of the total cesspools in Kea'au, Big Island, and
        - 43-78% of the total cesspools in Kappa/Wailua, Kauai.
- Cluster systems are more expensive than onsite systems regardless of the size of the cluster or the site conditions.
    - If allowed, "Septic Tank + Absorption Disposal" will always be cheapest option available for the homeowner.
    - However, the cost differential is smaller in priority 1 areas that require nitrogen removal and thus prefer "ATU + Absorption Disposal" over "Septic Tank + Absorption Disposal".
    - Keep in mind that these are very rough cost estimations, but they do tell an overarching picture of the feasibility for different options.
        - For approximately 5,000 gpd of treated flow:
            - Treatment train 1A (STEP-CW-ABS/ET) costs ≈**$8,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 2a (STEP-TXF-ABS/ET) costs ≈**$17,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 2b (STEP-TXF-DRIP) costs ≈**$17,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 4a (STEP-CAS/MBR-ABS/ET) costs ≈**$46,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
        - For approximately 10,000 gpd of treated flow:
            - Treatment train 1A (STEP-CW-ABS/ET) costs ≈**$7,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 2a (STEP-TXF-ABS/ET) costs ≈**$18,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 2b (STEP-TXF-DRIP) costs ≈**$25,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 4a (STEP-CAS/MBR-ABS/ET) costs ≈**$29,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.

        - For approximately 50,000 gpd of treated flow:
            - Treatment train 1A (STEP-CW-ABS/ET) costs ≈**$6,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 2a (STEP-TXF-ABS/ET) costs ≈**$9,500** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 2b (STEP-TXF-DRIP) costs ≈**$14,000** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
            - Treatment train 4a (STEP-CAS/MBR-ABS/ET) costs ≈**$16,500** more per household than ATU + Absorption Disposal over its 60-year-lifecycle.
    - As is shown in the results above, cluster systems make more sense as the number of houses/cesspools in the cluster increases. It is also important to note that these cost differences occur over a 60-year period, the initial(capital) costs can often be cheaper for cluster systems (see *Section 3.3).*
- The challenges of implementing cluster systems listed in *section 1.1* need to be considered, including availability of land, and the need for neighborhood level coordination and skilled operators.
- However, when the advantages from *section 1.1* outweigh these challenges, and when the system is financially competitive with onsite alternatives, **cluster systems can be a good solution for a community attempting to replace its cesspools according to ACT 125.**

This study leads to the following recommendations for future work:

- Evaluate large clusters of cesspools for possible centralized treatment systems or connection to existing sewers.
    - The cost estimations going up to 50,000 gpd created an upper bound of approximately 100/150 homes for this study.
    - It will be important for someone to look at the huge clusters in places such as Upcountry Maui or Kea'au, Hawaii to see what solutions make the most sense for them.
- Design a collection, treatment, and disposal system for a specific neighborhood, considering the following:
    - The number of systems in the cluster and the separation distance between them.
    - Terrain.
    - Availability of land.
    - Public support for a decentralized system, including shared funding for a utility service providing O&M.
    - Number of wastewater systems to oversee and manage.
    - Funding Opportunities.

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