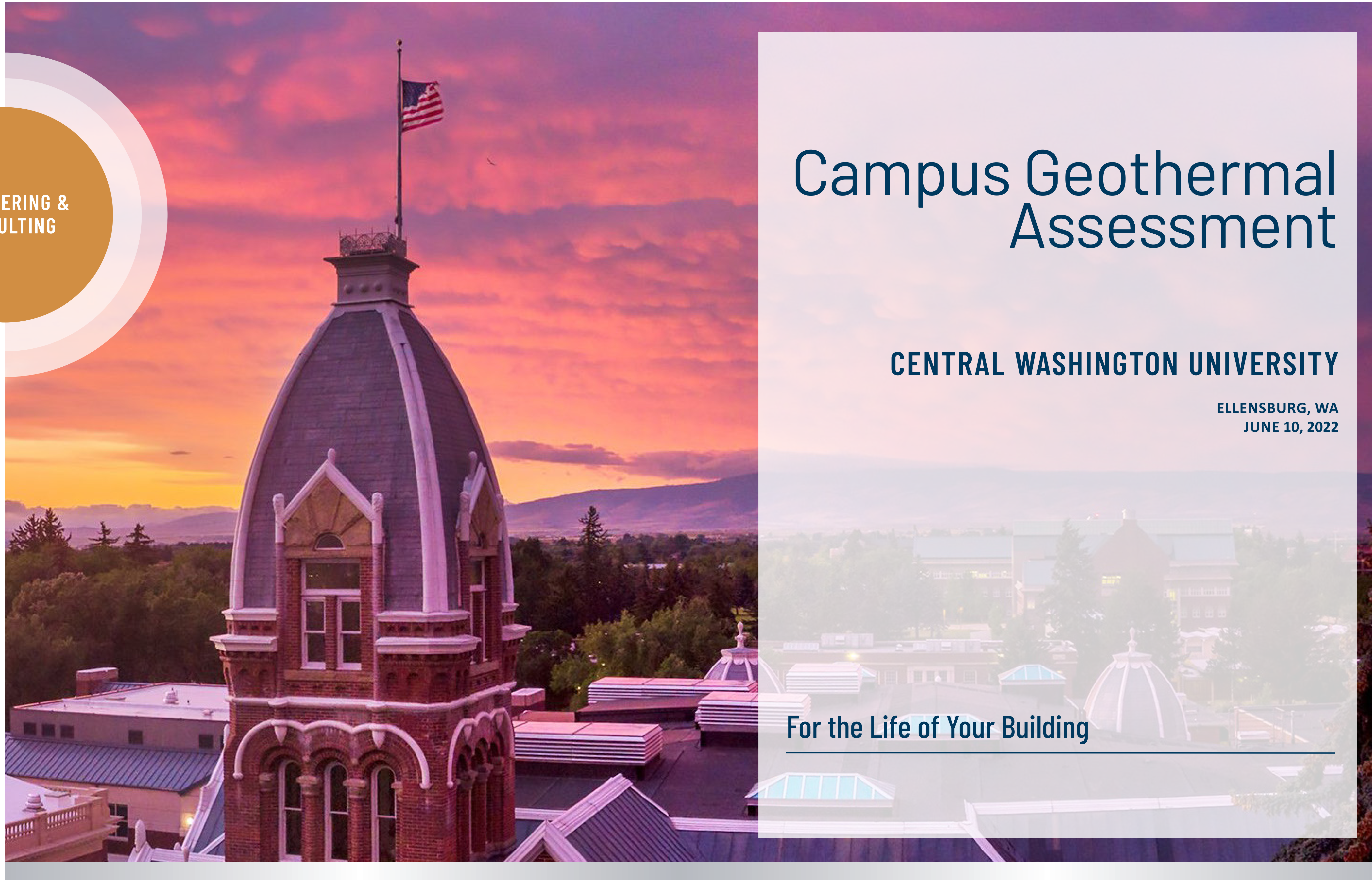
ENGINEERING & CONSULTING



Campus Geothermal Assessment

CENTRAL WASHINGTON UNIVERSITY

ELLENSBURG, WA
JUNE 10, 2022

For the Life of Your Building

McKinstry
For The Life Of Your Building

Background | Process and Content

PURPOSE

This report summarizes the **findings** and provides **recommendations** from exploring the feasibility options of an open-loop Ground Source Heat Pump system for the CWU Ellensburg campus.

The goal is to provide key information to CWU on how to reduce fossil fuel use at the central utility plant and ultimately achieve an **Energy Efficient Zero-Carbo**n campus.

REPORT CONTENT

WHY STUDY A GEOTHERMAL SYSTEM?

Geothermal systems eliminate the combustion of fossil fuels on site and dramatically lower the need to generate power by using the ground as a heat source and sink. They can significantly reduce the emission of greenhouse gases and the environmental damage associated with nonrenewable resource extraction.

WHY NOT CLOSED LOOP GEOTHERMAL WELLS?

Closed loop systems circulate water through buried piping to exchange heat with the ground versus an open loop system which pumps water directly in/out of the ground and through a heat exchanger. Closed loop systems require significantly more bore holes to have a similar capacity to that of an open loop, which can meet large capacities with only a few wells.

HIGH-LEVEL FINDINGS

- The Ellensburg Aquifer is productive and can support several buildings for heating and cooling demands
- With appropriate infrastructure, the aquifer could support most of the campus
- Cost is high for individual wells, so grouping buildings and sharing heat will improve economics
- Carbon and energy savings are significant compared to the existing steam heating system
- Many buildings on campus utilize steam and will need to be retrofitted to utilize heat pump systems in the future with implications of Washington Clean Building Performance Standard.

RECOMMENDED NEXT STEPS

CWU is sitting on a unique resource in the Kittitas Valley and has the special opportunity to consider **de-carbonization** unlike other universities. With proper long term planning the geothermal heat exchange can be maximized and leveraged to help CWU stand out as a public university in Washington State.

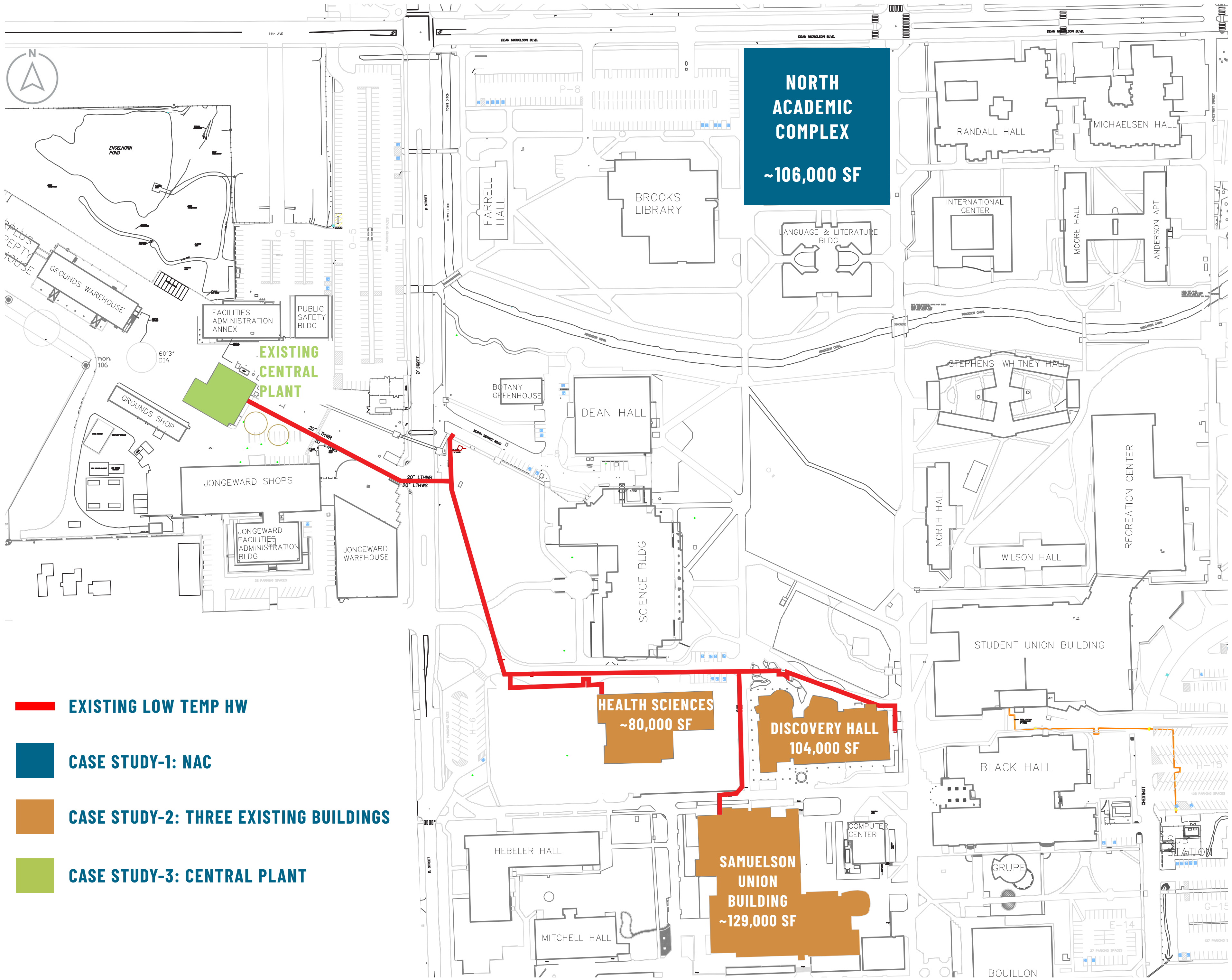
CAMPUS PHASED APPROACH — Create a playbook to achieve a zero carbon campus, leveraging geothermal

TEST WELL — Proceed with test well as part of the NAC building construction

MEP CONTRACT — New contract per the phased project approach

Geothermal Case Studies | Selection Process

CAMPUS SITE PLAN | EXISTING HYDRONIC LINES



Site Selection Case Studies | CRITERIA

Three discreet project options were chosen as case studies for this initial feasibility study that varied in size from one building, to campus wide. The options were chosen based on the ease of application for geothermal and the relative benefit to the buildings and systems. We utilized information about existing heating and cooling infrastructure on campus for almost 200 buildings over 4.6 million square feet. Buildings that required high temperature (>140F) water or steam were ruled out. Current heat pump technology favors heating water temperatures around 120F and retrofits of existing steam buildings to accept cooler water would likely be costly.

CASE STUDY - 1: NORTH ACADEMIC COMPLEX (NAC)

The easiest application of a geothermal system is to new construction before site work has been complete and HVAC systems are installed. The NAC is currently in design so it is an opportune time to assess the feasibility of a ground source system for this single new construction building. Additionally, based on communicated development plans, the infrastructure to support the building could possibly extend to future adjacent buildings.

CASE STUDY - 2: THREE EXISTING BUILDINGS

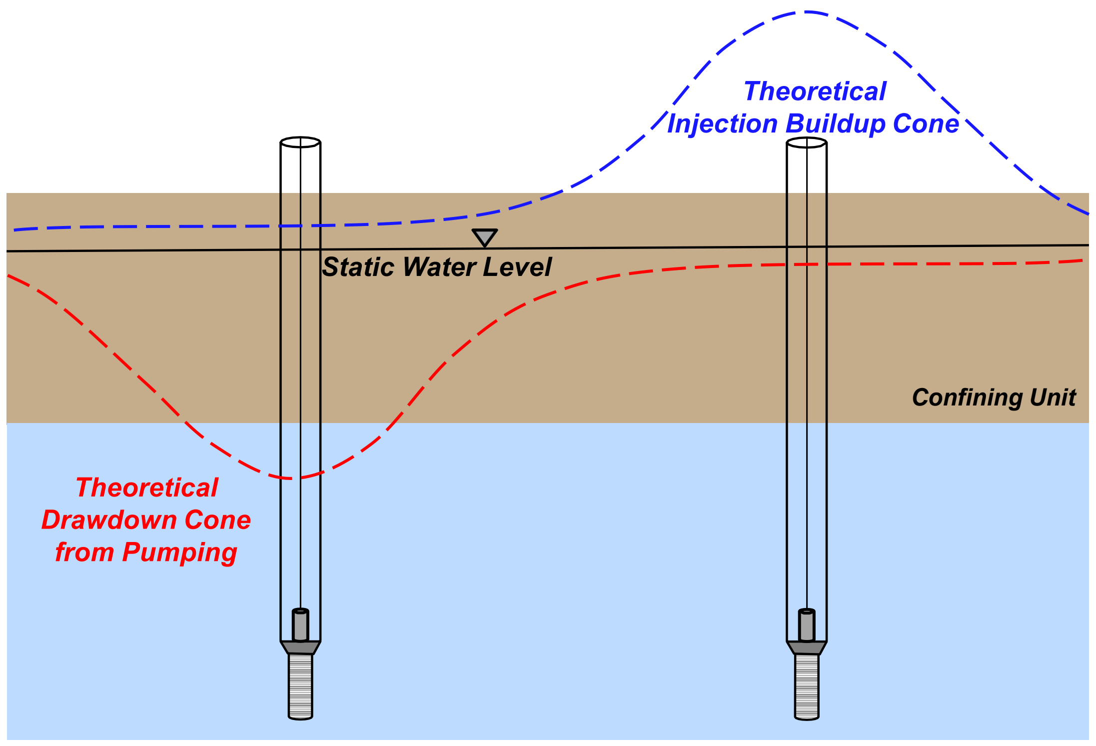
Health Sciences, Discovery Hall and Samuelson Union building are currently served by a single low temp HW loop from the central plant. In conversations with CWU, this 3-building cluster was selected as it provides the possibility for an easier connection between the required wells with a new heat exchanger to the existing HW piping network. Additionally, this site location also has several adjacent open green fields for proposed well locations.

CASE STUDY - 3: EXISTING CENTRAL PLANT

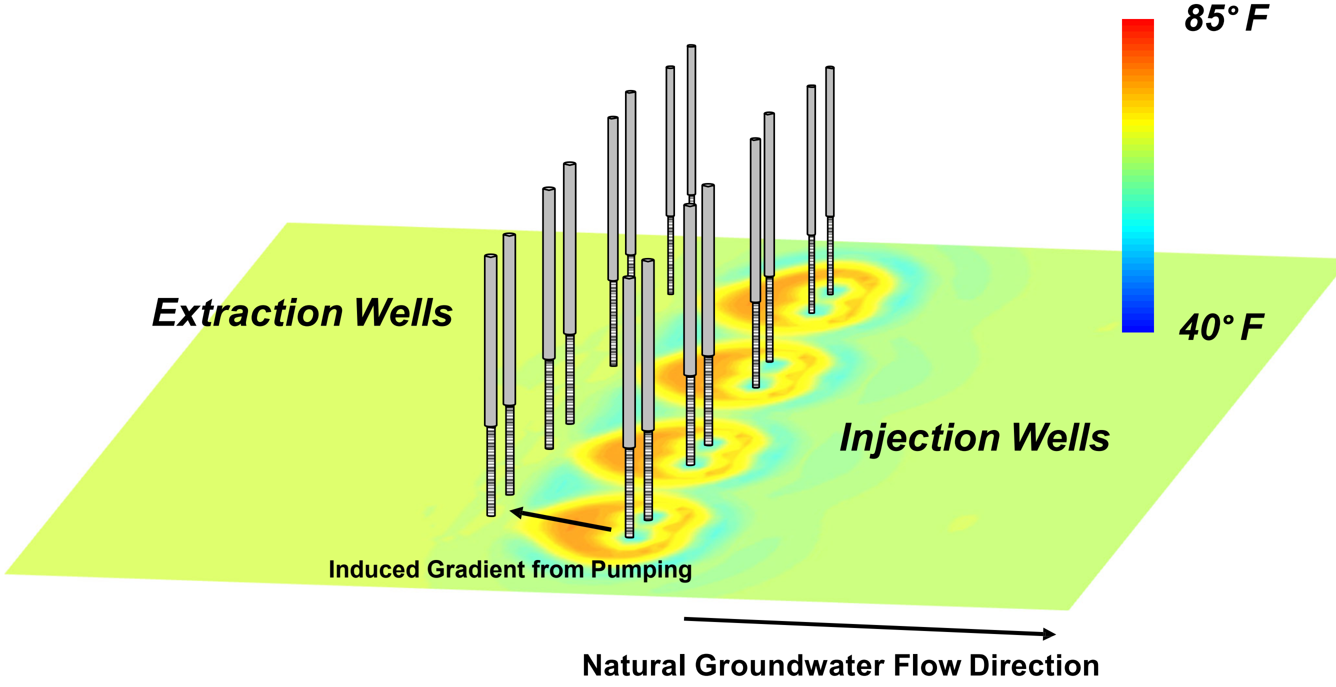
The existing central plant consists of 3-water cooled chillers and 4-steam-HW boilers. This option was selected as an upper boundary for the study, to provide an initial analysis on the number of wells required to meet the system capacity currently served by the central heating & cooling plant.

Hydro-geological Conditions | Ellensburg Aquifer

HYDRAULIC MODELING | THEORETICAL PUMPING IMPACTS



THERMAL MODELING | AQUIFER CONDITIONS



ELLENSBURG AQUIFER | EXISTING CONDITIONS

Based on the information available from the city of Ellensburg, following are the existing conditions for the aquifer:

- Regional groundwater flow direction follows Yakima river (North West to South East)
- It is the primary source for city of Ellensburg wells
- Shallow well completion zone (Unit A) - 300 to 600 ft deep (transmissivity 2,000 to 2,5000 SF/day)
- Deep well completion zone (Unit C) - 900 to 1,200 ft deep (transmissivity 3,000 to 4,5000 SF/day)
- Confined aquifer - no impact to surface water

MODELING RESULTS | DESIGN CONSIDERATIONS

Based on the early model analysis conducted by Aspect, following are the takeaways at this stage:

- Aquifer can supply more water than each of the scenarios require
- Case Studies-1 & 2 can be supported by 1-extraction well (paired with 1-injection well), completed in the shallow completion zone
- Case Study-3 can be supported by 8-extraction wells (paired with 8-injection wells), completed in the deeper completion zone
- Simulated well-field operation yielded no thermal breakthrough for Case Studies-1 & 2 and minor thermal breakthrough for Case Study-3
- Further modeling will take place during the design phase to optimize well spacing

RECOMMENDATION

Results Summary | Geothermal Case Studies

EXISTING CENTRAL PLANT Heating by Natural Gas to Steam Boilers (85% eff) & Cooling by WC-Chillers (COP - 7) Heat rejection via Cooling Towers	**CASE STUDY - 1** **ONE NEW BUILDING (NAC)** Stand-alone open-loop GSHP system for heating (COP - 4) and cooling (COP - 6.5)	**CASE STUDY - 2** **THREE EXISTING BUILDINGS** Open-loop GSHP system for heating (COP - 4) & supplemental cooling provided to existing WC Chillers (COP - 7) Heat rejection via Cooling Towers	**CASE STUDY - 3** **EXISTING CENTRAL PLANT** Open-loop GSHP system for heating (COP - 4) & supplemental cooling provided to existing WC Chillers (COP - 7) Heat rejection via Cooling Towers
ROM Mechanical First Costs* [$]	$3.7M	$7.0M	TBD
Utility Cost Savings [$/yr]	~$8,000/yr (26%)	~20,000/yr (27%)	~640,000/yr (30%)
Heating EUI Reduction [Kbtu/SF/yr]	~25	~20	~66
GHG Reduction [lbs of CO2e]	170 Tons/yr = 34 gas cars	400 Tons/yr = 80 gas cars	11,200 Tons/yr = 2,195 gas cars
Zero Carbon Heating and Cooling	✓	✓	✓
Water Savings [gal/yr]	~40,000	~120,000	~>5,000,000
No. of Wells Required	One - 10" Extraction | One - 10" Injection	One - 14" Extraction | One - 14" Injection	Eight - 16" Extraction | Eight - 16" Injection
Building Area Served (SF)	106,000 SF	313,500 SF	2,576,000 SF
Well Depth (ft)	500'	500'	1000'
Target System Capacity (tons /gpm)	100 tons / 250 gpm	300 tons / 750 gpm	3,320 tons / 8,300 gpm
Pros & Cons	Pro: Easier design application for a new building Con: Well sized for a single building limits the opportunity to expand	Pro: Well sized for multiple buildings provides better ROI Con: Difficult to add a new htg/clg system to an existing building	Pro: Provides an opportunity for a zero carbon & energy efficient campus Con: Complex design to retrofit an entire campus with a longer project duration

Next Steps

Based on the preliminary analysis of the three case studies, it is recommended to follow the design approach of case study-2 and apply this methodology for a cluster of new buildings.

Given the North Academic Complex is under the design process, the test well should be located on the proposed site under case study-1 and sized to meet the loads of future building additions.

*Costs provided are conceptual in nature and to used for directional decision making only. Building modification and other major GC scope has not been included. Prices are in today's dollars without escalation

Appendix

Case Study Details

Hydro-geology Analysis Memo

Existing Design | Central Plant

DESIGN DESCRIPTION | Existing Central Plant Diagram

EXISTING EQUIPMENT LIST

GAS TO STEAM BOILERS WITH STACK RECOVERY (CONDEX SYSTEM)

3-units (60 Klb/HR Steam)
1-unit (30 Klb/HR Steam)
Assumed Efficiency - 85%

WATER COOLED CHILLERS

3-units (1,200 tons each)
Assumed Efficiency
2015 WSEC - 0.5 kW/Ton

COOLING TOWERS

3-units

2021 UTILITY RATES

Electricity

Consumption Rate - $0.047/KWh
Demand Rate - $5.30/KW
Customer Charge - $3.78/day

Natural Gas

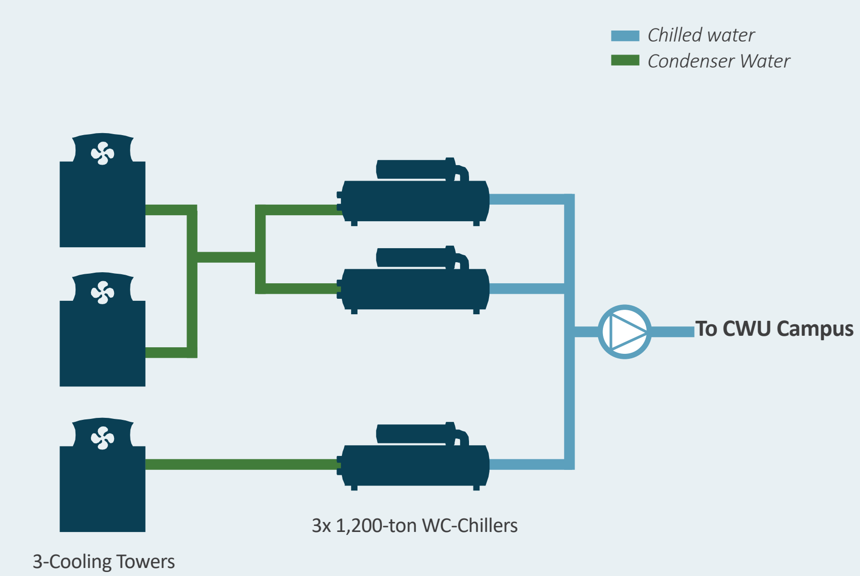
Consumption Rate - $0.67/Therm
Fixed Charge - $71/day

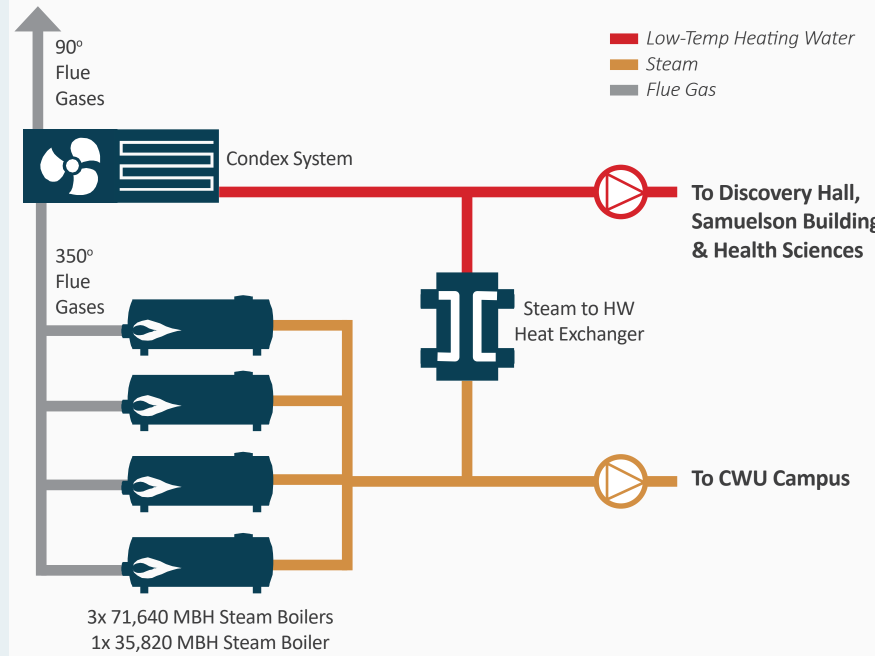
E-GRID WA STATE CO_2E FACTORS

Electricity CO_2e = 0.212 lb/KWh
Natural Gas CO_2e = 11.7 lb/Therm

CENTRAL PLANT AREA SERVED

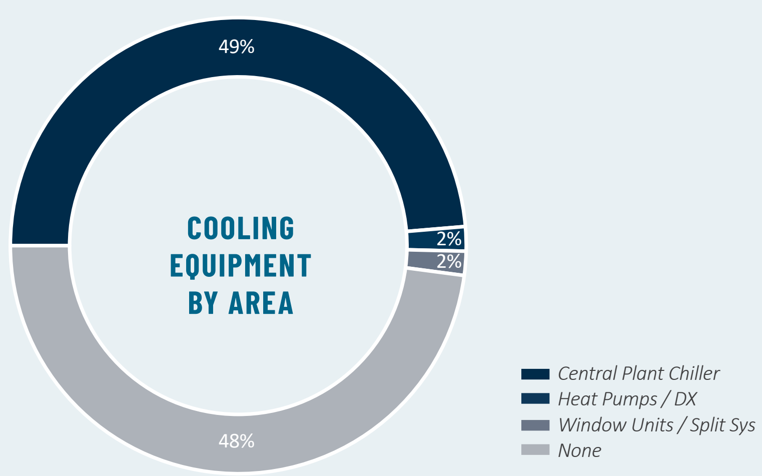
Heating - 2,576,156 SF
Cooling - 2,239,717 SF





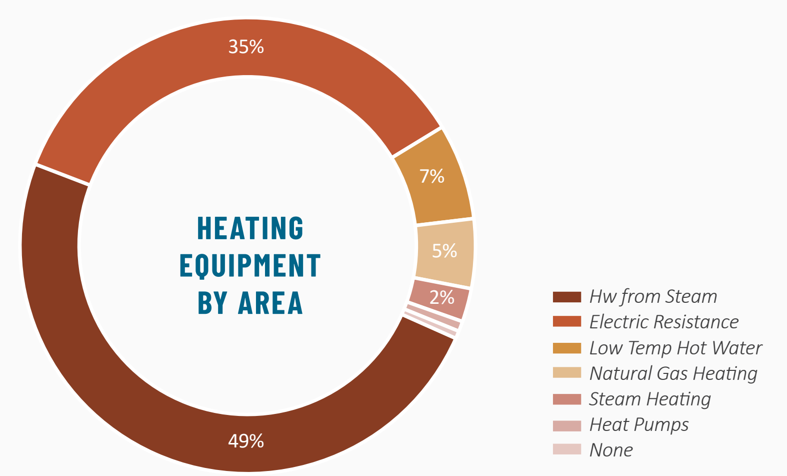
CAMPUS COOLING

About half of the occupied square footage is cooled by water cooled chillers with cooling towers. An additional chiller is planned to be added soon, to increase the capacity of the existing chiller water system. A 1-million gallon thermal storage tank provides additional peak shaving and efficiency gains. There are a small number of buildings that have their own cooling systems, but about 50% of the campus does not have mechanical cooling of any kind.

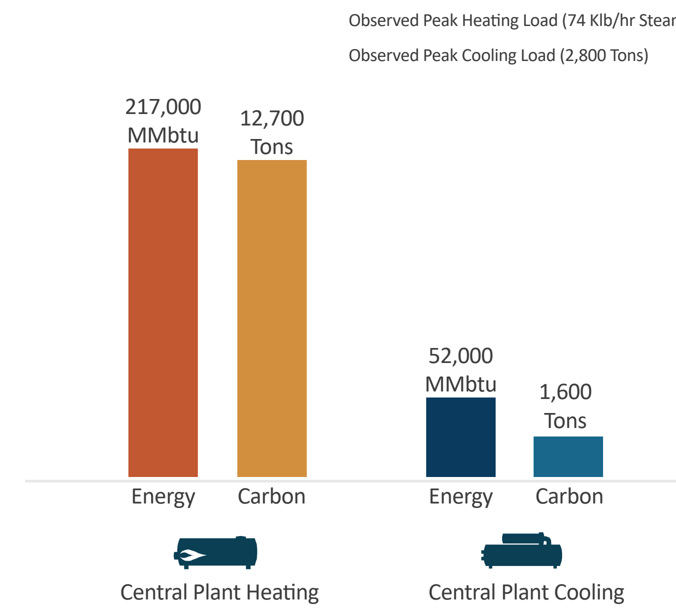


CAMPUS HEATING

Heating and Cooling for the CWU campus is provided by both central and distributed systems. About half of the occupied square footage is heated with steam produced from natural gas-powered boilers at the central plant. The remaining buildings are heated with non-centralized systems (electric resistance, heat pumps, gas boilers). Additionally, three buildings are served by a low temperature hot water loop, that is in part generated with recovered boiler stack heat (CONDEX System).



ENERGY & CARBON ANALYSIS



TARGET CARBON REDUCTIONS

Given the cold winter months of Ellensburg and the inefficient gas powered steam boilers, 72% of the total energy and 88% of carbon emissions from the central plant are from heating. This study focuses on reducing the heating energy while providing options to reduce the carbon impacts of the central plant equipment.

EXISTING CENTRAL PLANT METRICS

Htg EUI - 84 kBtu/sf/yr
Clg EUI - 23 kBtu/sf/yr

Natural Gas - $1,282,762/yr
Electricity - $886,208/yr

CO_2e
Natural Gas - 2,470 gas cars/yr
Electricity - 320 gas cars/yr

Case Study - 1 | North Academic Complex

DESIGN DESCRIPTION | Proposed System Diagram

NEW EQUIPMENT LIST

PLATE & FRAME HEAT EXCHANGER

1 unit (2,800 MBH, 450 gpm)

6-PIPE HEAT RECOVERY CHILLERS

2 units (1,400 MBH, 4x30 ton module)

2-GROUND WELLS

760 ft of 6" PVC piping to/from wells

PUMPS

Heating/Chilled water distribution,
Condenser Water Pumps,
Well pumps

GROUND WELL CHARACTERISTICS

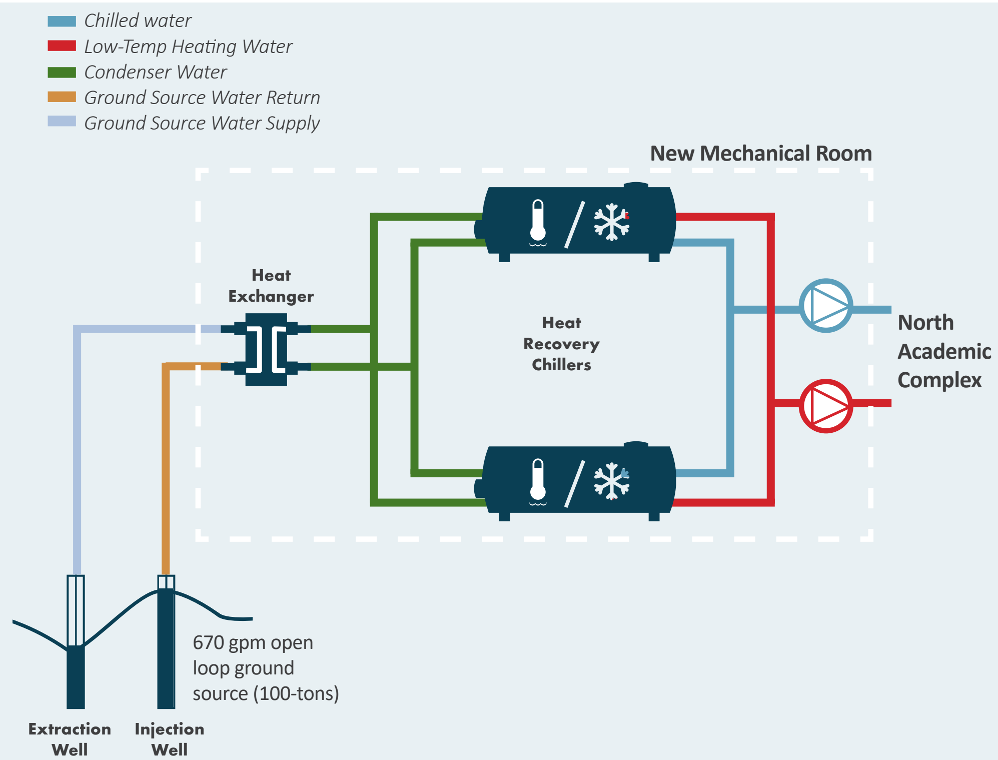
Target system capacity
100 tons

Ground water exchange flow
250 gpm

Spacing b/w extraction & injection well
670 ft

Total well depth
500 ft

Average injection pressure
5.5 PSI



SYSTEM DESIGN

The North Academic Complex (NAC) is a future 106,000 SF building that is currently in design. The baseline heating and cooling systems for the NAC are a steam to hot water heat exchange system and the utilization of campus chilled water.

The proposed ground exchange system will extract water from a well to the north of the building. The groundwater will be pumped through a heat exchanger before being injected back into the ground to the south of the building. Heat pumps will extract or reject energy through the heat exchanger to heat or cool the building as needed. Heat pumps utilize electricity and have an efficiency of 400% compared to gas boilers with an efficiency of only 85%.

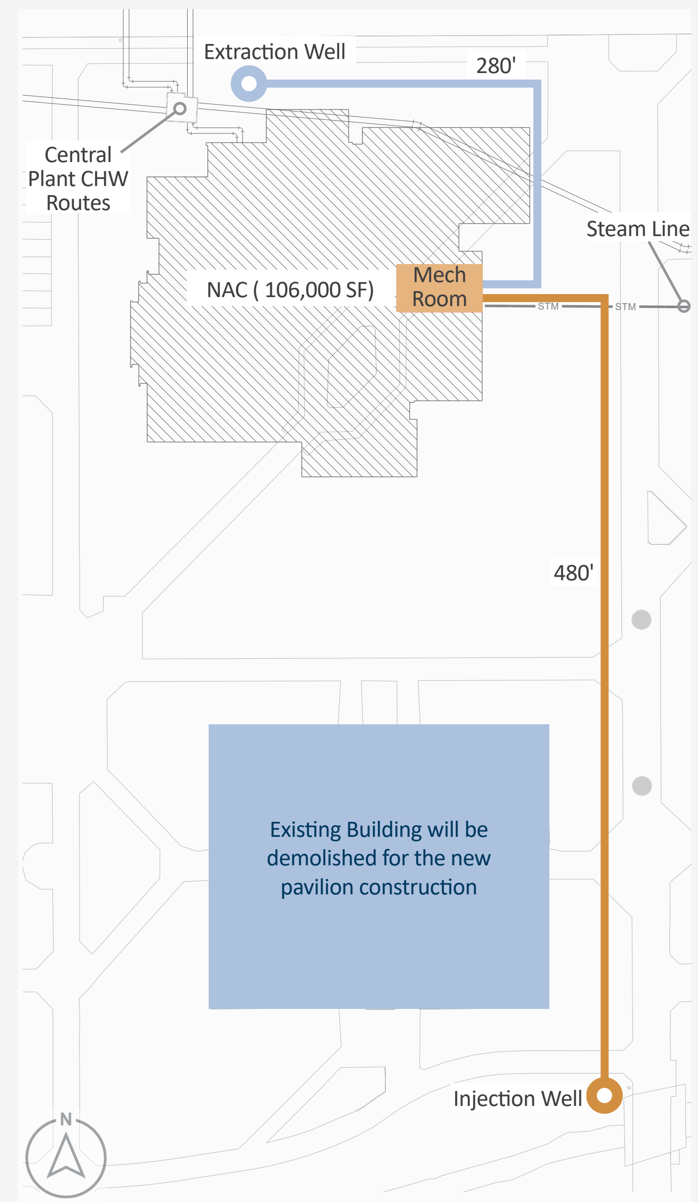
FIRST COST CONSIDERATIONS

Compared to the baseline steam heat exchanger system, the open loop ground source system will have significantly more first cost, because it requires new central infrastructure. The system requires more pumps, a heat pump, and a separate domestic hot water heating system. The costs given in the summary to not include the deduction of the baseline steam system from the NAC scope, or any operational savings to the central plant.

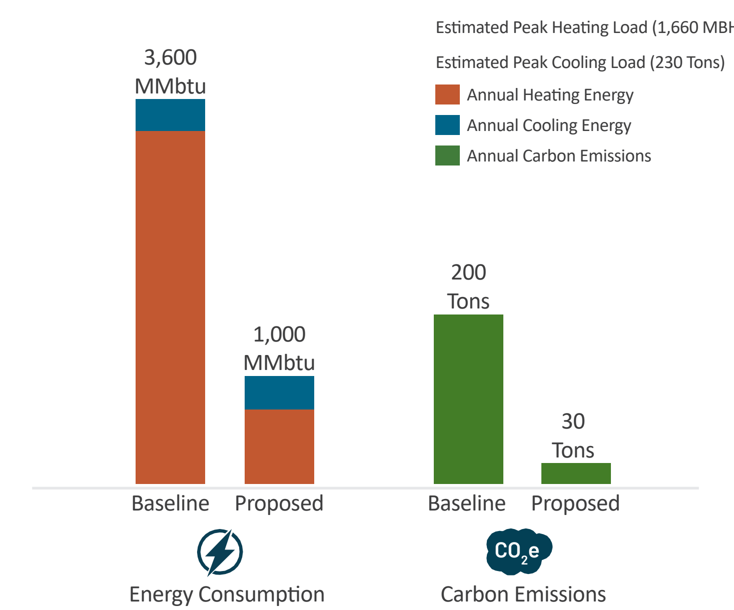
PROPOSED GROUND WELLS & PIPING LOCATION

The diagram below shows the proposed extraction and injection well locations with piping length and the entry to the NAC mechanical room.

The currently designed chilled water and steam lines from the central plant have been noted as well.



ENERGY & CARBON ANALYSIS



RESULTS SUMMARY

The open loop ground source system reduces the heating energy by 80% compared to the existing design. Cooling energy remains about the same. Additionally, it reduces the steam and chilled water loads imposed on the central system, thereby freeing up that capacity for other uses.

SAVINGS FROM EXISTING BASELINE DESIGN

Htg EUI - 25/sf/yr

Utility Cost- $8,000/yr

Carbon Emissions - 170 Tons/yr (34 gas cars off the road)

Case Study - 2 | Three Existing Buildings

DESIGN DESCRIPTION | Proposed System Diagram

NEW EQUIPMENT LIST

PLATE & FRAME HEAT EXCHANGER
1 unit (4,000 MBH, 665 gpm)

6-PIPE HEAT RECOVERY CHILLERS
2 units (8,400 MBH, 5x70 ton module)

2-GROUND WELLS
800 ft/8" PVC piping to/fro wells

PUMPS
Heating/Chilled water distribution
Condenser Water Pumps
Well pumps

WELL CHARACTERISTICS

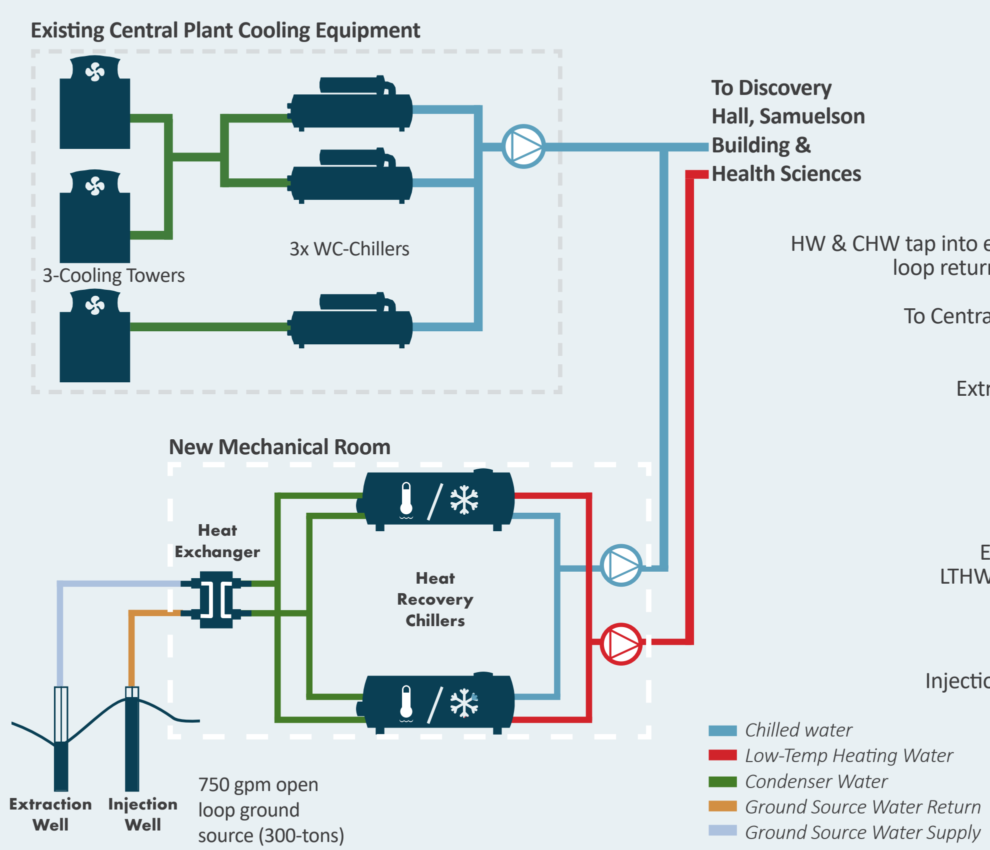
Target system capacity
300 tons

Ground water exchange flow
750 gpm

Spacing b/w extraction & injection well ***715 ft***

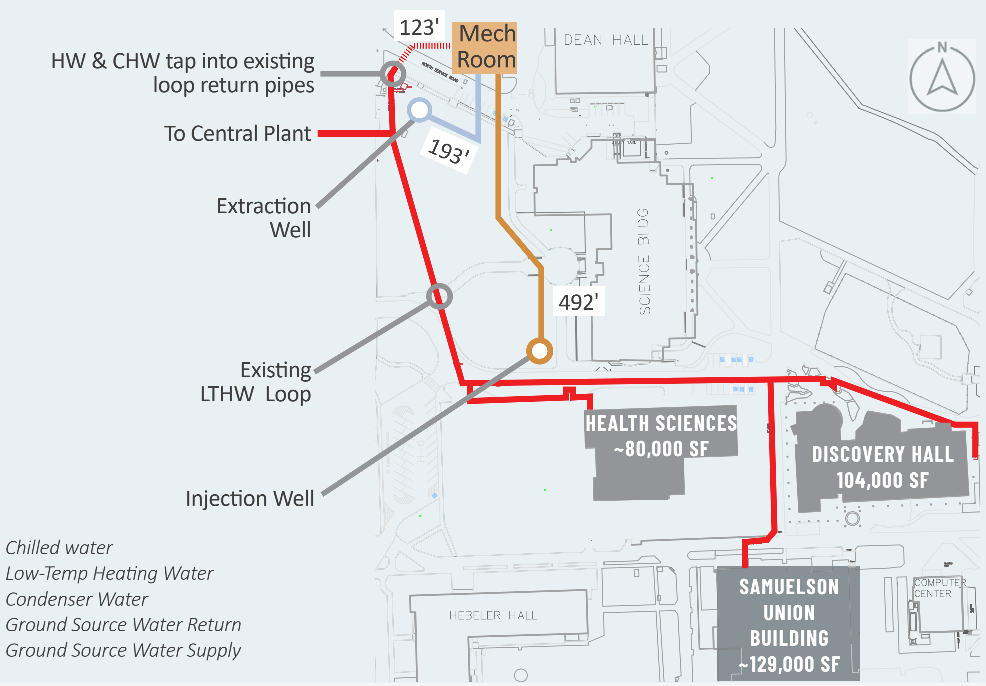
Total well depth
500 ft

Average injection pressure
32 PSI



PROPOSED GROUND WELLS & PIPING LOCATION

The diagram below shows the proposed extraction and injection well locations with piping length and the entry to the proposed mechanical room that hosts the new equipment.



SYSTEM DESIGN

Heath Sciences, Discovery Hall & Samuelson Union building are currently served by a single low temperature hot water (LTHW) loop from the central plant. Heat for this loop is provided by a combination of stack heat recovery and steam to HW heat exchangers. The proposed ground exchange system will extract water from a well to the north of this building cluster. The ground water will be pumped through a heat exchanger before being injected back into the ground near the Health Sciences building. Heat pumps will extract heat from the heat exchanger and produce low temperature hot water to offset the steam use associated with the current LTHW.

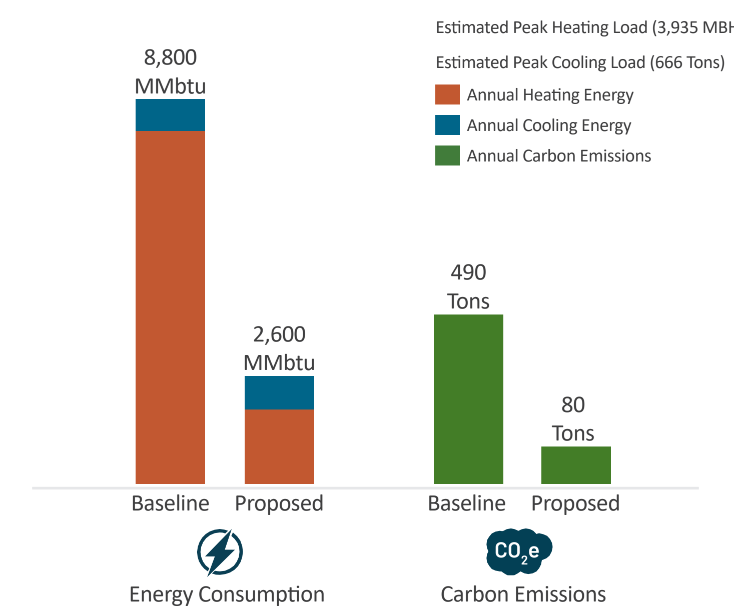
CONSIDERATIONS FOR EXISTING STACK HEAT RECOVERY

Based on the metered data it is unclear how much of the current LTHW loop's heat is provided by the heat recovery off the boiler stacks versus steam. The flue gas heat is recovered and considered "free" heat from an energy perspective, while the supplemental steam heat requires additional natural gas. We calculated savings based on zero free heat from the boilers, to show the maximum potential. The more "free" heat there is, the less benefit a ground source system will provide; assuming 30% of the load is served by the condex system the savings drop to ~$5,000/yr in energy cost and ~12 Kbtu/sf/yr in energy use.

FIRST COST CONSIDERATIONS

The economics of a ground source system improve when paired with more than one building. This option still only requires two total wells, but serves three times the square footage of case study-1.

ENERGY & CARBON ANALYSIS



RESULTS SUMMARY

The open loop ground source system reduces the heating energy by 80%. Additional energy benefit could be seen with the heat recovery modules of the heat recovery chillers depending on further analysis of the actual existing building load distribution for the next stage of this study.

SAVINGS FROM EXISTING BASELINE DESIGN

Htg EUI - 20/sf/yr

Utility Cost- $20,000/yr

Carbon Emissions - 400 Tons/yr
(80 gas cars off the road)

Case Study - 3 | Existing Central Plant

DESIGN DESCRIPTION | Proposed Central Plant Diagram

NEW EQUIPMENT LIST

HEAT EXCHANGE CENTER
Size & Units - TBD

6-PIPE HEAT RECOVERY CHILLERS
Size & Units - TBD

16-GROUND WELLS
Pipe size & length - TBD

PUMPS
Heating/Chilled water distribution
Condenser Water Pumps
Well pumps

WELL CHARACTERISTICS

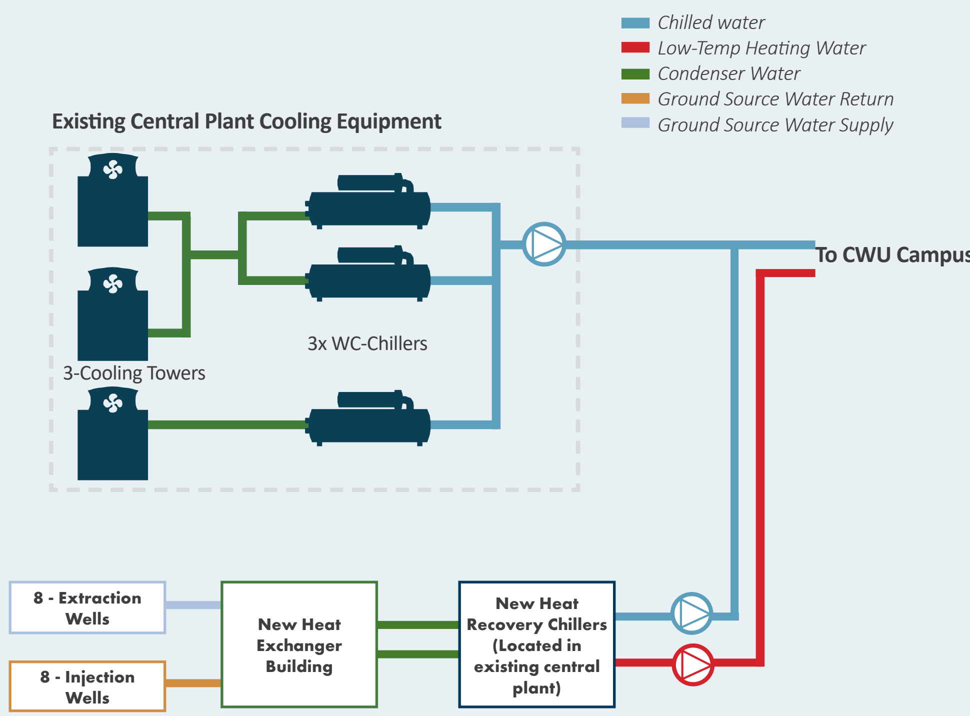
Target system capacity
3,320 tons

Ground water exchange flow
8,300 gpm

Spacing b/w extraction & injection well
700 ft

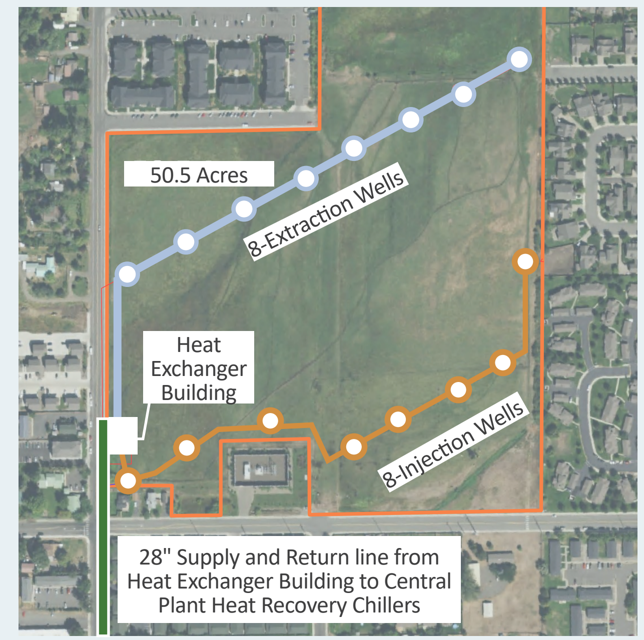
Total well depth
1000 ft

Average injection pressure
23PSI



PROPOSED GROUND WELLS & PIPING LOCATION

The diagram below shows the proposed extraction and injection well locations with piping length and the entry to the proposed mechanical room that hosts the new equipment.



SYSTEM DESIGN

This option is a full replacement of the steam system with a new central plant system that is based on open loop ground source. In reality, this will be a phased project, but we evaluated feasibility on a more simplistic large project level. The scope is not well developed as it is complex and spans over 4 million square feet of conditioned area.

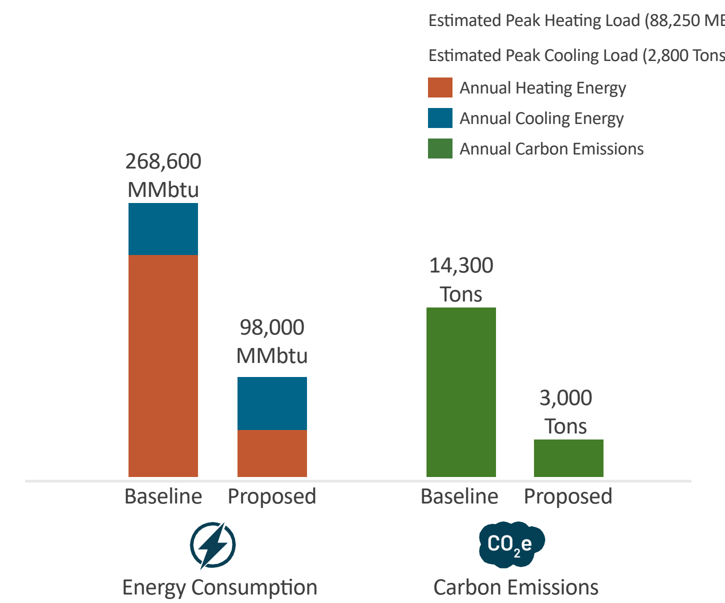
Hydro-geology has determined that 16 wells (8 injection and 8 extraction) will be able to meet the current peak demands of the campus. It may be prudent to downsize this, add thermal storage or other peaking capacity to reduce upfront cost. The scope below does not consider that. The most free open space that CWU owns is north of campus. Wells would be drilled at that location and piped to a heat exchange building that contains heat exchangers and condenser water distribution pumps.

Condenser water would be pumped from the heat exchange building north of campus to the central plant, so current piping and chilled water infrastructure can be utilized. This is a significant amount of large pipe (16,000 linear feet of ~28" pipe), with areas routing on non CWU owned property.

The current steam system will be demolished and replaced with a heat recovery system. Large heat pumps would provide low temperature hot water (it's possible to utilize large ammonia machines to generate hot water, possibly reducing the need for in building retrofits). New hot water piping across campus would need to be distributed to replace aging steam infrastructure. The current chilled water plant would be re-piped to utilize the new condenser water loop as a sink for heat, in addition to the current cooling towers. Current chilled water piping, pumping, and building level systems could all be re-used.

The existing chiller plant has a peak load of 2,800 tons, and includes redundancy. The current steam peak for heating is about 88 million Btu/h – this equates to around 7,500 "tons" of heating.

ENERGY & CARBON ANALYSIS



RESULTS SUMMARY

The open loop ground source system reduces the heating energy by 80%. Additional energy benefit could be seen with the heat recovery modules of the heat recovery chillers depending on further analysis of the actual existing building load distribution for the next stage of this study. This is a significant reduction in on-site carbon emissions only possible with a large steam conversion project.

SAVINGS FROM EXISTING BASELINE DESIGN

Htg EUI - 66/sf/yr

Utility Cost - $640,000/yr

CO2e - 11,200 Tons/yr (2,195 gas cars off the road)

Aspect CONSULTING

MEMORANDUM

Project No. 210270

June 10, 2022

To: Devon Powell and Tanvi Dhar, McKinstry Co.

From:

Andrew Austreng, LHG
Associate Hydrogeologist
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Isabellah von Trapp, LG
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Re: **Central Washington University Ground Source Heat Pump Hydrogeologic Evaluation**

This memo documents an initial hydrogeologic evaluation by Aspect Consulting, LLC (Aspect) of open-loop ground source heat pump (GSHP) wellfield alternatives for the Central Washington University (CWU) campus in Ellensburg, Washington (Site). The wellfield alternatives presented herein are based on three potential heat pump demand scenarios developed by McKinstry to represent a range of system sizes (i.e., supply to a single building, multiple buildings, or the entire campus).

The scope of this work was limited to a desktop hydrogeologic investigation of GSHP wellfield alternatives. A summary of findings is provided in the following section, with details of this work and future considerations provided throughout the remainder of this memo.

Summary of Findings

The following findings are supported by the existing aquifer characterization and modeling efforts described herein:

- The primary permitting requirements for construction and operation of the wellfield[1] include obtaining a new water right and registration of all injection (return) wells with the Department of Ecology's (Ecology) Underground Injection Control Program. No concerns were identified with obtaining either of these permits. Ecology guidance allows for priority processing of non-consumptive water right applications for GSHP systems.
    - The Site is underlain by a productive aquifer, often referred to as the upper Ellensburg Formation, which has potential to supply a high yield GSHP system. This aquifer system is expected to have 'shallow' (e.g., 300-600 feet) and 'deep' (e.g., 800-1,100 feet) production zones. The deeper production zone is expected to provide particularly

[1] City of Ellensburg building permit compliance would also be required for facility construction.

high water yields suitable for larger GSHP buildout scenarios (e.g., campus-wide), while the shallow system can likely supply a multi-building GSHP system, this is if aquifer conditions are similar to what has been encountered in the Site vicinity.

- Shallow and deep production zones of the Ellensburg Formation are confined by overlying impermeable silt/siltstone layers. These confining layers isolate the Site's productive aquifer system from nearby surface water, simplifying the permitting pathway and minimizing variability in water supply temperature. Both the deep and shallow production zones exhibit water temperatures that are considered ideal for efficient GSHP operation (i.e., 55 to 65 degrees F, depending on completion zone).
- Heating and cooling loads associated with multiple buildings (e.g., Scenario 2 described below) can likely be met by a single extraction and injection well pair completed within the shallow system (two wells total), but this will need to be confirmed as part of a future phase of work. Based on our analytical modeling (Section 4), the separation requirements between the extraction (supply) and injection (return) wells is less than 715 feet, allowing for flexibility in well placement and minimizing pipeline costs.
- Modeling suggests that a campus-wide GSHP wellfield (referred to as Scenario 3 below) would require eight paired extraction and injection wells (16 wells total) completed in the deep production zone to supply the entire heating and cooling loads.
- The costs for wellfield construction increase with well completion depth and well size (rough order-of-magnitude costs are presented in Section 5 of this memorandum). Therefore, to minimize the construction costs per ton of heating and cooling, multiple buildings should utilize a shared wellfield system, which could target the shallow completion zone. Depending on the size of the shared system and the actual geologic conditions encountered at the Site, completing fewer wells within the deep system may be necessary and cost-effective (compared to a greater number of shallow wells separated by a greater distance).

Overall, this study identified favorable conditions for a high capacity open-loop GSHP wellfield at the Site. Additional Site-specific information is needed to advance design, including well construction and pumping tests to verify aquifer yields and wellfield spacing and depth. A cost-effective solution for assessing hydrogeologic conditions and optimizing construction costs could involve drilling a deep boring (e.g., 800-1,100) that is either completed as an operational well or, depending on conditions identified, completed within the shallow production zone (e.g., 300-600 foot deep).

1 Project Background

In coordination with CWU, McKinstry identified open-loop GSHP as an alternative to supply heating and cooling to portions of the campus. At the Site, an open-loop GSHP system would pump groundwater from one or more supply wells, pass water through a heat exchanger, and return the water to the same groundwater system via a paired injection (return) well or wells.

Based on a preliminary hydrogeologic review in June 2021, Aspect found that hydrogeologic conditions on-Site may support a high yielding open-loop GSHP system but that uncertainties in associated wellfield requirements (depth, yield, and spacing) and costs exist for small to medium scale (e.g., 1 building) systems. Given this analysis, McKinstry sought to consider wellfield requirements over a range of system sizes, as this Site is likely to benefit from the economy of scale under certain buildout scenarios.

McKinstry provided Aspect with three scenarios representing a range of system sizes and loading profiles to evaluate a range in open-loop GSHP wellfield requirements. The analysis aimed to determine the feasibility and relative cost of installing each demand scenario so CWU may be well informed about possibilities and limitations of a GSHP system ahead of investments. Each McKinstry-provided GSHP scenario is described below and shown conceptually on Figure 1 and includes the following facility sizes considered for supply:

- **Scenario 1:** A new building at the North Academic Complex (NAC). This option would support one building.
- **Scenario 2:** A three building cluster comprising the Health Sciences, Science II, and Samuelson Buildings.
- **Scenario 3:** The entire campus, centered around the Central Plant.

2 Permitting Considerations

Based on recent experience with similar projects and an initial desktop evaluation of hydrogeologic, geologic, and surrounding site conditions, Aspect conducted a preliminary permitting assessment to evaluate 1) permitting requirements, 2) the permitting process, and 3) the anticipated outcomes of permitting efforts. Further details related to applying for a water right and registration with Ecology's Underground Injection Control (UIC) program are described below.

2.1 Water Right Permitting

Open-loop GSHP systems require a water right under RCW 90.44.050. An open-loop GSHP system is a beneficial use of groundwater that meets the definition of "non-consumptive" use, as defined by Ecology policy POL-1020, as it will not diminish water availability, is water budget neutral, and meets the criterion for expedited review under Washington Administrative Code (WAC) 173-152-050(2)(c) and Ecology policy POL-2020. These policies would allow the Washington State Department of Ecology (Ecology) to issue a water right to CWU, even though it is within an area where new consumptive water rights cannot be obtained without mitigation.

The main consideration for water right processing of open-loop systems is temperature impact considerations, which Ecology would evaluate after a water right application is submitted. The indirect temperature effect on surface water bodies in hydraulic continuity with groundwater underlying the Site is regulated under WAC 173-201A, which does not allow thermal discharges to any temperature-impaired surface water body. The closest temperature regulated surface water to the Site is a reach of Wilson Creek (located about 1.3 miles southwest of Scenario 2 in Figure 1), which is listed as a Category 2 impaired water.[2] This allows Ecology more flexibility in issuing a water right in consideration of Wilson Creek temperature impacts.

[2] The Category 2 water is characterized as "having some evidence" for temperature impairment but "does not show persistent impairment" to categorize the water as impaired under the listing policy [Ecology 2022]).

While our hydrogeologic assessment (Section 3) indicates a hydraulic gradient that directs groundwater generally from the northwest to the southeast to the south (toward the impaired reach of Wilson Creek), the creek flows as perched water on top of impermeable silt/siltstone layers of the Ellensburg Formation, which vertically isolates the creek from any potential thermal impacts. Furthermore, our preliminary thermal modeling (Section 4) suggests that thermal impacts on groundwater from GSHP operation do not migrate far from the Site and would dissipate before reaching the impacted reach of Wilson Creek even if the perched condition did not occur. This fact pattern is expected to provide relatively straightforward permit approval.

Although not a typical water rights permitting consideration, no groundwater temperature impairment is expected to occur to other groundwater users, including the City of Ellensburg.

2.2 UIC Registration

All injection wells (e.g., “return” wells for open-loop GSHP systems) in Washington State must be registered with Ecology’s Underground Injection Control (UIC) program. The UIC registration process is relatively simple and is typically initiated after well construction. If open-loop construction and implementation is advanced, any injection well will need to be registered in the State’s program.

Registration involves an application process separate from the Water Right Permit. The UIC registration, among other criteria, requires the applicant to identify any nearby groundwater cleanup actions from public records if the HAC (heating and cooling) system is within one mile of surface water and uses 5,000 gallons per day or greater. The purpose of this requirement is to evaluate if an extraction or injection well could either “pull” or “push” a nearby groundwater contaminant plume into an extraction well or mobilize a contaminant plume through injection. Our preliminary review of active contaminated sites indicates that they are too distant from the campus and/or would be vertically isolated by several hundred feet of confining material to negatively impact UIC permitting.

3 Hydrogeologic Assessment

The details provided in the following sections document Aspect’s desktop assessment of hydrogeologic conditions at the Site, with the overall findings incorporated into the preceding sections of this memo.

3.1 Geologic Setting

The Site is located within the Kittitas Valley, a geologically complex area that is structurally and topographically bound by the Taneum Monocline to the west, the Wenatchee Mountains to the north, the Naneum-Hog Ranch anticline to the east, and the Manastash Ridge to the south. Valley infill includes mid-Miocene aged Columbia River Basalts that are overlayed and interfingered with sedimentary units of the Ellensburg Formation. The Ellensburg Formation is typically blanketed by a thin layer (less than 50 feet) of Quaternary-aged alluvial sediments associated with deposition of the Yakima River (GeoEngineers, 1999).

3.2 Hydrogeologic Units

The Ellensburg Formation includes fluvial sand and gravel deposits, sandstone, and volcaniclastic sedimentary rocks that are up to thousands of feet thick near the center of Ellensburg (GeoEngineers, 1999). The formation is divided into the upper and lower Ellensburg Formations

(Owens, 1995). The lower is comprised of finer-grained, non-marine, clastic sediments that interfinger the Columbia River Basalts, while the upper is characterized by mudflow debris, much of which was reworked by streams with significant sand and gravel lenses.

The upper Ellensburg Formation contains multiple water-bearing zones that are heterogenous in texture (e.g., sand and gravel content) across the Ellensburg area. In many areas, it can be generally grouped into units corresponding to 'shallow' (e.g., 300-600 feet below ground surface [bgs]) and 'deep' (800-1,100 feet bgs) production zones. With the exception of its Ranney collector well completed in the shallow alluvial aquifer, all City of Ellensburg production wells are completed within the upper Ellensburg Formation, the aquifer central to this investigation. The generalized shallow and deep production zones within the upper Ellensburg are "confined" by overlying low-permeability sediments and are described in greater detail below.

- **Shallow Zone:** Wells completed within the shallow completion zone of the upper Ellensburg Formation are generally on the order of 300-600 feet deep. Aquifer material in this zone is generally composed of sand/sandstone and gravel/conglomerate interbedded with lenses of silt/siltstone. The City's Memorial Well (PW-3) is completed in this zone approximately 1,500 feet southeast of Scenario 2 shown in Figure 1. A safe yield of approximately 420 gallons per minute (gpm) was identified during well construction (Robinson & Noble, 1986).

- **Deep Zone:** The shallow and deep water-bearing zones have been identified in local well logs and past studies as being separated by an impermeable layer of silt/siltstone that ranges from 50 to 150 feet thick. Below this confining layer, several water-bearing zones exist comprising the 'deeper' completion zone of the upper Ellensburg Formation. Similar to the shallow zone, the deep completion zone is composed of sand/sandstone and gravel/conglomerate interbedded with lenses of silt/siltstone. Wells completed in this zone are generally 800-1,100 feet deep and include nine City water supply wells. The closest of these wells are the Kiwanis Well (located approximately 950 feet northwest of Scenario 3 shown in Figure 1, upgradient to the Site) and the Rodeo Well (located approximately 2,000 feet southeast of Scenario 2 shown in Figure 1). Robinson & Noble (1986) reported a safe yield of 1,000 gpm for the Kiwanis Well and 800 gpm for the Rodeo Well.

Groundwater contour maps created by GeoEngineers (1999) show groundwater in the shallow and deep completion zones, and show groundwater flow paralleling local Yakima River flow from the north/northwest to the south/southeast.

3.3 Aquifer Hydraulic Parameters

Well testing and hydrogeologic reports were reviewed to estimate hydraulic parameters for the shallow and deep completion zones of the upper Ellensburg Formation and are described in Table 1. A discussion on each parameter is included below the table.

Table 1. Hydraulic Parameters

Model Parameter	Shallow	Deep
Aquifer Transmissivity (ft^2/day)	2,000	3,000
Aquifer Storativity (unitless)	0.005	0.0004
Static Water Level (ft bgs)	18	50
Assumed Well Efficiency (%)	85	

3.3.1 Aquifer Transmissivity

- Aquifer transmissivity (T) is the ability of an aquifer to transmit groundwater throughout its entire saturated thickness. It is the product of hydraulic conductivity (soil permeability) multiplied by the saturated aquifer thickness (Transmissivity [T] = Hydraulic Conductivity [k] x Aquifer Thickness [b]). It can also be estimated through evaluation of pumping test data using conventional analytical techniques (e.g., Theis, 1935; Cooper and Jacob, 1946).

- Transmissivity was estimated through evaluation of existing pumping test analysis for the City. Robinson and Noble (1986) estimated an aquifer transmissivity value of 2,400 ft^2/day for the shallow production zone, based on analysis of pumping test data from the Memorial Well. For conservatism, the estimate was reduced by approximately 15 percent, and a value of **2,000 ft^2/day** was selected for modeling purposes.

- In the deeper production zone, Robinson and Noble (1986) reported transmissivity values ranging from 2,200-3,200 ft^2/day from analysis of pumping tests at the Mt. Stuart, Kiwanis, and Whitney wells, while Coho (2020) reported an aquifer transmissivity value of 4,000 ft^2/day based on analysis of the Illinois Well pumping test. We expect the large range in transmissivity estimates to be related to the number of water-bearing zones (e.g., saturated aquifer thickness depth) encountered by each well, which is related to the depth of the well. The Illinois Well, for example, is at least 100 feet deeper than the other three listed and appears to have encountered a greater number of water-bearing zones within the deeper production zone. For conservatism, a value of **3,000 ft^2/day** was selected for modeling purposes, but a well completed at least 1,100 feet deep at the Site could encounter a higher transmissivity.

3.3.2 Aquifer Storativity

- Aquifer storativity (S) is a unitless value, defined as the volume of water released from storage per unit surface area of the aquifer or aquitard per unit decline in hydraulic head for a confined aquifer. It can also be estimated through analysis of pumping test data if water level drawdown is measured in both a pumping and observation well.

- A storativity value of 0.005 was selected for the shallow production zone by averaging the values provided by GeoEngineers (1999). A value of 0.0004 was selected for the deep production zone based on analysis by Coho (2020) of the Illinois Well pumping test data.

3.3.3 Static Water Level

- The static water level is expected to experience limited seasonal variation. Static water levels of 18 and 50 feet bgs were selected for the shallow and deep production zones, respectively, based on static water levels of City wells.

3.3.4 Well Efficiency

- Well efficiency accounts for the turbulent head losses in an injection or extraction well that includes effects from imperfect well completion (e.g., screen design/placement and well development). A well efficiency of 85 percent was assumed in the model, although in practice, thoroughly developed wells that are properly constructed in sands and gravels often exceed 90 percent efficiency at their designed flow rate.

4 Modeling

Open-loop GSHP potential of the Ellensburg aquifer (i.e., extraction and reinjection of groundwater) was analyzed by creating a hydraulic model[3] from estimated aquifer parameters. The analytical hydraulic model provides an evaluation of well drawdown and pressure buildup in extraction and injection wells, respectively. This part of the analysis provides an estimate of maximum wellfield yields under different well separation arrangements corresponding to Scenarios 1-3 at the Site. The results of the hydraulic model were then considered iteratively within a preliminary two-dimensional thermal model. The thermal model[4] considers the well spacing from the hydraulic model to determine if “thermal breakthrough” or if thermal conditioning would occur within the wellfield. Thermal breakthrough indicates that some fraction of heated or cooled groundwater from the injection wells has migrated to the extraction well (thermal breakthrough could reduce GSHP performance if the system isn’t adjusted accordingly).

Hydraulic and thermal modeling were conducted within the Site footprint for each scenario to provide a preliminary estimate of total wellfield yield to supply a GSHP. Results of these analyses are described in greater detail in the following sections.

4.1 Hydraulic Modeling

Based on well yields and hydraulic parameters estimated from evaluation of hydrogeologic reports, well logs, cross-sections, and pumping tests, a hydraulic model was created to simulate changes in well water levels resulting from groundwater extraction and injection (water supply and return). The capacity of an open-loop wellfield is ultimately determined by:

- Availability of a sufficient water column in the extraction well during pumping (water column corresponds to the pump submergence below the water level in the aquifer, where the pump can typically be set only as low as the top of the well screen)
- Groundwater injection pressures (water level buildup) at the injection wells

[3] The hydraulic model is based on conventional analytical methods for a confined aquifer by Cooper-Jacob (1946).
[4] VS2DI Version 1.3, USGS (2018)

If the water level draws down too close to the pump in the extraction well, the risk for well pump cavitation increases (a pump submergence of 10 feet or more during pumping is typically targeted for safe operation). This can cause decreased pump performance and/or premature pump wear, so pumping rates are limited to those that maintain adequate pump submergence.

In confined aquifers, as is found at the Site, injection pressures (backpressure at the injection wellhead) in excess of 20 pounds per square inch (or more, depending on the size of installed pump) may be considered prohibitive due to added pumping lift and elevated pressure buildup in the aquifer. Pressures can be mitigated by dividing injection water among multiple injection wells or with the addition of a booster pump to overcome injection pressure buildup. To the extent practical, the system should be designed to avoid excess backpressures.

The Site's hydraulic model is based on conventional analytical methods by Cooper-Jacob (1946) simulating the effects from combined extraction and injection on the water level in the wells and aquifer. The model predicts water level drawdown in extraction wells and injection wells located a distance away from the pumping well. Drawdown in extraction wells is then offset by the return of groundwater through the injection wells, which has the opposite effect on the water level than pumping (i.e., water is replenished to the aquifer and water level rises). The available water column in extraction wells and injection pressures in the injection wells are ultimately determined by well spacing, extraction/injection rates, and aquifer parameters.

Aspect ran the model for an array of wellfield configurations to determine appropriate combinations of pumping rate, number of wells, and well spacing for each scenario outlined by McKinstry. Aspect based this model on the wellfield's ability to support the maximum flow rate identified for each option based on McKinstry's average loading profiles[5]. Along with loading profiles, McKinstry provided Aspect with site maps that delineated "drillable areas" for each option to assist with spacing and identify potential locations for future production wells. Hydraulic modeling results are summarized in Table 2. Modeled wellfield configurations are shown in Figures 2-4.

[5] McKinstry provided Aspect with daily load curves representing an average day across each month for Scenarios 1-3. The hydraulic model was built to accommodate the maximum hourly flow rate identified for each option. Scenarios 1, 2 and 3 correspond to maximum wellfield flowrates of approximately 250 gpm, 750 gpm, and 8,300 gpm, respectively.

Table 2. Hydraulic Model Results

	Scenario 1	Scenario 2	Scenario 3
No. of Extraction Wells **(No. of Injection Wells)**	1 **(1)**	1 **(1)**	8 **(8)**
Well Completion Zone	Shallow	Shallow	Deep
Well Spacing Between Extraction and Injection Well (ft)	670	715	700
Average Water Column in Extraction Well Above Pump (ft)[1]	200[2]	140[2]	240[3]
Average Injection Pressure (PSI)[4]	6[5]	30[5,6]	20[6,7]
Estimated Heating and Cooling Capacity (tons)[8]	100	300	3,320

Notes:
[1] The combined result of water level drawdown from extraction and water level buildup in the extraction well from injection.
[2] Assumes the pump is set at 350 feet bgs.
[3] Assumes the pump is set at 390 feet bgs based on the screened intervals in the Illinois Well.
[4] The combined result of water level drawdown in the injection well from extraction and pressure buildup in the injection well.
[5] Assumes a static water level of 18 ft bgs, based on the City's Memorial Park Well.
[6] This value could be mitigated by the addition of a second injection well to attenuate the pressure buildup throughout the aquifer or with the addition of a booster pump to overcome injection pressures.
[7] Assumes a static water level of 50 feet bgs.
[8] Assumes 2.5 gpm/ton. This value is dependent on the selected heat exchanger and other mechanical components and should be verified by a mechanical engineer.

Within the drillable areas of the Site footprint identified by McKinstry, one extraction well (paired with one injection well) was found to be the number of wells needed to achieve the target yield within the drillable footprint for Scenarios 1 and 2. Eight extraction wells (paired with 8 injection wells) were found to be the number of wells needed to achieve maximum wellfield yield within the drillable footprint for Scenario 3.

Due to the large flow rates needed to meet the loading profiles associated with Scenario 3, wells completed in the deeper production zone are expected. Aquifer transmissivity is likely greater in the deeper production zone, allowing the wells to be pumped at higher flow rates. Deeper wells also allow for more "available water column" which would also allow the wells to be pumped at higher rates.

Importantly, **the well spacing described in Table 2 does not represent the minimum well spacing required to accommodate the flow rates** associated with each scenario. Rather, spacing was based on placing wells in areas determined by McKinstry as "potential well locations." Actual well spacing and placement would be refined in a later design phase. Preliminary well spacing and mapped locations are intended to support planning level cost considerations and a conceptual system design.

4.2 Thermal Modeling

A numerical two-dimensional groundwater heat flow model was created in VS2DHI (Version 1.3) to simulate flow and heat energy transport associated with GSHP wellfield operation. Model inputs were based on McKinstry's anticipated energy modeling results for average monthly loading profiles, provided to Aspect in April 2022 for each scenario.

Thermal modeling considered average loading scenarios as presented in the following sections.

4.2.1 Model Assumptions

The model was designed to represent the monthly average system load profile across the year through the following assumptions:

- The daily load curve (flow rates) for each month was averaged over a 24-hour period and kept constant across the month (the model operates on a daily time step).
- Background groundwater temperature was kept constant throughout the year at 66 °F, based on the temperature of water encountered during testing of the City's Illinois Well.
- Injection (return water) temperatures are based on a 12°F ΔT when the system is in cooling mode (i.e., cooling the building/heating the ground; assumes a 78-degree reinjection temperature) and an 8°F ΔT when the system is in heating mode (i.e., heating the building/cooling the ground; assumes a reinjection temperature of 58 degrees).
- The model assumes the system is in heating mode from October through April and in cooling mode from May through September.
- All energy from reinjection wells is directly transferred to groundwater.[6]
- The model considered the same wellfield configuration depicted in Figures 2-4. Open-loop operation was simulated for three years based on the average loading profile for each option provided by McKinstry.

Modeling results are summarized and shown conceptually in Attachment 1. The model predicts no thermal breakthrough after three years of operation for Scenarios 1 and 2 and a minor to moderate degree of thermal breakthrough (e.g., ±6°F) after three years of operation for Scenario 3. The degree of thermal breakthrough could be lessened by increasing the spacing between injection and extraction wells, however, injection pressures would increase as a result. Thermal breakthrough or high injection pressures could be managed during the design phase through the selection of heat exchangers that can support a range of entering temperatures, additional injection wells, or addition of booster pumps to overcome head pressures.

4.3 Sensitivity Analysis

Sensitivity analyses of estimated hydraulic parameters were also completed to assess dependence of the thermal model results on estimated aquifer properties. Aquifer transmissivity and groundwater gradient were individually varied by plus or minus 25 percent from the initial input values and

[6] During actual system operation, some energy is lost to conveyance piping and well casing.

resulting changes in temperatures of extraction water were assessed. To observe the effects of sensitivity analysis, this assessment was only conducted for the Scenario 3 (deep production zone), because it was the only simulation to show any thermal breakthrough. The result of varying each parameter is described below.

Aquifer transmissivity. The transmissivity estimate used in the model (3,000 ft^2/) is a critical factor in determining aquifer productivity and is based on permeability, soil type, and aquifer thickness. The estimates are within the typical range for the upper Ellensburg Formation aquifer, but transmissivity can vary locally depending on the amount of silt, clay, and the saturated aquifer thickness, and is expected to show some variation across the Site. Transmissivity values 25 percent less and greater than the initial estimate were modeled to assess the effect on thermal impairment. This analysis showed no discernable impact on thermal breakthrough.

Groundwater flow gradient. The groundwater flow gradient influences the rate in which ambient groundwater can “wash away” a thermal plume when the system is not operating. The higher the gradient, the greater the aquifer’s ability to recover from thermal impairment. This analysis also showed that altering the groundwater gradient had no discernable impact on thermal impairment.

Because the flow rates associated with Scenario 3 are so large relative to the Site footprint, altering the transmissivity and groundwater gradient by small margins did not have a discernable impact on thermal impairment. The model is most sensitive to flow rate in this case.

5 Cost Considerations

Aspect solicited bids from drillers between the Spring of 2021 and 2022 to assist with rough order of magnitude (ROM) well construction costs. These bids were reviewed and adjusted based on estimated well depths. Costs of wellfield construction[7] for Scenarios 1-3 were compared to anticipated system yields. This analysis is summarized in Table 3 and discussed below.

Table 3. Cost Comparison Summary

	Scenario 1	**Scenario 2**	**Scenario 3**
Well Depth	Shallow (assumed 500 ft bgs)		Deep (assumed 1,000 ft bgs)
Well Production Casing Depth (ft) / Diameter (inches)	300 / 10	300 / 14	400 / 16
Screen Length (ft) / Diameter (inches)	200 / 8	200 / 10	200[1] / 12
System Capacity, gpm **(tons)**	250 **(100)**	750 **(300)**	8,300 **(3,320)**
ROM Well and Pump Cost	$550,000	$800,000	$20 million
Approx. ROM Well Cost Per Ton	5,500	2,700	6,000

Notes: [1] Additional solid casing of the same diameter as the screen will be included in the screen assembly (the balance of the difference between, assumed to be 400 feet in length for the example shown). Does not include wellhouse.

[7] These estimates only consider the costs associated with well drilling and testing. The estimate does not include costs associated with trenching/piping, mechanical equipment, well appurtenances, or maintenance.

6 Summary and Recommendations

The hydrogeologic system anticipated at the Site is well-suited to support a high yield open-loop GSHP system. Aspect's analysis of the Site and surrounding geologic and hydrogeologic information indicates that the upper Ellensburg Formation aquifer is present beneath this Site with significant extent and could support a range of system sizes, including the entire campus.

Based on this desktop evaluation, a mid-range system supplying multiple campus buildings is expected to be high performing, permittable, and cost efficient. Site explorations are needed to advance design and can be tailored to also provide operational GSHP infrastructure (a "usable" well). Well construction and pumping tests should be considered to verify aquifer yields and wellfield spacing and depth. A cost-effective solution to assessing hydrogeologic conditions and optimizing construction costs could involve drilling a deep boring (e.g., 800-1,100) that is either completed as an operational well or, depending on conditions identified, completed within the shallow production zone (e.g., 300-600 foot deep).

7 References

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8 Limitations

Work for this project was performed for McKinstry (Client), and this memorandum was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This memorandum does not represent a legal opinion. No other warranty, expressed or implied, is made.

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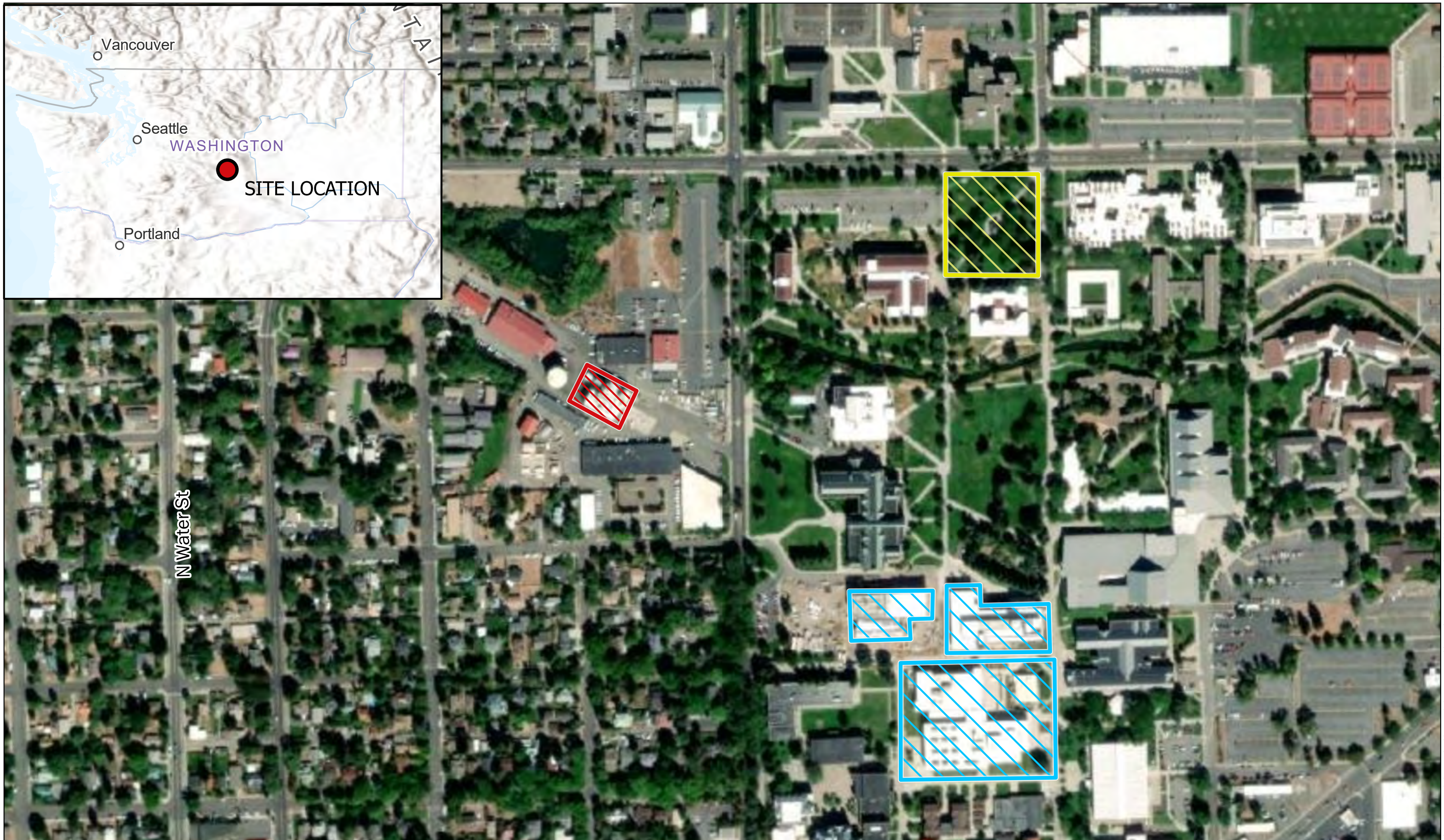
Attachments:
Figure 1 – Site Map
Figure 2 – Option 1
Figure 3 – Option 2
Figure 4 – Option 3
Attachment A – Thermal Modeling Results

V:\210270 McKinstry CWU\Deliverables\GSHP Feasibility Memo\CWU GSHP Feasibility Memo_2022.06.10.docx

FIGURES



Proposed Locations

- Scenario 1 - NAC
- Scenario 2 - 3 Building Cluster
- Scenario 3 - Entire Campus

N

0 200 400 Feet

1:7,500
(1 inch equals 625 feet)

Site Map

CWU Ground Source Heat Pump Feasibility Study
McKinstry CWU
Ellensburg, Washington

Aspect CONSULTING	JUN-2022	BY: DC	FIGURE NO. 1
	PROJECT NO. 210270-A	REVISED BY: - - - / - - -	

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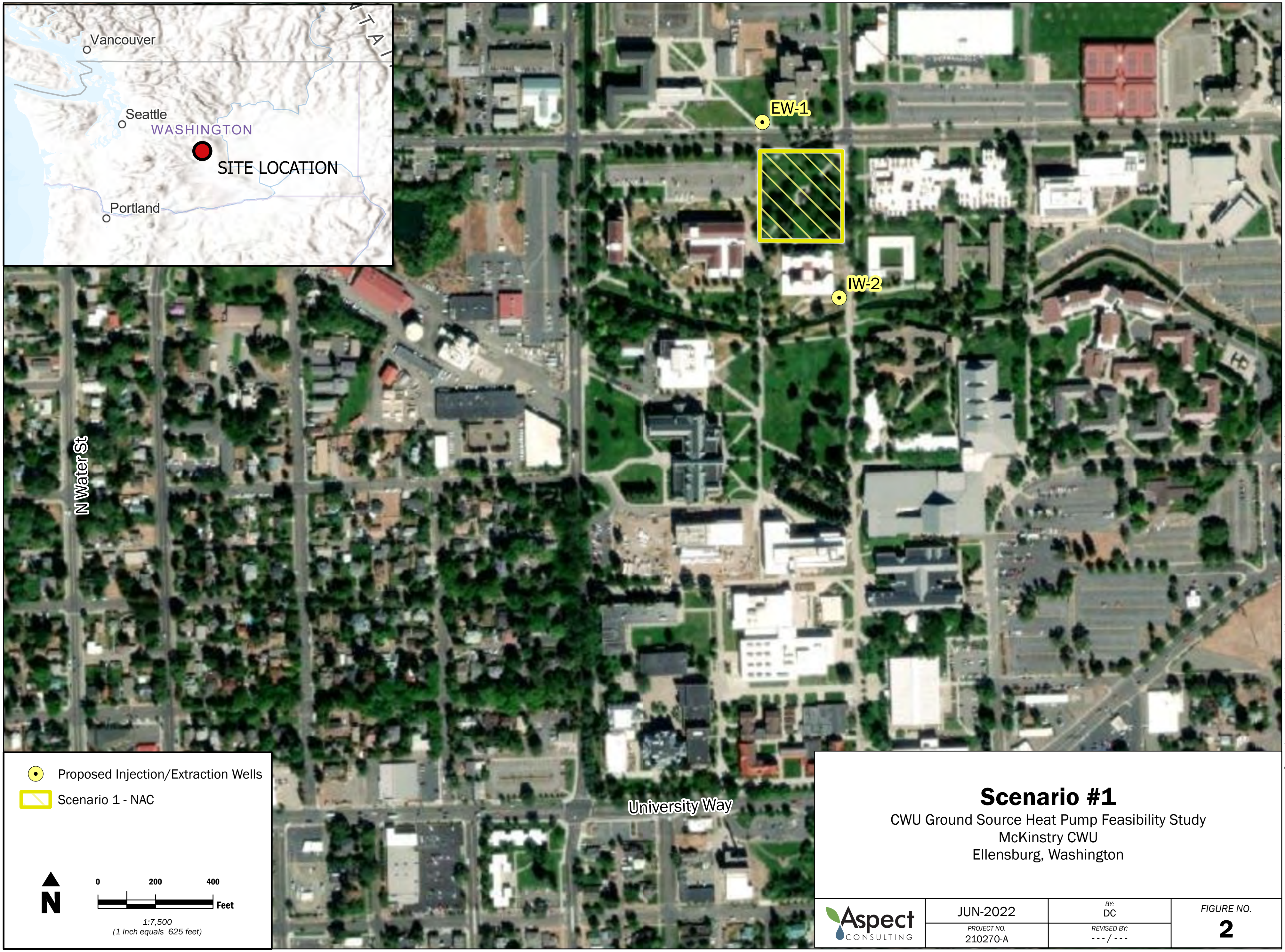

Scenario #1

CWU Ground Source Heat Pump Feasibility Study
McKinstry CWU
Ellensburg, Washington

Aspect Consulting	JUN-2022	BY: DC	FIGURE NO.
	PROJECT NO. 210270-A	REVISED BY: - - - / - - -	2

Data source credits: None || Basemap Service Layer Credits: Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, Esri, USGS, Maxar

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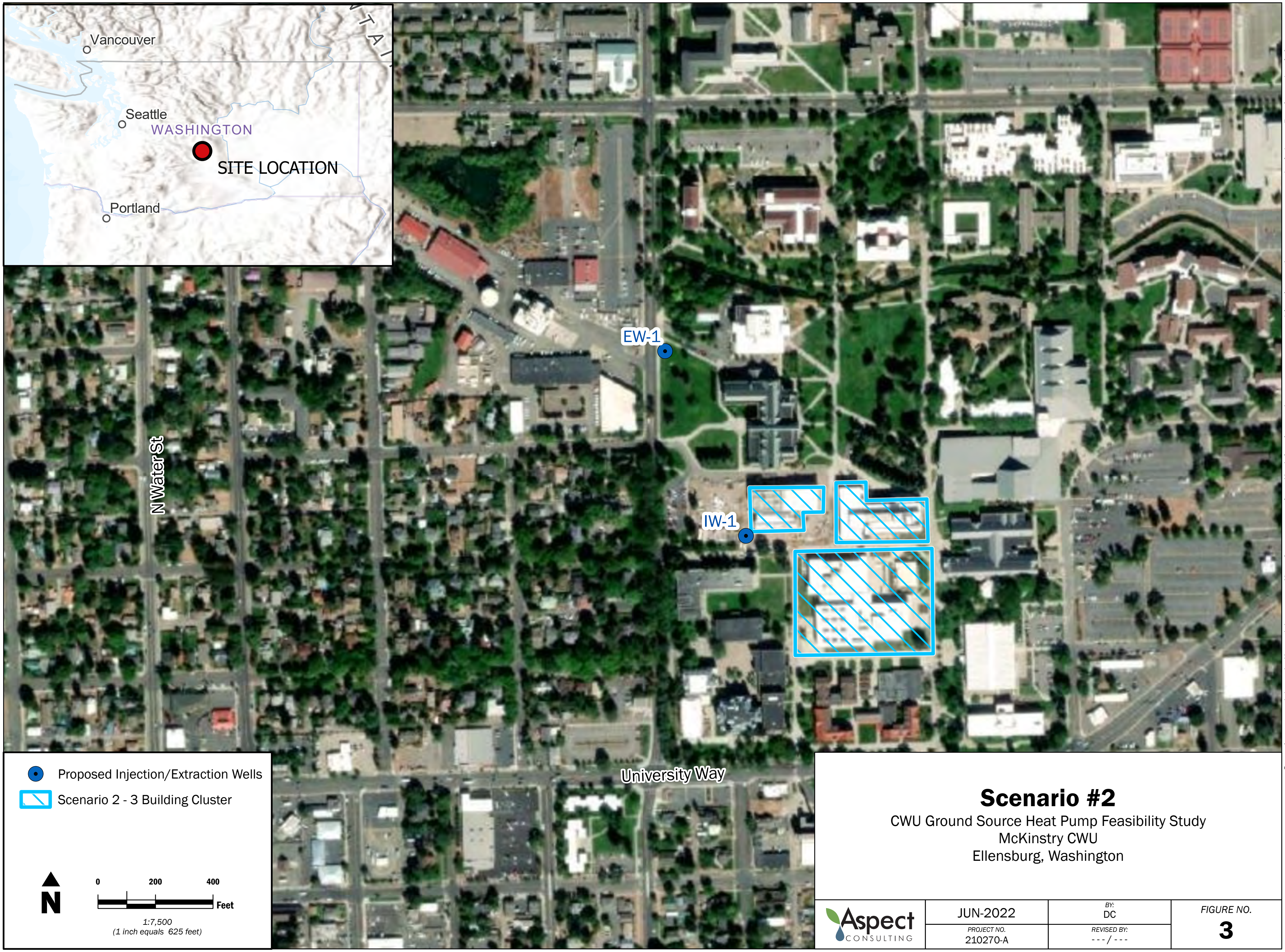

Scenario #2

CWU Ground Source Heat Pump Feasibility Study
McKinstry CWU
Ellensburg, Washington

Aspect CONSULTING	JUN-2022	BY: DC	FIGURE NO.
	PROJECT NO. 210270-A	REVISED BY: - - - / - - -	3

Data source credits: None || Basemap Service Layer Credits: Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, Esri, USGS, Maxar

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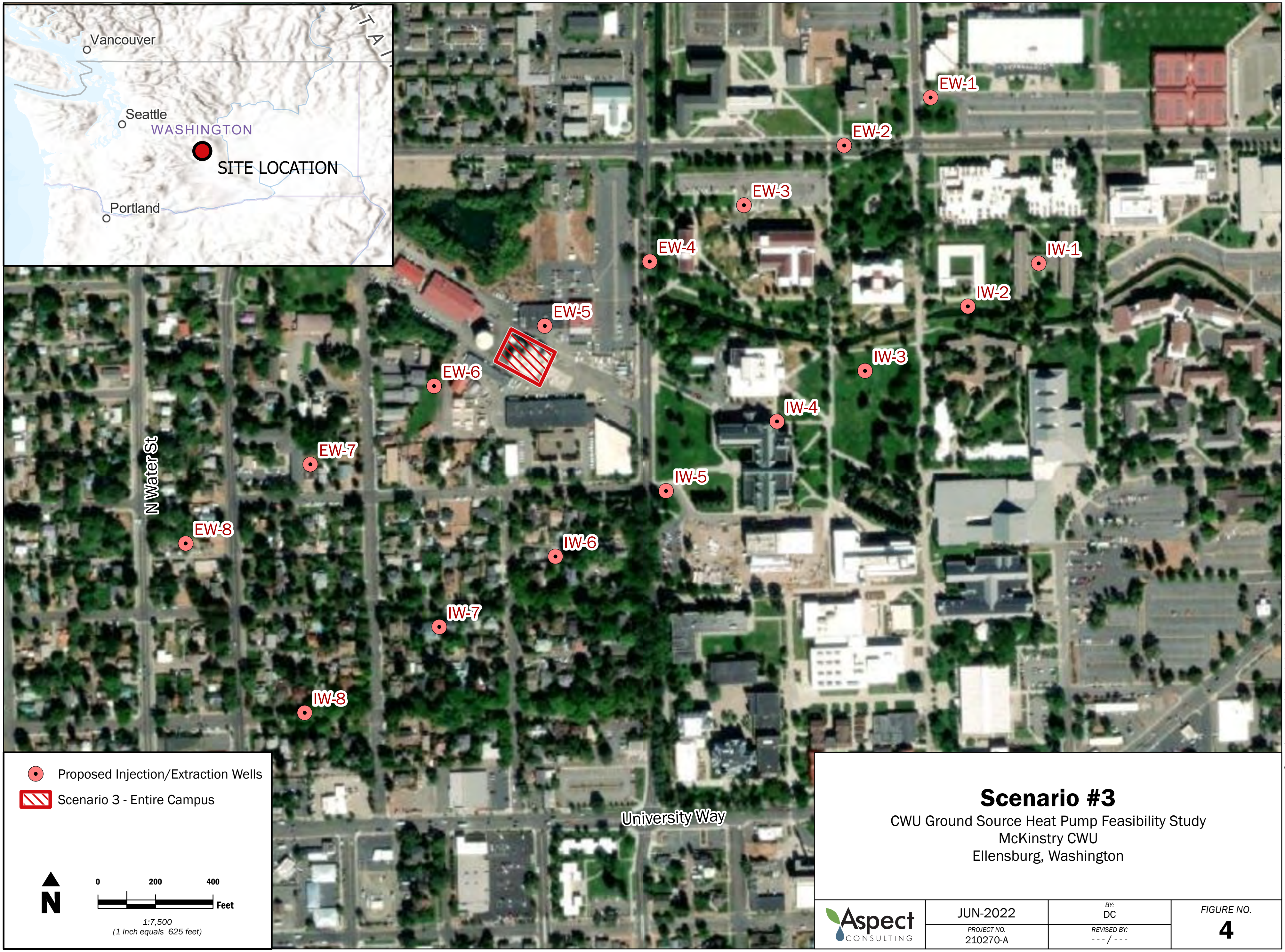

Scenario #3

CWU Ground Source Heat Pump Feasibility Study
McKinstry CWU
Ellensburg, Washington

Aspect CONSULTING	JUN-2022	BY: DC	FIGURE NO. 4
	PROJECT NO. 210270-A	REVISED BY: - - - / - - -	

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ATTACHMENT A

Thermal Modeling Results

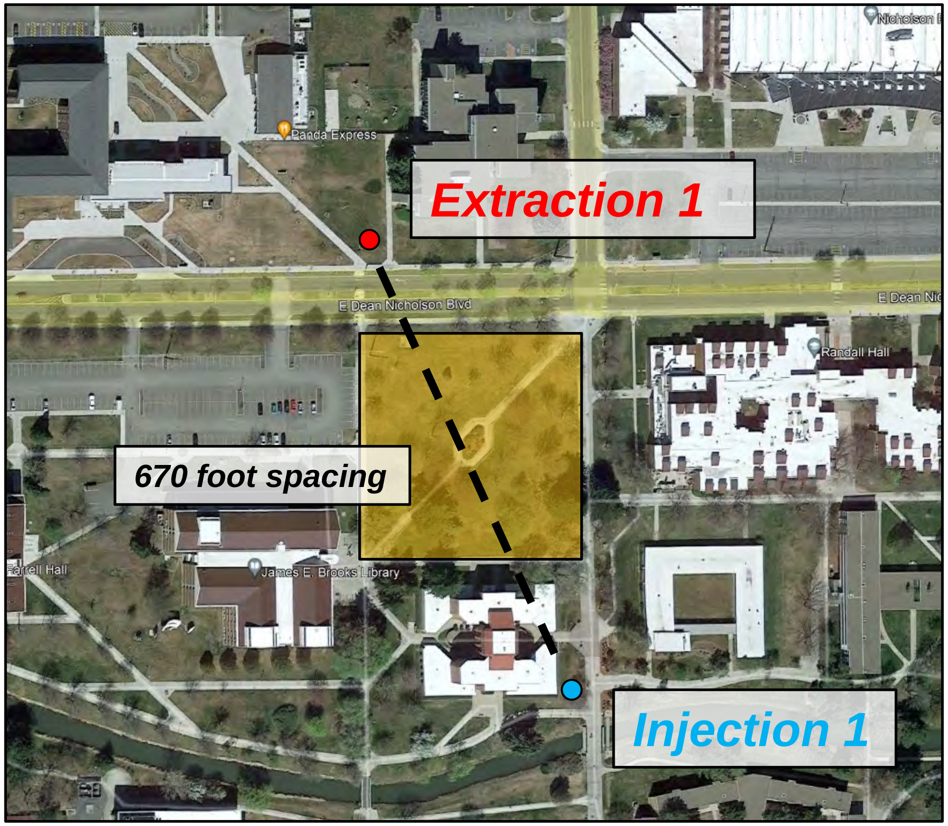
Attachment A

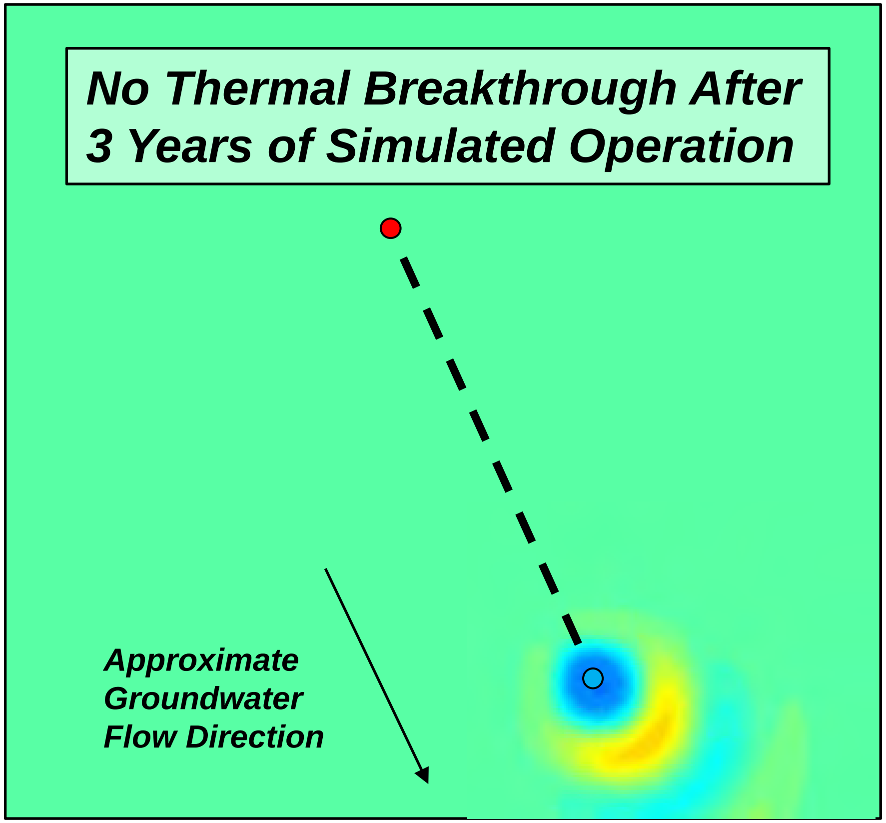
Project No. 210270, Ellensburg, Washington

Year	Month	Avg. Extraction Well Temp (degrees F)		
		Option 1	***Option 2***	***Option 3*** [1]
1	January	66	66	66
	February	66	66	66
	March	66	66	65
	April	66	66	64
	May	66	66	63
	June	66	66	62
	July	66	66	62
	August	66	66	63
	September	66	66	66
	October	66	66	69
	November	66	66	72
	December	66	66	69
2	January	66	66	64
	February	66	66	62
	March	66	66	62
	April	66	66	62
	May	66	66	62
	June	66	66	61
	July	66	66	62
	August	66	66	63
	September	66	66	65
	October	66	66	69
	November	66	66	72
	December	66	66	69
3	January	66	66	64
	February	66	66	62
	March	66	66	62
	April	66	66	62
	May	66	66	62
	June	66	66	61
	July	66	66	62
	August	66	66	63
	September	66	66	65
	October	66	66	69
	November	66	66	71
	December	66	66	69

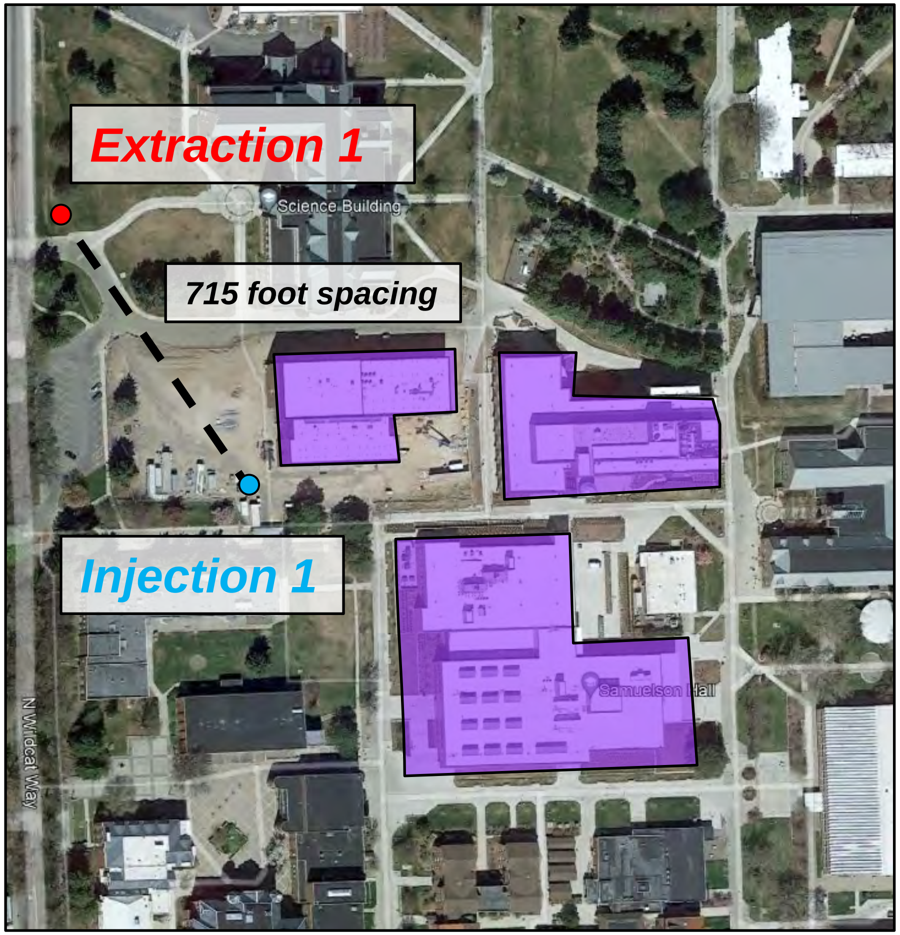
Note: [1] Temperatures were averaged across the 8 extraction wells for each time step. Extraction wells in the center generally experience a greater degree of thermal impairment as the capture zone for those wells pulls less ambient (66°F) groundwater than those on the edges.

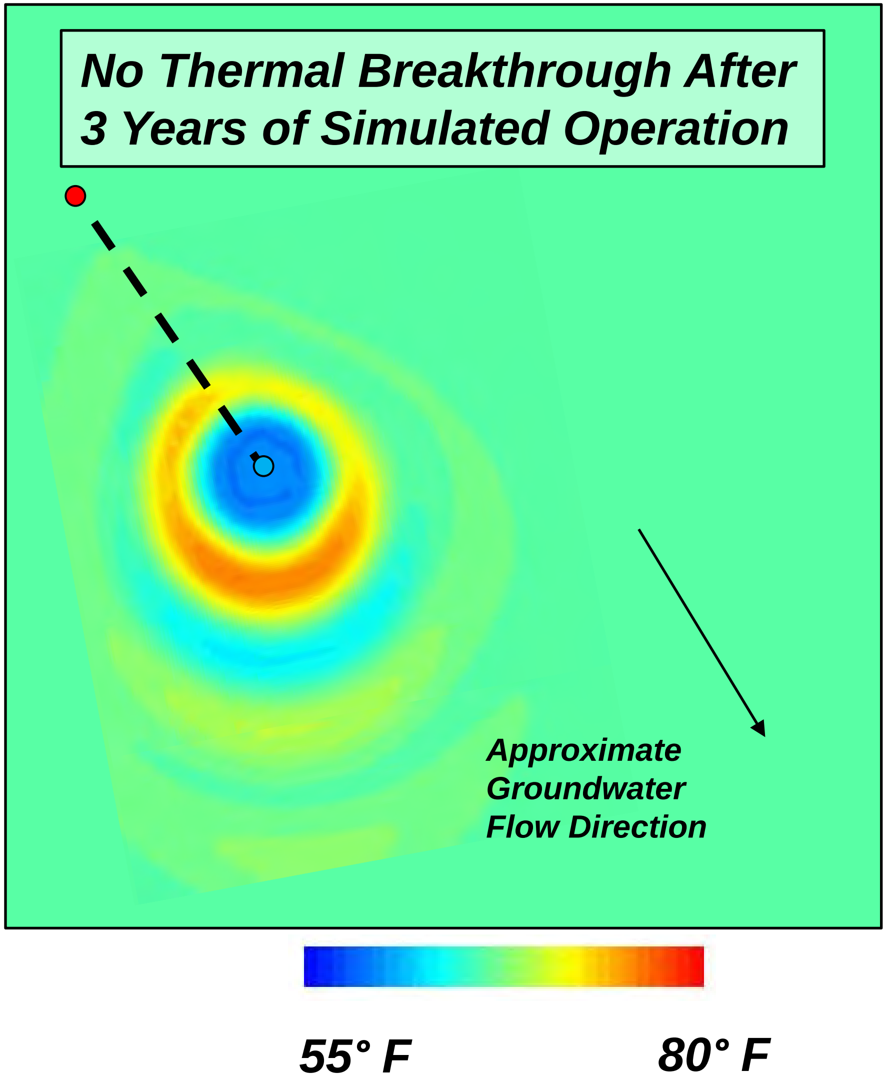
Option 1: NAC


Extraction 1
670 foot spacing
Injection 1
E Dean Nicholson Blvd
Panda Express
Randall Hall
James E. Brooks Library


No Thermal Breakthrough After 3 Years of Simulated Operation
Approximate Groundwater Flow Direction
55° F
80° F

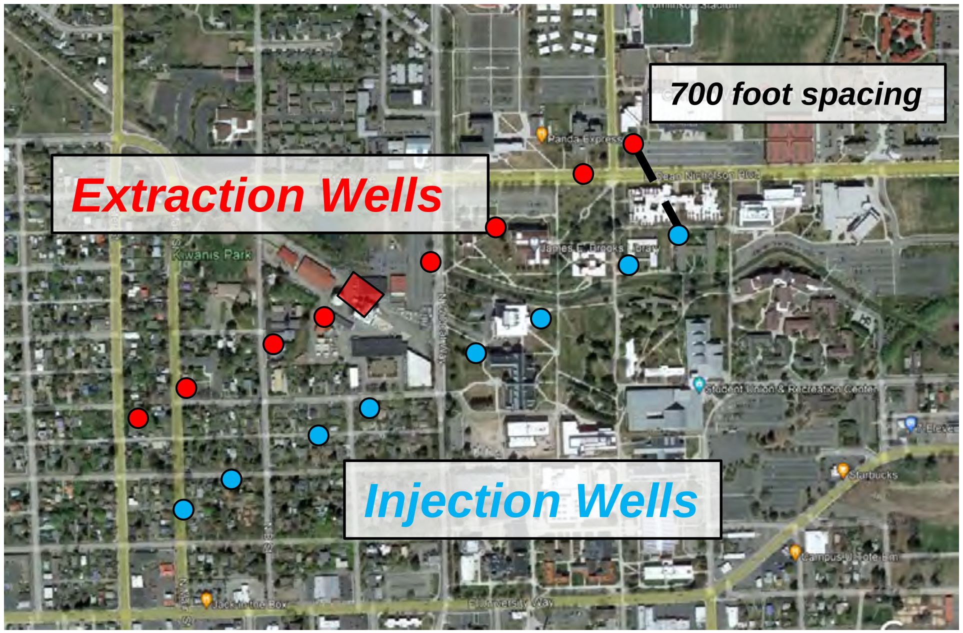
Option 2: 3 Building Cluster



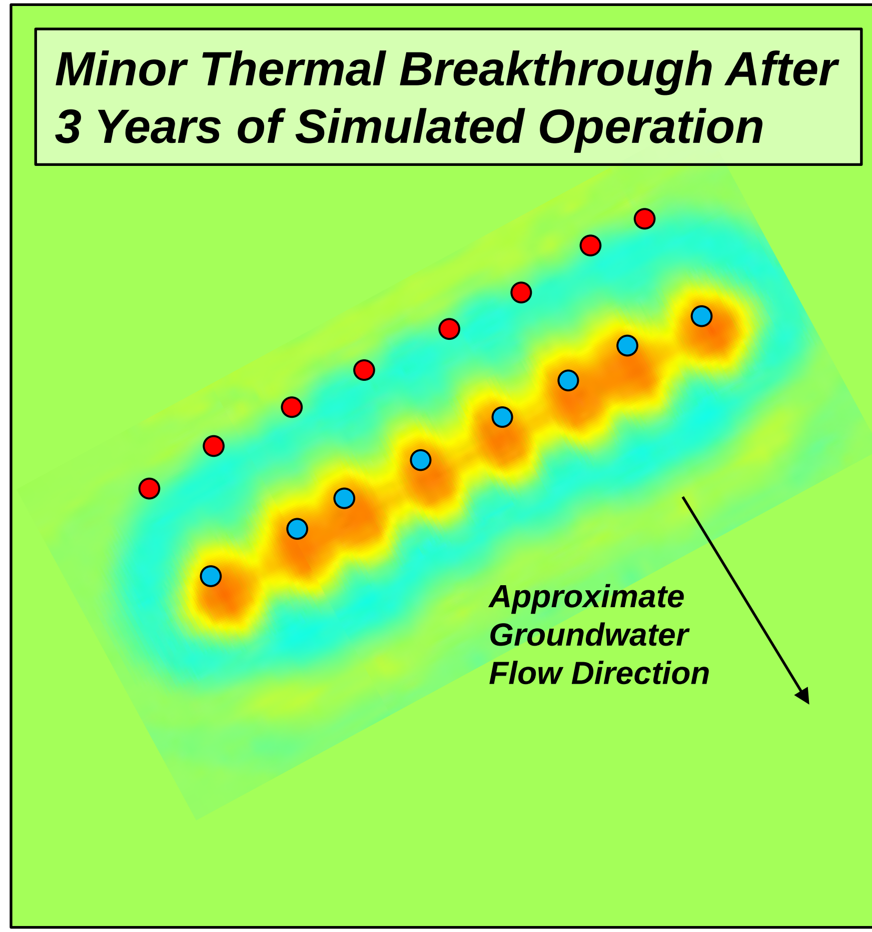


N

Option 3: Entire Campus



NOTE: *Due to scale, wellfield design does not consider current or planned buildings or utilities. Design was developed with regard to well spacing and groundwater flow direction.*



N ↑