Appendix E
Ecodistrict Report

SEPTEMBER 6, 2024

LIHUE GOVERNMENT CAMPUS

ECODISTRICT REPORT

PREPARED BY:
AARON COOK
UNDER THE SUPERVISION OF PAUL CRABTREE

719.539.1675
719.221.1799

325 D Street, P.O. Box 924, Salida, CO 81201
crabtreegroupinc.com

Contents

1 Executive Summary

Long-term sustainability requires that decisions in developments look at ways to reduce or harmonize the long-term ecological impacts of development. An Ecodistrict is an organizational structure to provide long-term funding for operating and maintaining several systems to achieve this reduced impact goal. This structure allows for a utility-scale investment in greener technologies, allowing for bonding and other funding mechanisms to pay for upgrades that will allow for long-term reductions in the total energy demand of a new development. This report examines the potential of an ecodistrict centered around the Lihue Government Campus. This location is undergoing a broader study for the infill development of very necessary housing on Kauai.

Utility capacity and development of the site is examined through the broader classifications of wet and dry utilities. Wet utilities include water, wastewater, and rainwater management. Water and wastewater is currently under a parallel study not available at the time of this report, but estimates for the system capacity are presented. From the site, there is both an 8” sewer line and a 12” sewer line in Rice Street. To the extent possible, putting the sewer lines to the gravity drained 12” line from the government campus site is preferable, compared to the pumping from the lift station on the 8” line. Without improvements, the 8” line is estimated to be able to support 480 units, and the 12” line 948 units (of which any units on the 8” line are tributary). For water recycling and rainwater management, onsite rain gardens, swales, and infiltration basins are recommended for landscape irrigation and maintenance. A mulch area of approximately 150 sq ft per 2 bedroom equivalent unit is estimated to be able to handle the per unit graywater recycling load.

Dry utilities are those generally concerned with energy consumption. In Hawaii, the total energy consumption of the residential and transportation sectors added up to 68%[1] of total statewide energy consumption, placing a large portion of available savings in these sectors. The design of the buildings should incorporate shade and shade structures appropriate for the Hawaiian climate and potential severe weather from cyclones to reduce the cooling load. Natural ventilation from trade winds should also be a priority in design of the buildings. For the cooling load beyond what these designs can handle, a geothermal cooling district, with a well field for tying into cooler underground temperatures would lead to higher efficiency heat pumps. This district would not have to be limited to the government campus, and a cooling district could eventually create enough customer base for a higher efficiency sea water air conditioning district, though at a scale beyond that contemplated for this site alone. Approximately 580 sq ft of solar

[1] DBEDT, State of Hawaii. *State of Hawaii Energy Data and Trends*. Research and Economic Analysis Division. April 2022.

panels per unit can and as shade structures over parking and sidewalks can provide multiple benefits. Finally, the transportation aspect of the units is the final area analyzed. Zoning and land use codes should be revised near the government campus to increase the number of destinations within walking[2] distance of the site. For destinations throughout the island, an increase in frequency for the bus network is recommended to increase the usefulness and vitality of non-personal vehicle modes, taking into account the proximity of the main transportation hub to the government campus.

[2] "Walking" throughout the report includes mobility aids and ADA accommodation, but is not further enumerated each time for clarity.

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4 Introduction

This analysis is for a proposed adaptive reuse of the Lihue Government Campus Site. The site was a former shopping center, with conventional mall shopping and parking surrounding it. This report deals with the feasibility of creating an Ecodistrict kick-started by the units built as part of this project. This kickstart can be part of the initial construction of these units, and provide a revenue source for a new entity to scale up to providing utility to unit scale ecological and environmental benefits. An ecodistrict is not an all-or-nothing approach, but rather, should be as comprehensive as possible without jeopardizing the entire endeavour. Some strategies only work with a scale larger than contemplated in this report. Other strategies do not require more than a dedicated staff member to educate the public and be a resource for others.

Ecodistrict

"A resilient urbanism strategy [which] changes energy demand, efficiency and generation, decreasing demand via transit-rich compact development patterns, increasing efficiency with high performance infrastructure and green architecture, and increasing generation with renewable energy sources."
Reinvent Phoenix: Ecodistrict. 2014.

5 Ecodistrict Basics

Ecodistricts are designated areas where the elements of urbanization work towards sustainable planning on a neighborhood scale. This includes Physical Infrastructure Elements (electric utilities, transportation facilities, heating or cooling districts), Biological Elements (Street Trees, landscaping, community gardens), and Social Elements (School location and availability, social clubs, or technical support of house-level ecological improvements).[3] Integrating the transportation, utility, and civic infrastructure in a green 'best practices' approach can have greater effects than individual tasks and burdens. The degree of utility integration may vary, though more integrated will make a more efficient approach possible.

The purpose of an ecodistrict is to reduce the total impact on the environment of development within the ecodistrict. This can take many forms, and one strategy to prioritize what can be done for benefit is looking where the greatest impacts are already occurring. In Hawai'i,

[3] Argerious, Natalie Bicknell. "What is an Ecodistrict?" *The Urbanist*. July 2, 2022. https://www.theurbanist.org/2022/07/02/urbanism-101-what-is-an-ecodistrict/

electricity generation is the single largest contributor to emissions, at approximately 39% of total emissions. This is followed by aviation, at 25% of all Hawai'ian emissions, then ground transportation at almost 21% of total emissions. These three areas account for 85% of all carbon emissions statewide.[4] While addressing aviation is not a matter within the scope of this report, the energy consumed by the contemplated buildings and transportation to surrounding areas are.

The ability for a governmental or utility arm to integrate many of the grid-level infrastructure required for increased urban sustainability is the main benefit of an ecodistrict. This entity can leverage financing, bidding, construction, and long-term maintenance of these systems in a sustainable manner. One of the largest issues in Hawaii is the cost burden of housing, Area Median Income (AMI)[5] being $102,200 while median sale prices are in the range of $867,500 to $1,092,000, depending on whether discussing a condominium or single family home, respectively.[6] On the low end, with the 7.5% mortgage rate anticipated for a jumbo loan, even assuming 20% down, the monthly payment for the condominium loan is $4,853, or 57% of the gross AMI. This means that for any household on Kauai, would spend double the general financial stability guideline that no more than 30% of net (take-home, or after taxes) pay should be spent on housing. Therefore, funding for ecological upgrades maybe out of reach of buyers in the market, and funding may well need to be built into utility bills or other regular payments, amortized across a longer time span.

6 PHYSICAL INFRASTRUCTURE

The infrastructure of the ecodistrict is the most obvious and straightforward element. Residents and businesses within the ecodistrict require transportation facilities, power, water, sanitary sewer, rainwater management. Discussion of Infrastructure is divided into Service Bundles – Service Bundle 1 is Water, Sewer, and Rainwater management. Service Bundle 2 is energy related, whether electricity, gas, or heating and cooling district. Service Bundle 3 involves communication infrastructure, whether digitally with telecommunications, or in person (transportation).

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[4] *Hawai'i Pathways to Decarbonization*. December 2023. Act 238 Session laws of Hawai'i 2022 Report to the 2024 Hawai'i State Legislature. Hawai'i Department of Energy. https://energy.hawaii.gov/wp-content/uploads/2022/10/Act-238_HSEO_Decarbonization_FinalReport_2023.pdf

[5] From County of Kauai 2023 Annual Income Limits table, at https://www.kauai.gov/files/assets/public/v/1/housing-agency/documents/kmhi/2023-income-limit-data-5.15.2023.pdf

[6] Kauai Real Estate Report. Locations Hawaii. https://www.locationshawaii.com/learn/market-reports/kauai-real-estate-report/ June 2024

7 SERVICE BUNDLE 1 – WET UTILITIES

(DOMESTIC WATER, SANITARY SEWER, RAINWATER MANAGEMENT, GRAYWATER REUSE)

7.1 WATER SUPPLY

The current water supply is via Kauai Water. A Facilities Reserve Charge (impact fee) is assessed against new units to help fund capital improvement and increased water supply[7] as new units increase demand against the water supply. The fees, as of 2020, are summarized in Table 1.

Table 1. Water Supply Charges

Type of Unit	Facilities Reserve Charge
New Parcels and new SFH	$14,115
Multi-Family (MF) or Resort, per unit	$9880
Existing SFH to two-dwelling conversion	50% of MF unit ($4940)
Affordable Housing per KCO 7 A-1.3	$4940
Guest House with Kitchen or Additional Rental Unit (ARU)	$9880

The current capacity of the water treatment system is approximately 1.2 million gallons per day, and it is currently at 70% capacity. There are plans for expansion of the water treatment plant in two steps of 2.5 MGD and 3 MGD.[8]

[7] Kauai Water. "Part 5 – Facilities Reserve Charge." *Kauai Water Rules and Regulations*. June 15, 2020. http://kauaiwater.org/cp_rules&regs.asp

[8] Personal Communication, Kauai County Department of Water, September 29, 2023.

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Scale: 1:6,000
1 inch equals 500 feet

N

250 125 0 250 500
Feet

References:

- Sewer & water line data received from the County of Kauai on 11/14/2023
- Contour data retrieved from the USGS National Map on 02/07/2024
- Streams data retrieved from the Hawaii Geoportal on 02/21/2024

Figure 1. Existing Sewer Lines and Design Points for Existing Flow Analysis

Design Points
Sewer Tributary Areas
Sewer Pump Stations
Nawiliwili Stream
Property Parcels

Existing Sewer Lines
Pipe Size, Inches
0
6
8
10
12
15
18
21
24
27
Sewer Laterals
Sewer Force Main
Existing sewer manhole invert
Proposed sewer manhole invert

COUNTY OF KAUAI
HAWAII, USA

SEWER LINE TRIBUTARY AREAS

SHEET NO. 1 OF 1

PROJECT 23014

S:\23014 Lihue Civic Center\GIS\23014-LihueCivicCenter.aprx

7.2 WASTEWATER

The wastewater treatment plant serving this area currently processes 1.2 MGD[9], and is permitted for 2.5 MGD of processing. While there is a pipe capacity constraint near Ahikuna Rd and Kuhio Highway, the site is downstream from this bottleneck, where a larger capacity pipe is installed.

7.2.1 CAPACITY ANALYSIS OF WASTEWATER COLLECTION SYSTEM

7.2.1.1 Existing Sewer Flow Conditions

The county has indicated that they are currently undergoing an in-depth analysis of the current sewer and water line capacities, which is occurring simultaneously to this analysis. Unfortunately, results from that in-depth analysis are not yet available at the time of writing. Therefore, the below was performed to guide recommendations, with the caveat that the more detailed analysis forthcoming on the detailed infrastructure study should be used for final capacity analysis.

A map of the current sewer infrastructure and the areas outlined as tributary to each is shown in Figure 1. Wastewater flows were analyzed between the intersections at Kuhio Highway and Ehiku Streets (upstream of the site), to Rice and Hoolako Streets (downstream of the site). The upstream limit of study is defined by the existing at-capacity flow in a 10" pipe, as described by the Wastewater management department and discussed in the following paragraph. The downstream end of analysis is defined by the point where the sewer line upsizes from 15" to 18" at Rice St and Hoolako St. A detailed study for the development scenario(s) chosen should be made to ensure additional anticipated growth past the end of analysis point does not overwhelm the system downstream. For now, the assumption is that capacity constraints imposed by the pipes immediately downstream of the government campus control the capacity available, rather than pipes further downstream (where the government campus pipes meet the main line through downtown Lihue, at design point 1.2).

From the wastewater department[10], a capacity constraint exists upstream from the area of the Government Campus before an upsizing in the pipe size in the vicinity of Wal-Mart. This limits the number of additional units which can be located upstream of this chokepoint. To determine available capacity, sewer pipes are conventionally considered 'full'[11] when they handle 80% of the total pipe capacity's flow rate. This is the limit used in this study, with the

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[9] Personal Communication, Kauai Wastewater Management Division. March 13, 2024.

[10] Idem

[11] In the sense that, once this point in flow demand is reached, a plan for the upgrading of the line size should be actively underway. It does not necessarily mean that a measured allowance of additional taps cannot be provided in the interim, as long as upgrading the sewer line is well underway.

exception of the upstream capacity constrained 10” pipe (at Design Point 1.3) which is assumed at 100% pipe capacity to account for all upstream flows, or 2.52 cfs (1,130 gpm) to ensure that this flow is not underrepresented downstream.

To calculate the current demand in the existing conditions sewer pipe through the area of study downstream of design point 1.3, existing demand flows in each area tributary to the sewer line were then added to the flow calculated for the full 10” pipe at each design point through the tributary area. These flows are based on the number of lots and condominiums in each tributary area, and, where available, data on the floor area of office spaces, assembly halls, and enrollment counts at schools. The resulting flow demand, listed as the assumed daily sewer demand and peak hour flow (with a peak hour factor of 4[12]), at each design point are shown in Table 2. These data were compiled from available sources, but were not verified against sewer customer record counts or water meter data.

Table 2. Estimated Demand Flows in Sewer

Area Identifier	**Lots**	**Condominiums**	**Assembly hall area**	**Office Area**	**School**	**Estimated Total Flow**	
Unit:	Each	Each	ft^2	ft^2	Students	GPD	GPM with Peak Hour Factor of 4 Applied
GPD per unit	300	300	0.14	0.075	20		
A	48	64	29000	13,743	915	56,990	158
B	95	88	25000	0	0	58,400	162
C	8	0	0	79,200	0	8,340	23
D	98	2	3800	0	0	30,530	85
E	151	58	0.0	0	0	62,700	174
F	14	2	0	31,250	0	7,140	20
G	0	0	0	118,900	0	8,920	25

The total available sewer capacity was then calculated using the pipe size and slope given in the County’s sewer GIS database as inputs into Manning’s equation at each design point. The current peak hour flow demand was applied to each design point, and the remaining available capacity of each line is shown in Table 3. Therefore, the line capacity immediately adjacent to the government campus is anticipated to be the limiting factor if attached to the 8” line, or the overall line capacity downstream if attached to the 12” line. This is highlighted in light yellow for the 8” line or light green for the 12” line in Table 3.

[12] A peak hour factor of 4 may be relatively high and indicates a fairly strong peak flow, such as in the morning as many bathe before work. In Lihue, the morning rush may be less compressed and warrant a lower peak hour factor, with a commensurate resulting increase in modelled pipe capacity.

Table 3. Anticipated Capacities and Sewer Flows

Design Point	Design Location	Pipe Size	Full Pipe Capacity		80% of Full Pipe Capacity		Estimated Current Peak Hour Flow Demand (PHF = 4)		Remaining Flow to 80% capacity	
		(in)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)
	Offsite Upstream Flow	10	2.43	1090	1.94	870	2.54	1140	-0.60	-270
1.1	Rice U/S Hoolako	15	7.17	3220	5.74	2570	3.97	1780	1.77	790
1.2	Rice D/S Umi	15	7.17	3220	5.74	2570	3.25	1460	2.48	1110
1.3	Hardy @ Kuhio	15	7.17	3220	5.74	2570	3.12	1400	2.62	1170
2.1	Rice U/S Umi	12	3.46	1550	2.77	1240	0.11	50	2.66	1190
2.2	Government Site	8	1.2	540	0.96	430	0.07	30	0.89	400

*Small Discrepancies may exist due to rounding

The main sewer line has a greater capacity for additional flow at design point 1.2 (790 gpm available) compared to either the 8" or 12" line (400 gpm or 1,190 gpm remaining at design points 2.2 or 2.1, respectively).

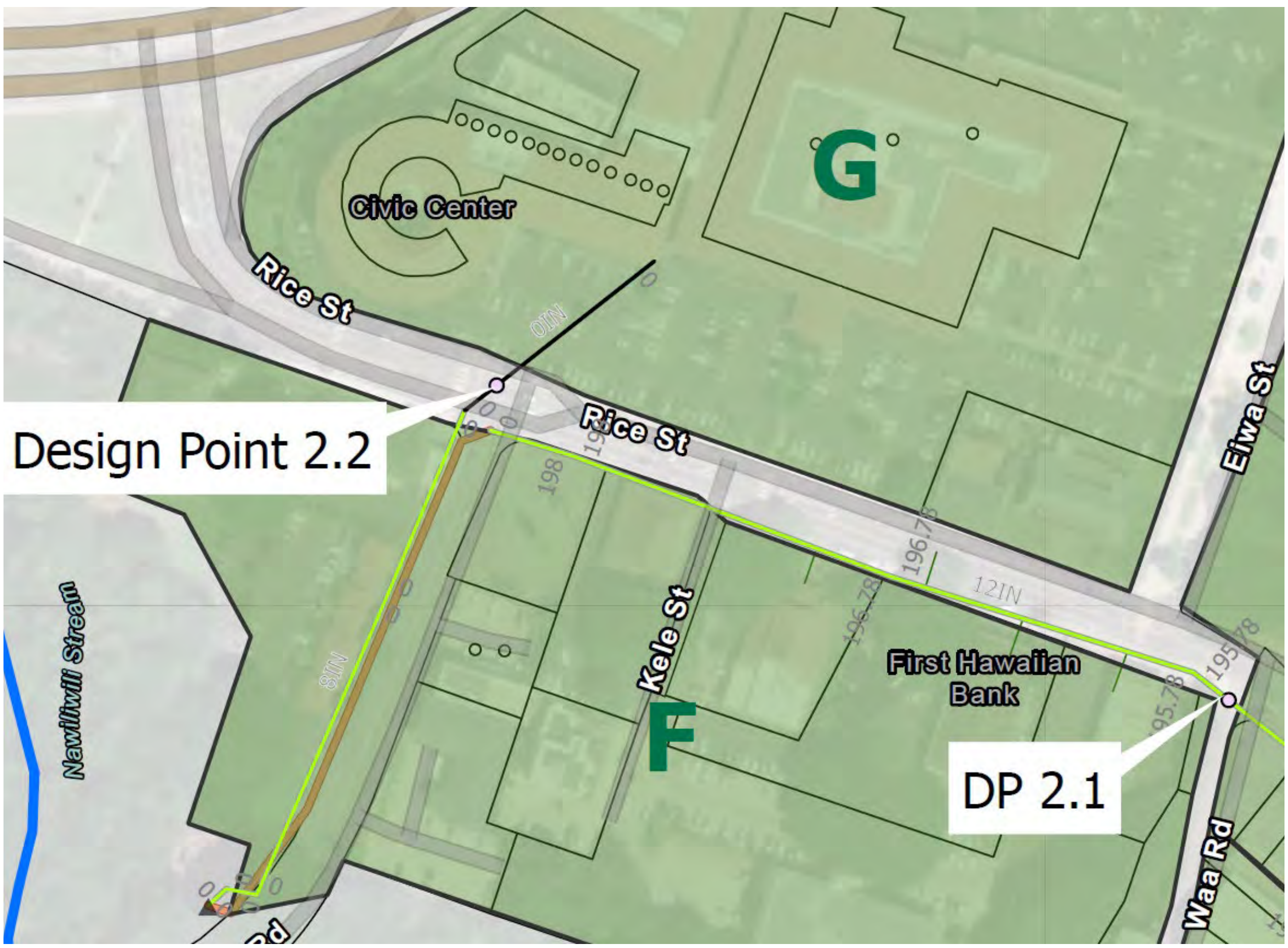

Figure 2. Showing the existing 8" and 12" sewer lines adjacent to the government campus (Excerpt from Sewer Tributary map, not shown to scale here).

7.2.1.2 Future Sewer Flow Conditions

Using an assumed daily demand of 300 GPD for each residential unit, and a peak hour factor of 4 (meaning that the average peak demand of each residential unit is 4 times the average daily flow rate, or 0.833 gpm), the available (existing) 400 GPM of capacity in the 8 inch line could support up to about 480 units[13]. If the flows were routed to the 12" line instead, which would require specific site location of the housing closer to the southeast corner, then the available capacity is limited by the downstream section in Rice Street at Hoolako (DP 1.1) of 790 GPM. This would have a limit of ~948 units based on sewer counts alone.[14]

The existing pipe from the government campus site is shown as an 8" pipe which goes down Haleko Road to a pump station at the bottom of the hill, which then goes back up the hill to a 12" line in Rice Street. This would seem to indicate the 12" line is not deep enough for gravity flow from the entire government campus, but this should be verified for the final plan, as the 12" line has both greater capacity and does not require power for sewer drainage to occur. Even if only a portion of the proposed units lead to the 12" pipe rather than the 8" pipe leading to the Kaleko lift station, this would reduce power demand for the overall system, and reduce the ecological impact. This is more likely to be viable in the southeast portion of the site, as this is closer to the existing 12" pipe. (See Figure 2).

These calculations assume that all capacity could be used by the government site. Additional development on other parcels tributary to the same design points reduce the available capacity on a one-to-one basis per unit.

7.2.2 Sewer Expansion Options

Should additional units be desired above these sewer capacity limits, some options exist. One would be to expand the sewer line in Rice Street, to raise the capacity of the constrained area leading to the expansion point at Hoolako St. This would presumably include deepening the bury depth of the 12" line next to the government site, obviating the need to drain to the 8" line leading to the Haleko Pump Station. Another option would be to provide a small 'package plant' which handles and treats the waste on-site or in the immediate vicinity. In Figure 1, the expansion of the existing line would be between Design Point 1.2 and Design Point 1.1. For the other options, a map showing these options is in Figure 3. The broad categories of expanding the existing sewer line and package plant options are compared in the next two sections, with recommendations immediately following.

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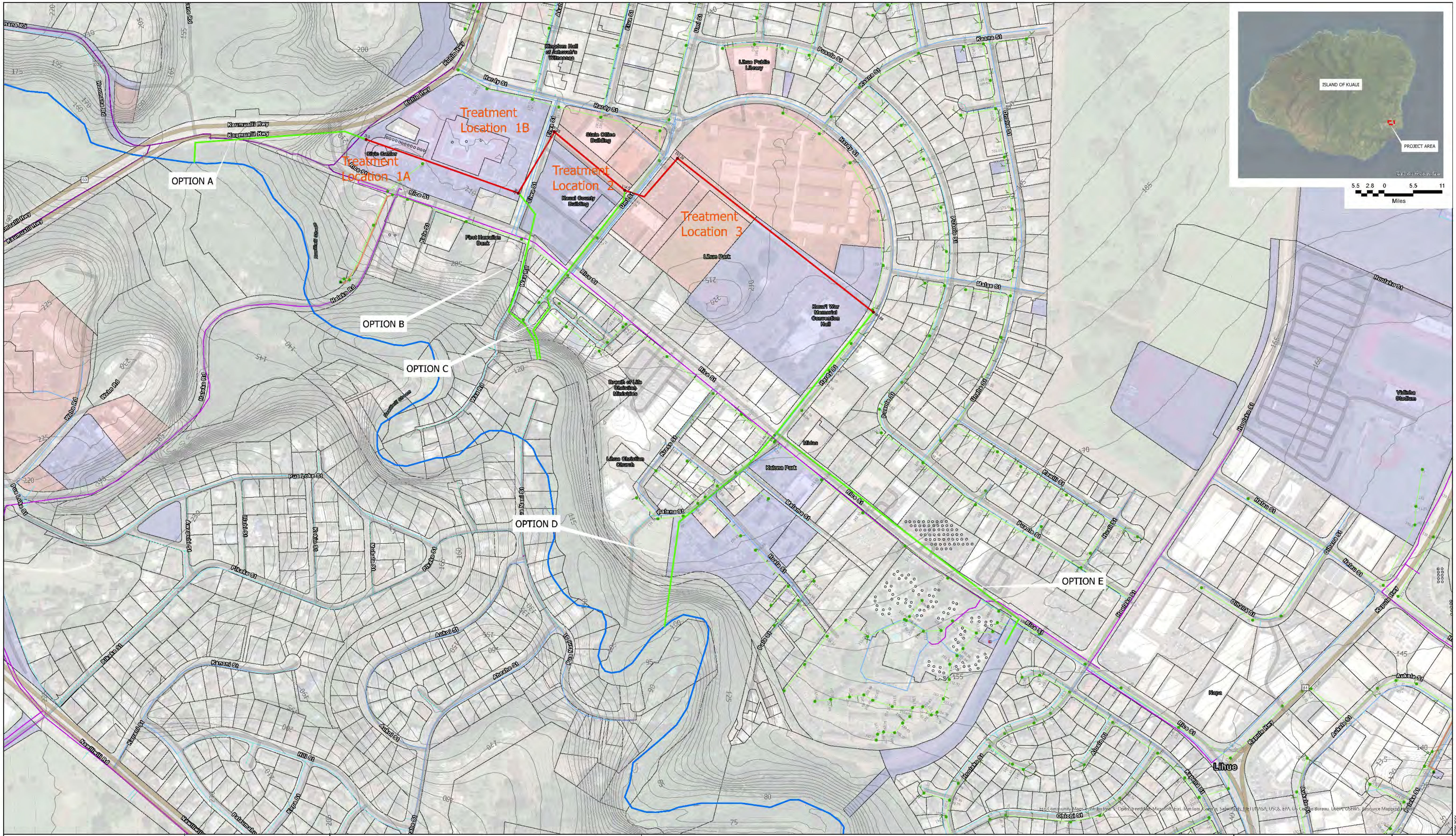
[13] 400 GPM / (0.833 GPM/Unit) = 480 Units

[14] 790 GPM / (0.833 GPM/Unit) = 948 Units

7.2.2.1 Sewer Line Expansion

As the sewer line at Rice Street limits capacity if connecting to the 12" line, an analysis of extending the section of the 18" sewer line at Hoolako St northwest to Umi Street is estimated. This would expand the capacity to allow the full 12" line to be used, allowing 1,190 gpm peak flow, or ~1,428 units on that line. This would not be the only area, as additional units could be developed along Rice Street feeding directly to the 18" line. In replacing a sewer line, while larger pipe is marginally more expensive, the most expense is in the physical placement of the pipe and labor to install. At an estimated installed cost per linear foot of sewer upgrade of $90/LF, with approximately 3,100 feet of pipe to upgrade, the pipe component is anticipated to cost on the order of $280,000. Additionally, the cost to cut and replace a 5' wide asphalt patch for that 3,100 feet, at least 42 service lines, and at least 8 manholes at $6000 each will be likely part of the project. No other costs, such as traffic control, surveying, or project management are included in this opinion of probable cost but leads to a total upgrade cost of approximately $485,000, assuming no other major work is included in the project related to other things such as street upgrades, curb work, restoration, utility relocates, or sidewalk and street tree improvements. These would be additional costs to the project. The major downside to this option would be impacts to Rice Street and to businesses along the corridor. The upside would be an increase in use in the available capacity at the existing sewage treatment plant, capitalizing on capacity already available at the plant. This would allow the full capacity of the 12" line to the government campus to be used, allowing ~1,420 units[15] to be built (if constrained solely by the sewer line capacity).

[15] 1190 GPM / (0.833 gpm/unit), rounded down



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Scale: 1:2,400
1 inch equals 200 feet

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200 100 0 200
Feet

References:

- Sewer & water line data received from the County of Kauai on 11/14/2023
- Contour data retrieved from the USGS National Map on 02/07/2024

Figure 3. Additional Sewer Line and Treatment Location Options

LEGEND

- 1 FT Contour
- 5 FT Contour
- Nawiliwili Stream
- County of Kauai owned property
- State of Hawaii owned property
- Property parcels
- Sewer pump stations
- Existing Sewer Main & Manholes
- Sewer Laterals
- Sewer Force Main
- ≤ 3" Ø Water line
- 3" Ø ≤ 6" Ø Water line
- 6" Ø ≤ 8" Ø Water line
- 8" Ø ≤ 14" Ø Water line
- 14" Ø ≤ Water line
- Water Laterals
- Water Tanks
- Water Pumps
- Proposed Sewer Line
- Proposed Effluent Line
- 175.73 Existing sewer manhole invert
- 178.80 Proposed sewer manhole invert

COUNTY OF KAUAI
HAWAII, USA

SEWER CONCEPTS

SHEET NO. 1 OF 1

PROJECT 23014

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Table 4. Estimate of Rice Street Sewer Line Upgrade, select elements[16]

Item	Cost Per Unit	Unit	Quantity	Item Estimate
18" Sewer Line Installed	$160	LF	3100 LF	$496,000
Cut and Replace Asphalt	$42	Sq Yd	1,725 sq yd	$72,500
Replace Sewer Taps	$2000	Each	At least 42	$84,000
Manholes	$4000	Each	At least 8	$32,000
Total				$1,168,000

7.2.2.2 Package Plant Options

Many package plants use a Membrane Bioreactor to treat the sewage into dischargeable effluent. An overview of this process is outlined in the EPA Wastewater Management Fact Sheet (2007). This technology, specified for cleaning effluent to a level sufficient for discharge to overland streams, is assumed for options specified. These locations may also serve development in the vicinity or, if an overflow bypass is built, provide relief capacity to the main sewer line as well.

There are two main areas for the package plant initial analysis: 1) Package Plant operation and cost, and 2) Feasibility and estimated cost of connections and effluent line. The existing sewer system has a capacity constraint upstream of the government campus, and while additional units immediately on the government campus can be handled, further additional units may be limited by total pipe capacity, especially if additional units in the area use the available capacity first. The location of the package plant's tributary line, and its 'sewershed' may influence capacity for additional housing.

7.2.2.2.1 Package Plant Location Alternatives

Three government-owned parcels (whether state or county) are deemed potentially feasible for Package Plants These correspond to the government campus, the block immediately southeast of the government campus (with the Kauai County Building), and the next block southeast (with the Elsie Wilcox school and the convention Center) and are numbered accordingly, as shown in Figure 3 and Table 5. There is flexibility on the exact location of the package treatment plant for each option, though preference towards a downhill direction within each option will result in less challenging installation of mains. For the onsite option (1) two options are analyzed – one with effluent directed towards Umi and Rice Streets (1B), and the other directing effluent towards the northwest across Kaumualii Highway (1A). Option 1A would

[16] As with all costs in this document, these are not bids or guarantees, only estimates of probable cost

need to be in the northwesterly portion of the government campus and 1B would need to be in the southwesterly portion.

Table 5. Package Plant Location Options with Qualitative Pro/Con Listing

Package Plant Location	Description	Likely Effluent Line	Pros	Cons
1A	Onsite Government Campus (Western)	A	Shortest Option	Narrowest alignment (Waa Road narrowness adds additional constraints). Requires easement across Nuhou Land. Least ability for collateral benefit to serve adjacent sites
1B	Onsite Government Campus (Eastern)	B, C	Allows for location 1 & 2 of treatment plant	Requires easement acquisition across private land (non Nuhou Corp)
2	Kauai County Building Block	C, B	Allows for location 1, 2, or 3 of Treatment plant. Midrange potential for collateral benefit	Easement across private land, construction past existing government apartments
3	School/Convention Center Block	D, E (Possibly C if NW end of Block)	Opportunity for overland flows, "rain garden" feature. Allows for location 1, 2, or 3 of the treatment plant, greatest 'collateral benefit' option.	Longest Option, most disruption to Rice Street

7.2.2.2.2 Package Treatment Plant Options

Various suppliers and capacities of package sewer treatment plants exist. These technologies allow for various capacities of sewage treatment, and the number of units planned will affect the level of treatment needed. Some options will allow for additional units to be built tributary to the treatment location, so a plant may provide additional 'collateral benefit' based on the location chosen. Table 6 shows estimated costs from various package plant suppliers, sorted by the anticipated capacity in gallons per day. As is typical of a presentation of prices from a third party, these prices are approximate and subject to change over time.

Table 6. Package Treatment Plant Suppliers, approximate costs, and capacities

GPD Capacities	# of Units Equivalent	Septic Tank & Leach	ReUse Innovations	Sabre	Advantex	US Water	Aquatech
1,500	7.5	$ 100,000					
3,200	16	$ 160,000			$160,000		$ 100,000
18,000	90	$ 900,000	$ 800,000	$ 300,000	$900,000		$ 250,000
26,800	134	$1,340,000		$ 400,000			$ 350,000
38,800	194			$ 550,000			$ 500,000
45,400	227		$1,200,000	$ 900,000			$ 590,000
106,400	532		$1,600,000	$1,200,000		$1,200,000	$1,200,000

Based on 200 gpd/unit

7.2.2.2.2.1 Effluent Line Options

Effluent lines have varying levels of impact from length of construction, number of manholes, and how much collateral benefit there is available based on which line is selected. These options treat the sewer and effluent lines as roughly similar in price, and flexibility for the exact location of the sewer treatment plant along the line exists (e.g., a plant location can be located more upstream, resulting in more effluent line and less sewer, or vice versa). The options shown on the map in Figure 3 assume a 0.7% slope and 2’4” minimum cover over the top of pipe. Data on existing sewer lines is from the county of Kauai, and contours are from the national map. While sufficient for conceptual evaluation, survey ensuring the same datum for all elevation sources should be obtained before design of effluent or sewer lines.

Installed cost per linear foot assumes that there is sufficient topsoil or clay to bury the pipe on the older geology of Kauai in the immediate Lihue area. The National Soil Survey for the Lihue area indicates that the area of the site is classified as “Lihue Silty Clay,” with a depth to restrictive features (such as solid rock) as greater than 80”. However, this classification is at a large scale and may not reflect on-site conditions in detailed portions. Should the soil layer be thinner and a rock layer closer to the surface, the estimated cost of construction for sewer lines will be significantly greater than shown below. Further, the area between the developed portion of Lihue and Nawiliwili stream is classified as “Rough Broken Land,” with a depth to restrictive features of 20 to 55”. This may provide more constraints, and daylighting the effluent flow for overland channels may be more desirable than burial of pipe if the rock layer is higher. An excerpt from the soil map, showing the Lihue Silty Clay (LhB) and Rough Broken Land (rRR) is in Figure 4.

Figure 4. Excerpt from National Soil Survey map of the Study Area

Table 7. Effluent Line Option Cost Comparison

Effluent Line Option	Total Length Sewer Line	Minimum Manholes (400' spacing)	Total Length Effluent Line	Daylight Ditch	Manhole (per)	Estimated Installed Cost per LF: 8" Sewer	Effluent Line	Ditchline	Estimated Cost: 8" Sewer	Effluent Line	Ditchline	Manholes	Subtotal Conveyance	+50% Contingency
A	855	3	925		$4,000	$150	$ 150	$ 60	$128,250	$138,750	$55,500	$12,000	$ 335,000	$ 502,500
B	1205	4	1200		$4,000	$150	$ 150	$ 60	$180,750	$180,000	$72,000	$16,000	$ 449,000	$ 673,500
C	1640	5	1025		$4,000	$150	$ 150	$ 60	$246,000	$153,750	$61,500	$20,000	$ 482,000	$ 723,000
D	3882	10	1175		$4,000	$150	$ 150	$ 60	$582,300	$176,250	$70,500	$40,000	$ 870,000	$1,305,000
E	3882	10	1475	1250	$4,000	$150	$ 150	$ 60	$582,300	$221,250	$88,500	$40,000	$ 933,000	$1,399,500

Table 8. Effluent Line Options Qualitative Pro/Con Listing

Effluent Line Option	Pro	Con
A	Shortest Overall Option	Requires construction across highway
B	Shortest Option to Southeast	Narrowest alignment (Waa Road narrowness adds additional constraints). Requires easement across Nuhou Land
C	Allows for location 1B & 2 of treatment plant	Requires easement acquisition across private land
D	Allows for location 1B, 2, or 3 of Treatment plant	Easement across private land, construction past existing government apartments
E	Opportunity for overland flows, "rain garden" feature. Allows for location 1B, 2, or 3 of the treatment plant.	Longest Option, most disruption to Rice Street

All options require easement on at least NuHou Corporation Land (Nawiliwili Stream goes through it, as well as most of the steep dropoff to the stream).

7.2.2.3 *Aesthetics and Space*

As sewer treatment is something that is usually handled in larger sites, with large setbacks from development, the aesthetics of a treatment plant are an important consideration. With a smaller package plant, it is possible to enclose the treatment plant within a shell building, making odor control more manageable and aesthetics capable of being adjusted in the cladding.

Figure 5. An example package plant, as seen indoors (Left).
An example shell building for package plant (right).

The images in Figure 5 show two images for scope and size. On the left is an Aquatech system within a warehouse, on the right is a concept of how a shell building, with treatment inside, could look. The architectural style can be adapted to be more suitable for Lihue.

7.2.3 Sewer Capacity Recommendation

Given all the analysis outlined in this section, our recommendations for sewer line capacity expansion, while somewhat dependent on the number of units proposed, are as follows:

1. The existing pipe capacity, (or any capacity that will exist due to expansion), should be used as much as possible. This is because, all other things equal, it is better to locate new housing where sewage treatment is already in place, already exists, and already functions. When sewer upgrades are performed, it is often 'lumpy' – unlocking capacity in large steps, as is the case with a pipe size upgrade. There is little impact of additional units added between the design size and the actual capacity of a sewer line upgrade, but the upgrade costs and ongoing operations and maintenance can be spread across more households. This reduces the burden of that system on any one household.
2. When the capacity of a line is reached, expanding the existing sewer line should be the default preference over adding an additional package treatment plant. The additional permitting, operation, maintenance, site acquisition, and sewer and effluent lines will generally make the package plant option less financially attractive.

3. The exception to Recommendation #2 would be if additional units add enough demand that either the upgrade of the sewer line would need to be performed all the way to the existing sewage treatment plant, or the existing sewage treatment plant reaches capacity. Either of these would warrant a detailed cost-benefit analysis of the situation and may warrant a package plant. We do not anticipate this tradeoff below the level of approximately 480 units in the currently available sewer line.
4. In any scenario, locating new housing units on the government campus closer to the southeast corner will reduce the total pipe length to the existing main, and increase the chances of more units viably gravity draining to the existing 12" line, rather than needing to drain to the existing 8" line to the lift station.

7.3 RAINWATER MANAGEMENT

Detaining runoff from an increase in impervious surface area is conventionally handled with detention ponds and underground piping. Rain gardens, pervious paving surfaces, and bioswales can increase water quality while achieving conventional detention.

Most soils in the project area are Hydrologic Soil Group (HSG) C which is an average infiltration rating. The soil under the government campus site is a Lihue Silty Clay, 0 to 8 percent slopes, allowing for infiltration rates of 0.2 to 0.6 inches per hour (though a geotechnical report is necessary for better infiltration rate understanding and estimate). This makes rain gardens, swales, or other infiltration-treatment feasible, though soil amendment could increase the effectiveness.

7.3.1 BIOSWALES

Bioswales are typically placed adjacent to roadways and consist of a medium to shallow trench which collects water sheet flowing from the street and draining from the yards and buildings fronting the street. Bioswales infiltrate through the soil and replenish the groundwater. The water is filtered through the root zone of grasses and other plants growing in the swale (hence, bioswale), which can help prevent many pollutants associated with urbanized runoff from continuing downstream.[17] These also serve as first line detention facility, storing the rainwater from more frequent, routine storms (typically up to the 1-year or 2-year return period storm, or around 1" of rainfall). As the swale can also have a large conveyance capacity, thoughtful design of the swale can eliminate the need for underground concrete structures and piping, shifting conveyance to daylight.

Bioswales can have two design objectives, and which dominates depends on the location within a watershed. In the top of the watershed, a greater portion of the swale volume can be used for detention.

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[17] Huff & Huff Inc. *Stormwater Management/Bioswale Design*. University of Illinois Urbana-Champaign Extension. https://extension.illinois.edu/sites/default/files/bioswale_presentation_iasfm.pdf

As the swale is lower down, more of the swale volume can be used for conveyance. This adjustment can be made based on the height of check dams along the way.

7.3.2 RAIN GARDENS OR PARK PONDS

Rain gardens and park ponds can be thought of as a larger bioswales, where conveyance is not a concern – it is where water can collect and infiltrate as a primary purpose. It has the same filtration and water quality benefit purposes as a bioswale, and without focusing on conveyance, a greater emphasis can be placed on the infiltration and detention functions.

On the government campus, the existing Isenberg Japanese Garden has the form of many rain gardens. Adopting this form for a rain garden (e.g., directing surrounding area flows to the garden and subgrade preparation) would be a nod to local culture and history (Figure 6)).

Figure 6. On-site Near-Rain Garden Precedent

7.3.3 Pervious Pavers

Where paving is required, rainwater can flow through the pervious paving material and infiltrate into the ground. Pervious pavers increase the land area available for infiltration and reduce the volume of runoff generated.

7.3.4 Minimizing Paving

The less an area is paved to begin with, the less runoff is generated. Most of the impediments to reducing the paved area are legal, social or political, the largest being parking and circulation. Using the minimum width lane possible for a given context, reducing or eliminating parking minimums, and providing other viable methods of transportation to private automobiles are all necessary steps for the reduction of paving areas. Hardscape reduction in turn reduces the demand placed on detention and conveyance facilities.

While site design is required to determine quantities and costs, most studies show that the costs of green infrastructure are commensurate with gray infrastructure but provide more benefits.

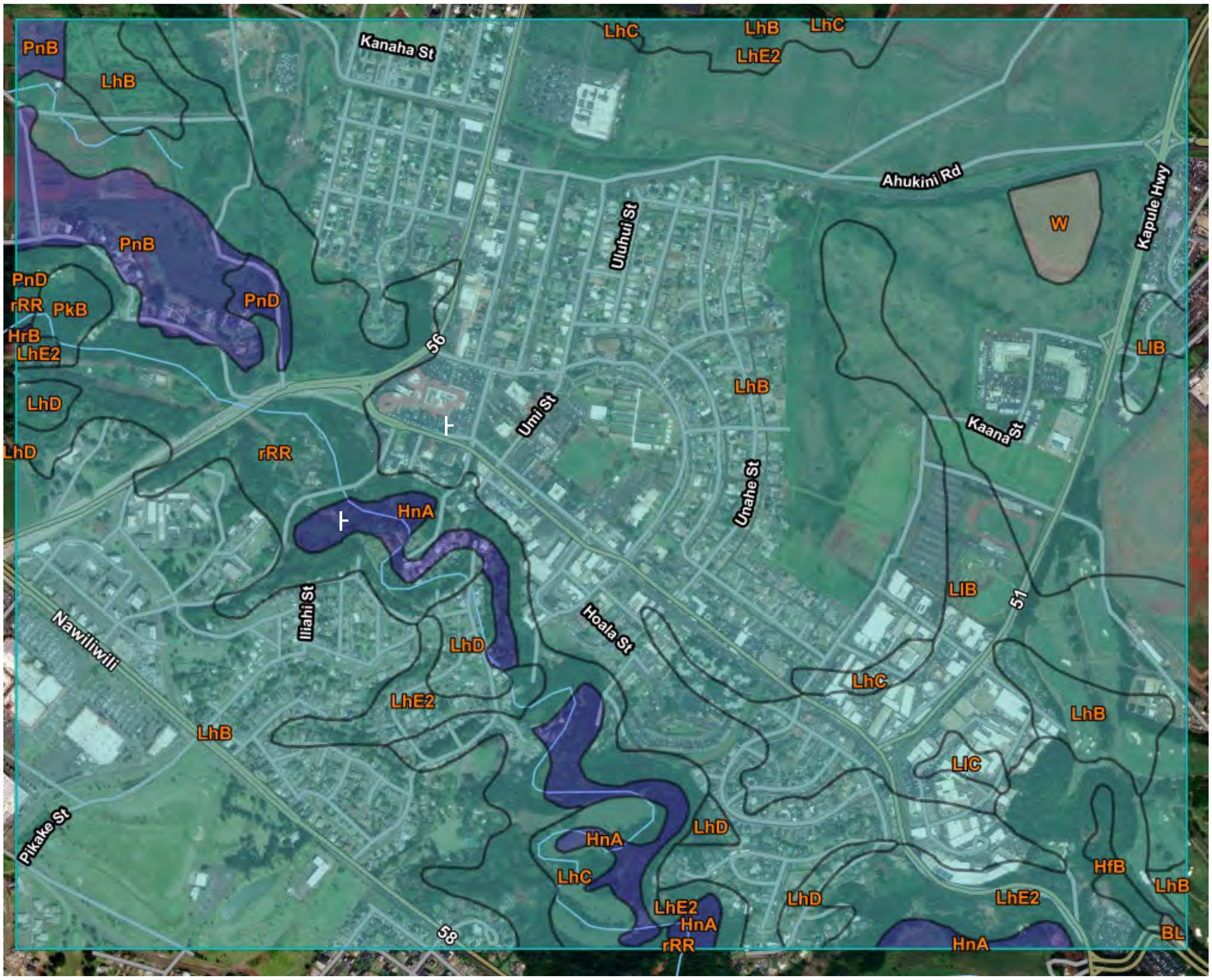

Figure 7. NRCS Soils Map of area showing areas classified as Hydrological Soil Group C (Teal) and D (Blue)[18]

7.4 GRAYWATER AND WATER REUSE

The Hawaii Department of Health divides wastewater into two categories: *blackwater* and *graywater*. Blackwater is "wastewater discharged from Toilets and urinals and Food Preparation sinks (kitchen sinks)."[19] Graywater is permittable to discharge for irrigation or to recycle, as outlined in the 2018 Uniform Plumbing Code (UPC)[20], which is what Hawaii has adopted as of the writing of this report. This code

[18] Natural Resources Conservation Service, United States Department of Agriculture. *Custom Soil Resource Report for Island of Kauai, Hawaii*. November 14, 2023.

[19] Hawaii State Department of Health. Wastewater Branch. *Guidelines for the Reuse of Gray Water*. June 22, 2009. https://health.hawaii.gov/wastewater/files/2016/03/14_Gray_Water_GL.pdf

[20] Department of Accounting and General Services, State of Hawaii. "Building Code Rules." https://ags.hawaii.gov/bcc/building-code-rules/. Accessed March 14, 2024.

will be the plumbing code for the foreseeable future, as the *Governor's Proclamations Relating to Affordable Housing*[21] precludes adjustments or changes to the current adopted codes to ensure regulatory certainty for housing projects. The 2018 UPC, Chapter 15[22], contains provisions for reuse of water in nonpotable applications. Graywater systems allow for a mulch basin to receive diverted flows from single and multi-family dwellings. Reuse or Recycling systems allow for reuse in appropriate fixtures. Reuse or Recycling require that use in fixtures where the water may spray or be exposed (e.g., flush toilets) be disinfected[23] before use.

The 2018 UPC distinguishes between Graywater (flows diverted to mulch basins in lieu of sanitary sewer) and recycling/reclaiming water. Both are allowed under separate provisions (§1502 vs §1503), but more involved cross-connection testing procedures are listed for recycled/reclaimed water, as these systems anticipate pressurization and reuse in fixtures that are conventionally connected to potable water lines. Recycled or reclaimed water may be diverted to a graywater tank, but not the reverse (UPC 1503.3). Graywater discharge fields must be sized to drain the anticipated daily use and have minimum setback requirements from various site components, as shown in Table 9. Additional footnotes or restrictions exist, the reader is encouraged to reference UPC 2018 Table 1503.4 for more information.

Table 9. Minimum Separation Distances for Graywater Discharge Area

Minimum Horizontal Distance in Clear Required from	Surge Tank (feet)	Subsurface and Subsoil Irrigation Field and Mulch Bed (feet)
Building Structures	5	2
Property Line Adjoining Private Property	5	5
Water Supply Wells	50	100
Streams and Lakes	50	50
Sewage pits or cesspools	5	5
Sewage disposal field	5	4
Septic Tank	0	5
On-site Domestic Water Service Line	5	5
Pressurized Public Water Main	10	10

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[21] Office of the Governor Josh Green, M.D., State of Hawaii. *Emergency Proclomation Relating to Housing*. October 24, 2023. https://governor.hawaii.gov/emergency-proclamation-relating-to-housing/

[22] International Association of Plumbing and Mechanical Officials (IAPMO). *2018 Uniform Plumbing Code*. 2018. https://epubs.iapmo.org/2018/UPC/

[23] Acceptable methods include chlorination, ultraviolet light, ozone, or other methods approved by the Authority Having Jurisdiction.

Therefore, a 2 bedroom apartment would have a total graywater sizing demand of 120 gallons per day.[24]

Graywater flows can be directed to a surge tank, where overflows from the tank are directed to the normal wastewater sewer system and regular flows are directed to the mulch bed or subsurface irrigation. The UPC provides guidelines for maximum infiltration rates based on the soil type; based on the National Resources Conservation Service soil map[25] for the project area, it is anticipated that the area under the government campus site is a “Lihue Silty Clay.” The code allows for either prescriptive infiltration assumptions, or a soils infiltration test for specific design. While an infiltration test will likely give a higher capacity, as the code must be conservative for the generalized case, the clay without sand or gravel on the study site would require 120 square feet of irrigation area for every 100 gallons of graywater discharge per day. Using the information given and the same methods discussed, the following Table 10 is developed showing the required graywater treatment areas for each unit of 1, 2, or 3 bedrooms. These areas apply whether the infiltration is done via mulch bed, subsoil irrigation, or subsurface irrigation.

Table 10. Occupant Load vs. Required Graywater Discharge Area

Bedrooms	Occupants	Graywater Demand (Washing & Laundry, 40gpdpp)	Minimum Square Feet of Irrigation area per unit (Clay with small amounts of sand or gravel, 120 sf/100 gallons)
1	2	80	96
2	3	120	144
3	4	160	192

As can be seen from the table, the required subsurface irrigation area ranges from approximately 100 to 200 square feet per unit. A smaller field may be possible if an on-site soils infiltration test demonstrates a higher infiltration rate or a higher sand or gravel content in the clay than assumed for this desktop study.

For the three contemplated unit counts of 100, 200, and 500 units, assuming an average 2 bedroom unit size, there would need to be the following allocated to graywater irrigation area (Table 11). For comparison, the entire government campus block is approximately 420,000 square feet and the percentage area that each scenario would require for a graywater irrigation area is shown below. Additionally, at an estimated landscaping cost of $5/square foot, the irrigation beds are included in this cost estimate.

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[24] 3 occupants in the two bedrooms, with (25+15) gallons/day/occupant * 3 occupants = 120 gallons/day

[25] National Resources Conservation Service (NRCS), US Department of Agriculture (USDA). *Custom Soil Resource Report for Island of Kuaii, Hawaii*. November 14, 2023.

Table 11. Graywater Discharge Estimated Cost

Units	Irrigation Area (Sq Ft)	Approximate % of Campus Block	Estimated Cost	Estimated Cost Per Unit
100	14,400	3.4%	$57,600	$576
200	28,800	6.8%	$115,200	$576
500	72,000	17%	$288,000	$576

As the table shows, dedicating enough room on-site for graywater reuse area becomes more challenging with more units from a space perspective alone. Since landscaping cost and area required for each unit to have graywater reuse is constant, the cost per unit is assumed constant at around $576.

If the area of the graywater reuse is combined with overhead solar panel shade structures, an area with shade-tolerant plants being evaporatively cooled by graywater around the residential structures may provide a microclimate as an outdoor amenity space, in addition to being an area immediately adjacent to the buildings fighting the urban heat island effect.

7.5 Direct and Indirect Potable Reuse

Direct Potable Reuse is the feeding of treated wastewater directly back into the potable water supply. *Indirect Potable Reuse* is the feeding of treated wastewater directly back into the source of potable waters of domestic supply. This is possible and a proven technology currently in use.[26] For obvious reasons, only the highest levels of filtration and treatment are used for these configurations, and extra scrutiny from the state department of health is warranted. In Hawaii, recycled water is classified as R-1, R-2, and R-3, in descending order of filtration, disinfection, and treatment.[27] Recycled water in each classification category are allowed to be recycled for specific uses, and are specifically enumerated in the Hawaii Department of Health's regulations on recycled water.[28] For R-1 recycled water, suitable uses include irrigation for agricultural and domestic uses[29], drinking water for non-dairy livestock, flushing toilets, cooling in air conditioner systems, and boiler feed water, among other uses. Direct Potable Water reuse is not listed in this enumeration and is not allowed under current regulations. While the Hawaii Department of Health does have the language "The DOH may deem other uses suitable on a case-by-case basis" in their recycled water regulations (in *Volume II*), direct potable reuse is an area that will require careful study and scrutiny before a plant could be operational, or even seriously considered.

[26] Such as the *Raw Water Production Facility* operated by the Colorado River Municipal Water District in Big Spring, TX.
[27] R1 is cleaner than R2, which is cleaner than R3.
[28] Hawaii Department of Health. *Recycled Water Program*. https://health.hawaii.gov/wastewater/home/reuse/
See also *Volume I: Recycled Water Facilities* and *Volume II: Recycled Water Projects* for details on the regulations concerning recycled water in Hawaii, linked from the above website.
[29] Provided there is an onsite recycled water manager, as described further in the Hawaii Department of Health's regulations. Single-family home reuse is not allowed without a recycled water manager.

For either direct or indirect potable water reuse to be considered, new regulatory frameworks and rules must be developed. As this is a statewide recommendation, this is outside the scope of this report. Some states have allowed for direct potable reuse. Texas[30] has implemented direct potable reuse regulations. Arizona has laws allowing direct potable reuse[31] and is currently going through a rulemaking update process[32] to clarify regulatory burdens (Arizona now calls Direct Potable Reuse by Advanced Water Purification). Other states with either rules or serious policy proposals to allow for Direct Potable Reuse include Colorado, Oklahoma, North Carolina, and Florida. Finally, the US Environmental Protection Agency has released a report outlining the regulatory burdens and approaches for Potable Water Reuse.[33]

8 SERVICE BUNDLE 2 – ENERGY CONSUMPTION AND DRY UTILITIES (ELECTRIC, GAS, TELECOM)

Lihue has some very beneficial advantages based on its climatic situation. In the following sections, an analysis is made of several strategies related to the energy consumption of units in Lihue. A summary of some of the climactic and energy demand of each unit is shown in Table 12. Working with these values can positively influence the energy demand of each unit to allow for a less intensive demand for unit's energy demand. Some of these data come from the State of Hawaii Renewable EnerGIS system, shown in Figure 8.

Table 12. Energy and Existing Conditions for Lihue

Location	Terrain	Soils	Annual Avg Rainfall	Avg Ground Water Temp	Heating Degree Days	Cooling Degree Days	Annual Avg Wind Speed @ 30m	Annual Avg Daily Hoizontal Solar Irradience	Annual Avg Residential Energy Use	Annual Output of 1000 sf (15 kW) Solar PC (kWh)	Avg Daily SFD Water Use	Avg Daily SFD WW Effluent
			inches	(f)			MPH	kWh/m2/day	kWh/unit	kWh	GPD	GPD
Lihue, HI	Hilly	Silty Clay	47.9	72	0	3883	12.8	4.5	8,800	15,500	315-772	300

[30] United States Environmental Protection Agency. *Water Reuse*. "Summary of Texas' Water Reuse Guideline or Regulation for Potable Water Reuse." Last updated August 18, 2024. https://www.epa.gov/waterreuse/summary-texas-water-reuse-guideline-or-regulation-potable-water-reuse

See also: Texas Commision on Environmental Quality. *Direct Potable Reuse for Public Water Systems*. RG-634. November 2022. https://www.tceq.texas.gov/downloads/drinking-water/rg-634.pdf

[31] A.A.C. Title 18, Chapter 9, Article 7. https://apps.azsos.gov/public_services/title_18/18-09.pdf

[32] Arizona Department of Environmental Quality. *Advanced Water Purification (previously DPR): Active Rulemaking.* https://azdeq.gov/awp-rulemaking

[33] US Environmental Protection Agency. *Mainstreaming Potable Water Reuse in the United States: Strategies for Leveling the Playing Field*. April 2018. https://www.epa.gov/sites/default/files/2018-04/documents/mainstreaming_potable_water_reuse_april_2018_final_for_web.pdf

See also this white paper, which goes into more detail on regulatory framework, cost of treatment, and further examples:

Mosher, Jeffer J. & G.M. Vartanian. WateReuse, American Water Works Association, Water Environment Federation, and National Water Research Institute. *Framework for Direct Potable Reuse*. ISBN 978-1-941242-30-8. 2015. https://watereuse.org/wp-content/uploads/2015/09/14-20.pdf

8.1 ELECTRIC POWER

KIUC The Kauai Island Utility Cooperative[34] has 235 MW of power generation available, with an average demand of 50 MW. Rated generation capacity of the plants is 110 MW for fossil-fuel based plants, and a non-battery bank capacity of 101 MW. The power cooperative plans to have 70% renewable sources of power by 2030. Energy Sources for Hawaii include a significant portion of imported petroleum, petroleum byproducts, and coal. In 2016, these categories accounted for 57% of all import tonnage to the state.[35] There is a statewide law mandating that 100% of electricity sales to come from renewable fuel sources by 2045.[36] While the scope of this ecodistrict does not solve the problem for the entire state, this law does provide impetus for providing electricity for the needs of new units for the site.

The average housing unit in Hawaii uses 30.3 million BTU (8,880 kWh)[37,38] annually from all energy sources. Assuming a fully electric apartment, this translates to an hourly average demand of just over 1.0 kW per hour or 24.3 kWh/day. Hawaii's low demand for electricity partly stems from having the highest electricity prices of any state, as all fossil fuels needing to be imported for power generation.[39]

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[34] Kaua'I Island Utility Cooperative https://www.kiuc.coop/generation-portfolio

[35] Hawaii State Energy Office. *Hawai'i's Energy Facts & Figures*. 2020 Edition. https://energy.hawaii.gov/wp-content/uploads/2020/11/HSEO_FactsAndFigures-2020.pdf

[36] Hawaii State House of Representatives. *House Bill Act 97: A bill for an act relating to Renewable Standards*. 2015. https://www.capitol.hawaii.gov/sessions/session2015/bills/GM1197_.PDF

[37] *Summary Annual Household Site Consumption and Expenditures in United States homes by state – Totals and Intensities, 2020*. US Energy Information Administration. June 13, 2023. https://www.eia.gov/consumption/residential/data/2020/state/pdf/ce1.1.st.pdf

[38] 3,412.12 BTU = 1 kWh

[39] US Energy Information Administration. "Hawaii." *State Profile and Energy Estimates*. March 16, 2023. https://www.eia.gov/state/analysis.php?sid=HI

Area (acres): **6.979**
State LUD: **Urban**
County Zoning: **No data**
LSB (A-E Soil Ratings): **Urban area**
ALISH: **Unclassified**
IAL: **No data**
Ag Land Use (2011-2015): **No data**
ALUM: **No data**
Reserves: **No**
Critical Habitat: **No**
SMA: **No**
Thermal Springs/Potential: **No data**
High Temperature Resource Areas: **No data**
Ditches: **No**
Studied Hydro Projects: **No**
Streams: **No**

POINT DETAILS

NOAA Elevation (m): **63.6268**
USGS Slope (%): **1.03128**
USGS Aspect: **45.4159**
Temp. Average Difference (degrees C): **No data**
Temp. Amplitude Difference (degrees C): **No data**
Benthic Habitat: **No data**
Whale Sanctuary: **No data**
MMA: **No data**
Ocean Boundary (3 mile): **Not applicable**
Ocean Boundary (12 mile): **Not applicable**
Annual Rainfall (inches): **47.981503**
Solar Radiation (calories/cm2/day): **400-450**
DNI Annual (Wh/m2/day): **4,796**
GHI Annual (Wh/m2/day): **5,321**
Wind Power Density at 50m (W/m2): **239.00**
Wind Speed at 30m (m/s): **5.733057**
Wind Speed at 50m (m/s): **6.375203**
Wind Speed at 70m (m/s): **6.743526**
Wind Speed at 100m (m/s): **7.072364**
Flood Zone: **X**

Figure 8. Renewable Energy Resource Values for Site[40]

[40] State of Hawaii. *Renewable EnerGIS*. (Web GIS Portal). https://geodata.hawaii.gov/energis. Accessed Nov 11, 2023.

8.1.1 SOLAR

From the National Renewables Energy Laboratory (NREL), there is an average solar irradiance of 4.5 $kWh/m^2/day$[41] available in the Lihue Area.[42] Assuming a solar panel efficiency of 10% at converting total irradiance to useful power, each unit needs a minimum of 54 m^2 (580 ft^2) of solar panel area[43] to average out demand and provide more than the 24kWh/day average demand. Additional battery infrastructure, either batteries or a reliance on a grid-connection and reverse metering, will be necessary for each unit to smooth peak demand and peak production mismatches throughout the day/night cycle.

Solar in an ecodistrict can take many forms. These include conventional rooftop panels, standalone panels in a park, or as combination shade and solar structures over parking areas (Figure 9). They can also be credits bought for participation in a utility-scale solar field elsewhere; while not as obvious, this can allow for additional solar energy from the grid even if the unit count gets high enough to make solar not viable on a space constrained basis.

For the development scenarios, the area required as solar panels, as well as its relative coverage of the area of the site, is shown in Table 13. At 20 watts per sq foot, the total area required to net zero balance demand is estimated. Assuming a cost of $3.10 per installed watt[44], the installation costs are shown as well. Any additional structures supporting the panels are assumed to be in addition to the 'roof mounted' price assumed below.

As all the assumed prices scale linearly, the ROI period for one unit should match that for all units. At $0.20/kWh, and assuming the units' net metering ends up at effectively nothing for continued power bills, then the savings in power cost will be the rate at which electricity would have otherwise been consumed, or ~$148/month/unit.[45] For each level of investment, with a straightline payoff, the ROI breakeven point is anticipated to take 9.4 years. This may reduce if the cost of electricity increases within that period.

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[41] The units "$kWh/m^2/day$" are sometimes referred to as "Peak Sun Hours," or the equivalent number of hours that would have an average solar irradiance of 1 kWh/m^2.

[42] Roberts, Billy J. "Global Horizontal Solar Irradiance: National Solar Radiation Database Physical Solar Model." National Renewables Energy Laboratory (NREL). February 22, 2018. https://www.nrel.gov/gis/assets/images/solar-annual-ghi-2018-usa-scale-01.jpg

[43] 54 m^2 = ((24.3 kWh/day)/(4.5kWh/m^2/day))/10%

[44] Unit install cost: Need 5.4 kW of solar for the 4.5 hour peak solar day to make 5.4kW/unit * 4.5 hour = 24.3kWh/unit.
24.3 kWh/unit @ $3.10/watt = (5.4 kW) * (1000 Watt/kW) * $3.10/watt
= $16,700/unit

[45] $0.20/kWh * 24.3 kWh/day/unit * 365 days/12months = $147.83/unit/month

Figure 9. Example of Solar Panel Shading for a Parking Lot

Table 13. Solar Panel Areas for each Development Scenario

Units	Solar Panel Area (sq ft)	% of total site area (420,000 sq ft)	Install Cost at $3.10/watt
100	58,000	14%	$1,674,000
200	116,000	28%	$3,348,000
500	290,000	69%	$8,370,000

8.1.2 WIND

Small scale wind turbine production generally requires a regulatory allowance for the heights required for feasibility of small-scale wind power feasible. The reliability and consistency of wind power generally increases with greater distance above the ground and Wind Power – individual or community wind generation. Figure 10 shows average wind speeds in Lihue at 30m above surface around 5.5 to 6.5 m/s (12 to 14 mph). Wind speeds at higher elevations above the ground surface generally have faster and more consistent wind speeds. At 30m (98 ft), the stated wind speed is good for small wind turbines (>4 m/s), but is on the low end of feasibility for utility-scale production of wind power (>5.8m/s).[46] Due to the need for a tower no matter what size the turbine is, wind power may be considered less incremental than a solar installation, however, a balance of wind and solar generation may be desirable. Further, the geometry of turbines means that there is a greater increase in captured energy from a slight increase in wind speed. Conceptually, fewer taller towers which reach faster windspeeds higher in the air may generate more power than more short towers closer to the ground.

The available annual power available at a given average windspeed is given by the equation[47]:

$$AEO = 0.01328\ D^2V^3$$

Where,

AEO = Annual Energy Output, kWh/year
D = Rotor Diameter, Feet
V = Annual Average Wind Speed, MPH

Solving for the annual demand of 8,880 kWh and the windspeed of 12.3 mph (5.5 m/s), a 66' diameter windmill could provide the annual power need for one unit. If a taller tower could be erected to reach 70m (230 ft), where the average windspeed is 7.0 m/s (15.7 mph), then only a 52' diameter windmill is required for each unit. As can be seen from these results, the space required for a windmill system is less efficient (in terms of kWh per area of collection mechanism) than for solar, and further analysis was not performed. This does not mean that wind is not appropriate in any sense, only that it is more likely that solar will be more efficient in providing clean energy than wind.

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[46] US Energy Information Administration. "Wind Explained: Where Wind Power Is Harnessed." April 20, 2023. https://www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php

[47] US Department of Energy, Office of Efficiency and Renewable Energy. *WindExchange: Small Wind Guidebook*. https://windexchange.energy.gov/small-wind-guidebook.

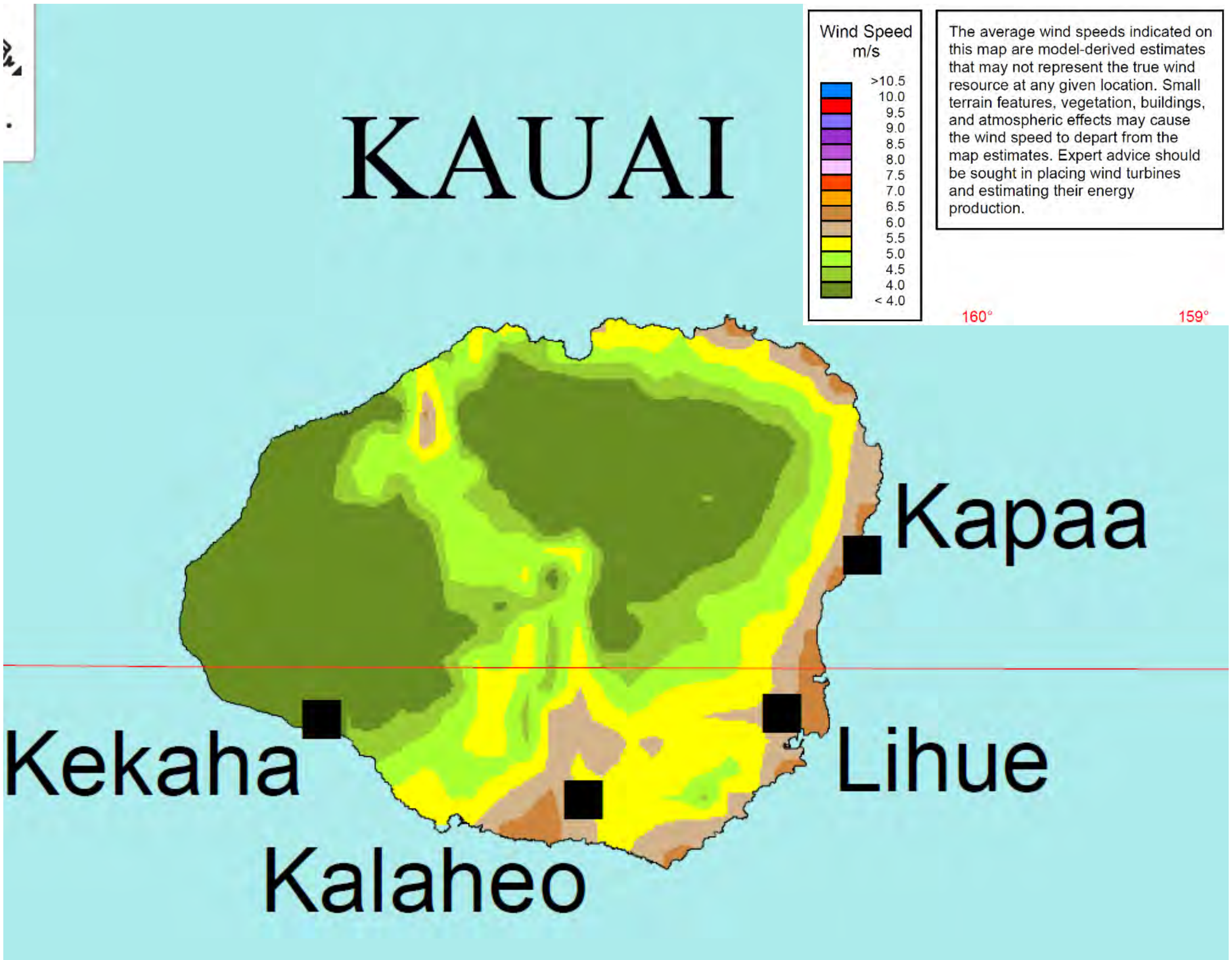

Figure 10. Wind Speed Diagram of Kauai[48]

8.1.3 Battery Bank Backups

Localized backups for power can increase resiliency regardless of power source. Battery bank capacities scale easily. Costs for battery backups can range and several studies have shown decreasing prices for battery backups in recent years, and predict continuing downward price movements.

The local power provider, Kauai Island Utility Cooperative, is known for being one of the first utilities to provide utility-scale combined solar and battery banks.[49] There is generally an efficiency of scale for installation of larger systems, as the cost of systems range from a residential $3,600/kwH to utility-scale

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[48] National Renewable Energy Laboratory. "Hawaii-Annual Average Wind Speet at 30 m." *WindExchange*. https://windexchange.energy.gov/maps-data/161 9 April 2012.

[49] Spector, Julian. "Kauai Became a clean energy leader. Its Secret? A publicly owned grid." *Canary Media*. 7 November 2023. https://www.canarymedia.com/articles/clean-energy/kauai-is-a-clean-energy-leader-its-secret-a-publicly-owned-grid

$625/kWh.[50, 51] Local installations will be able to benefit from peak solar generation and provide power independent of the grid for overnight usage, reducing the load or demand on other utility-scale storage mechanisms, such as the West Kauai Energy Project (a pumped storage project proposed to provide longer-term energy storage),[52] which may not occur due to delays in approvals and litigation delays.[53] Localized battery banks do not have the same regulatory approval risk as utility-scale banks.

Another option for battery backups is to use the household's battery installed in an electric vehicle. This generally requires bidirectional charging infrastructure but can tap into the larger (15-100 kWh) batteries typical for electric vehicles. Since most private vehicles are parked for 95% of the day, and electric vehicles are essentially portable batteries, making charging infrastructure bidirectional increases the flexibility of battery backup options. If other renewable energy infrastructure is on site, then coordination of components may reduce costs (for example, by sharing the inverter between the photovoltaic panels and bidirectional EV charger). Reversed currents can feed either vehicle to Building (V2B) or Vehicle to Grid (V2G). In the former, electricity can be fed to the buildings on the site during peak demand periods or outages, reducing the peak demand of the building onto the grid. In the latter, power can be sold directly to the grid. Either option can reduce the ongoing cost of an electric vehicle by providing a revenue source balancing peak production and peak demand.

8.2 GAS

The supply of Natural Gas relies on petroleum imports for the creation of synthetic gas in the state of Hawaii. Very few homes in Hawaii use natural gas (3 in 100) for primary heating. Therefore, for this area, natural gas is not assumed to be a viable "bridge" fuel in conversion to cleaner sources of energy.[54] While options exist, the delivery of propane or LNG is handled by private utilities.

8.3 HEATING & COOLING DISTRICT

Economies of scale may reduce the energy burden of heating and cooling homes. While the most straightforward heating district may be the use of waste heat from a nearby power plant for domestic heat, options exist for distributed heating and cooling.

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[50] US Energy Information Administration. "Utility-scale battery storage costs decreased nearly 70% between 2015 and 2018." *Today in Energy*. October 23, 2020. https://www.eia.gov/todayinenergy/detail.php?id=45596

[51] US Department of Energy, National Renewable Energy Laboratory. "Residential Battery Storage." *Annual Technology Baseline*. https://atb.nrel.gov/electricity/2023/residential_battery_storage

[52] Kauai Island Utility Cooperative. "West Kauai Energy Project." https://www.kiuc.coop/wkep

[53] Kauai Island Utility Cooperative. "Project Delays Jeopardize West Kauai Energy Project." Press Release. December 13, 2023. https://www.kiuc.coop/project-delays-jeopardize-west-kauai-energy-project

[54] US Energy Information Administration. "Hawaii." *State Profile and Energy Estimates*. March 16, 2023. https://www.eia.gov/state/analysis.php?sid=HI

While other islands in Hawaii may benefit from direct geothermal energy production, Kauai is one of the older islands and no longer has the hot spot geothermal activity it once had.[55] However, two other sources of heating and cooling are conceptually feasible – ground source and ocean thermal source heating/cooling districts. Ground source heat pumps have a closed liquid loop which exchanges heat with the ground using either a deep well (vertical) or a buried trench loop (horizontal). These exchangers will dump wasted heat into the ground. Individual wells do experience an increase of ground temperatures after use of a heat pump. However, the ground temperature drops when rainfall infiltrates, so colocation of these ground loops with infiltration raingardens and other areas with pervious surfaces is preferred to installation under impervious areas.[56] The exchange fluid running in the closed loop will receive the rejected heat, which is then rejected to the ground loops. The opportunity for a cooling district arises because: 1) A ground source heat pump does not "care" how the source loop exchanges heat with the ground, 2) A significant cost of well drilling is mobilization of the equipment, 3) a greater number of customers using a ground source well amortizes the cost burden across a larger pool, and 4) future efficiency upgrades for either the heat pump or ground source loop can be made independently from the other side of the loop.

If the ground source loop is enlarged enough, a seawater air conditioning (SWAC) unit could be used in lieu of or in addition to ground source wells for the heat pumps in the heating/cooling district. This technology uses an open loop to bring deep, cooler ocean water to a heat exchanger, which then cools the water in the closed exchange loop. In either system, customers of the Ecodistrict would tap into this loop and use their building's heat pump to cool their building.

A diagram of these schemas and the direction of heat flow in a cooling regime is shown in Figure 11 and Figure 12.

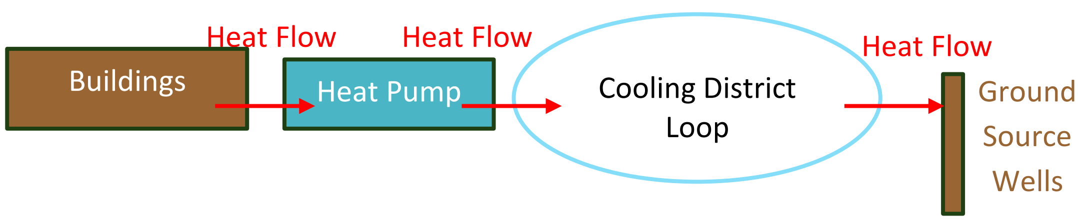


Figure 11. Ground Source Well Cooling District

[55] Hawaii State Energy Office. "Renewable Energy Resources." https://energy.hawaii.gov/what-we-do/energy-landscape/renewable-energy-resources/ Accessed March 19, 2024.

[56] Widiatmojo, Arif et al. "Ground-Source Heat Pumps with Horizontal Heat Exchangers for Space Cooling in the Hot Tropical Climate of Thailand." *Energies*. https://doi.org/10.3390/en12071274. 2 April 2019.

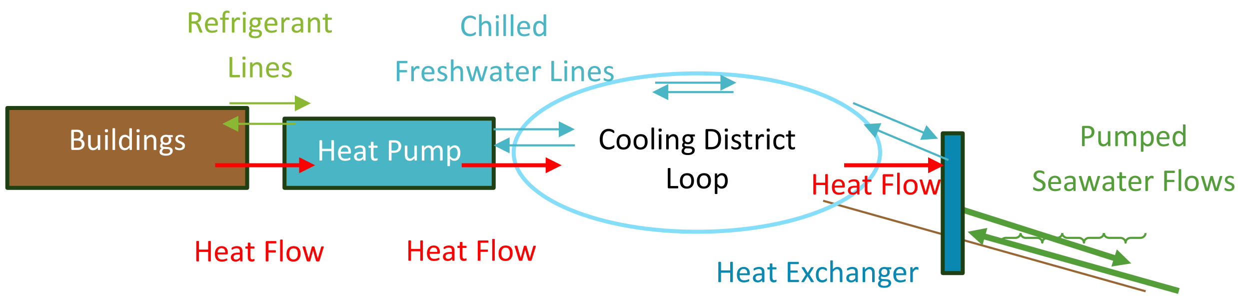


Figure 12. Sea Water Air Conditioning Cooling District

Given that the cooling district loop needs only a cooled liquid circulating through the loop, and the particular technology either drawing heat away or dumping heat into the loop is 'agnostic' to the loop size or other technologies connected to it, a smaller loop could be started with this project (e.g. with ground source wells) and gradually expanded as more cooling capacity as more and more homeowners, businesses, and other housing developments are built out and more wells are added. Eventually, if that initial loop reaches near enough to the shoreline to make the seawater cooling source viable, then the sea water cooling source could be added to the loop. In this manner, the entire capital investment of the approximately 9,000 feet from the government campus to the nearest shoreline does not need to be made at one time.

8.3.1 Building Design

The way in which any building is constructed will have a major impact on how demanding it will be to cool effectively and efficiently. If a building is 100% glass in a 'sealed' envelope, with no shading for the rooms inside, the solar heat gain load will be significantly greater than an otherwise comparable building with shading (such as awnings, curtains, or deep porches) and operable ventilation.[57]

Climate-Conscious Design on Kauai must recognize a pattern of relatively consistent conditioning loads, with most days between 67F and 84F year-round[58]. Throughout the year, the major differences in humidity/temperature comfort (comfortable to muggy transition) make natural ventilation essential to the feasibility of a non-air conditioned space being comfortable (Figure 13, Figure 14).

[57] See also *Original Green,* by Stephen Mouzon; and the *Hawaii Commercial Building Guidelines for Energy Efficiency*. Hawaii Department of Business, Economic Development, & Tourism. 2004. https://energy.hawaii.gov/wp-content/uploads/2012/06/Hawaii-Comm-Bldg-Guide-for-Energy-Efficiency5.pdf

[58] https://weatherspark.com/y/150356/Average-Weather-in-Kauai-Island-Hawaii-United-States-Year-Round

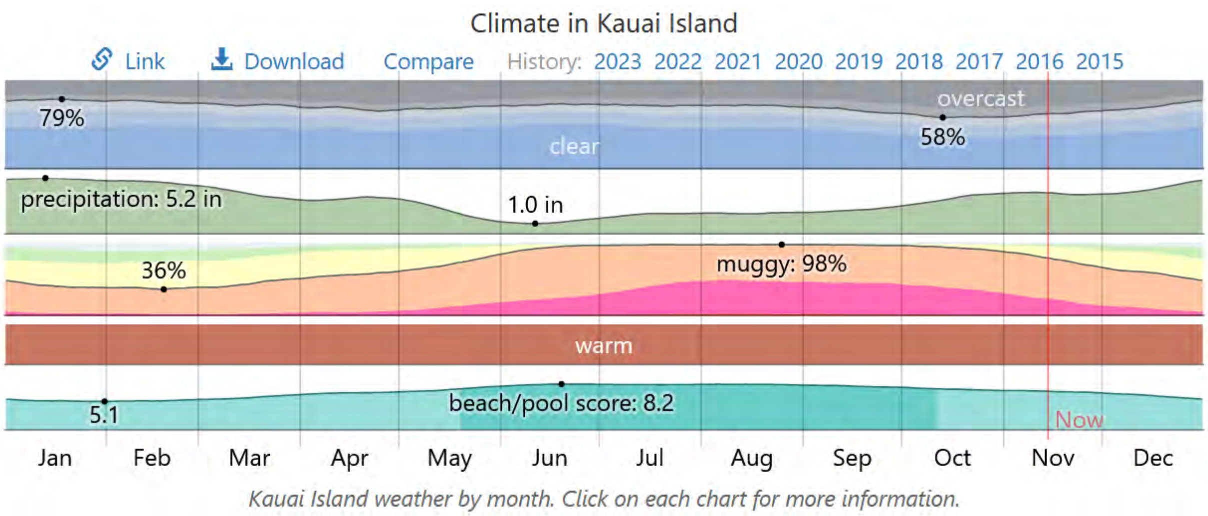
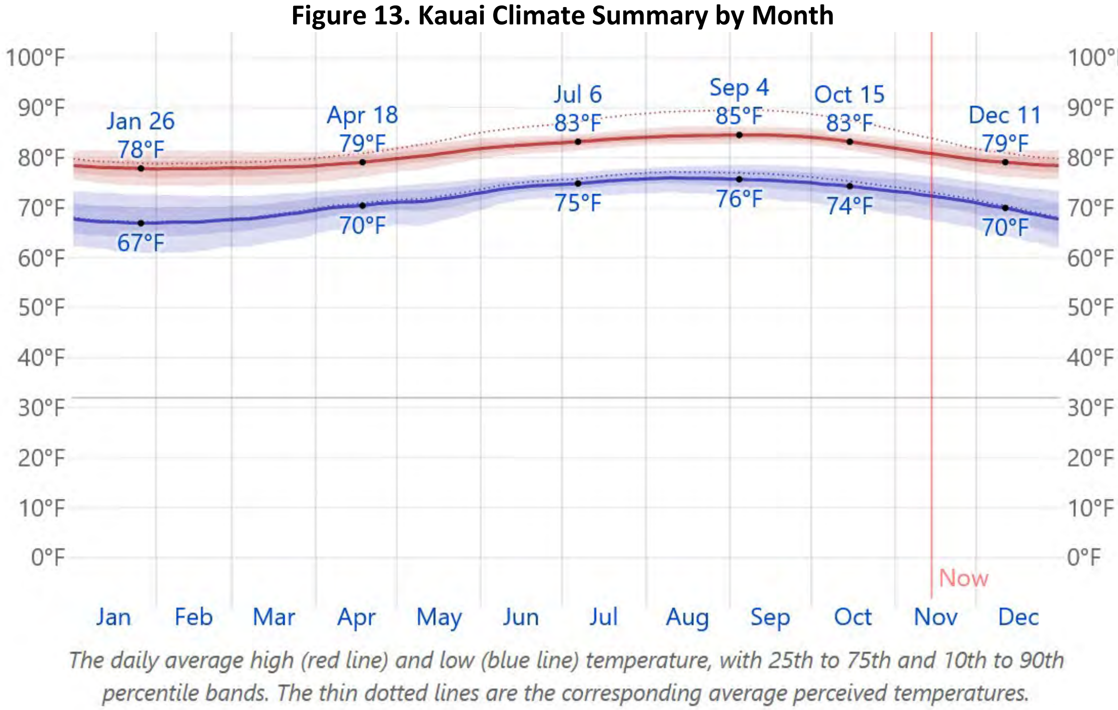


Figure 13. Kauai Climate Summary by Month



Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	78°F	78°F	78°F	79°F	81°F	83°F	84°F	84°F	84°F	83°F	81°F	79°F
Temp.	72°F	72°F	73°F	74°F	76°F	78°F	79°F	80°F	79°F	78°F	76°F	74°F
Low	67°F	67°F	68°F	70°F	72°F	74°F	75°F	76°F	75°F	74°F	72°F	69°F

Figure 14. Typical Kawai High/Low Temperature Band

For an example of the importance of awnings alone, the National Park Service described the energy savings from one project on the Florida State Capitol Building (see Figure 15) thus: “Awnings were reinstalled on the east, west, and south windows of the Florida State Capitol in the 1980s. With a design based on those seen in historic photographs of the building, the new awnings allowed a downsizing of the HVAC System by 25 tons. After installation, the exposed glass surface in a typical first floor office accounted for only 46% of the required cooling load, down from 72%."[59]

Cross ventilation of living spaces also reduces the demand for air conditioning, as trade winds provide natural cooling. By integration of design elements, such as 'windcatcher' towers[60] designed to funnel wind energy through cooler underground areas, or through apartments and common areas. Care must be taken when adapting the windcatcher tower to the tropical climate to avoid issues with occasionally higher windspeeds with tropical storms.

Figure 15. Florida State Capitol Building, with Replaced Awnings
(Left: Michael Rivera, Creative Commons, 2013.
Right: Division of Historical Resources, Florida Department of State, n.d.)

Walls and roofs should be of materials that reflect rather than absorb the sun's energy. Windows should have awnings, discussed in the next section, and have appropriate glazing to reflect light outside the visible spectrum, which only adds heat energy to the building envelope if allowed through.

8.3.2 Typical Heating/Cooling Demand

For simplicity, it is assumed that each unit in the new development is designed to minimize the cooling load, and that, on average, each residential unit will require approximately 2 tons[61] of cooling. More detailed analysis will only be possible with a building design. Each well requires approximately 150' of bore

[59] Chad Randl. "The Use of Awnings on Historic Buildings: Repair, Replacement, and New Design." *Preservation Briefs*. No. 44. National Park Service, US Department of the Interior, Heritage Preservation Services. April 2005. https://www.nps.gov/orgs/1739/upload/preservation-brief-44-awnings.pdf

[60] "Windcatcher." *Wikipedia*. https://en.wikipedia.org/wiki/Windcatcher

[61] 1 ton of cooling = 12,000 BTU (per hour if in a time-based context)

depth per ton of cooling required, meaning approximately 300 feet of well depth per unit.[62] The cost to drill a well varies based on the exact geology of the area being drilled, but can vary on the order of $25 to $65 per foot. Therefore, for each unit's 300' well, the geothermal well can be anticipated to cost between $7,500 and $19,500. HVAC Equipment is anticipated to be on the order of $2000 to $5000 per unit, resulting in the costs in Table 14. It is anticipated that economy of scale discounts (such as the reduced per-well mobilization fees amortized across several wells in a well field) would be accounted for within the high and low range estimates.

Table 14. Estimated HVAC Ground Source Geothermal Well Field Cost

Units	Cost (low)	Cost (High)
100	$950,000	$2,450,000
200	$1,900,000	$4,900,000
500	$4,750,000	$12,250,000

For comparison, a conventional air-source HVAC system is estimated at $5k to $12k per unit, for the following costs in Table 15:

Table 15. HVAC Air Source Estimated Installation Cost

Units	Cost (Low)	Cost (High)
100	$500,000	$1,200,000
200	$1,000,000	$2,400,000
500	$2,500,000	$6,000,000

These estimates imply that the cost of installing a geothermal system is approximately twice that of a conventional system. Commercially available geothermal systems have a coefficient of performance (COP)[63] of approximately 5, in part due to the high thermal capacity of the heat sink fluid (the water) and its relatively constant groundwater temperature, compared to a COP of an air-source a/c of approximately 4. If, as part of the general heat source loop, water heaters are tied into the waste heat rejection loop, further energy efficiency could be gained, though domestic water heating is not likely to offset all the cooling demand. Using the same 2 ton/hr estimate, each 10-hour day of cooling[64] takes ~20 tons (~70.3 kWh) of energy removed from the home. With a COP of 5, the geothermal system can remove that heat with about 14.1 kWh per day; with air source's COP of 3.5, it takes about 20.1 kWh/day. At the current average electricity rate of 19 cents per kilowatt hour[65] from June 2022 to June 2024, this is a cost of $115

[62] John W. Lund. "Geothermal Heat Pump Utilization in the United States." US Office of Science, Technology and Innovation. https://www.osti.gov/etdeweb/servlets/purl/892033

[63] For an explanation of Coefficient of Performance and other HVAC efficiency terms, see *Understanding COP (Coefficiento of Performance)*. Adams Air. https://www.adams-air.com/houston/what-is-COP.php.

[64] Assuming 2/3 duty cycle, total cooling load of 20 tons/day/unit, and electricity cost at 20 cents per kWh.

[65] From Kauai Cooperative data, hosted at https://www.kiuc.coop/sites/default/files/documents/rates/PerkWh_June.pdf

vs $80 per month for air source vs ground source heat pumps in each unit, respectively. Multiplying this savings delta (~$35) per month, per unit, across the scenarios gives a break-even Return on Investment (ROI) period of between 11 and 30 years for the geothermal system compared to an air-source heat pump, depending on the exact cost of each system.[66]

As mentioned prior, if the rejected heat is used to provide a source for domestic hot water heat pumps, the ROI period can be further reduced by including the energy savings compared to using additional power to heat domestic water.[67]

9 SERVICE BUNDLE 3 – TELECOMMUNICATIONS AND TRANSPORTATION

This service bundle deals with how people communicate with one another and provide the sociability, which is one of the key benefits of urbanization.

9.1 TELECOMMUNICATIONS

The immediate area surrounding Rice Street generally has service through fiber, cable, fixed wireless, and satellite providers.[68] Both Hawaiian Telecom, a local fiber provider, and Spectrum, offer up to gigabit internet in the Rice St Corridor,[69, 70] and multiple wireless services (fixed wireless, 5g home, or satellite) all compete in this area. While particular site plans will need to coordinate connections to service, the existence of both fiber and cable gigabit providers along with the wireless competitors providing 250 mbps+ services means that this particular area has options and flexibility in telecom services.

9.2 TRANSPORTATION

Ground transportation accounts for about 20% of the total emissions in Hawai'i,[71] about half that of stationary combustion (electricity generation). As part of any initiative to reduce carbon emissions and environmental impacts, efforts to make low-impact transportation modes more comfortable and more convenient should be employed where possible. The site is located near the commercial core of Lihue,

[66] Difference in Cost for one Unit Geothermal to Air Source was estimated at $4,500 to $12,500. With a monthly savings of ($1.69*30) = $50.70, the break even point is $4,500/($50.70/month) or $12,500/($50.70/month), giving the range of 89 to 246 months, or the 7 to 21 years stated.

[67] https://www.energy.gov/energysaver/heat-pump-water-heaters

[68] BroadbandNow. "Internet Providers in Lihue, Hawaii." https://broadbandnow.com/Hawaii/Lihue. Accessed March 19, 2024.

[69] Hawaiian Telecom. "Check Availability: Products." https://shop.hawaiiantel.com/cart/orderwizard/products. Accessed March 19, 2024. (Checked against address 4265 Rice St, Lihue, HI)

[70] Spectrum. "Internet." https://www.spectrum.com/buy/internet. Accessed March 19, 2024. (Checked against address 4265 Rice St, Lihue, HI).

[71] *Hawai'i Pathways to Decarbonization*. December 2023. Act 238 Session laws of Hawai'i 2022 Report to the 2024 Hawai'i State Legislature. Hawai'i Department of Energy. https://energy.hawaii.gov/wp-content/uploads/2022/10/Act-238_HSEO_Decarbonization_FinalReport_2023.pdf

reducing the travel distance and baseline household transportation burden level to accomplish day-to-day tasks. Allowing for more shops, residences, and jobs to be located within the eco-district will increase the options available when taking low-carbon modes of transportation. Allowing more destinations to be within a 5 minute walk of housing will reduce obligatory automobile travel to and from destinations. Whether electric or internal combustion engine driven, the amount of carbon emission generated by a short walk is practically nonexistent compared to a trip in a vehicle powered by either electric motor or internal combustion.

9.2.1 Bus Network

The island of Kauai has a bus transit network with a main hub located adjacent to the proposed site. The current hourly routes serving the site (Eiwa Street) are the 100-200 pair serving Kekaha (South), the 400-500 pair serving Hanalei (North), and the 70 Lihue shuttle which stops at Eiwa Street twice in each hour. These routes are shown in Figure 16. Two additional routes, 800 and 850 to Wailua, also stop at Eiwa Street, though with only 5 total trips each day.[72] These routes serve a broad portion of the island, though efforts to increase frequency will increase the convenience of transit. Linking the Eiwa Street Bus Terminal with the development site is an important aspect of the Eco district (see Figure 16 and the discussion on four ingredients to walkability).

[72] The Kauai Bus. https://thekauaibus.com/. Timetables Last Updated February 14, 2022.

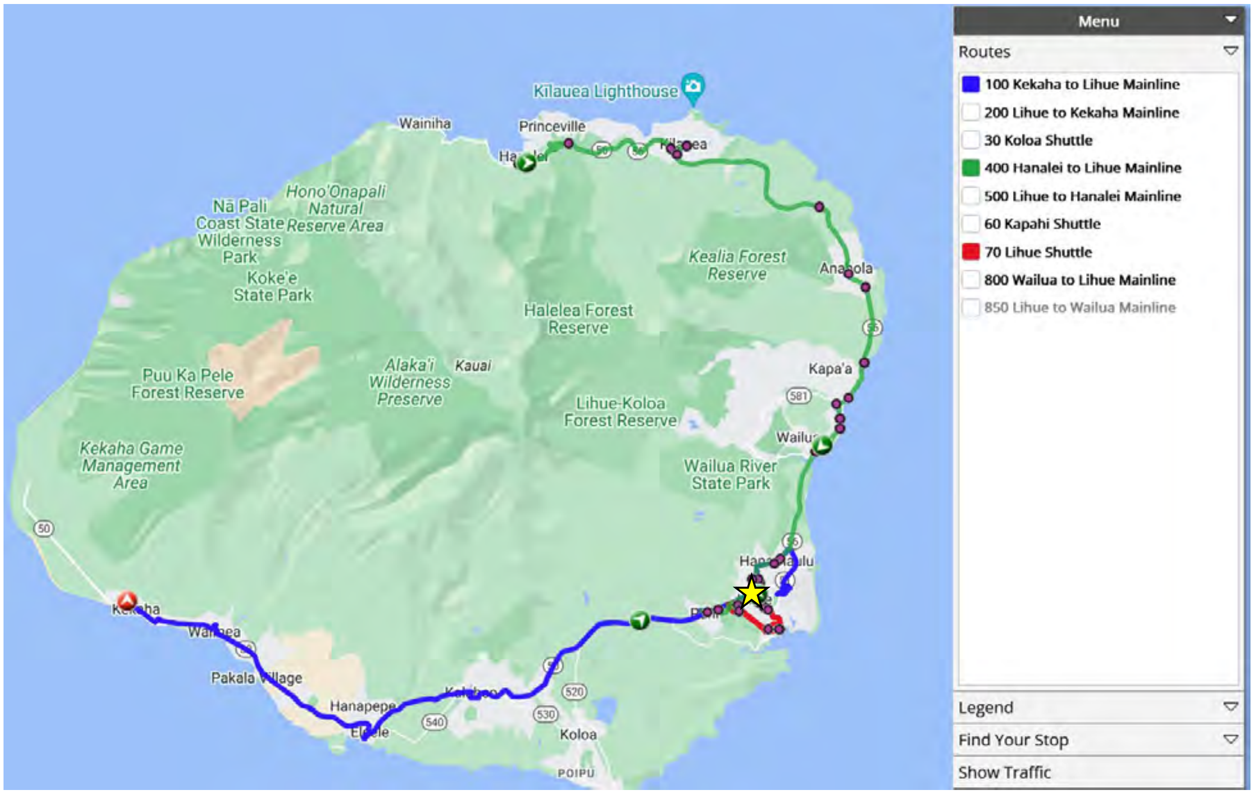


Figure 16. Map showing Routes with Hourly Frequency from Eiwa Street

9.2.2 Pedestrian Comfort – Shadeways and Rain Roofs

From Jeff Speck[73], to be favored over other modes a walk[74] must have four elements, namely, a walk must be: Useful, Safe, Comfortable and Interesting. In places with a walkable core where all four of these elements are present, the 'edge' of that area is often where one of these elements is missing. Part of the ecodistrict funding can be for the improvement of the pedestrian network through the site.

9.2.2.1 Useful

The location of the Lihue Civic Center means that there are several locations already nearby which serve as destinations, whether school, shops, employment, or park and recreation space, making the potential for *useful* walks high. The corridor along Kuhio Highway has further businesses.

9.2.2.2 Safe

Rice and Hardy Streets are two-lane roads leading to the Rice Street Business District, the Elsie H Wilcox School and the bike path behind the school, and these routes are relatively *safe* routes (low in risk from vehicles, crime, or other peril). In comparison, walking routes along or across Kuhio Highway do not

[73] Speck, Jeff. *Walkable City: Tenth Anniversary Edition.* Picador Paper. 2022.
[74] Used in the broadest sense, including wheelchairs and other pedestrian mobility assistance devices

have the same perception of a level of safety as vehicles travel at greater speeds and frequencies, though there are useful destinations in the area.

9.2.2.3 Comfortable

In Lihue, the greatest discomforts to pedestrian travel are heat from the sun and rain. Several options exist to improve the pedestrian comfort, all involving increasing shade or shelter and increase the *comfort* of the walk. Shown in Figure 17 are examples of structures including awnings over commercial sidewalks increasing shade and some shelter from the rain; in Figure 18 is a larger pedestrian area with large shade trees providing mottled shade. For areas where it will take years to establish trees large enough for shade of a larger area, and frontage awnings are not viable, a small freestanding structure with native climbing vegetation can provide shade quickly (Figure 19).

9.2.2.4 Interesting

A walkable route has something pleasant or interesting throughout its length. Monotony of uses, monoculture in building use or landscaping should be avoided. Gaps in a commercial street frontage should be built in or landscaped well to give definition to the edge of the walkway.

Figure 17. Vernacular Hawaiian Commercial Frontage routinely includes deep awnings or sidewalk coverings (Hanapepe, Kauai, Hawaii).

Figure 18. Pedestrian areas with large shade trees make for greater pedestrian comfort

Figure 19. Covered Walkway Example (Paseo Esteban Huertas, Panama City)[75]

10 CONCLUSIONS

For the area of the government campus, an ecodistrict is feasible with several aspects of design addressed.

1. Building designs should incorporate natural ventilation and shading as much as architecturally feasible to reduce cooling loads
2. A cooling district with geothermal loops will reduce the day-to-day costs of cooling units, and if integrated with domestic hot water production, can significantly reduce the total energy demand of units.

[75] Rolo3014. "Paseo Esteban Huertas.jpg" *Wikimedia Commons*. 11 September 2012. https://commons.wikimedia.org/wiki/File:Paseo_Esteban_Huertas.JPG

3. Zoning reform allowing more businesses, residences and other beneficial land uses within walking distance of the government campus will reduce the energy burden of transportation to or from the new residences.
4. Increasing the pedestrian comfort through improvements to the usefulness, comfort, safety, and interest of pedestrian routes surrounding the campus will increase the mode share of pedestrian trips, especially in conjunction with the previous recommendation.
5. Sewer expansion should first look at using existing capacity (up to about 480 units), then expanding existing sewer lines (this analysis showed feasibility up to about 1,420 units), then a detailed analysis of the tradeoffs between further sewer line expansion and a package plant on or near the site performed, should the previous options be prohibitive.
6. With enough site coverage, the electrical demand of the site should be capable of being generated on site with solar panels and batteries. However, in the 500-unit higher-density scenario, additional land off-site for solar panel coverage may be preferable to nearly 70% solar panel coverage.