THERMAL ANALYSIS OF FUTURE COOLING WATER DISCHARGE

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PREFACE

This report has been updated from the original version dated May 1, 2018, to incorporate new information and to address Hawaii Department of Health technical comments and questions. Below is a summary of relevant changes in this updated document:

- Spent cooling water injection temperature has been updated based on recent engineering analysis. The average temperature of spent cooling water has been changed from 30.0°C to 30.7°C.
- The locations of the proposed underground injection control (UIC) wells have been slightly adjusted to account for current planned locations.
- In the groundwater model, cooling water is produced at equal flow rates from the three existing production wells, and none is extracted from the planned backup well (cooling water well #4).
- Further description of the groundwater and surface water models has been provided, including several supplemental figures and clarification of the use of two surface water model simulations: (1) without UIC injection (ambient conditions) and (2) with active UIC injection of spent cooling water. The relative increase in water temperature, between the scenario with no UIC injection (24.90°C) and the active UIC injection scenario (25.02°C), in the bottom model layer where maximum discharge temperatures occur (e.g., within 1 meter of the bottom of the ocean floor), was only 0.12°C (0.22°F).
- Description has been provided for estimated travel times for migration of UIC injected water to discharge locations at the ocean based on particle tracking analysis.

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ACRONYMS AND ABBREVIATIONS

HAR	Hawaii Administrative Rules
HHB	Hu Honua Bioenergy, LLC
Integral	Integral Consulting Inc.
m	meter(s)
mgd	million gallon(s) per day
mg/L	milligrams per liter
msl	mean sea level
NOAA	National Oceanic and Atmospheric Administration
UIC	underground injection control

1 EXECUTIVE SUMMARY

This technical memorandum has been prepared by Integral Consulting Inc. (Integral) for Hu Honua Bioenergy, LLC (HHB) to evaluate the potential thermal effects of once-through non-contact cooling water discharged into underground injection control (UIC) wells on adjacent coastal ocean waters near the HHB facility in Pepeekeo, Hawaii. The UIC wells are located on the HHB property, which is adjacent to the Pacific Ocean coastline. This analysis utilized numerical models of the groundwater and ocean water systems to evaluate theoretical (non-empirical) thermal effects of the proposed underground injection of spent cooling water.

The groundwater model simulated transport of warm spent cooling water, injected into UIC wells, through the basalt rock groundwater aquifer to an assumed discharge area on the seafloor (aquifer/ocean interface). The groundwater model is conservative, since factors are not included to account for basalt aquifer heterogeneity (such as fractures or lava tubes), and no sediment layer between the rock aquifer and the ocean is included. The nature and extent of direct connectivity within the aquifer from UIC wells to an ocean discharge location is not fairly traceable or known, and would need to be confirmed with empirical (field) measurements once operations commence. Based on these conservative assumptions, the groundwater model indicated waters discharge from the aquifer above the model background ocean temperature of 25°C (77°F), which quickly attenuate in dynamic ocean water.

Based on overly conservative assumptions, the groundwater model indicated that the warmest waters discharging from the aquifer are approximately 5.5°C (9.9°F) above the model background ocean temperature of 25°C (77°F), which quickly attenuate in dynamic ocean water within the zone of mixing.

Surface water modeling was conducted using output from the groundwater model under a no UIC injection scenario (ambient conditions) and an active UIC injection scenario. The no UIC injection scenario predicted ocean water temperature within 1 meter (m) of the bottom at 24.90°C (76.82°F), compared to a maximum temperature under the active UIC scenario in that same location at 25.02°C (77.04°F). The relative increase in water temperature in this bottom layer between the scenario with no UIC injection (ambient conditions) and the active UIC cooling water injection scenario was 0.12°C (0.22°F).

Therefore, the surface water model indicates a *de minimis* temperature difference would occur within 1 m of the bottom of the ocean. This analysis supports the conclusion that spent cooling water injection to UIC wells at the HHB facility will not significantly raise ocean water temperatures upon migration through the aquifer and discharge to the adjacent ocean.

2 PROJECT OBJECTIVES AND TECHNICAL APPROACH

The purpose of the study is to evaluate the potential thermal effect of heated power plant cooling water discharged via UIC wells into the groundwater aquifer on the adjacent State coastal ocean water.

2.1 BACKGROUND INFORMATION

Based on information provided to Integral by HHB,[1] we assumed 21.6 million gallons per day (mgd) of cooling water produced from three existing production wells and one proposed production well, with all water discharged to three proposed UIC wells. The time-weighted average temperature of spent cooling water of 30.7°C (87.3°F)[2] was used for modeling, based on the temperature mass balance through the boiler and condenser when operating at low load for 10 hours per day (temperature of 28.2°C [82.7°F]) and high load for 14 hours per day (32.5°C [90.5°F]) (ACSI 2018; ESI 2018). The locations of existing and proposed wells are provided on Figure 1. Basic well construction data for existing and proposed wells is provided on Table 1.

2.2 MODELING APPROACH AND UNCERTAINTIES

A numerical groundwater model was used to transport the injected spent cooling water to a discharge location on the ocean floor where it was evaluated in a separate surface water model. Due to uncertain physical and hydraulic properties of the basalt rock aquifer, conservative simplifications were necessary. The aquifer was modeled as a homogeneous porous media, when it is likely to be highly heterogeneous due to irregularities such as fractures and lava tubes (the extent and orientation of which are not known), in effect allowing the warm water plume to travel to an assumed discharge location on the ocean floor as an intact plume. It is unknown whether this plume configuration will occur under actual operating conditions; it is possible that unknown heterogeneities will cause the plume to spread and dissipate in temperature much more than estimated by the simplified model. The nature and extent of direct connectivity within the aquifer from UIC wells to an ocean discharge location is not fairly traceable or known, and would need to be confirmed with empirical (field) measurements once operations commence.

The thickness and physical/hydraulic properties of a sediment layer, located above the rock aquifer on the seafloor, are unknown at this site and therefore not included in the groundwater

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[1] County of Hawaii Windward Planning Commission's Findings of Fact, Conclusions of Law, and Decision and Order, dated June 7, 2011, at p. 8, paragraph 18, which limits the groundwater withdrawal to 21.6 mgd of non-contact cooling water from brackish water supply wells.

[2] Spent cooling water injection temperature has been updated based on recent engineering analysis.

model. A sediment layer would act to further disperse (spread) the warm groundwater plume near its discharge to the ocean, and reduce its temperature by thermal attenuation. Because of these simplifying assumptions, the groundwater model represents a highly conservative ("worst case") scenario of warm groundwater discharging directly from the rock aquifer to ocean water, with no thermal attenuation allocated for the sediment layer.

3 GROUNDWATER MODELING OF SPENT COOLING WATER DISCHARGE

A groundwater flow and transport model of the aquifer system in the vicinity of the HHB facility was constructed in order to evaluate the migration and discharge of heated water injected into the aquifer by the proposed UIC wells. The aquifer system consists of a basal freshwater lens overlying brackish and salt water in a basalt aquifer hydraulically connected to the adjacent ocean surface water system. The results of the groundwater model were used as inputs to the surface water modeling presented in the sections below. The actual hydraulic properties of the aquifer, and the nature and extent of direct connectivity from UIC wells to ocean discharge, are not fairly traceable or known and would need to be determined with empirical data once operations commence. The groundwater model described below was constructed using the best available information on physical and hydraulic properties in the vicinity of the HHB facility. It should be stressed that there are no actual data[3] with respect to the temperature of groundwater or hydraulic properties in the portion of the aquifer from the planned UIC wells to the assumed offshore discharge location.

3.1 MODEL DESIGN

The groundwater model was constructed within the SEAWAT modeling package (Langevin et al. 2008). SEAWAT works within the MODFLOW and MT3D family of groundwater modeling codes, and was selected for its ability to simulate variable-density groundwater flow. Variable-density water occurs in the coastal region of the Onomea aquifer[4] near the HHB facility, where a basal "lens" of fresh groundwater is present in the basalt rock aquifer above salt water (seawater), separated by a transition zone of brackish water (see Figure 2).

A model grid extending 9500 m from east to west and 1700 m from north to south was oriented such that the long axis of the model extended from the onshore area of the HHB facility offshore parallel to the west-to-east lateral groundwater flow direction within the aquifer (Figure 3). The grid is divided into cells of variable width ranging from 50 to 100 m on a side. The model domain is considered to be a single aquifer system with 13 vertical layers (horizontal orientation) extending to a depth of 450 m below mean sea level (msl). The shallowest active model layer at any point within the model was assigned by the ground surface elevation or bathymetric depth of the ocean (seafloor elevation). A non-variable background groundwater flow was assumed to exist across the model domain, and recharge (simulating infiltration of

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[3] No boreholes or wells, from which data could be collected, have been installed in this portion of the aquifer.

[4] The HHB facility is located within the Onomea aquifer system, as defined by the U.S. Geological Survey in its 2011 water budget and recharge assessment of the Island of Hawaii (Engott 2011).

rainfall) was assigned as a single, non-variable input to the shallowest active model layer that outcrops to the land surface.

3.2 MODEL BOUNDARIES

The flow regime within the model domain was established by the assignment of constant-head boundary conditions, which are summarized as follows:

- An inland (upgradient) boundary at the westernmost edge of the model domain was assigned a constant groundwater head of 10 m above msl, consistent with static water levels in nearby wells. Water entering this upgradient boundary was assumed to have a constant temperature of 17.5°C (63.5°F)[5] and a salinity of 0 milligrams per liter (mg/L) (fresh water).
- An offshore boundary was assigned to be representative of the area of the outcropping aquifer to the ocean floor. This boundary was assumed to have a constant groundwater head of 0 m msl, and a salinity of 35,000 mg/L equivalent to the salinity of seawater. The temperature of this boundary condition was spatially variable in the model, with a representative temperature for each layer assigned based on offshore temperature depth profiles (based on average annual temperatures from PacIOOS Regional Ocean Modeling System[6], which are summarized in Table 2).
- An offshore boundary corresponding to the easternmost edge of the model domain was assigned with groundwater elevation, salinity, and temperature criteria in the same manner as the ocean floor outcrop boundary.

3.3 GROUNDWATER WITHDRAWALS AND INJECTION

Groundwater extraction/injection in the model was assigned to the following wells:

- Three groundwater extraction (pumping) wells corresponding to the existing cooling water production wells (5005-03, 5005-04, and 5005-05). No pumping was allocated to the proposed backup extraction well 5005-09.[7] Flow was allocated to the open borehole interval of each well (see Table 1).

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[5] Based on a depth-averaged temperature from temperature depth profiles collected from existing cooling water production wells at the HHB facility by ACSI.

[6] Ocean temperature, waves, and currents provided by the PacIOOS Regional Ocean Modeling System supported by the Department of Oceanography in the School of Ocean and Earth Science and Technology at University of Hawaii at Manoa (http://www.pacioos.hawaii.edu).

[7] Hawaii Commission on Water Resources Management provides a sequence number for each new well in a particular latitude/longitude block. The HHB facility is located in Block 5005.

- Three spent cooling water injection wells representing the proposed UIC wells (UIC-1, UIC-2, and UIC-3). Flow was allocated to model layers corresponding to the open borehole intervals based on proposed well design criteria provided by HHB. These wells were assumed to inject spent once-through non-contact cooling water with a salinity of 0 kg/m^3 and an average operating temperature of 30.7°C (87.3°F). As a simplifying assumption, spent cooling water injected into UIC wells within the fresh groundwater zone is treated as fresh water (salinity of 0 mg/L). Therefore, the injected spent cooling water has the same density properties as comingled fresh groundwater from upgradient.[8]

A total flow of 21.6 mgd was withdrawn equally from the three production wells and distributed equally to the three UIC wells, so that the total withdrawals and injection flow rates were balanced within the model domain.

3.4 FLOW AND TRANSPORT PARAMETERS

Hydraulic flow and transport parameters assigned to the model are summarized in Table 3. Initial model runs included manual adjustment of the inland constant-head boundary and hydraulic conductivity to achieve a reasonable flux of approximately 50 mgd into the model domain through the inland boundary, based on evaluation of average recharge to the Onomea aquifer system (Engott 2011). The recharge for the site model was scaled (proportional) to the total recharge for the width of the Onomea aquifer. Based on the model output, the parameters assigned to the groundwater model are considered reasonable for this aquifer system and the goals of this investigation (Oki 1999).

3.5 GROUNDWATER MODEL RESULTS

The groundwater model was run for a 30-year period, to ensure equilibrium ("worst case") conditions were evaluated. This time duration was considered sufficient to achieve an equilibrium with respect to groundwater flow, salinity, and temperature within the model under pumping conditions, and can be considered consistent with respect to the anticipated lifespan of UIC operations. SEAWAT simulations were run with the conditions described in the sections above, and the resulting salinity and temperature conditions within the aquifer system were reviewed.

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[8] Historical pumping tests indicate that produced cooling water could be slightly brackish, with salinity up to 800 mg/L; water with this salinity would behave in the model the same as fresh water (0 mg/L) when interacting with the underlying seawater zone with a salinity of 35,000 mg/L.

3.5.1 Temperature Analysis

The model simulates a plume of heated water assumed to migrate downgradient of the UIC wells and to discharge through the offshore seafloor boundary.[9] This plume magnitude, direction, and shape is hypothetical; the actual nature and extent of direct connectivity from UIC wells to ocean discharge are not fairly traceable or known, and would need to be determined with empirical data once operations commence. Figure 4 shows the temperature distribution after the duration of the pumping period (30 years) along a cross-section through the centerline of the groundwater model grid. This figure shows a distinct area of slightly warmer water discharging to the ocean downgradient of the UIC well injection area. The discharging groundwater reaching the ocean floor is warmer than the background aquifer temperature, although it has been cooled to some extent from the injection temperature of 30.7°C (87.3°F) by mixing with cooler water flowing toward the ocean from upgradient of the UIC wells, as well as from thermal loss to the basalt rock in the aquifer. As described in Section 2.2, the model was designed to deliver heated UIC water to the ocean in a "worst case" scenario, and does not take into account thermal attenuation and diffusion effects caused by unknown heterogeneity within the basalt rock aquifer or the sediment layer located between the rock aquifer and ocean water. Both rock aquifer heterogeneity and sediment thickness and hydraulic properties are unknown at this project location.

Figure 5 shows the hypothetical extent of the discharge area offshore of the HHB facility where groundwater discharges at temperatures above 18.5°C (65.3°F). These are theoretical temperatures for groundwater leaving the bedrock aquifer, and are not indicative of ocean water temperatures. In the absence of warm UIC water, groundwater offshore from the HHB facility would discharge at a temperature slightly above the assumed background aquifer temperature of 17.5°C (63.5°F), estimated to be about 18.5°C (65.3°F). Groundwater discharging to the ocean at temperatures above approximately 18.5°C (65.3°F) are used to define the extent of a discharge plume of warmer UIC well injected water. Figure 6 provides a three-dimensional oblique view of the temperature data presented in Figure 5 within the model domain in the offshore model layers at the aquifer/seafloor interface. In summary, the model predicts that warm spent cooling water, injected into UIC wells, will migrate through the groundwater aquifer and discharge to a limited area of the seafloor (at the aquifer/ocean interface). Based on overly conservative assumptions, the maximum predicted temperature in the offshore discharge area was approximately 30.5°C (86.9°F), about 5.5°C (9.9°F) warmer than the model background nearshore ocean temperature of 25°C (77°F). The discharging groundwater temperature and flux (volumetric flow per unit time) from this groundwater discharge area were coupled with the surface water model as described below in Section 4.

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[9] As described in Section 2-2 (Modeling Approach and Uncertainties), the model was designed to deliver heated UIC water to the ocean in a "worst case" scenario, not taking into account the likely heterogeneity of the basalt rock aquifer or the thermal attenuation that would occur as water passed from the rock aquifer through sediment into ocean water.

3.5.2 Injected Water Travel Time to Ocean Discharge

A particle tracking analysis was performed on the groundwater model output using MODPATH (Pollock 2012) to evaluate theoretical travel times and distances of heated injected water from the UIC wells though the aquifer to the ocean. Simulated particles followed the groundwater flow path from UIC wells to their discharge locations at the aquifer/ocean interface. The time for particles to travel from the UIC wells through the aquifer to the ocean discharge area (shown in Figure 5) ranged from approximately 11 days to reach the nearshore discharge area (approximately 120 m from the UIC wells[10]) to 130 days to reach the farther offshore portion of the discharge area (1000 m from the UIC wells). The average modeled particle traveled for approximately 50 days from the UIC wells to discharge at the ocean. The travel velocity of modeled particles through the aquifer was approximately 8 to 10 m per day.

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[10] This references the total distance along the groundwater flow path, rather than the "straight line" map distance.

4 SURFACE WATER MODELING OF GROUNDWATER SEEPAGE

The effect of warmer groundwater seepage (discharge) on the coastal ocean was evaluated using a screening-level, three-dimensional hydrodynamic numerical model. The discharging groundwater temperature and flux (volumetric flow per unit time) from the groundwater model were used as inputs to the surface water model. The results of this analysis indicate a *de minimis* increase in surface water temperature due to the presence of the groundwater discharge plume is less than 1°C relative to simulated surface water temperatures without spent cooling water (warm water) injection to UIC wells. It should be stressed that there are no actual data regarding the temperature of surface (ocean) water in the immediate vicinity of the HHB facility.

4.1 NUMERICAL MODEL DESIGN

The effect of the groundwater plume was evaluated with a screening-level numerical model. The coastal numerical model was developed using Delft3D-FLOW (Gerritsen et al. 2008), a full hydrodynamic, three-dimensional, and temporally resolved numerical model. The model domain and bathymetry[11] are shown in Figure 7; the western and southern model boundaries represent coastlines and the eastern and northern model boundaries are open-ocean boundaries. The horizontal grid resolution was 300 m at distance from the site and was refined to 100 m in the region near the site to better resolve the dynamics near the potential UIC groundwater discharge at the HHB facility. The vertical variability in the model was represented using 20 layers, which are evenly distributed over the model depth. The layers are sigmoidal in vertical dimension, in that they are thinner in shallower water (nearshore) and thicken as water deepens ocean-ward. The thickness of each of the 20 layers is fixed at 5 percent of the thickness of the water column. The thickness of the bottom boundary layer, where maximum temperature effects from discharging warm UIC water would occur, was less than 1 m thick throughout the region of UIC groundwater discharge (shown as cells with black dots in Figure 7). The region of warmest UIC discharge occurs at approximately 11-m water column depth such that the layer nearest the sediment bed is approximately 0.6 m thick.[12]

To assess the relative effect of the discharge, a 2-month-long simulation (using boundary conditions from January to March of 2016) was conducted with two different groundwater discharge conditions. The two model scenarios were: (1) no UIC injection scenario (ambient

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[11] The bathymetry used is the U.S. Coastal Relief Model for Hawaii from the National Oceanic and Atmospheric Administration's National Geophysical Data Center, available online at: https://www.ngdc.noaa.gov/docucomp/page?xml=NOAA/NESDIS/NGDC/MGG/DEM/iso/xml/711.xml&view=getDataView&header=none.

conditions)—a scenario with groundwater discharge temperatures set to a constant 18.5°C (65.3°F), representing natural groundwater discharge without spent cooling water injection to UIC wells, and (2) UIC injection scenario—a warm groundwater discharge scenario using temperatures and discharges from the groundwater model described above considering active spent cooling water injection to UIC wells. The 2-month-long simulation duration was chosen to fully characterize the range of spring and neap tidal conditions at the site and to allow for the numerical model to reach equilibrium. The hydrodynamics in the surface water model are forced with astronomic tidal constituents at the northern and eastern open-ocean boundaries in the model. The groundwater discharges from the groundwater model analysis (with spent cooling water injection) were interpolated to the nearest numerical model grid cell (shown on inset in Figure 7 and in Table 4). The model discharges were specified in grid cells greater than 5 m depth to avoid numerical issues with discharges into very shallow waters. Discharge rates and temperatures of all groundwater discharge sources incorporated in the numerical model are included in Table 4.

The screening-level numerical model was initialized with a uniform temperature of 25°C (77°F) and the temperature at the open-ocean boundaries was also specified as 25°C (77°F). The groundwater discharges occurred within the well-mixed region of the water column (above the thermocline). Therefore, the uniform vertical temperature representation in the numerical model reasonably approximated the assumed conditions within the groundwater discharge region. The chosen surface water temperature was representative of average annual water temperature (based on average annual temperatures from PacIOOS Regional Ocean Modeling System[13] included in Table 2) at the depth of warm groundwater discharges, which range from 5 to 75 m depth.

4.2 MODEL VERIFICATION

The numerical model performance was evaluated by comparing the measured water level and a National Oceanic and Atmospheric Administration (NOAA) gauge station in Hilo Bay, Hawaii (NOAA Station No. 1617760) with modeled water level (Figure 8). A commonly used metric to evaluate a numerical model's performance relative to measured data is the model skill score (Murphy and Epstein 1989). The skill score metric, which ranges from 0 (poor performance) to 1 (perfect performance), was computed at 0.94 indicating excellent model performance. The verification of the model performance provides confidence that the numerical model is accurately representing the physical dynamics in the region.

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[13] Ocean temperature, waves, and currents provided by the PacIOOS Regional Ocean Modeling System supported by the Department of Oceanography in the School of Ocean and Earth Science and Technology at University of Hawaii at Manoa (http://www.pacioos.hawaii.edu).

4.3 NUMERICAL MODEL RESULTS

The maximum ocean temperature within the numerical model (under the active UIC injection scenario) occurred in a bottom layer cell, nearest the sediment bed, where the warmest groundwater discharged as indicated by the groundwater model. For the entire 2-month simulation, the maximum ocean temperature was 25.02°C (77.04°F). The maximum ocean temperature occurred in a model cell at approximately 11-m water column depth in the bottom layer of the ocean, which was 0.6 m thick. The temperature at this location under the no UIC injection scenario was 24.90°C (76.82°F), indicating a minor cooling of the model background ocean water temperature (25°C) due to discharge and mixing of cooler groundwater discharge (18.5°C). This value of 24.90°C (76.82°F) can be considered a best estimate of ambient ocean temperature in the bottom 1-m layer of the ocean, at the same location where the maximum temperature of 25.02°C (77.04°F) was observed under the active UIC scenario.

The relative increase in water temperature in this bottom layer between the scenario with no UIC injection and the active UIC cooling water injection scenario was 0.12°C (0.22°F). This model cell has horizontal dimensions of 100 m by 100 m, and a thickness of 0.6 m. The modeled water temperature in this cell can be considered a mixing zone analysis for a nominal 100-m by 100-m by approximately 1-m thick zone. Since this cell exhibited the largest temperature increase in the model, any larger mixing zone (calculated by averaging multiple cells) would result in even smaller temperature effects.

Surface water modeling results are shown in Figure 9, including a plan view and vertical (cross section) view of modeled temperature due to the presence of the groundwater discharge. The maximum temperature (within the cell at 11-m water depth) varies slightly over the spring and neap tidal cycles, as shown on Figure 10; the top panel shows the absolute temperature within the cell, and the bottom panel shows the difference between the active UIC injection scenario and the background (no UIC injection) scenario. The results indicate a *de minimis* temperature difference in ocean water within 1 m of the bottom due to the effect of injected cooling water discharging as a groundwater plume. Furthermore, the numerical model is conservative since it only includes tidal forcing; the addition of currents and waves in the model would enhance rates of mixing in the coastal ocean and further dilute the warm groundwater discharge.

5 SUMMARY AND CONCLUSIONS

Numerical groundwater and surface water models were used to evaluate the potential thermal effects of spent cooling water injection on adjacent coastal ocean waters. The groundwater model simulated transport of warm spent cooling water, injected into UIC wells, through the basalt rock groundwater aquifer to an assumed discharge area on the seafloor (aquifer/ocean interface). The groundwater model is conservative, since factors are not included to account for basalt aquifer heterogeneity (such as fractures or lava tubes), and no sediment layer between the rock aquifer and the ocean is included. The nature and extent of direct connectivity within the aquifer from UIC wells to an ocean discharge location is not fairly traceable or known, and would need to be confirmed with empirical (field) measurements once operations commence.

Based on these overly conservative assumptions, the groundwater model indicated that the warmest waters discharging from the aquifer are approximately 5.5°C (9.9°F) above the model background ocean temperature of 25°C (77 °F), which quickly attenuate in dynamic ocean water within the zone of mixing. The discharging groundwater temperature and flux (volumetric flow per unit time) from the groundwater model were used as inputs to the surface water model.

Surface water modeling under the no UIC injection scenario (ambient condition) predicted ocean water temperature within 1 m of the bottom at 24.90°C (76.82°F), compared to a maximum temperature under the active UIC scenario in that same location at 25.02°C (77.04°F). The relative increase in water temperature in this bottom layer between a scenario with no UIC injection (ambient conditions) and an active UIC cooling water injection scenario was 0.12°C (0.22°F).

The surface water model indicates a *de minimis* temperature difference would occur within 1 m of the bottom of the ocean. This analysis supports the conclusion that spent cooling water injection to UIC wells at the HHB facility will not significantly raise ocean water temperatures upon migration through the aquifer and discharge to the adjacent ocean.

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FIGURES

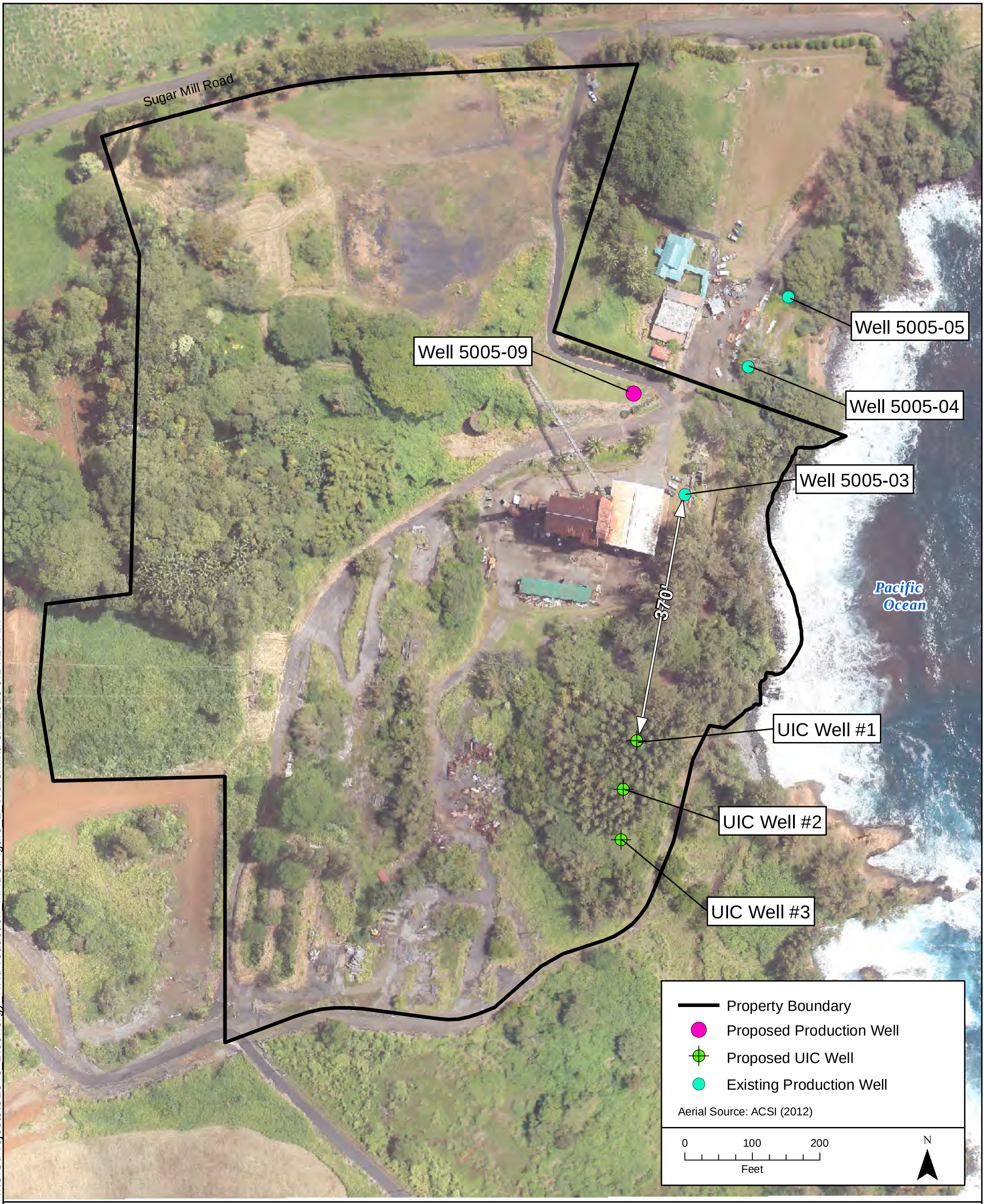

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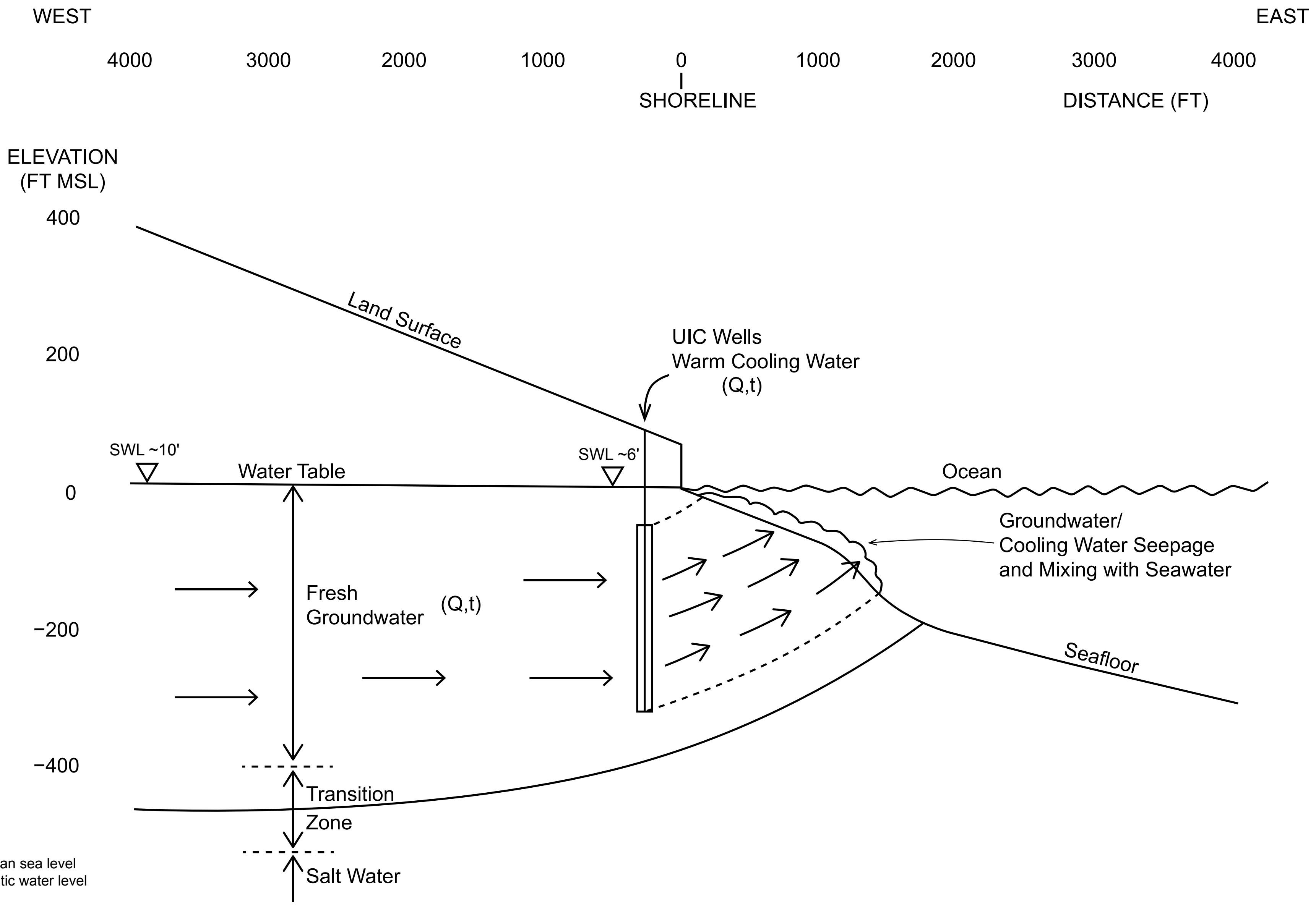
Figure 1.
Existing and Proposed Well Locations
Hu Honua Bioenergy
Pepeekeo, Hawaii



Notes:
MSL = mean sea level
SWL = static water level
Q = flow
t = temperature

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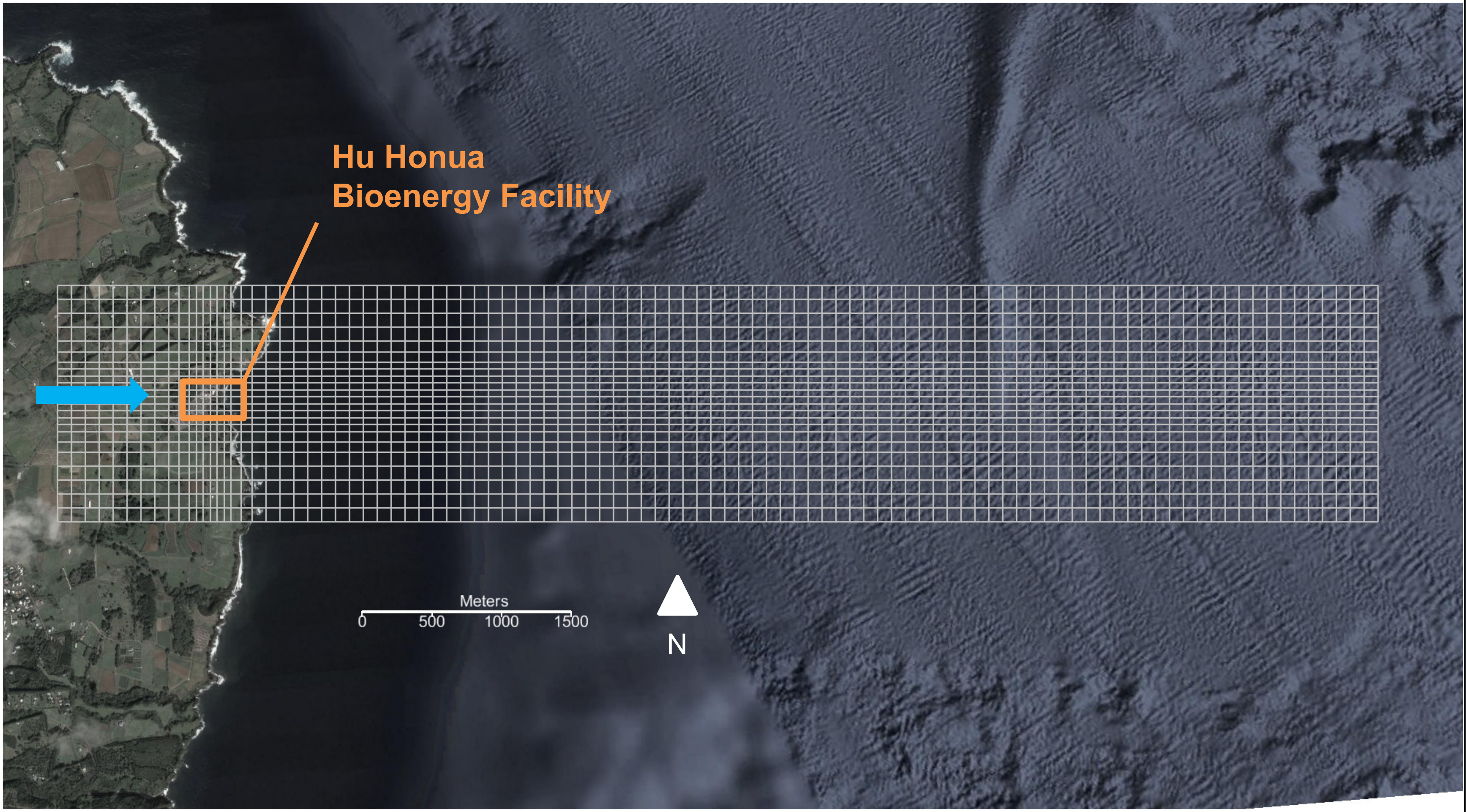
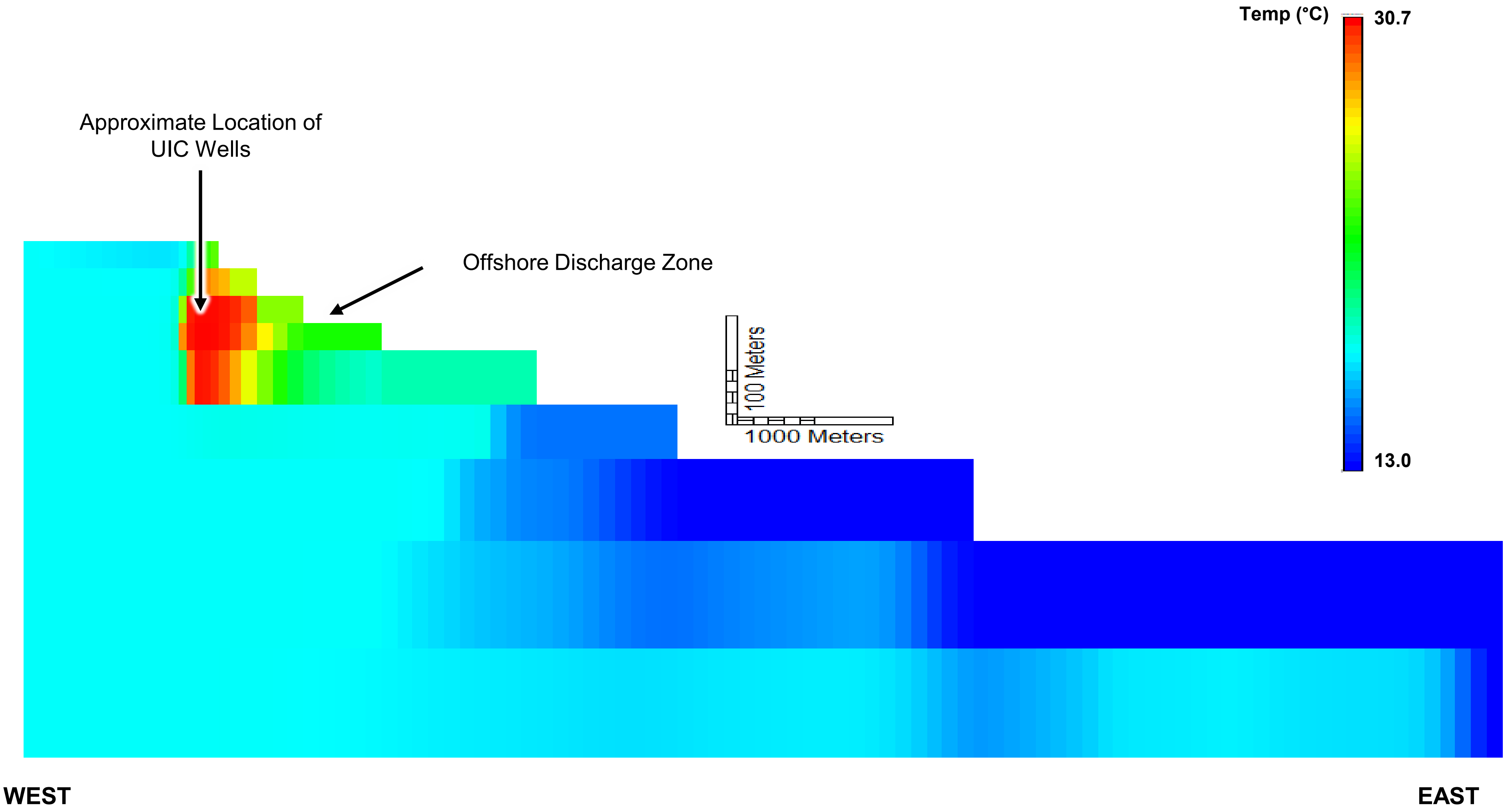
Figure 2.
Conceptual Site Model Cooling Water Injection



➡ Assumed groundwater flow direction in aquifer, for modeling purposes

Figure 3.
Map View of Groundwater Model Grid



Note: Assumed temperature distribution during UIC operations, based on modeling assumptions

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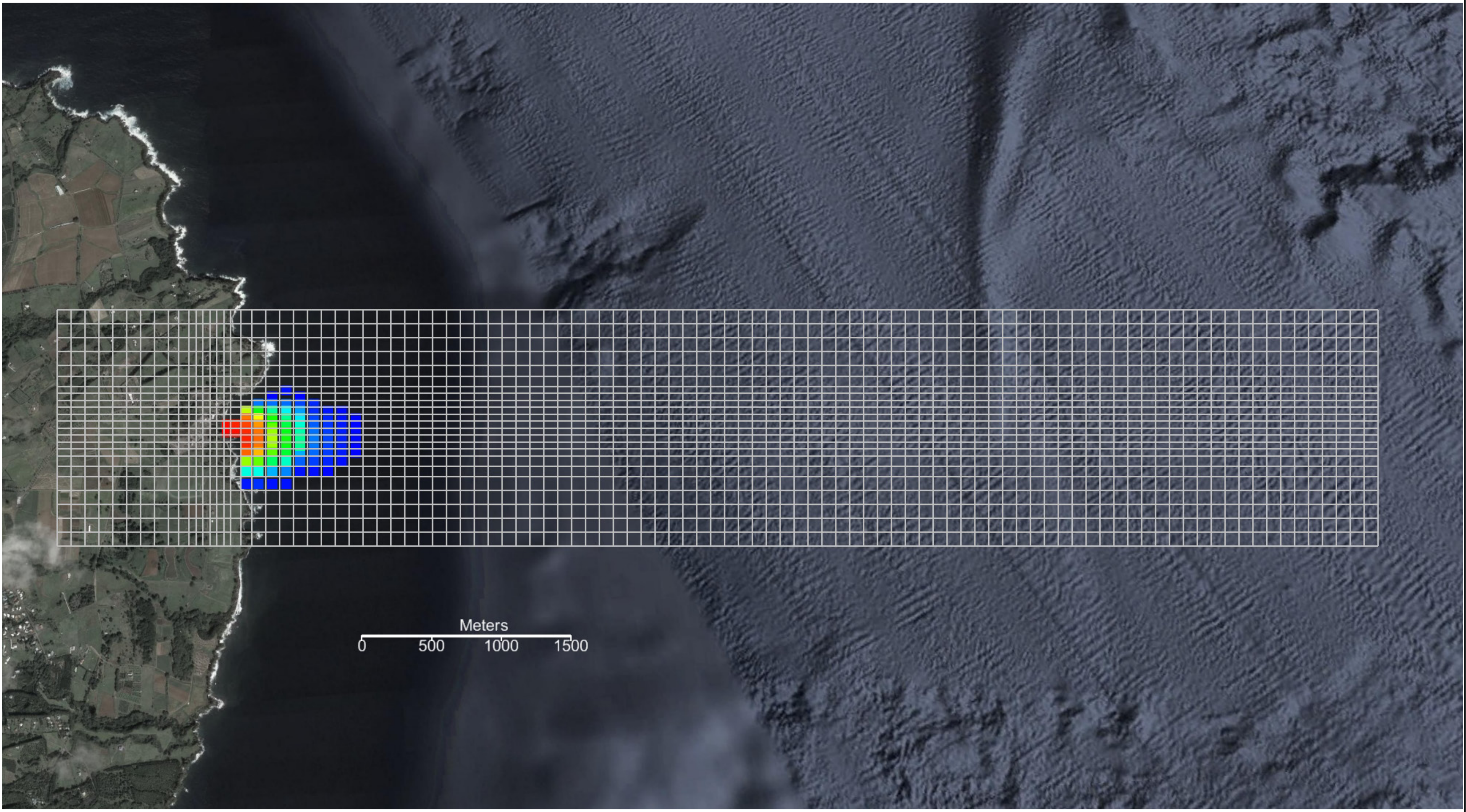
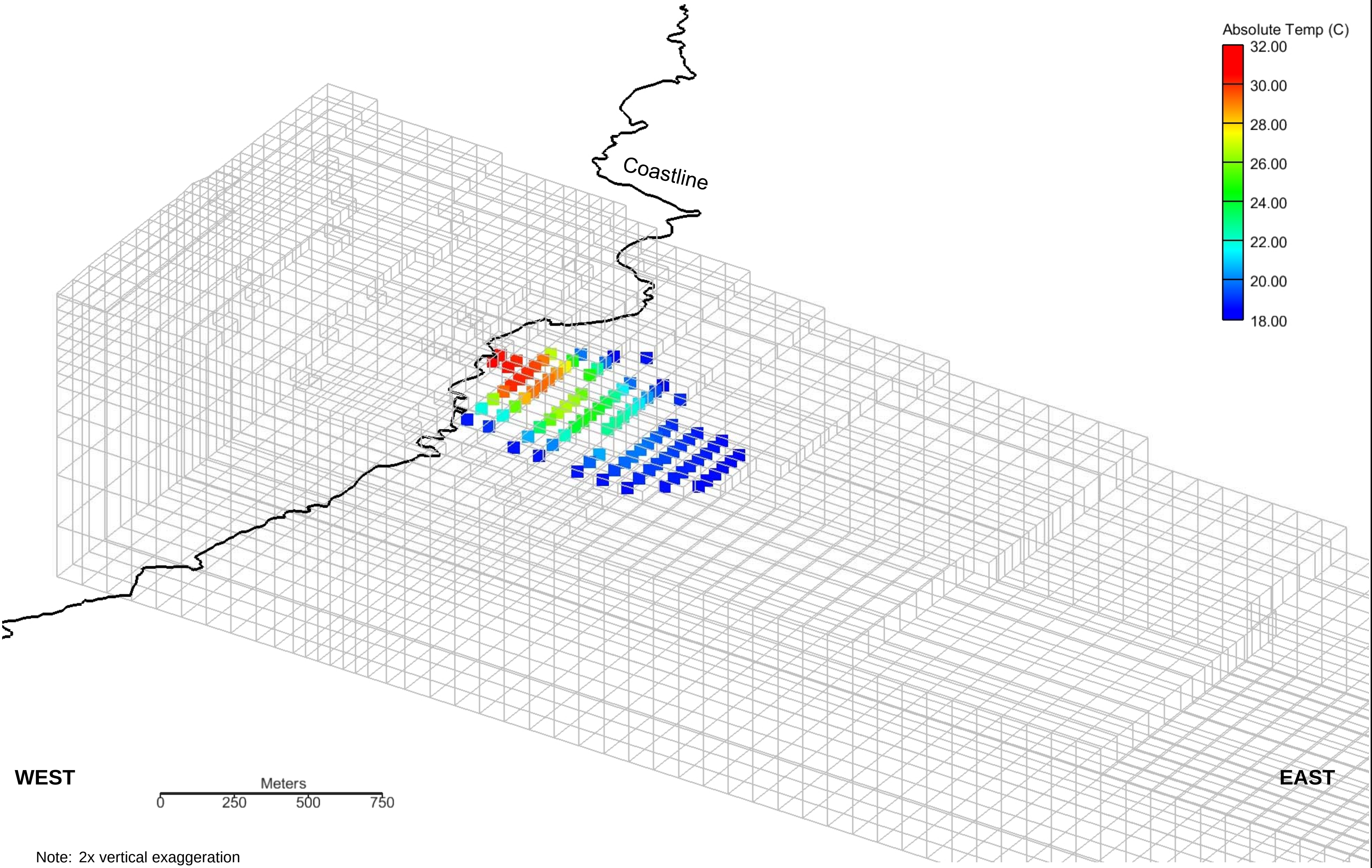
Figure 4.
Cross Section of Temperature Distribution in Groundwater Model



Note: Assumed temperature distribution during UIC operations, based on modeling assumptions

Figure 5.
Temperature Distribution in Discharging Groundwater



Note: 2x vertical exaggeration
Assumed temperature distribution during UIC operations, based on modeling assumptions

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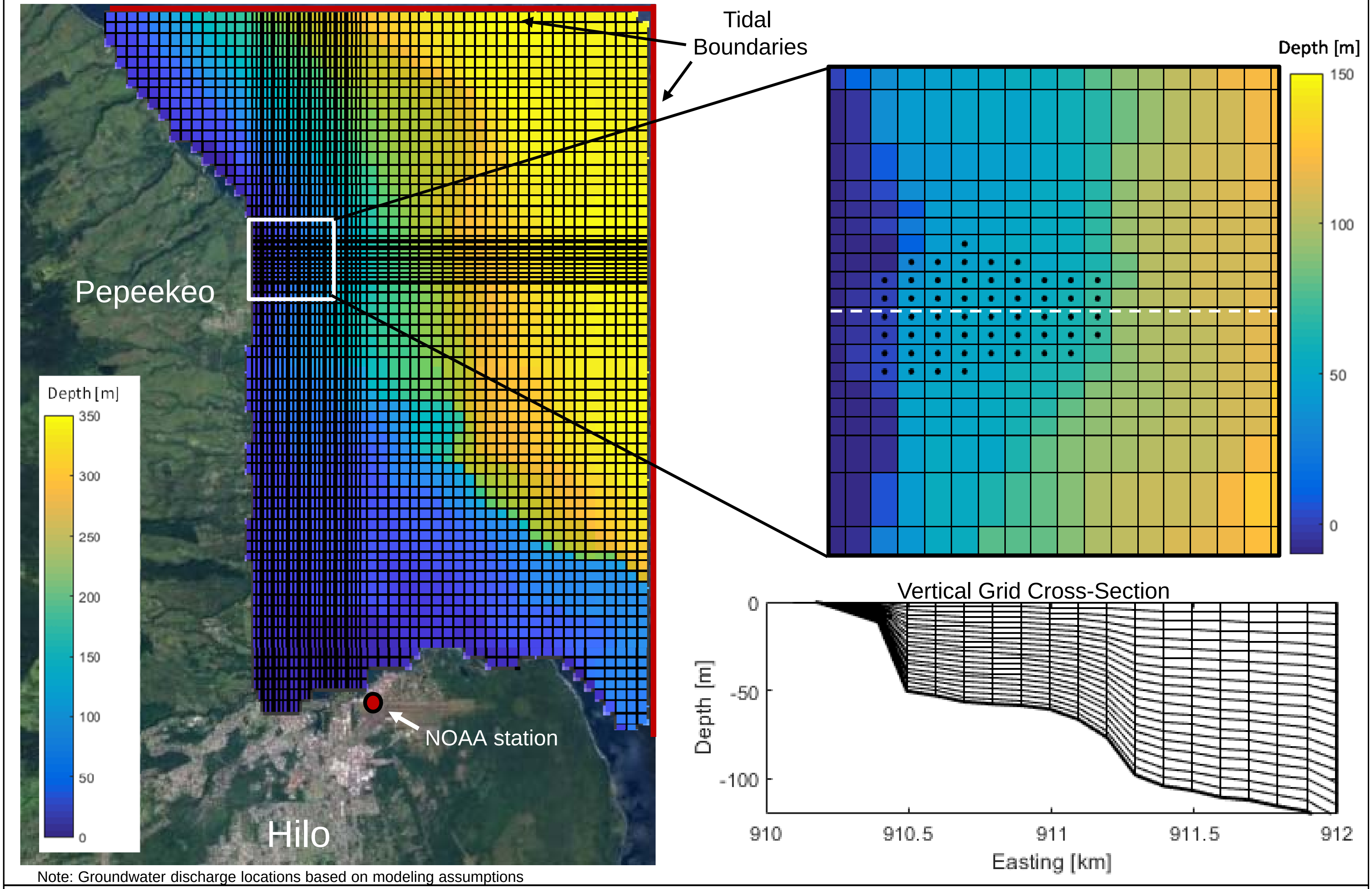
Figure 6.
Three-Dimensional View of Temperature Distribution in Discharging Groundwater



Note: Groundwater discharge locations based on modeling assumptions

Figure 7.
Surface Water Model Domain with Zoomed-in Panel
Showing Groundwater Discharge Locations

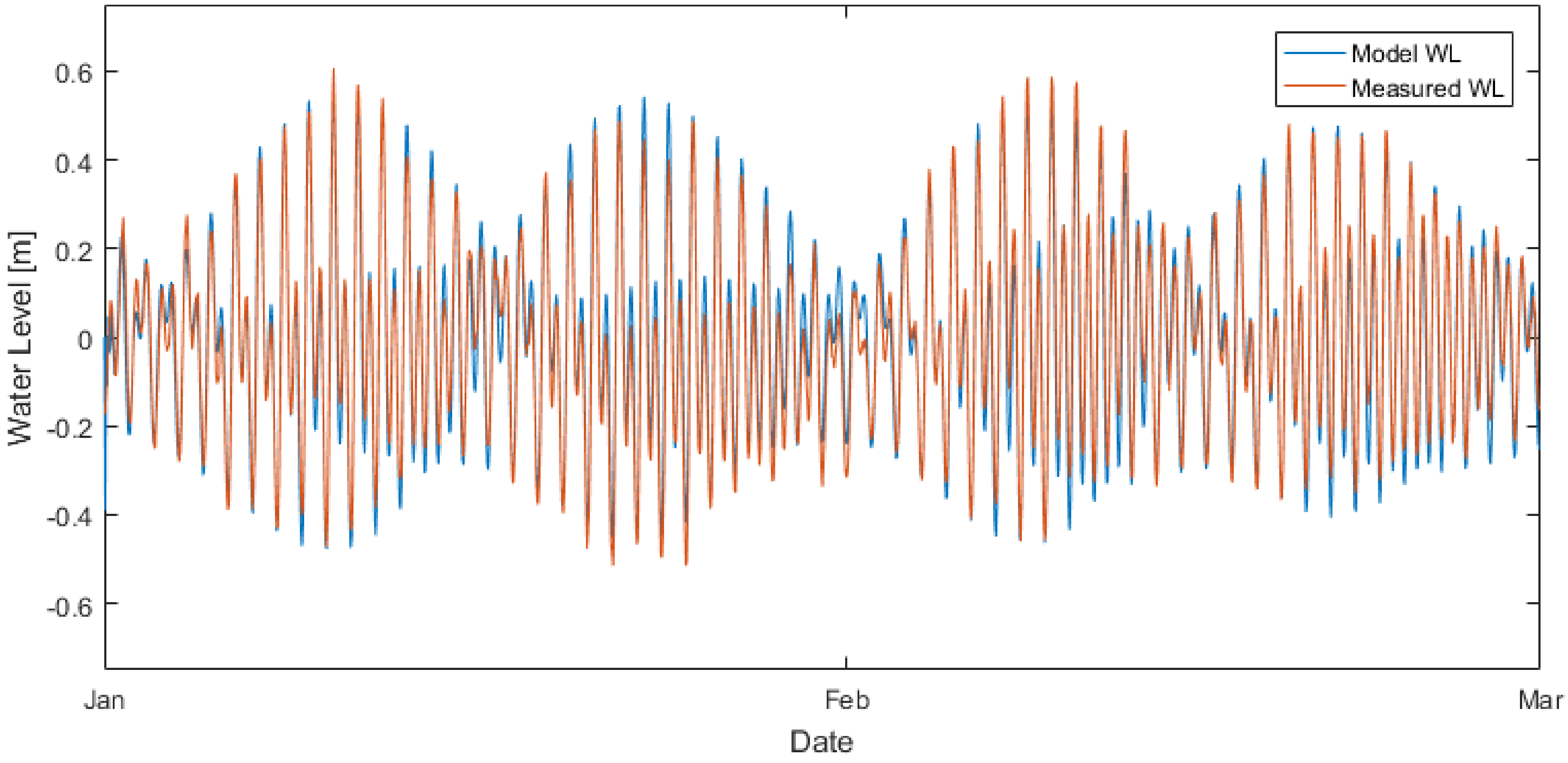


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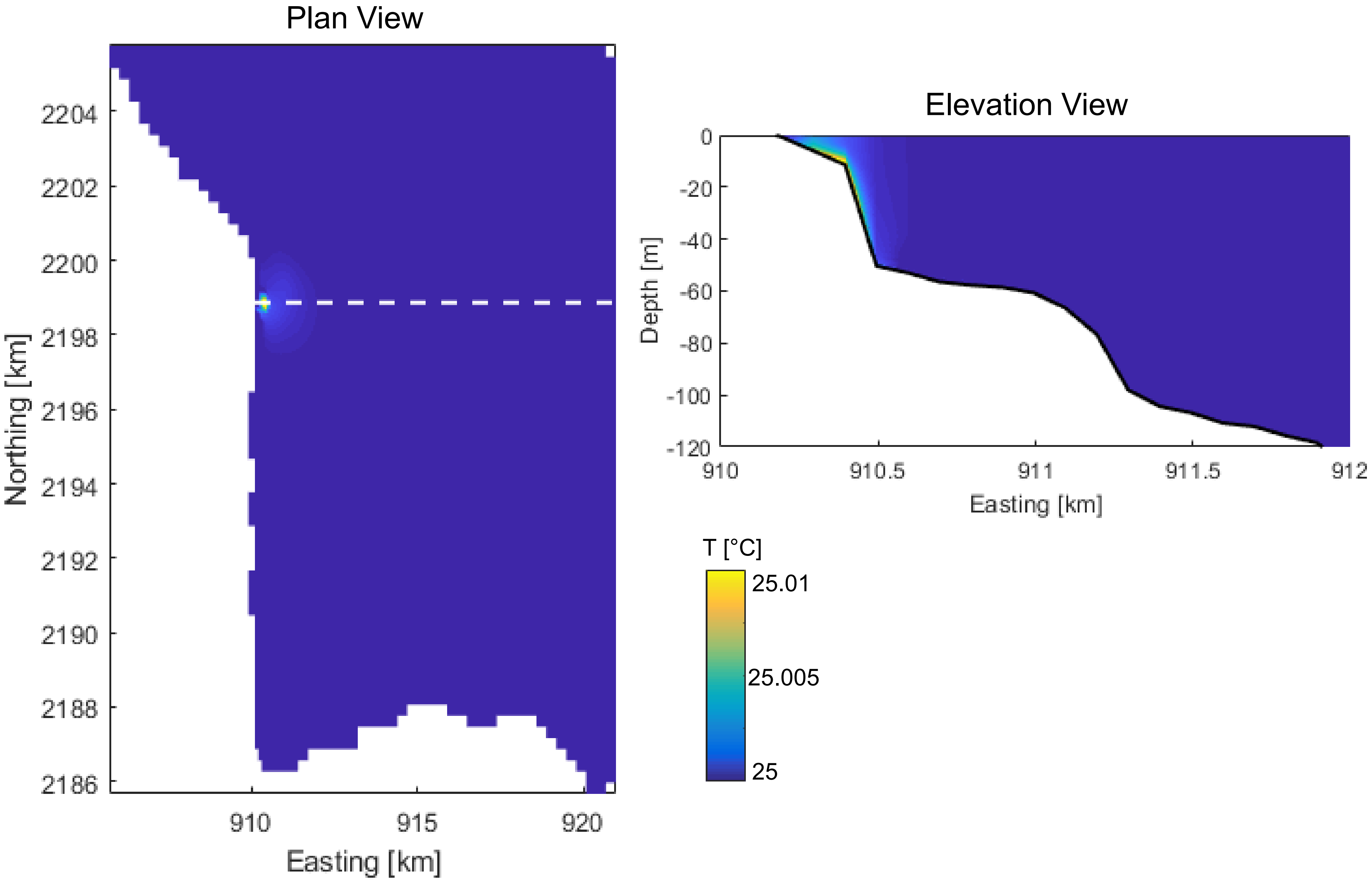
Figure 8.
Comparison of Modeled and Measured Water Level at NOAA Gauge Station at Hilo, HI

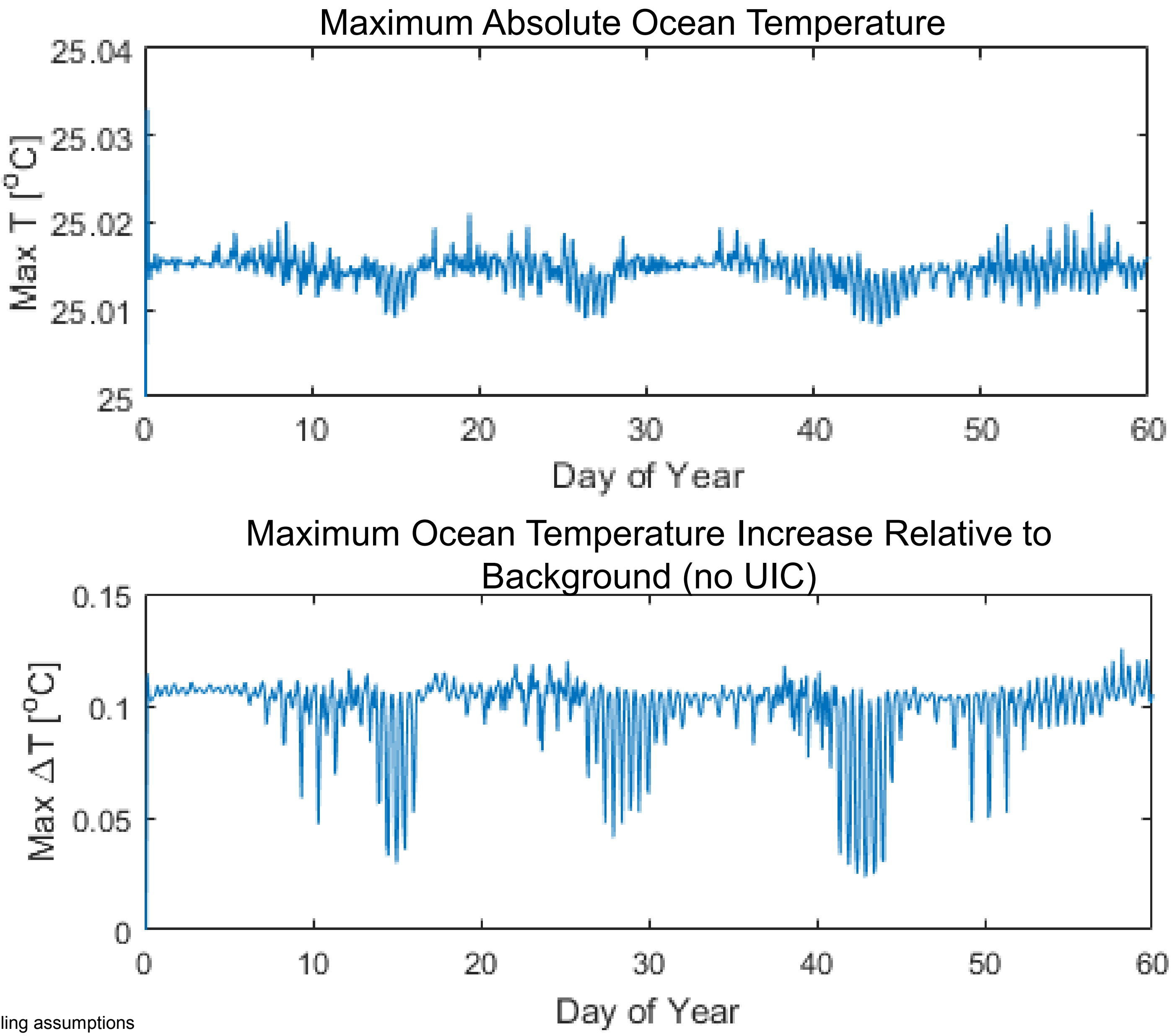


Plan View

Elevation View

Note: Ocean temperatures based on modeling assumptions

Figure 9.
Plan View and Elevation View of Ocean Temperature Due to UIC Groundwater Discharge from Surface Water Modeling



Maximum Absolute Ocean Temperature

Maximum Ocean Temperature Increase Relative to Background (no UIC)

Note: Based on modeling assumptions

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Figure 10.
Maximum Absolute Ocean Temperature and Maximum Relative Ocean Temperature Increase over Time across Surface Water Model Domain

TABLES

Table 1. Well Construction Details

Well Name	Ground Surface Elevation (ft msl)	Casing Diameter (in.)	Well Casing		Open Borehole Interval		Static Water Level[a]	
			Depth (ft bgs)	Elevation (ft msl)	Depth (ft bgs)	Elevation (ft msl)	Elevation (ft msl)	Date Installed
Cooling Water Production Wells								
5005-03	77	26	120	-43	120 to 381	-43 to -304	8	12/1/1971
5005-04	74	26	114	-40	114 to 375	-40 to -301	6.8	3/1/1972
5005-05	76	26	120	-44	120 to 380	-44 to -304	6.8	5/8/1972
UIC Wells								
UIC-1 (proposed)	83	26	120	-37	120 to 400	-37 to -317	N/A	N/A
UIC-2 (proposed)	83	26	120	-37	120 to 400	-37 to -317	N/A	N/A
UIC-3 (proposed)	83	26	120	-37	120 to 400	-37 to -317	N/A	N/A

Notes:
bgs = below ground surface
msl = mean sea level
N/A = not applicable
UIC = underground injection control

[a] At time of well installation

Table 2. Ocean Temperature Depth Zones for Offshore Groundwater Model Boundary

Model Layer[a]	Elevation of Ocean Boundary (m msl)	Temperature (°C)
1	N/A	N/A
2	N/A	N/A
3	N/A	N/A
4	N/A	N/A
5	N/A	N/A
6	-25	25.2
7	-50	24.2
8	-75	22.2
9	-125	18.8
10	-175	15.0
11	-250	13.0
12	-350	13.0
13	N/A	13.0

Notes:
msl = mean sea level
N/A = not applicable

[a] Model layers 1–5 are above sea level. Layer 13 does not outcrop to the ocean.

Table 3. Parameters Assigned to HHB Groundwater Model

Parameter Name	Value	Units
Hydraulic Parameters		
Hydraulic Conductivity	83.3	m/day
Vertical:Horizontal Conductivity Ratio	50	--
Effective Porosity	5%	--
Transport Parameters		
Longitudinal Dispersivity	10	m
Transverse Dispersivity Ratio	0.1	--
Vertical Dispersivity Ratio	0.005	--
Aquifer Bulk Density	1761	kg/m^3
Sorption Coefficient for Temperature	$2x10^{-4}$	m^3/kg
Thermal Diffusivity	0.15	m^2/day

Notes:
HHB = Hu Honua Bioenergy, LLC

Table 4. Groundwater Discharges used in Surface Water Model—Active UIC Wells

Easting (km)	Northing (km)	Flux (m^3/day)	Temperature (°C)
910.4	2198.5	1054	18.8
910.4	2198.6	1570.8	24.1
910.4	2198.7	517.5	29.3
910.4	2198.8	985.4	30.1
910.4	2198.9	2918.8	30.2
910.4	2199.0	706.2	27.9
910.5	2199.1	397.4	19.9
910.5	2199.0	750.7	26.0
910.5	2198.9	755.3	28.9
910.5	2198.8	814	29.2
910.5	2198.7	422.2	28.3
910.5	2198.6	1290	23.7
910.5	2198.5	871.5	19.1
910.6	2199.1	568.4	19.2
910.6	2199.0	438.4	23.7
910.6	2198.9	925.3	26.0
910.6	2198.8	948.4	26.5
910.6	2198.7	477.6	25.6
910.6	2198.6	1434.3	22.0
910.6	2198.5	954.7	18.7
910.7	2198.5	615.8	18.7
910.7	2198.6	931.8	21.1
910.7	2198.7	318.5	23.9
910.7	2198.8	675.9	24.5
910.7	2198.9	699.6	24.0
910.7	2199.0	718.6	22.1
910.7	2199.1	368.3	19.8
910.7	2199.2	182	18.7
910.8	2199.1	569.3	18.9

Table 4. Groundwater Discharges used in Surface Water Model—Active UIC Wells

Easting (km)	Northing (km)	Flux (m^3/day)	Temperature (°C)
910.8	2199.0	515.5	20.8
910.8	2198.9	481.7	22.3
910.8	2198.8	397.9	22.8
910.8	2198.7	371.4	20.5
910.8	2198.6	1102	19.2
910.9	2198.6	905.8	19.0
910.9	2198.7	310.2	19.8
910.9	2198.8	636.8	19.9
910.9	2198.9	646.9	19.7
910.9	2199.0	650.8	19.2
910.9	2199.1	163.4	19.0
911.0	2199.0	553.6	18.9
911.0	2198.9	547.6	19.2
911.0	2198.8	536.8	19.3
911.0	2198.7	260.9	19.2
911.0	2198.6	744.3	18.8
911.1	2198.6	318.8	18.7
911.1	2198.7	220.1	18.8
911.1	2198.8	454.7	18.9
911.1	2198.9	466.6	18.8
911.1	2199.0	474	18.7
911.2	2199.0	201.3	18.5
911.2	2198.9	395.7	18.6
911.2	2198.8	382.4	18.6
911.2	2198.7	183.8	18.5

Notes:
UIC = underground injection control