Title

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Journal

Transactions Geothermal Resources Council, 48

ISSN

0193-5933

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Publication Date

2024

GRC Transactions, Vol. 48, 2024

Shallow Geothermal Resources for Cooling Applications at the University of Hawai‘i

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Keywords

Geothermal heat exchanger, building cooling, Hawai‘i, favorability map, numerical modeling

ABSTRACT

Scientists at Berkeley Lab have teamed up with The University of Hawai‘i at Manoa (UH Manoa) through the U.S. Department of Energy’s (DOE’s) Energy Transitions Initiative Partnership Project (ETIPP) to evaluate the technological and market feasibility of shallow geothermal heat exchanger (GHE) technology for building cooling, energy efficiency, and emissions reduction applications in Hawai’i. The team is assessing the data necessary to model the feasibility of deploying this technology, the actual models that will be used, and what hurdles need to be overcome to install a demonstration case. UH has an abundance of geologic and geothermal data and is looking to the national labs’ expertise to execute this analysis. UH is also interested in investigating policy, regulatory, and business conditions advantageous for implementation of a pilot project, and more broad deployment of this technology in Hawai‘i.

In many locations around the world, the demands for heating and cooling are roughly balanced over the course of the year, so GHEs do not cause significant long-term changes in subsurface temperature. This is not the case in Hawai’i, where the demand for heating is very small, meaning that over time, GHEs will add heat to the subsurface. If temperatures increase significantly, GHE systems will not work as designed. Regional groundwater flow has the potential to sweep heated water away from boreholes, thereby maintaining the functionality of the GHE system. Significant regional groundwater flow requires two things: a sufficiently large driving hydraulic head gradient

(usually closely related to surface topography), and sufficient porosity and permeability to enable groundwater to flow in large enough quantities to enable near-borehole temperatures to be maintained at ambient values. Hawaiʻi's volcanic terrain offers ample surface topographic variation. The lava itself shows an extremely large range of porosity and permeability, making it crucial to select sites with large enough values of these properties. Numerical modeling of coupled groundwater and heat flow can be used to determine how large is large enough. Both closed-loop and open-loop systems are being investigated. Another option being considered is using cool seawater as the source of chill.

Currently work is progressing on two fronts. A hydrogeologic model for a closed-loop system is being developed for the Stan Sheriff Center at the UH Manoa campus, where a subsurface karst system immediately downgradient of the borefield may provide efficient removal of heated groundwater. The team will also develop a technoeconomic model for this site to compare the cost of cooling using a GHE system with the costs of operating the current air conditioning system. At the state scale, geographic information system (GIS) layers of various attributes relevant for GHE are being combined to develop an overall favorability map for employing GHE in Hawaiʻi.

1. Introduction

This study is a DOE Energy Transitions Initiative Partnership Project (ETIPP), which seeks to partner DOE national laboratory scientists with remote, coastal, and island communities looking to transform their energy systems and increase energy resilience. The overall goals of this project with the University of Hawaiʻi include analyzing the potential for geothermal cooling in buildings across its 10 campuses by modeling shallow geologic conditions and building heating and cooling loads and evaluating potential geothermal technologies that could improve energy efficiency and significantly increase sustainability for these communities. This could contribute to decarbonizing building energy requirements throughout the United States (e.g., Liu et al., 2023).

This project builds upon an earlier assessment by Dores and Lautze (2020), who evaluated a variety of scenarios relating to the applicability of ground source heat exchangers for space cooling in Hawaiʻi. They examined a number of important parameters for six of the Hawaiian Islands, such as shallow geology, depth to water table, and groundwater and measured air temperatures. These datasets were then projected onto GIS maps of each of the studied islands. For effective cooling to occur using GHE technology, a threshold maximum water table depth of 80 m was assigned. The groundwater temperature was used as a proxy for subsurface ground temperature at the same depth as the groundwater measurement, and a comparison was made between air and subsurface temperatures throughout the year for the major population areas on the four most populated islands. Using literature values for the thermal conductivities of the four main rock types—alluvium and fill, basalts and other volcanic rocks, sand and dune deposits, and limestone and reef deposits—the basalts and limestones were identified as having the most prospective thermal properties for deploying GHE systems. Both seasonal and yearly operational scenarios were evaluated. The study concluded that space cooling would be feasible using GHE systems in Hawaiʻi, and that more detailed modeling would be needed to assess the impacts of advective heat transfer.

The current project has two primary objectives: 1) expanding the GIS-based screening methodology of Dores and Lautze (2020) to further assess the feasibility of deploying GHE technology in Hawai‘i, and 2) conducting a more detailed technical and economic assessment of the potential for developing such a system for cooling of the Stan Sheriff Center athletic complex at the UH Manoa campus. This involves developing a detailed 3-D geologic model of the area that can be used to create a hydrogeologic framework for numerical modeling. One of the key concerns for applying GHE in tropical environments is that heat is continually added to the subsurface with only cooling being used, and that lateral flow of groundwater is required to sweep the heat away so that the system can continue to operate.

2. GIS-based Screening Criteria for GHE in Hawai‘i

As noted earlier, Dores and Lautze (2020) used the shallow geology, depth to water table, and groundwater and air temperatures to help identify prospective areas within six of the Hawaiian Islands where GHE might be feasible. Our team expanded this list of parameters to include additional screening criteria that would be useful in evaluating the suitability of a particular location for installing a closed-loop GHE system. We also looked at the potential of using open-loop systems as well as seawater cooling systems (e.g., Leraand and Van Ryzin, 1995), but this evaluation is confined to closed-loop GHE applications. The criteria consist of a variety of physical (i.e., geographic, geologic, hydrologic), ecological/environmental, and cultural factors that would influence the viability of deploying a GHE system. Two examples of these GIS screening criteria (soil permeability and the locations of schools and Department of Defense (DOD) land) on O‘ahu are displayed in Figure 1. Table 1 summarizes these features and provides some suggestions as to what might constitute favorable versus unfavorable conditions for each of these parameters. Many of these parameters can be mapped using corresponding GIS layers, so that multiple factors can be examined and areas that have favorable or unfavorable conditions can be easily identified using this approach.

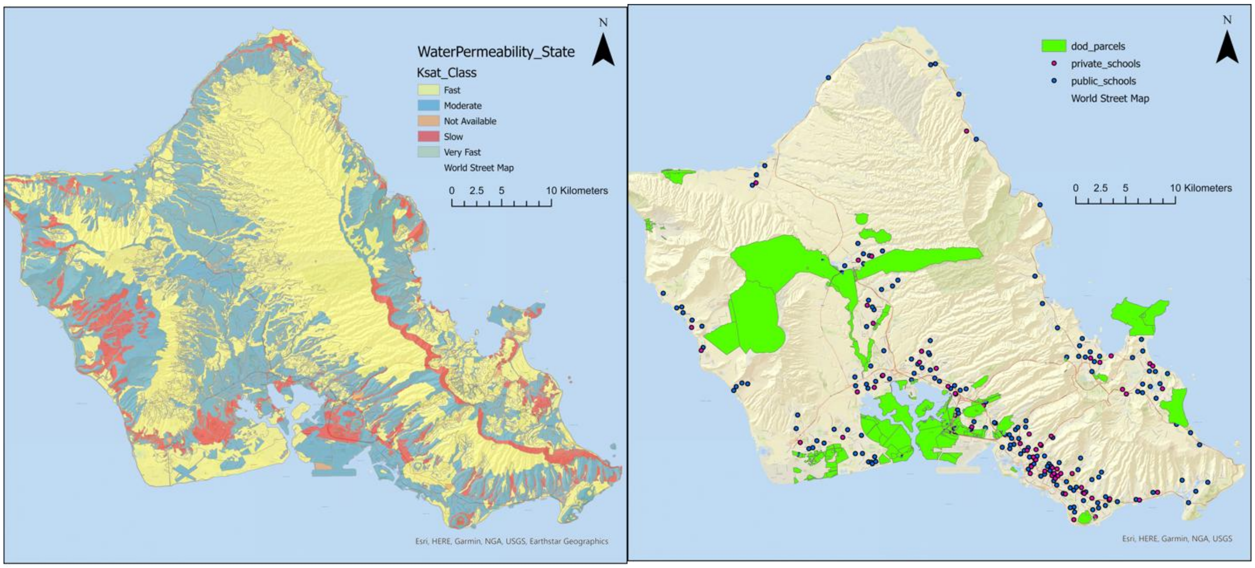

Figure 1: Left – GIS map of O‘ahu depicting different soil permeability zones: slow = <3µm/s; moderate = 3 – <10 µm/s; fast = 10 – <100 µm/s; very fast = ≥100 µm/s. Right – Locations of DOD lands and public and private schools on O‘ahu. See Table 1 for data sources.

2.1 Key Physical Parameters

A number of physical parameters are important for GHE installations. To meet the needs of cooling, the groundwater temperature needs to be low enough to be able to effectively cool buildings. Given that the GHE system will not be balanced between heating and cooling, there needs to be sufficient groundwater flow so that heat can be swept away from the boreholes. Having a sufficiently sloped piezometric surface and hydraulic head will promote higher lateral water flow rates needed to remove the heat, but it’s also important to consider the ground surface slope (i.e. from the Digital Elevation Model), as it will add complexity to siting the GHE. The subsurface geology needs to have high enough permeability to facilitate a high flux of groundwater flow through the area where the borefield will be situated. Finally, the boreholes need to be located in an area with a fairly shallow water table, as the bulk of the boreholes need to be located in the saturated zone to allow for effective heat transfer between the closed-loop boreholes and the surroundings.

2.2 Key Ecological and Environmental Parameters

The siting of a GHE will require drilling numerous boreholes. This may not be possible in densely vegetated and forested lands, and in areas that have endangered species. There are areas with restricted watersheds that might not permit GHE deployment. There may be conflicts with existing use of the subsurface for freshwater production or water injection. The use of a closed-loop system may minimize such conflicts. Areas with existing wells will be better characterized with respect to their hydrogeology, which can help develop better constrained models that can be used to predict long-term GHE performance and estimate the cost effectiveness of such systems.

2.3 Key Cultural Parameters

There are a variety of cultural factors that may promote or restrict the deployment of GHE systems. Areas with an elevated community heat index and high cooling needs may be good candidates for such a system. Disadvantaged communities often lack access to housing with resilient and inexpensive cooling systems, so developing such systems within those neighborhoods could have very beneficial impacts. Some organizations, such as schools and the U.S. military, have prioritized decarbonizing their facilities and making them more climate resilient, so they may be good candidates for GHE cooling systems. There are some locations, such as national parks and sites of cultural and archeological sensitivity, where such systems cannot be deployed.

Table 1: Summary of key screening parameters for siting GHE installations

Parameter	**Importance**	**Data range**	**Favorable**	**Acceptable**	**Unfavorable**	**Comments**	**GIS data source**
Physical parameters							
Elevation	Useful	0 to >3,000 m	0-20 m	20-100 m	> 100 m	Proxy for depth to water table	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Slope	Useful	0 to 90°	2-5°	0-2°, 5-10°	>10°	Higher slope harder to build on, but provides steeper hydrologic gradient	Calculated from Elevation model
Depth to water table	Critical	0 to >100 m	0-10 m	10-80 m	> 80 m	GHE needs to be deployed within saturated zone for heat to be dissipated effectively via advection	Dores and Lautze, 2020 https://waterdata.usgs.gov/hi/nwis/gw/
Geology	Critical	Basalt lava flows, breccia, tuff, limestone, alluvium	Fractured basalt, limestone		Unfractured basalt (dike-rich zones)	Fractured basalts typically have good horizontal permeability. Caverns in limestone may be problematic for drilling and well completion.	https://ngmdb.usgs.gov/Prodesc/proddesc_111883.htm
Soil moisture	Useful	Arid to very wet (7 classes)	Wet zones	Intermediate zones	Arid zones	Wet zones likely have higher subsurface flow, arid zones may have deeper water table	https://www.sciencebase.gov/catalog/item/57a902e8e4b05e859bdf3c83

Permeability	Critical	Ksat classes (fast, moderate, slow, very fast)	High permeability	Intermediate permeability	Low permeability	High permeability zones more likely to effectively dissipate heat	http://gis.ctahr.hawaii.edu/SoilAtlas
Groundwater temperature	Critical		< 20°C	20-25°C	>25°C	Warm water less favorable for cooling applications	https://www.higp.hawaii.edu/hggrc/projects/hi-play-fairway/pf-project-data/
Tsunami zone	Useful		outside		inside	Borehole installations are below ground surface, so this should be less critical	https://www.honolulugis.org/apps/39a9e07068a14d01a85b437adcf50beb/explore
Ecological and environmental parameters							
Vegetation cover	Useful	Bare ground, sparse vegetation, forested	Bare ground	Sparse vegetation	Forested	Densely forested areas would be impacted by developing a GHE borefield	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Critical species habitat	Critical		No critical species present		Critical species present	It may be possible to install a GHE system and not disturb critical species habitat	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Restricted watersheds	Useful/Critical		Unrestricted		Restricted	With a closed-loop system, deployment of a GHE system might be permitted in a restricted watershed	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Underground injection zones	Useful		Distant		Proximal	There may be competing uses to the subsurface, injection may perturb	https://planning.hawaii.gov/gis/download-gis-data-expanded/

						subsurface temperatures; these areas may have better subsurface characterization	
Recycled water management zones	Useful		Unrestricted	Conditional	Restricted	There may be competing uses to the subsurface, water recycling may perturb subsurface temperatures; these areas may have better subsurface characterization	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Water quality	Useful	Water to be left in natural state, discharge allowed, water known to be toxic/corrosive	Discharge allowed	Water to be left in natural state	Water known to be toxic/corrosive	For closed-loop system, main concern would be corrosion to underground installation. Heating of subsurface over time would perturb natural state conditions.	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Existing wells	Useful					Existing wells may provide useful information regarding subsurface conditions, but may also indicate competing uses of the subsurface	https://www.higp.hawaii.edu/hggrc/projects/geothermal-digital-collection/groundwater-collections/
Cultural parameters							

Land ownership	Useful	Private and public lands	DOD, UH lands		Some private land, protected land	Landowner needs to provide access to site, some landowners are motivated to decarbonize operations	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Schools	Useful	Public and private	School sites			Schools often have significant cooling load, interest in developing renewable energy resources, GHE system provides educational opportunities	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Parks	Useful		No parks	Urban, multi-use parks	National parks and preserves	Parks often restrict or prohibit development. Also, parks may not have a need for cooling nearby.	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Archeology/cultural site	Critical		No identified sites		Identified sites	Presence of archeological or cultural features would likely preclude GHE deployment	https://planning.hawaii.gov/gis/download-gis-data-expanded/
Community heat index	Useful		High heat index – greater need for resilient cooling		Low heat index – lesser need for resilient cooling	Linked to cooling demand	https://www.arcgis.com/apps/View/index.html?appid=ff1b73d836074cf6b2aca420fffbd930 (for O‘ahu)
Population density	Useful		High density	Intermediate density	Low density	Greater cooling demand with more concentrated population density,	https://files.hawaii.gov/dbedt/op/gis/maps/2010_pop_density.pdf

						impact of urban heat island effect	
Cooling demand	Critical		High cooling demand		Low cooling demand	GHE systems in greater need where cooling demand is higher	https://www.honolulugis.org/
Disadvantaged communities			Areas with disadvantaged communities		Areas with affluent communities	Deployment of GHE in disadvantaged communities can address energy poverty	https://screeningtool.geoplatform.gov/en/#6.3/20.657/-157.697

3. Evaluation of the Stan Sheriff Center at UH Manoa

The UH team members identified the Stan Sheriff Center at the UH Manoa campus as an ideal candidate to evaluate for cooling using GHE technology. It has a very high cooling load and is surrounded by open space and athletic fields where GHEs could be deployed. The following sections describe our efforts to characterize the local geology, develop a 3-D hydrogeologic model, create a numerical grid, and conduct some scoping simulations with different lateral groundwater flows to evaluate the potential for this area to sustainably provide cooling using GHE.

3.1 Geologic Model of the Stan Sheriff Center Site

A variety of data sources were used to create a 3-D geologic model of the area surrounding the Stan Sheriff Center at the UH Manoa campus (Wolf, 1975; Finstick, 1996; Holliday, 1998; Clague et al., 2016; Okuhata, 2017; Sherrod et al., 2021). The campus is partially located in an old quarry within the 76 ka Sugarloaf melilite nephelinite flow, which is reported to have a thickness of 15 m (Clague et al., 2016), and a series of limestone underground caves have also been reported in the area (Halliday, 1998); limestone reef deposits outcrop just seaward of the campus, on south side of H1 (Figure 2). Just to the north is Waʻahila Ridge, representing a series of older lava flows from the Koʻolau volcano. A number of engineering geology borings in the area help constrain the shallow subsurface geology as well as the depth to the water table, which is generally around 2.4 m to 3 m (8 ft to 10 ft) depth below ground surface. All of this information was georectified and imported into the Leapfrog 3-D geologic modeling tool. Figure 3 displays the plan view image of the study site, as well as a cross-sectional view of the area. For simplicity, six geologic units were identified: the older Koʻolau basalt (which forms the basement rock of this area), the younger Sugarloaf lava flow, limestone, coralline sand, alluvium, and fill. The locations of identified shallow limestone caves are also represented in this geologic model.

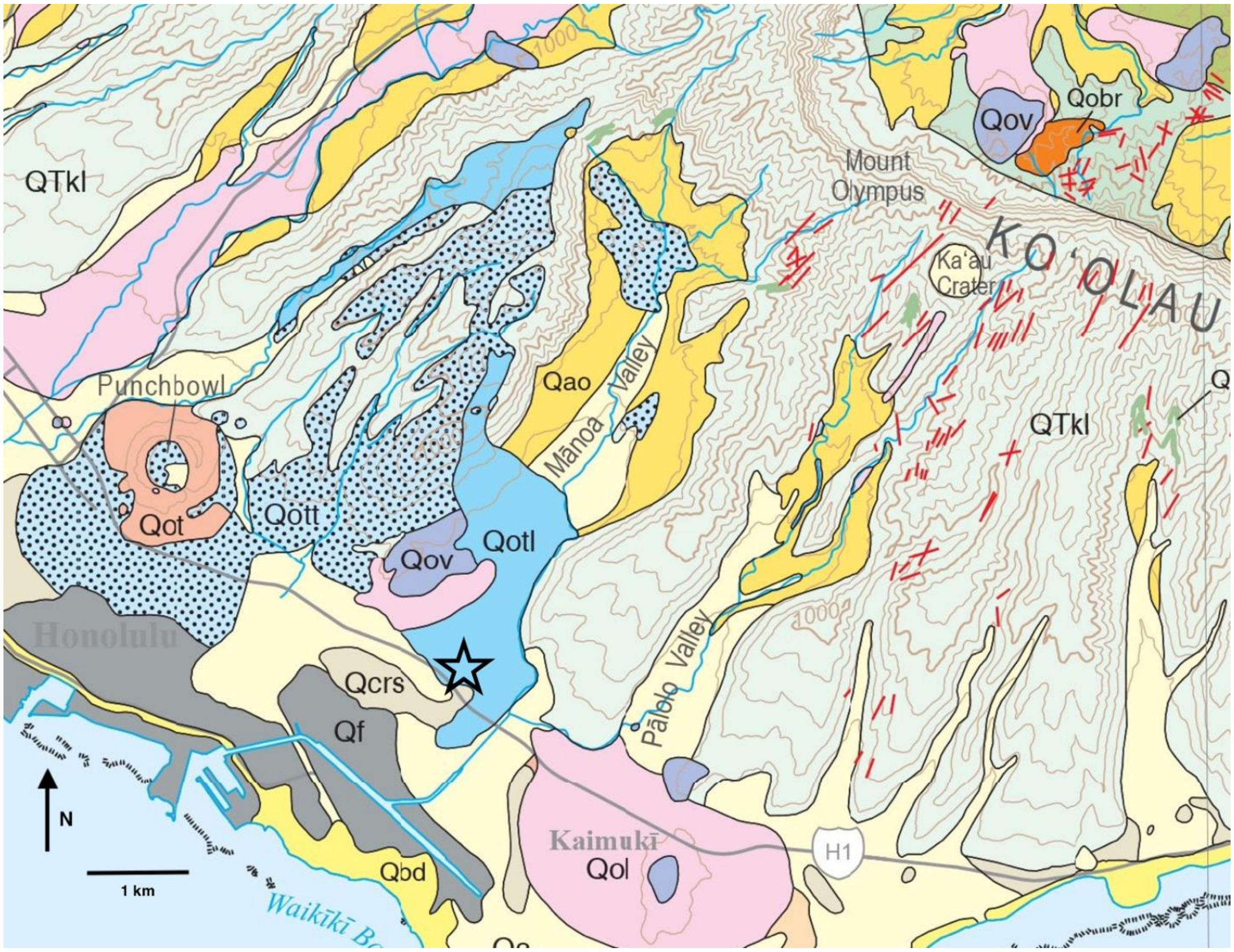

Figure 2: Portion of the geologic map featuring southern O‘ahu, from Sherrod et al. (2021). Depicted geologic units are as follows: Qf - Fill (Holocene); Qa - Alluvium (Holocene and Pleistocene); Qao - Older alluvium (Pleistocene); Qbd - Beach deposits (Holocene); Qcrs - Calcareous reef rock and marine sediment (Pleistocene); Qol - Lava flows, Honolulu Volcanics (Pleistocene); Qov - Cinder vent deposits, Honolulu Volcanics (Pleistocene); Qot - Tuff cone deposits, Honolulu Volcanics (Pleistocene) Qotl - Lava flows from Tantalus Peak and Sugarloaf vents, Honolulu Volcanics (Pleistocene); Qott - Tuff from Tantalus Peak and Sugarloaf vents, Honolulu Volcanics (Pleistocene); QTkl - Lava flows from Ko‘olau Basalt (Pleistocene and Pliocene). The star denotes the location of the Stan Sheriff Center at the UH Manoa campus.

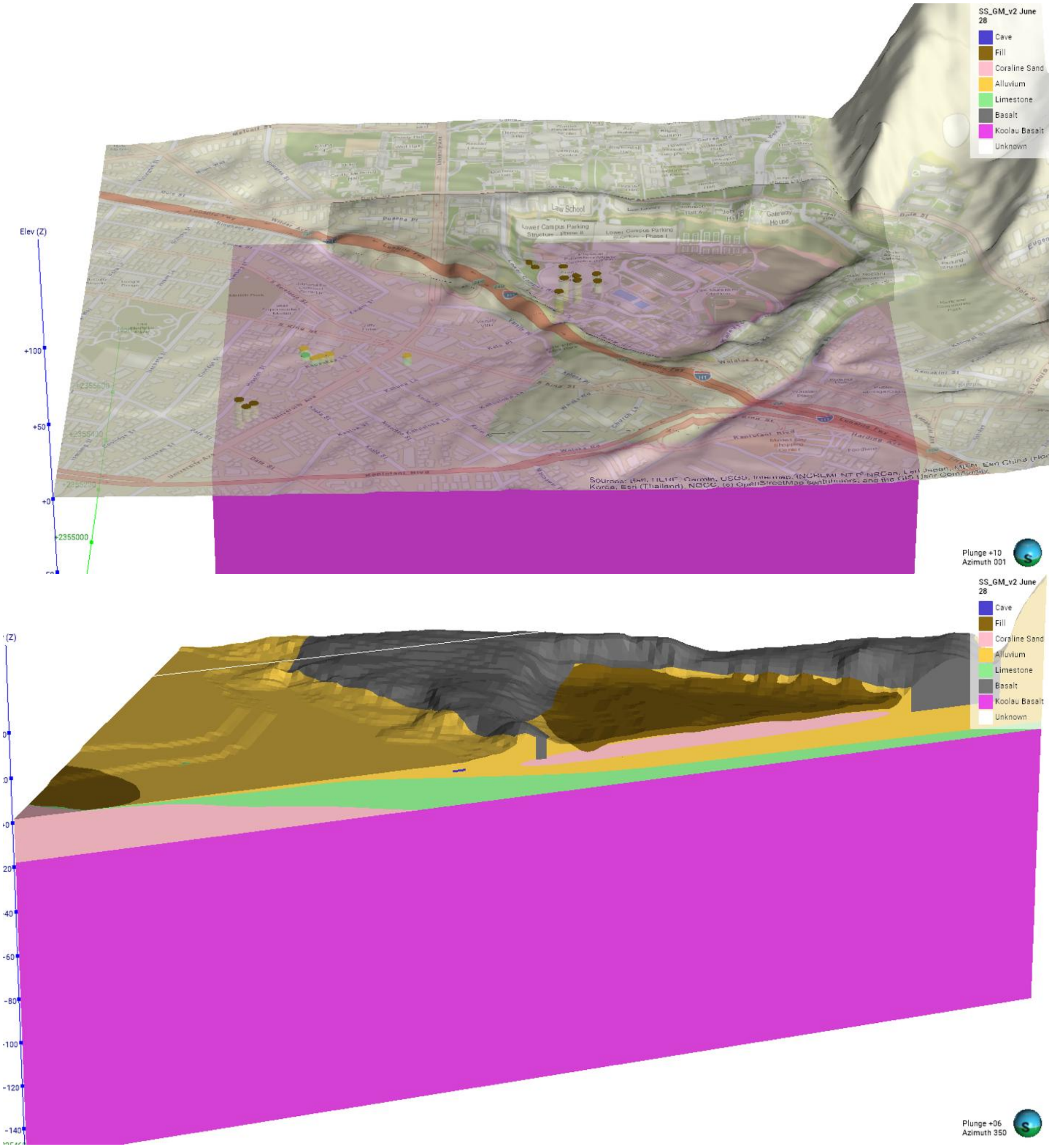

Figure 3: Three-dimensional images from the geologic model of the UH Manoa Stan Sheriff Center. Upper figure shows the excavated quarry in the Sugarloaf lava flow where the athletic complex is located, along with locations of engineering boreholes. The lower figure depicts a cut section through the 3-D geologic model, with the exposed cross section parallel to the main hydrologic flow direction (from right to left). Note that the majority of the geologic section is comprised by the older Ko‘olau basalt flows.

3.2 Hydrogeologic Model and Heat Exchange Model of the Stan Sheriff Center Site

One of Leapfrog’s capabilities is to convert the 3-D geologic model into a grid for the numerical simulations, where the grid blocks are assigned the appropriate petrophysical, thermal, and hydrologic properties corresponding to those pertaining to the units in the geologic model (e.g., Milicich et al., 2015). The grid was oriented so that the grid blocks would be parallel to the primary groundwater flow direction, which flows down from the crest of the Koʻolau Range towards the coastline in a southwesterly direction (Nichols et al., 1996) (Figure 4).

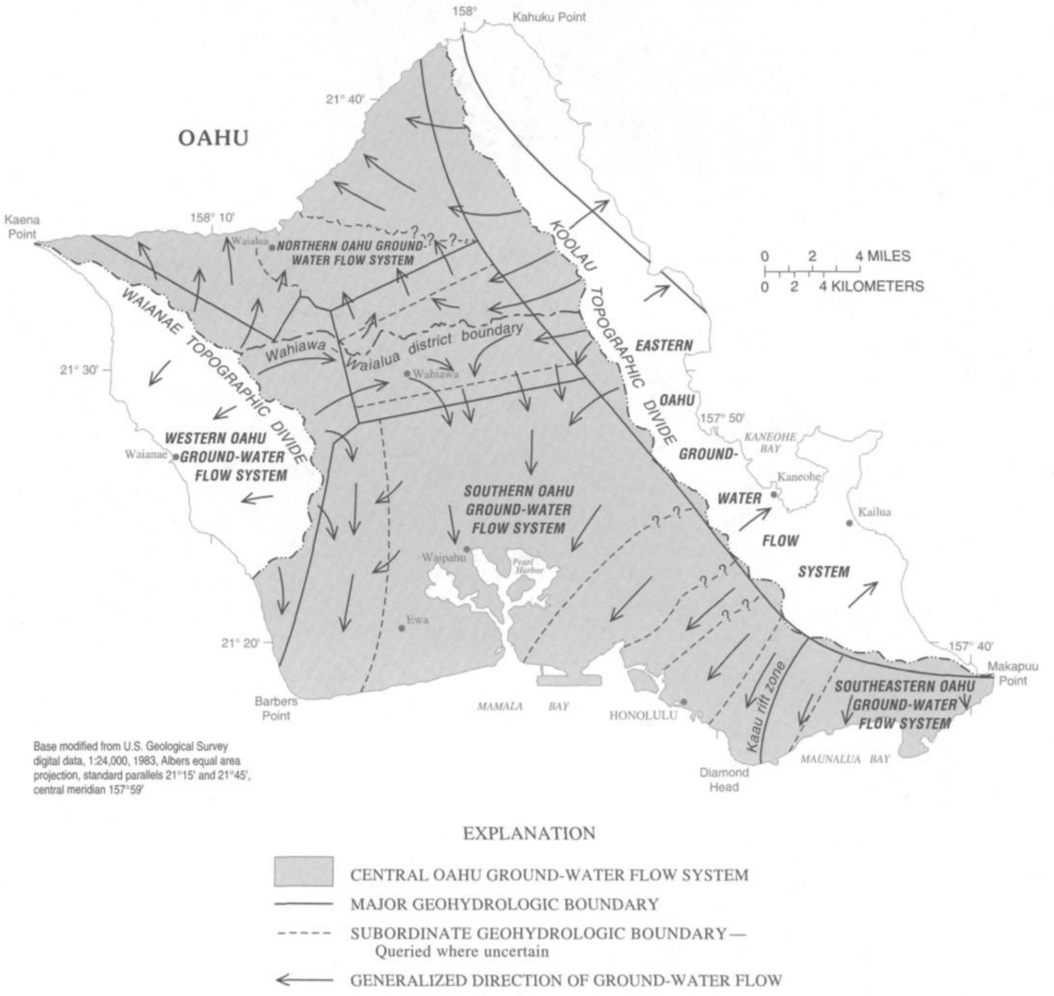

Figure 4: Groundwater flow systems for Oʻahu (Nichols et al., 1996). The UH Manoa campus is located within the southern Oʻahu groundwater flow system, just west of the Kaau rift zone.

The grid extent and thickness were designed to contain the potential region where a GHE system would be potentially deployed for cooling the Stan Sheriff Center. The grid extends from the ground surface to a depth of about 150 m. It contains 21 layers, with each layer thickness about 10 m. The upper five layers are incomplete, representing the variable surface elevation. The lower 16 layers all contain 2771 grid blocks. The total number of grid blocks in the model is about 46,000. Lateral grid spacing is 25 m, but the central portion of the grid is refined to 12.5 m, to better resolve caves and the borefield. The lateral extent of the model is about 1.3 km in the east-west direction and 1 km in the north-south direction. Although the model itself is oriented east-west/north-south, the grid is rotated laterally to align with the regional groundwater flow direction. Figure 5 shows the grid. The numerical simulator being used is Transport of Unsaturated Groundwater and Heat (TOUGH) (Jung et al., 2018), a multi-phase, multi-component simulator for fluid flow and heat transport through porous or fractured geologic media.

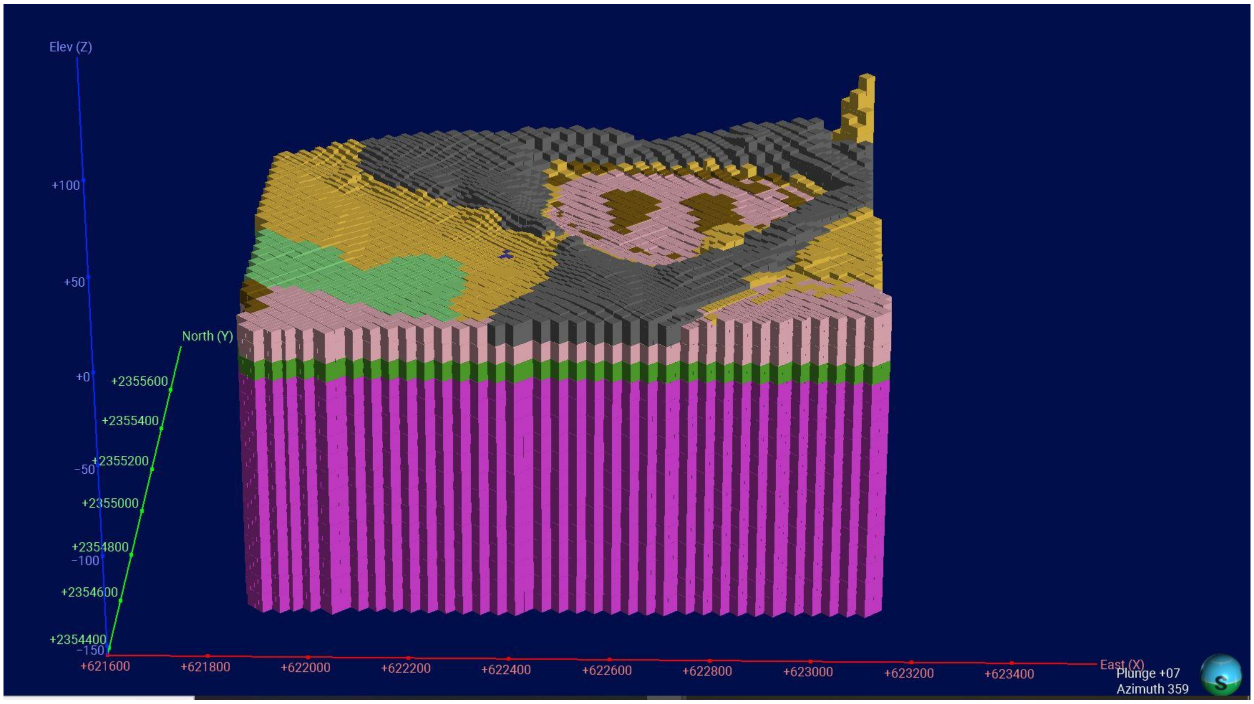

Figure 5: TOUGH grid used for the preliminary simulations.

There have been a number of hydrogeologic studies that have modeled groundwater flow in southern Oʻahu (e.g., Finstick, 1996; Nichols et al., 1996; Hunt, 1996; Lau and Mink, 2006; Rotzoll and El-Kadi, 2008; Okuhata, 2017; Izuka et al., 2018; Izuka and Rotzoll, 2023); they have summarized the hydrologic properties of the main geologic units of this area. In addition, Dores and Lautze (2020) have reported representative thermal conductivity values of the main lithologic units; these have been supplemented by data from Clark (1966) and Robertson (1988). Tables 2 and 3 present a summary of these properties, which are needed to properly simulate the groundwater flow and heat exchange of a GHE system. It is important to note that if 100 m closed loop borehole heat exchangers are to be used, then the Koʻolau basalt unit will be the primary hydrogeologic unit controlling the heat exchange (the geologic model depicted in Figure 3 suggests that this unit will be present at depths greater than 20 m).

Table 2: Summary of key hydrologic properties of primary geologic units

Rock type	**Hydraulic conductivity (m/d)**	**Effective porosity (%)**	**Comments**	**Sources**
Koʻolau basalt (dike-free lava)	600 (horizontal – longitudinal); 150 (horizontal –		HC values used in our simulations	Okuhata (2017)

	transverse); 0.75 (vertical)			
	152-1524			Hunt (1996)
	457, 305-1524	5	Porosity value used in our simulations. Vertical permeability estimated to be much lower than horizontal	Lau & Mink (2006)
	401-550		Based on Fig. 8a for study area	Rotzoll & El-Kadi (2010)
Honolulu volcanics	3 (horizontal – longitudinal); 1 (horizontal – transverse); 0.05 (vertical)		HC values used in our simulations	Okuhata (2017)
	0.3-152			Hunt (1996)
Limestone	100 (horizontal – longitudinal); 100 (horizontal – transverse); 0.5 (vertical)		HC values used in our simulations	Okuhata (2017)
	30-6096			Hunt (1996)
	0.43-53 (13)	15-45 (35)	Used average porosity value in our simulation. Coral ledge	Finstick (1996)
Alluvium	0.05 (horizontal – longitudinal); 0.05 (horizontal – transverse); 0.05 (vertical)		HC values used in our simulations	Okuhata (2017)
	0.0009-2.9 (0.9)	38-71 (54)	Used average porosity value in our simulations	Finstick (1996)
	0.006 – 0.113	46.4-62.4	Values for older alluvium	Lau & Mink (2006)
	0.3-152			Hunt (1996)
Fill	0.015-86 (43)	28-69 (46)	Used average HC and porosity values in our simulations	Finstick (1996)

Average values shown in parentheses

Table 3: Summary of thermal properties of primary geologic units

Rock type	**Thermal conductivity (W m^{-1} K^{-1})**	**Specific heat (10^3 J/kg K)**	**Comments**	**Sources**
Basalt	2.0		TC value used in our simulations	Dores & Lautze (2020)
	2.1-3.1		TC mean values for 2 different lavas measured at 20°C	Clark (1966)
	2.1	1.03	TC determined for non-porous rock with 10% mafic phenocryst content at 300 K; SH value for Dresser basalt at 20°C	Robertson (1988)
Limestone	3.1		TC value of 3.0 used in our simulations	Dores & Lautze (2020)
	2.18-3.05		TC mean values for 3 different limestones measured at 20°C	Clark (1966)
	2.7	1.01	TC determined for non-porous rock at 300 K; SH value for Bedford limestone at 20°C	Robertson (1988)
Alluvium	0.8		TC value used in our simulations	Dores & Lautze (2020)

As noted in Table 2, permeability in the basalt is anisotropic, with horizontal permeability much greater than vertical permeability, and longitudinal permeability (i.e., in the direction of the lava flow) higher than transverse permeability. In basalts, permeability is dominated by the presence of fractures. The TOUGH code is able to independently model fracture and matrix permeability by employing a dual continua model, where grid blocks are subdivided into fracture and matrix grid blocks by using the multiple interacting continua (MINC) approach (Pruess, 1992). The orientation and spacing of the fracture network can be specified using this approach. For these preliminary simulations, only a single continuum was used, but by orienting the grid with the direction of groundwater flow, we also align it with the orientation of the major fractures, enabling the code to model anisotropic fracture permeability effectively.

Another important input for this model is the initial temperature distribution in the subsurface. There are a number of deep groundwater monitoring wells in southern Oʻahu, including three (Kaimuki High School (HS), Kaimuki Station, and Waahila) that are fairly close to the UH Manoa campus. As part of the groundwater monitoring effort, multi-parameter sensors that measure fluid electrical conductivity, temperature, and pressure are regularly run in these wells to detect changes in the fresh water-brackish water interface (Rotzoll et al., 2010). The temperature information from these wells can be used to constrain the general temperature-depth gradient that can be expected for the Stan Sheriff site. For these preliminary simulations a uniform initial temperature of 21.5°C is used – Dores and Lautze (2020) report an average groundwater temperature of 21.36°C for Honolulu. These temperatures are consistent with the thermal profiles from the nearby monitoring wells mentioned above that were shared by the Honolulu Board of Water Supply.

The details of the vadose zone and heat and moisture transfer to the ground surface are not addressed in these preliminary simulations, but they are within the TOUGH simulator capabilities and will be included in future modeling. Here, the entire model domain is water-saturated and the top model boundary is closed.

Initially, all lateral boundaries of the model are closed, and a gravity-equilibration simulation is done to create a hydrostatic pressure distribution throughout the model. Next, columns at the upgradient and downgradient extremes of the model are held fixed with a given pressure difference, and the model is run to steady state, to create a regional groundwater flow. Finally, heat sources are specified to represent five 100-m long boreholes, with a total heat source strength of 400 kW, roughly comparable to the cooling load for the Stan Sheriff arena, and the model is run for 20 years.

3.3 Preliminary Heat Exchange Simulations of the Stan Sheriff Athletic Complex Site

Where the heating and cooling loads of a geothermal heat exchange system are unbalanced, it is important that heat that is discharged into the subsurface is dissipated through advective flow caused by groundwater flow to the sea so that the GHE system retains its efficiency over time. Such a system operates more like a radiator (such as the Verona ground source heat exchange (GHX) system, which has over 6000 GHX boreholes (Hart et al., 2022)), where heat dissipation is needed to maintain the heat balance of the subsurface reservoir over time. Thus, capturing the impact of lateral groundwater flow and its ability to sweep heat out of the system is critical in developing numerical models to help design and predict the system performance. Most GHE models utilize a simple g-function to represent heat exchange between the closed loop system and the subsurface, which does not capture the thermal impact of lateral groundwater flow, as it only captures the effects of conductive heat transfer. A more rigorous representation of subsurface heat and flow processes can be realized using the TOUGH simulator, which can accurately model the effects of both advective and conductive heat flow. This simulator has been used to model geothermal district heating and cooling systems, and has been adapted to connect with the Modelica Buildings library (Wetter et al., 2014) developed by Lawrence Berkeley National Laboratory (LBNL), which includes dynamic simulation models for building and district energy and control systems (e.g., Doughty et al., 2021; Hu et al., 2022). Building upon these past efforts, our initial models examine the heat dissipation that can be achieved using a range of reasonable lateral groundwater flow rates based on reported transmissivity values.

Figure 6 shows some results of the preliminary modeling. Three cases were considered: no regional groundwater flow, small regional groundwater flow, and large regional groundwater flow. The plots show plan views of the temperature field at the top of the central portion of the model surrounding the borefield, after 20 years of heat injection. It is clear that the magnitude of regional groundwater flow has a significant effect on the long-term temperature in the borefield, with the maximum temperature decreasing as the magnitude of groundwater flow increases. The five injection boreholes are each separated by 12.5 m, and are arranged in a square.

Figure 7 shows an alternative suite of cases where the same load is distributed between 25 boreholes, also with 12.5 m separation, arranged in a square. It is apparent that the maximum temperature is much smaller in this case.

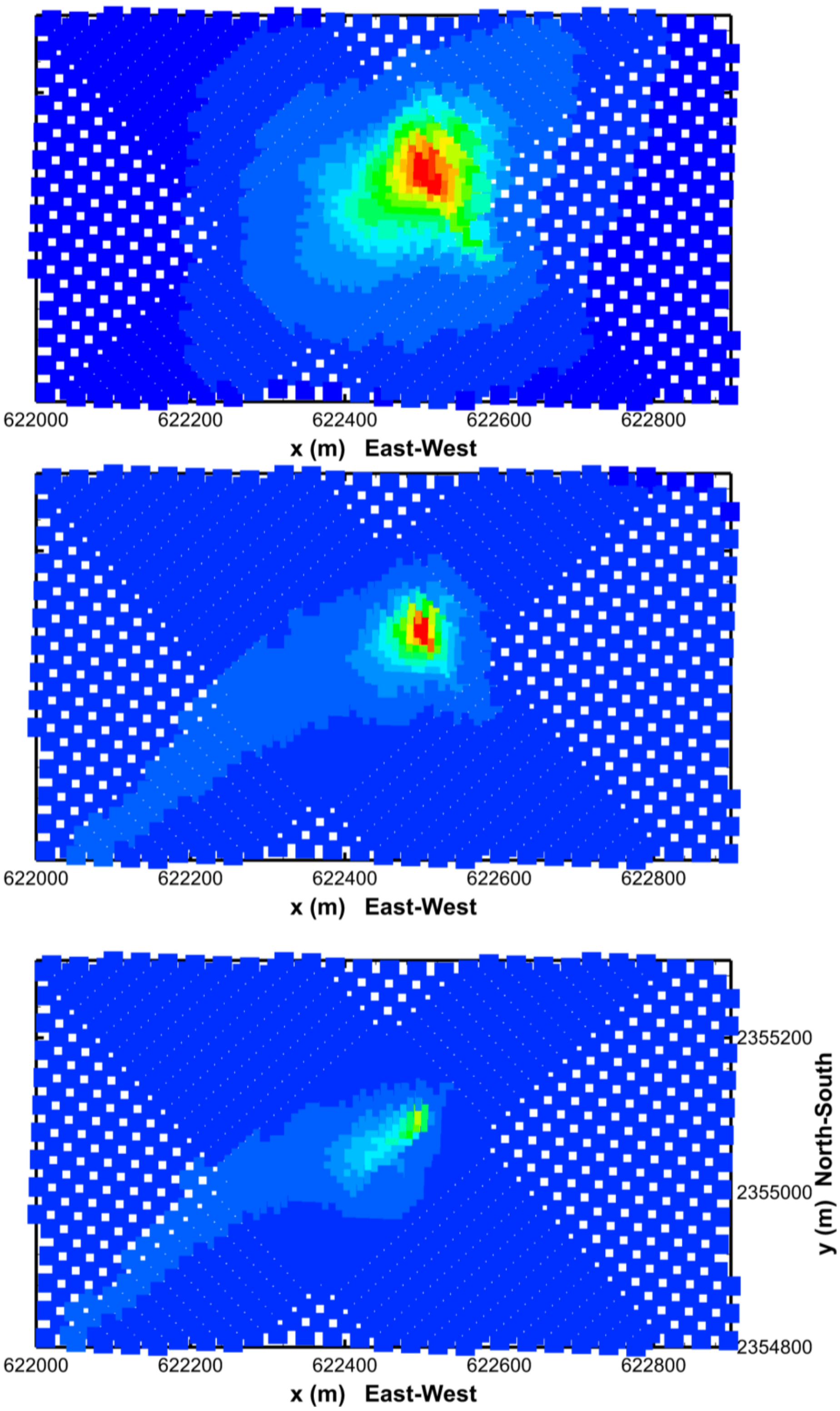

Figure 6: Preliminary TOUGH simulation results for a borefield with five boreholes. Temperature distributions at the top of the model after 20 years of heat injection. Top to bottom: increasing groundwater flow. Warmer colors indicate higher temperatures.

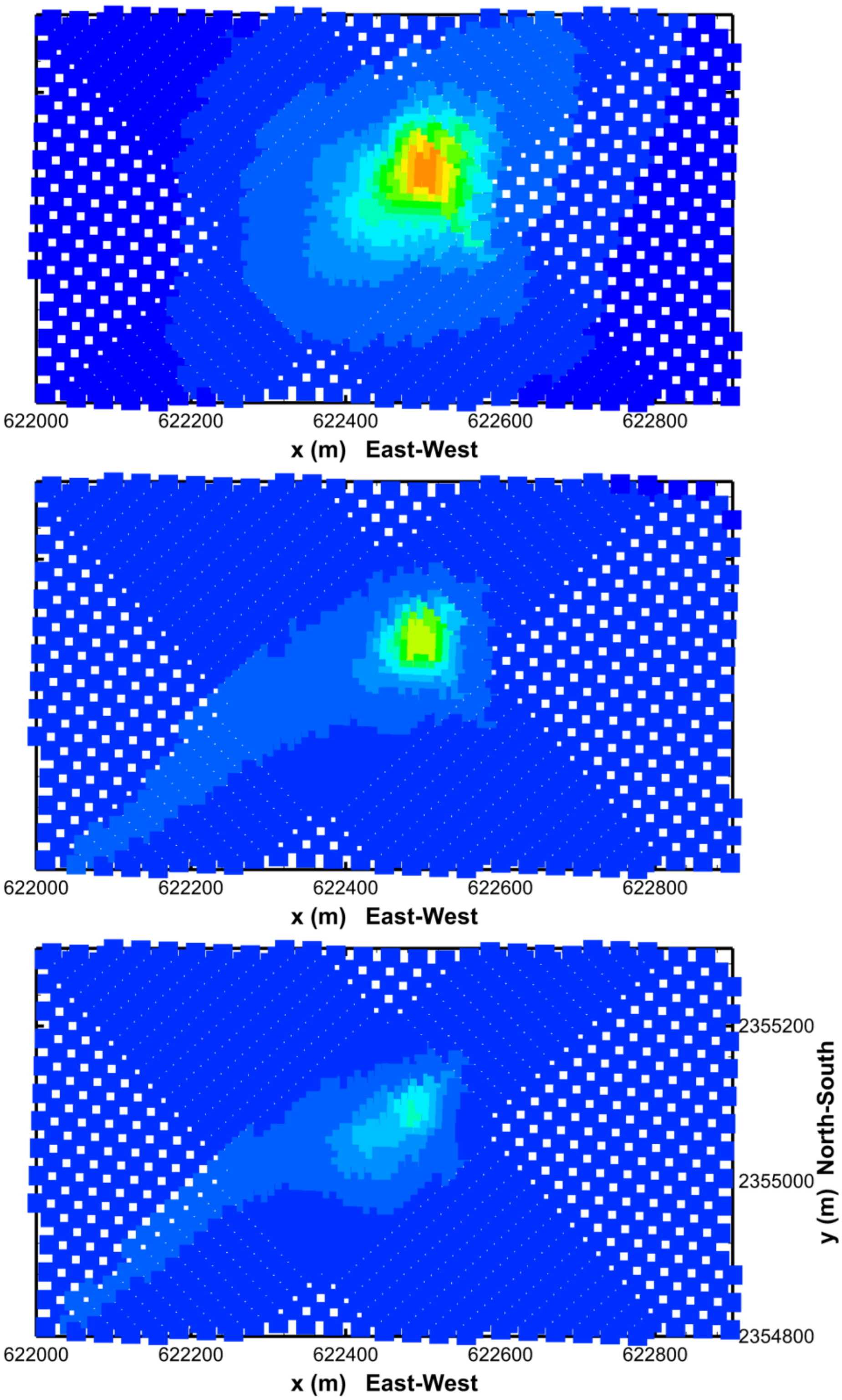

Figure 7: Preliminary TOUGH simulation results for a borefield with 25 boreholes. Temperature distributions at the top of the model after 20 years of heat injection. Top to bottom: increasing groundwater flow. Warmer colors indicate higher temperatures.

4. Next Steps

The preliminary TOUGH model can be improved in several ways to improve representation of the hydrogeologic setting: (1) the model can be reoriented in the direction parallel to groundwater flow to allow better assignment of pressure boundary conditions, (2) the vadose zone (with a smaller thermal conductivity due to drier conditions) can be represented, (3) moisture and heat transfer to the atmosphere, including evaporation and infiltration, can be included. Double-porosity or MINC methods can be used to better represent heat transfer in fractured rock. More accurate representation of the borehole heat exchangers can be implemented (e.g., Falta et al., 2023).

The results of the initial TOUGH simulations will then be coupled with Modelica runs to evaluate the effectiveness of a GHE system in providing sustained seasonal cooling to the Stan Sheriff Center. We will build a mechanical and thermal model of the Stan Sheriff Center's heating, ventilation, and air-conditioning (HVAC) system to assess the energy and demand impacts of transferring heat to the geothermal resource. We will then calculate the electricity bill savings associated with those energy and demand impacts. Finally, we will calculate the net present value of the geothermal exchange system, accounting for the capital costs of its installation, the lifecycle electricity bill savings, and tax credits made available in the Inflation Reduction Act (IRA).

There are several key economic incentives that could support the development of a GHE project such as the one described in this paper. The IRA includes the Clean Energy Investment Tax Credit, which applies to geothermal heat pumps, and includes a monetization pathway for non-taxable entities, such as universities. Eligible projects can claim up to 40% of the project cost as a credit. The base credit is 6%, but is increased 5 times to 30% if the system is less than 1 MW, or if the project meets prevailing wage and apprenticeship requirements. An additional 10% credit can be obtained if the project meets domestic content requirements. In addition, Hawaiian Electric Company offers incentives for custom energy efficiency project of up to 50% of incremental project costs–this effort would need to be coordinated with the utility, requiring an application that includes the energy savings calculations.

Acknowledgments

This project was supported by DOE's Energy Transitions Initiative Partnership Project (ETIPP) with the University of Hawaiʻi and under the U.S. Department of Energy Award Number DE-AC02-05CH11231 with LBNL. We thank our colleagues Kendal Leonard, and Miles Topping at the University of Hawaiʻi, Mark Glick, and Dora Nakafuji (formerly of Kamehameha Schools) for their contributions to this project. The geologic model output for this paper was generated using Leapfrog Software. Copyright © Seequent Limited. Leapfrog and all other Seequent Limited product or service names are registered trademark or trademarks of Seequent Limited. We thank Jay Egg for sharing his insights with our team on deploying geothermal heat pumps in tropical environments. We also thank Nancy Matsumoto from the Honolulu Board of Water Supply for generously sharing measured thermal profiles from three deep monitoring wells near the Stan Sheriff study area.

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