Cascade, Idaho:

Geothermal-Inspired Design

Graduate Defense Project Compilation

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Applications of Low Temperature Geothermal Resources and Considerations for Sustainable Community Direct Use Development in the United States

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Part I:
Cascade, Idaho: Geothermal-Inspired Design

Geothermal energy is the internal heat of the earth. It is this energy that powers many of the large scale processes of the earth as the heat is redistributed from the inner core to cooler outer regions. For human utilization, geothermal energy is defined as our resource base, which is made up of all accessible and inaccessible heat. Geothermal resources are the portion of the resource base that is technologically accessible, regardless of economic viability. However, there are many regions where this resource base is readily accessible.

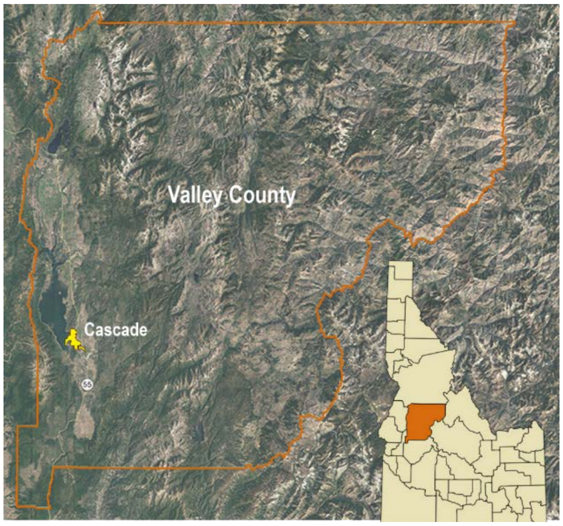


Figure 1 *County and City location*

Cascade, Idaho, is a scenic rural city settled between the mountains of west-central Idaho in Valley County. Bordered by Cascade Lake on the west and the Payette River on the east, the city has much to offer in the way of recreation and beauty. Since the closing of the Boise Cascade lumber mill—one of the city's major employers and occupier of a large parcel of land along the Payette River—the town's economic base is in a transitional phase from a lumber town to one more focused its other abundant natural resources.

An investigation conducted in 1976 concluded that Cascade has potential for direct use applications because the area is highly faulted by the north-south trending Long Valley Fault. The predicted subsurface temperatures based on a silica geothermometer is up to 354°F. The depth of wells drilled in Cascade has thus far revealed temperatures up to approximately 103°F. Of the eight drilled wells within the town, three are in use: the Cascade School District well, the Leisure Time well, and, most recently, the Mill well. Both the School District well and the Mill well have more capacity than what is used. Untapped potential also exists in dormant wells.

In the *City of Cascade Geothermal Feasibility Report* (2015), Hand and Mink explored the potential for the expansion of a geothermal district heating system. While one scenario looked at further use of the Mill well for district heating, the rest of the potential systems used some portion of the School District system either directly from the well or from the outflow system. No other direct use applications were investigated.

CASCADE GEOTHERMAL WELL DATA   DATA SOURCE: HAND, DAN & R. MINK, 2015

Well Name	Flowing Temperature, °F	Bottom Hole Temperature, °F	Depth, Feet
Wellington	?	78	1085, open to 651
LSD1	63-65	?	First to 406 then deepened to 560, lost 2°F of temperature, deeper was colder
Leisure Time	78	82	1006
Mill Well	98	?	431
Mill Well #2	62	?	320
CSD-1	73	81	1120
City Well	72	?	260
Davis Cattle Well	61.7	?	300

Figure 2
Geothermal well data

The following is an exploration of direct use applications of geothermal resources through design.

City of Cascade Background

Recent History: In 1914, the Union Pacific Railroad completed its track from Emmett to McCall, providing the area with the connection it needed to create a viable economic base to attract more residents. Logging, farming and ranching became the largest industries of the county, and the towns closest to the railroad—Cascade, Donnelly and McCall—would thrive and become the population hubs of the county. Many of the cities formed farther from the railroad would disappear.

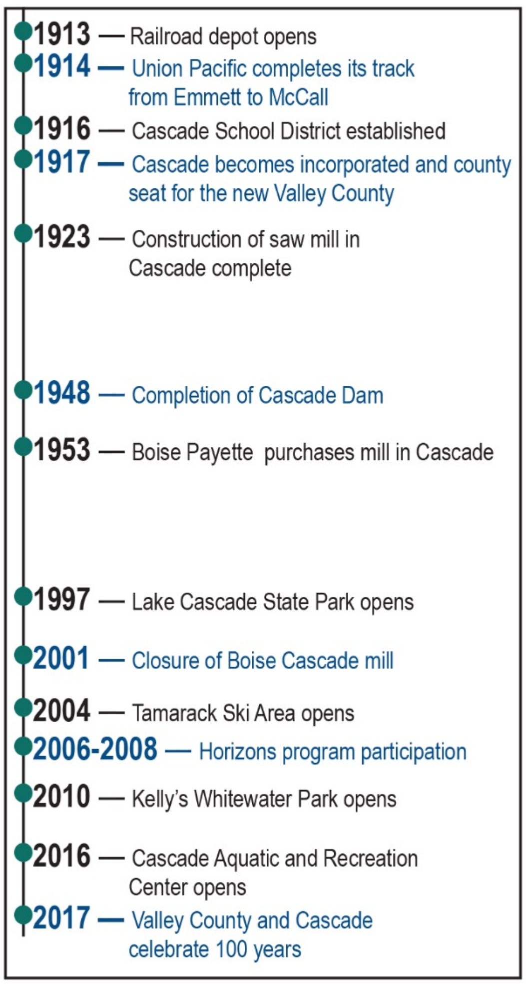


Figure 3 Recent history timeline: notable dates

Boise Cascade Corporation set up sawmills in both McCall and Cascade, providing employment for many of the area's residents. McCall's mill closed in 1977, but the town was able to shift to a recreation focused economy, one which thrives today. The mill in Cascade closed in 2001 and had more detrimental effects on the city's economy.

The Cascade Dam on the Payette River was completed in 1948 and created a reservoir that retains water for irrigation and flood control. Its completion flooded much of the northern valley creating Cascade Reservoir. Known today as Cascade Lake, it has become a fishery and serves as a recreation resource for the community and visitors to the area.

Economy: The closing of the Boise Cascade Mill in 2001 was a substantial economic blow to Cascade. As the then largest employer in Cascade, its closure took away 78 jobs, affecting not only individuals of the community, but the identity of the community. However, the town took the opportunity to shift focus toward new industry: tourism and recreation has since blossomed in the community and Cascade has developed amenities such as Kelly's White Water Park, Ashley Inn, Fischer Pond Park and the Cascade Sports Park, among others. The provision of supplies and services to recreational enterprises—such as backcountry excursion guides, wilderness guides, rafting guides, positions at equipment rental shops and hospitality-related jobs—provides further opportunity for employment. Additionally, ranching and logging remain major industries of the area.

Whether referencing past or present economy of the city, Cascade has always relied on its natural resources and beauty for its economic livelihood. Surrounded by national forest, fertile lands and beautiful rivers and lakes, Cascade's dependence on its natural setting is well established.

Connectedness: The city of Cascade is divided east and west by Highway 55, which is also the city's Main Street. The downtown area of the corridor contains sidewalks, curb extensions, crosswalks and other aesthetic features. Several other streets are paved, but most are unimproved and do not have designated pedestrian or bike routes.

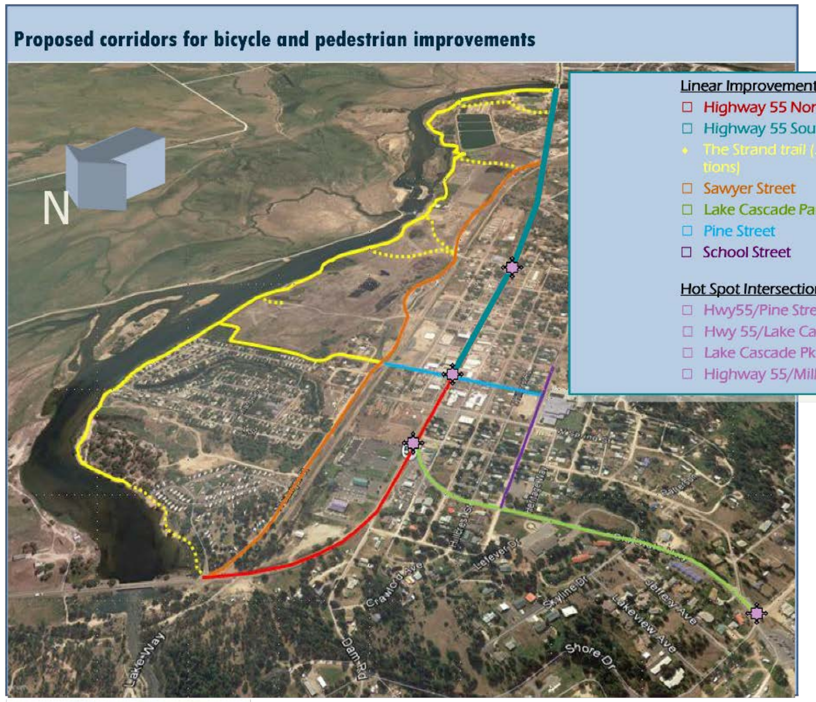
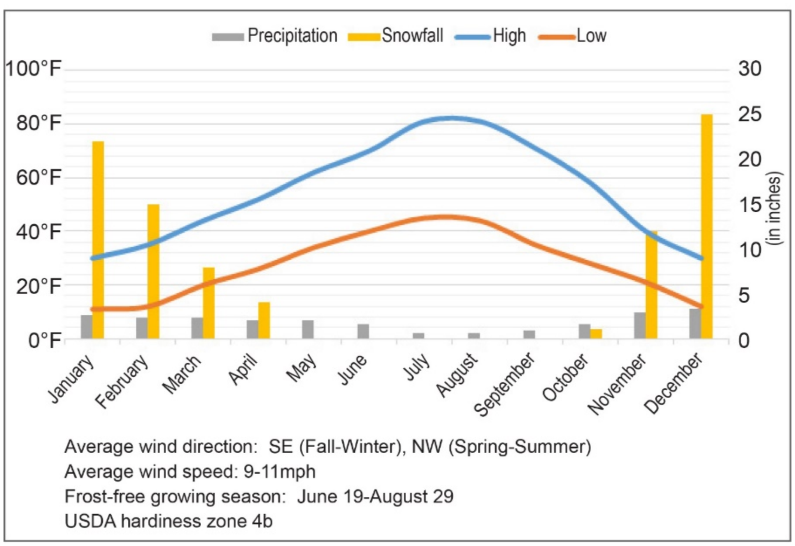


Figure 4 *Bicycle and Pedestrian Plan, New Mobility West, June 2015*

In 2015, the city of Cascade and the Cascade Mobility Team partnered with New Mobility West to develop a community transportation vision. The result was a comprehensive plan that included improvements to specific corridors and intersections as well as creating new connection trails, wayfinding signage and bike stations for the existing Strand Trail. The connection trails suggested were similar to those developed within the Cascade Pathways Master Plan in 2010. The top priority identified by the New Mobility West evaluation was improvement to pedestrian and bicycle lanes on Pine Street along with creating a safer crossing at the intersection of Pine Street and Highway 55.

Climate Chart



Climate: At approximately 4,750' above sea level, Cascade has a moderately cool climate with winter snowfall beginning as early as October and lasting into April. Total accumulation averages just under 100 inches per year. The cold, snowy winters are offset by moderately short but warm, dry summers. Nights are cool, even throughout the summer.

Figure 5
Climate Chart and Hardiness Zone

Former Boise Cascade Mill Site: The site on the eastern side of the city of Cascade that formerly hosted the Boise Cascade Mill is an area rife with opportunity. The land, largely under the ownership of Friends of Kelly's Whitewater Park Inc. is a recognized asset within Cascade and by those interested in the city's development.

The brownfield designation currently hinders development on the northern half of the site while the southern half is limited to commercial and industrial uses. The southern half has seen two major developments: Kelly's Whitewater Park and the Cascade Aquatic and Rec Center.

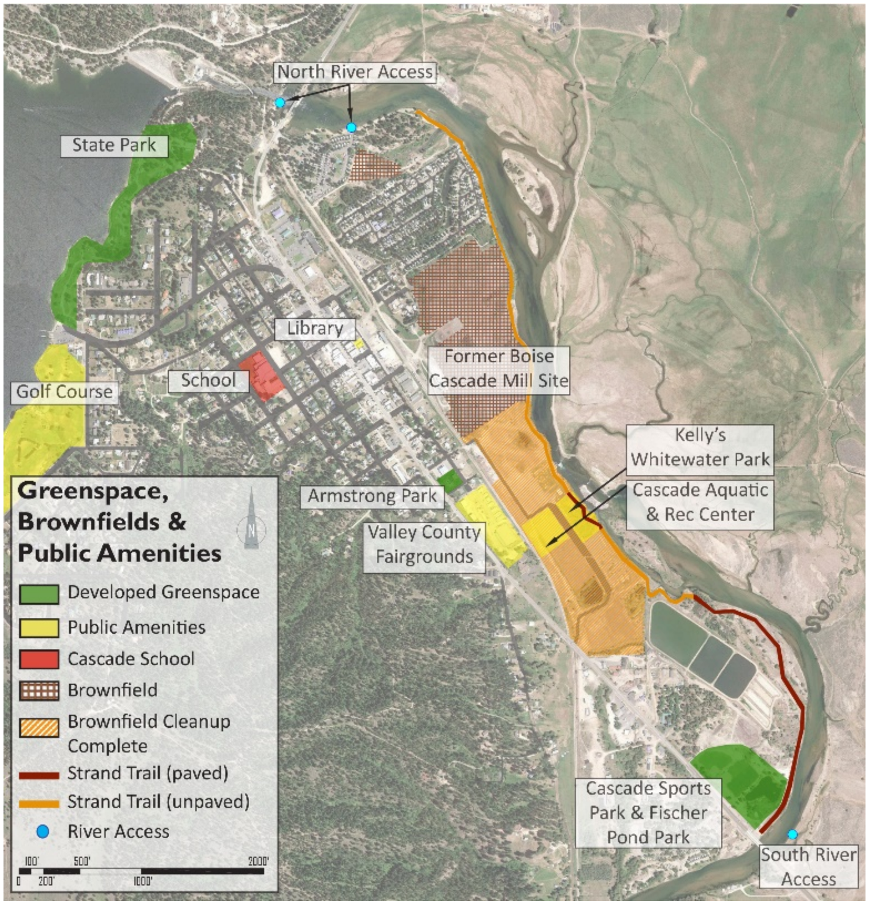


Figure 6 *Former Mill Site and Public Amenities*

- Kelly's Whitewater Park opened in 2010 and was made possible by the vision and direct investment of the owner along with collaboration and fundraising by the community through its involvement from 2006 to 2008 in the Idaho's Horizons program, a community leadership program sponsored by University of Idaho Extension program.
- The Cascade Aquatic and Rec Center opened in 2016 was the culmination of a project conceived over 30 years ago and made possible by the formation of the Southern Valley County Recreation District for fundraising in 1998.

BROWNFIELD: The 120-acre property once occupied by the Boise Cascade Mill was classified as a brownfield because activities associated with the storage and handling of logs prior to processing could lead to environmental impacts. After the mill's closure, Boise Cascade officials, Valley County officials, city of Cascade officials, the DEQ and members of the public met to decide upon the future of the area. The stakeholders decided that the property should be assessed and measures for cleanup should be taken if necessary in order to redevelop the land.

Beginning in 2004, the lumberyard was assessed, comprising 80 acres of the site. Pentachlorophenol, petroleum hydrocarbons, and arsenic found in the soils were above allowable concentrations. Pentachlorophenol is used to treat lumber for utility poles and railroad ties; petroleum hydrocarbons are made up of several hundred chemicals that come from crude oil; the presence of arsenic is possible from past mining practices. From 2004 to 2010, a Voluntary Cleanup Program was successfully implemented and completed, involving the excavation and treatment or removal of contaminated soils, groundwater monitoring, and screening and processing of log yard debris.

Currently, the 60 acres in the southern portion of the former Boise Cascade site is considered safe for commercial and industrial uses only, and has begun transformation into an area of recreational opportunities, including Kelly's Whitewater Park and the Cascade Aquatic and Recreation Center. Assessment and cleanup of the northern 60 acres may be required for further development.

GEOLOGY & GEOTHERMAL RESOURCES: Much of the city of Cascade is built upon the alluvial deposits of sand and gravel from the North Fork of the Payette River. The remainder is colluvium derived from granite rocks or man-made fill. Granite rocks are found at shallow depths beneath the alluvial sediments throughout the city. Man-made fill occurs throughout the former mill site and south near the river. It also occurs at the zoned earthfill Cascade dam which forms Cascade Lake and controls the floodplain to essentially remove risk of flood from the area of the city that lies next to the Payette River. There are major north-south trending faults in Valley County as well as east-west trending faults. There has been recent minor seismic activity of faults in the area and the intersection of the two types of faults could provide pathways for geothermal fluids.

Several thermal springs are identified in Long Valley near Cascade. These include Carbarton Hot Springs (6 miles south of Cascade), Belvidere Hot Springs (5 miles south of Cascade), and Davis Hot Springs (2 miles east of Cascade). Several other thermal springs occur north of the city ranging in temperature from 81°F to 122°F. Overall, there are 91 geothermal water sites recorded in Valley County, 54 of which have temperatures greater than 85°F, but less than 212°F, so are classified as low temperature geothermal resources.

SURFICIAL GEOLOGIC MAP OF CASCADE, VALLEY COUNTY, IDAHO

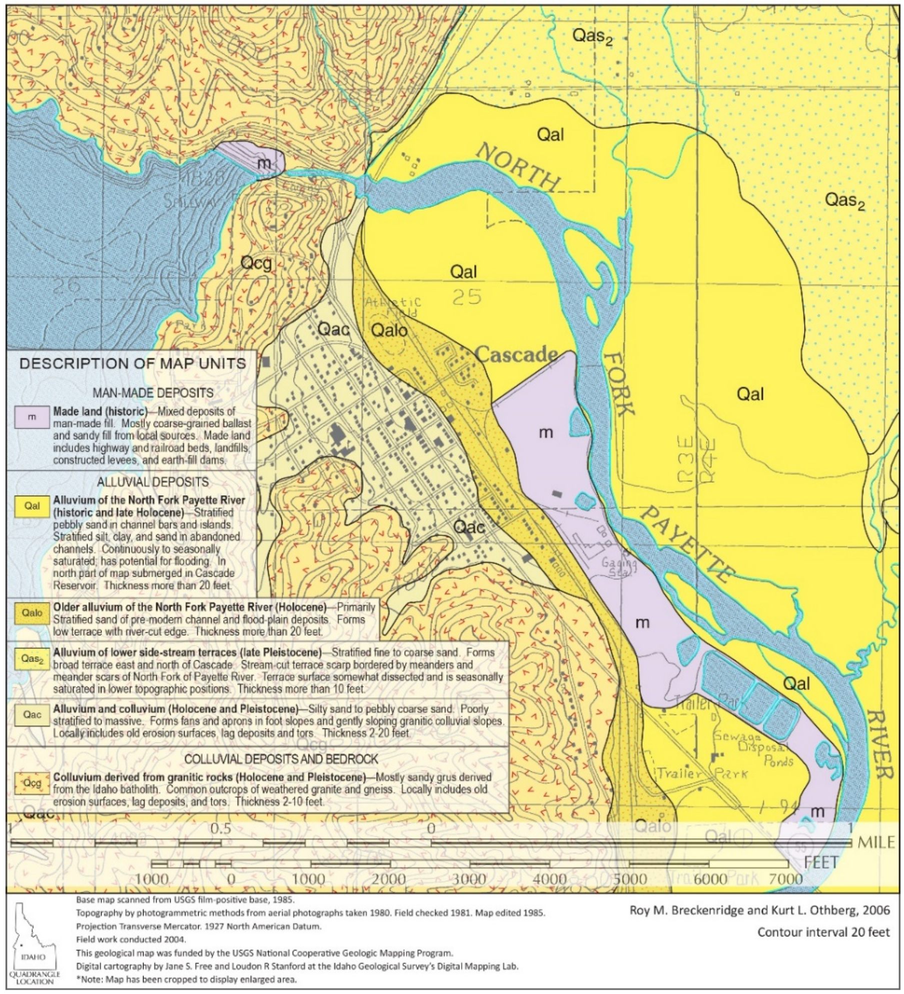


Figure 7 *Surficial Geologic Map*

LOW TEMPERATURE GEOTHERMAL RESOURCES & MAJOR FAULTS

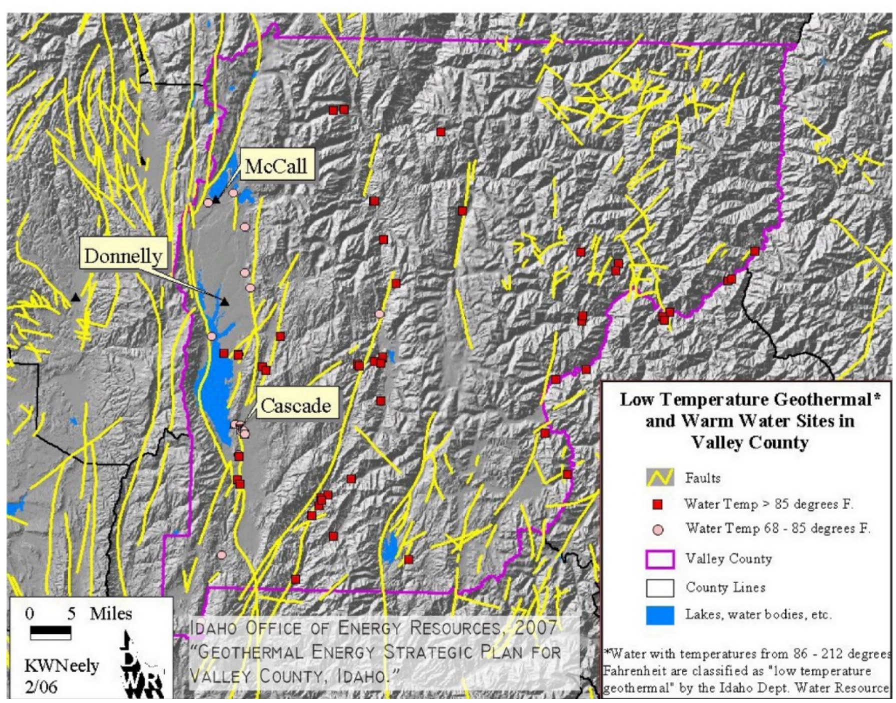


Figure 8 *Geothermal Resource Map*

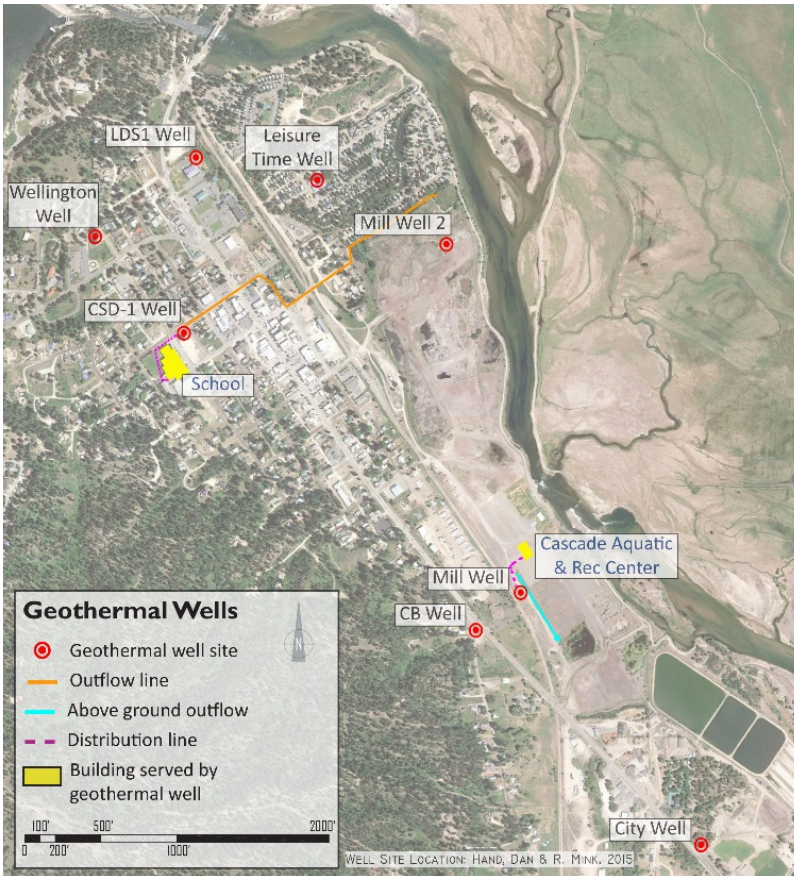


Figure 9 *Geothermal well location*

GEOTHERMAL SPENT FLUID DISPOSAL IN CASCADE: There are three basic options when it comes to disposal of spent fluids in order to avoid both thermal and solid waste pollution to land and water: subsurface injection, disposal to surface waters, and/or disposal to the ground. Of these, reinjection is considered the most sustainable as it helps to maintain reservoir pressure and can replenish the reservoir. However, the high cost and complexity can be prohibitive for smaller direct use developments.

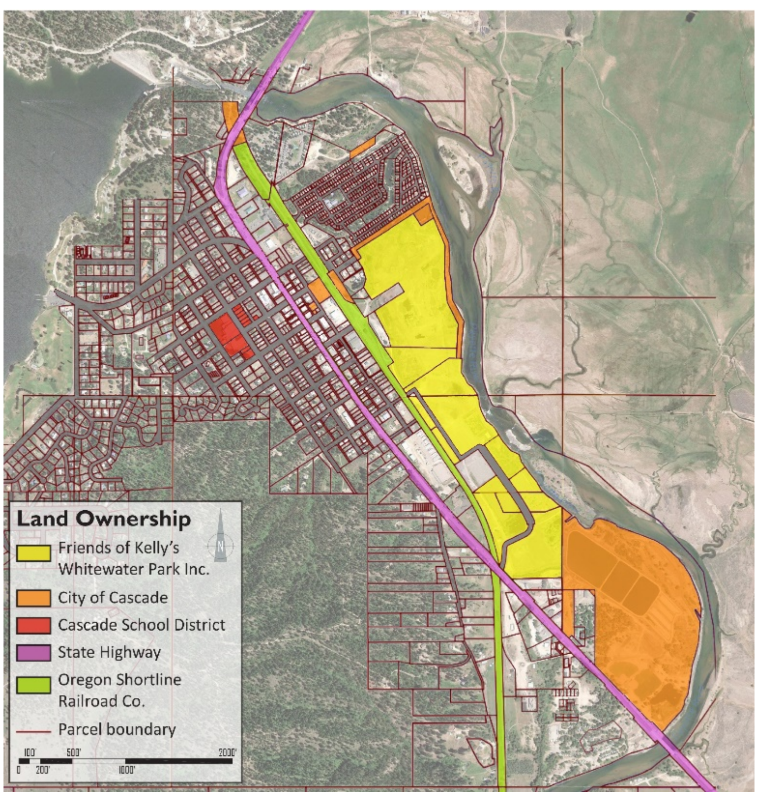
Disposal of geothermal spent fluids from all geothermal well usage in Cascade is accomplished above ground. The School District originally installed injection wells but was hampered with flooding issues related to the reinjection method. The outflow line installed in 2014 solved the flooding issue and discharges water to an area adjacent to the Payette River. Additionally, seven tees were placed along the outflow line to allow for future ease of expansion of the system. The Mill well utilizes a short outflow line and its above ground disposal follows a channel to a wetland area within the former mill site.

FEASIBILITY OF DEVELOPMENT: While economic incentive to develop geothermal resources for heating is tied directly to the cost of alternative fuels as outlined in the 2015 *City of Cascade Geothermal Feasibility Report,* the feasibility of pursuing implementation of a range of direct use geothermal projects lies in community commitment to city improvement and foresight for unique economic and social opportunities. Additionally, relatively easy access to the resource is important along with available land for development. In the case of Cascade, each of these conditions can be met.

- **Community Commitment:** In 2003, University of Idaho Extension launched Idaho's Horizons program, a community leadership program that focused on reducing poverty in small rural communities across the state. By helping communities to first understand poverty and then develop a plan to bring about lasting change in the community, Horizons seeks to develop interest, leadership and involvement within small towns as well as strengthening collaboration between government, non-profit and grass-root groups. Cascade took part in the second phase of the program between 2006 and 2008. Inciting leadership and excitement, the community accomplished several goals: providing better access to library books; developing a community newsletter; and completely revamping an existing park to include a basketball court and playground. Additionally, enthusiasm was generated for Kelly's Whitewater Park, promoting an enhanced schedule for planning, organization and fundraising and served as an engine to complete the project.

This serves as an example of the support that can be generated within the community and the proven dedication that exists to complete a larger-scale project. While time has passed since the initial zeal created by the Horizons program, the community has shown commitment to transitional change in projects such as the Cascade Aquatic and Recreation Center and continued investigation into community enhancement developments such as geothermal resource expansion and a community transportation vision and pathways master plan.

- **Economic Opportunity:** The use of geothermal resources to enhance the economic operation of several opportunities that necessitate specific heat requirements has a proven track record. Geothermal resources have allowed for the economical operation of commercial greenhouses in cold climates where such operations were previously not a financially viable option. This same benefit can be applied to aquaculture operations. Investment in these types of geothermal applications can not only add to food security but the proven availability of the unique and sustainable resource can attract further development, as seen in Klamath Falls, Oregon. There, the availability of geothermal energy was attributed with attracting a large-scale nursery that provides both employment for the community as well as tree seedlings for local reforestation projects.
- **Land and Resource Availability:** The city owns the land from Highway 55 to the existing river path. (The river path is not entirely within the city's ownership, but is a recognized issue within the leadership of the community.) Also, the pipe for the spent geothermal fluid from the school geothermal heating system currently runs directly under the same city owned land.



The city also owns the land as shown in the southwestern portion of the map. The unused city-owned well sits at the western corner of the site.

The largest parcel of land is owned privately by Friends of Kelly's Whitewater Park, Inc.—an organization known for its support of community enhancing projects. Given an attractive and appropriate proposal for land usage, the company has shown willingness to lease land for a negligible amount.

Figure 10
Selected Land Ownership Map

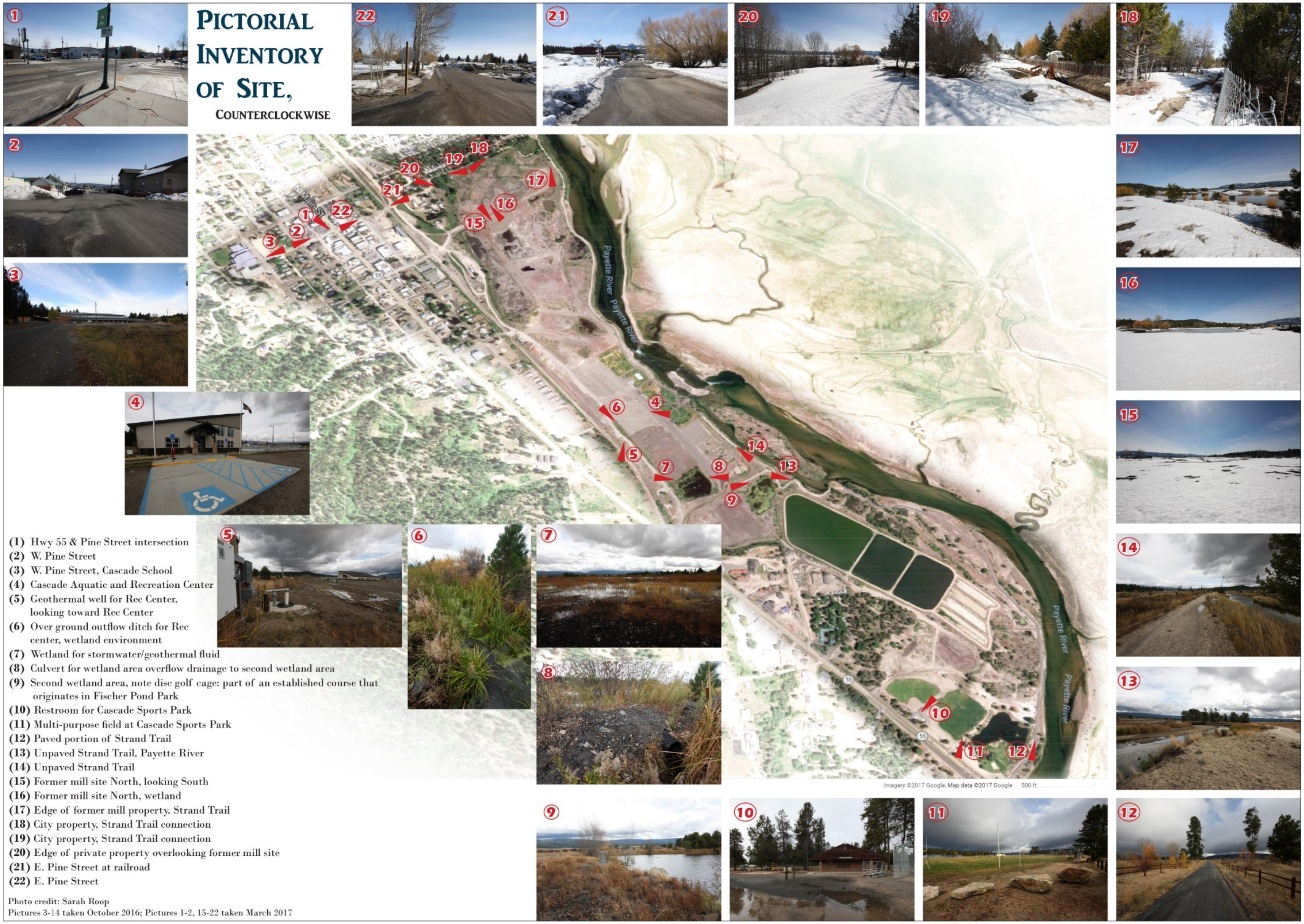
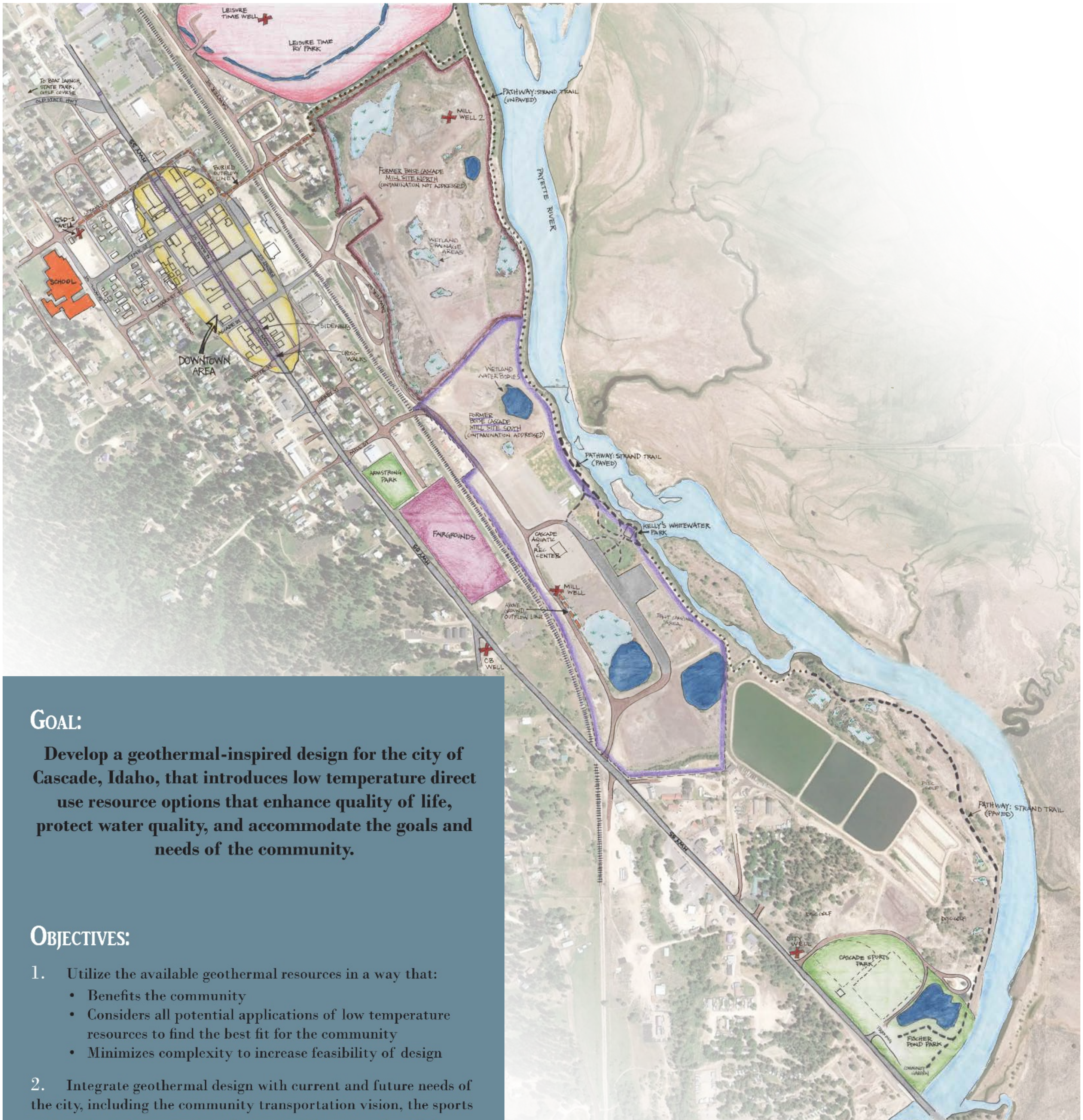


Figure 11 *Pictorial inventory*

Project Development



Goal:

Develop a geothermal-inspired design for the city of Cascade, Idaho, that introduces low temperature direct use resource options that enhance quality of life, protect water quality, and accommodate the goals and needs of the community.

Objectives:

1. Utilize the available geothermal resources in a way that:
   - Benefits the community
   - Considers all potential applications of low temperature resources to find the best fit for the community
   - Minimizes complexity to increase feasibility of design

2. Integrate geothermal design with current and future needs of the city, including the community transportation vision, the sports park goals, and preservation of its natural beauty and wildlife

3. Provide safe and convenient connectivity between the east and west sides of the city across Highway 55 with special consideration to school crossings

4. Protect water quality, both in regard to spent geothermal fluid disposal and stormwater runoff

5. Create further opportunity within Cascade for economic, recreational and educational growth utilizing the integration of sustainable resources and design

Figure 12 Site Composite with project Goals and Objectives

Site Analysis & Conceptual Design

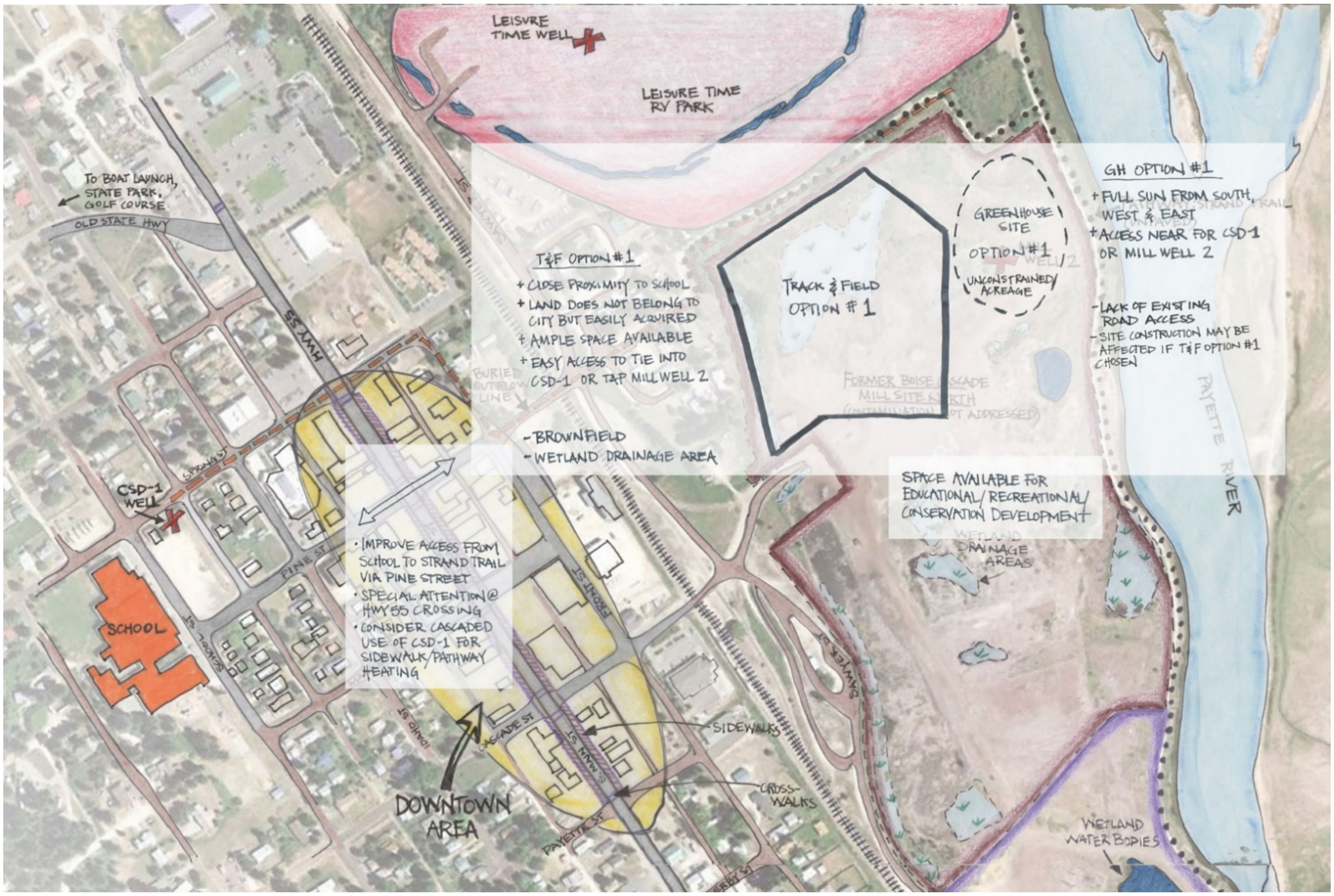


Figure 13 *Site location analysis, Part I*

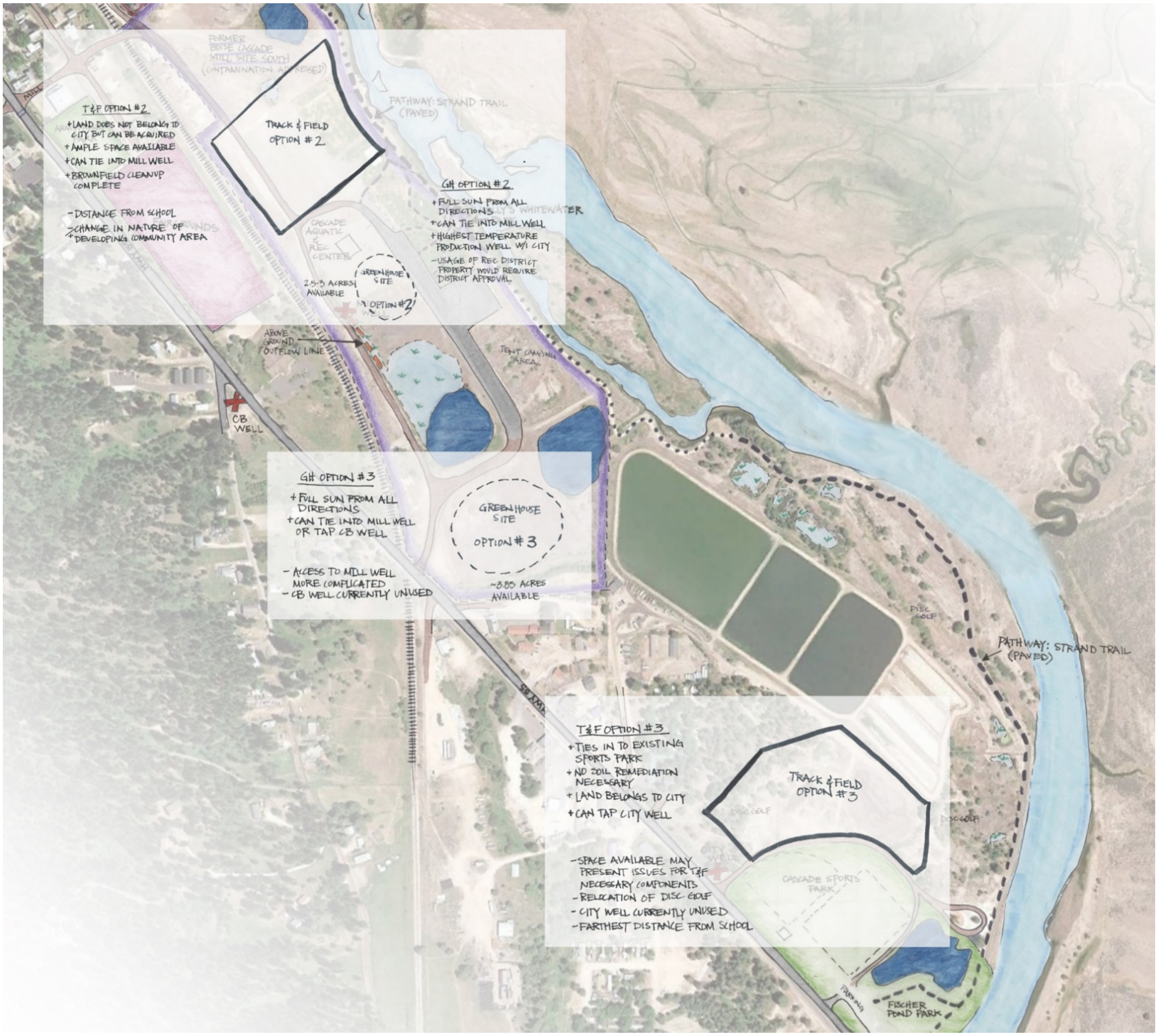


Figure 14 *Site location analysis, Part II*

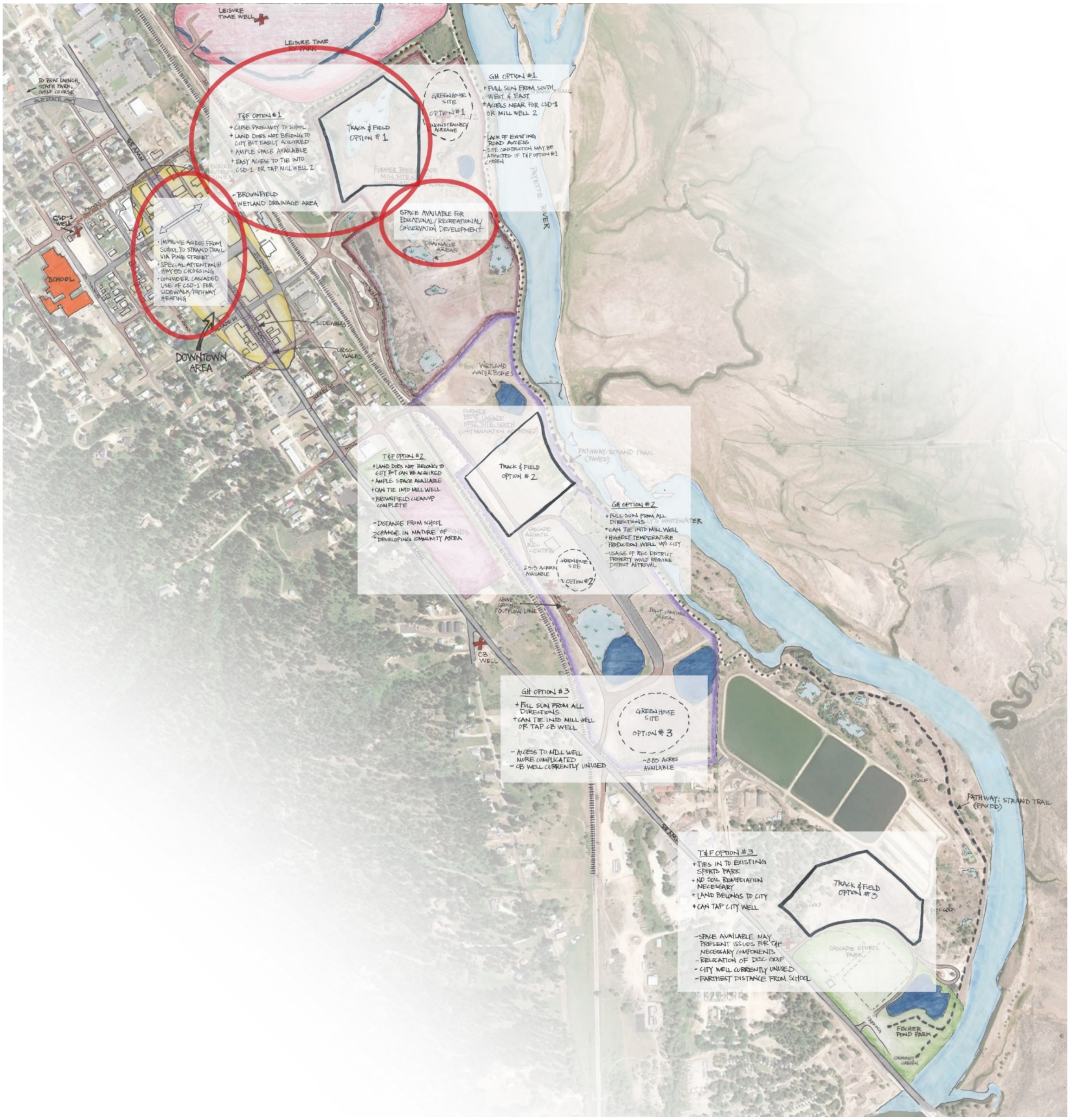
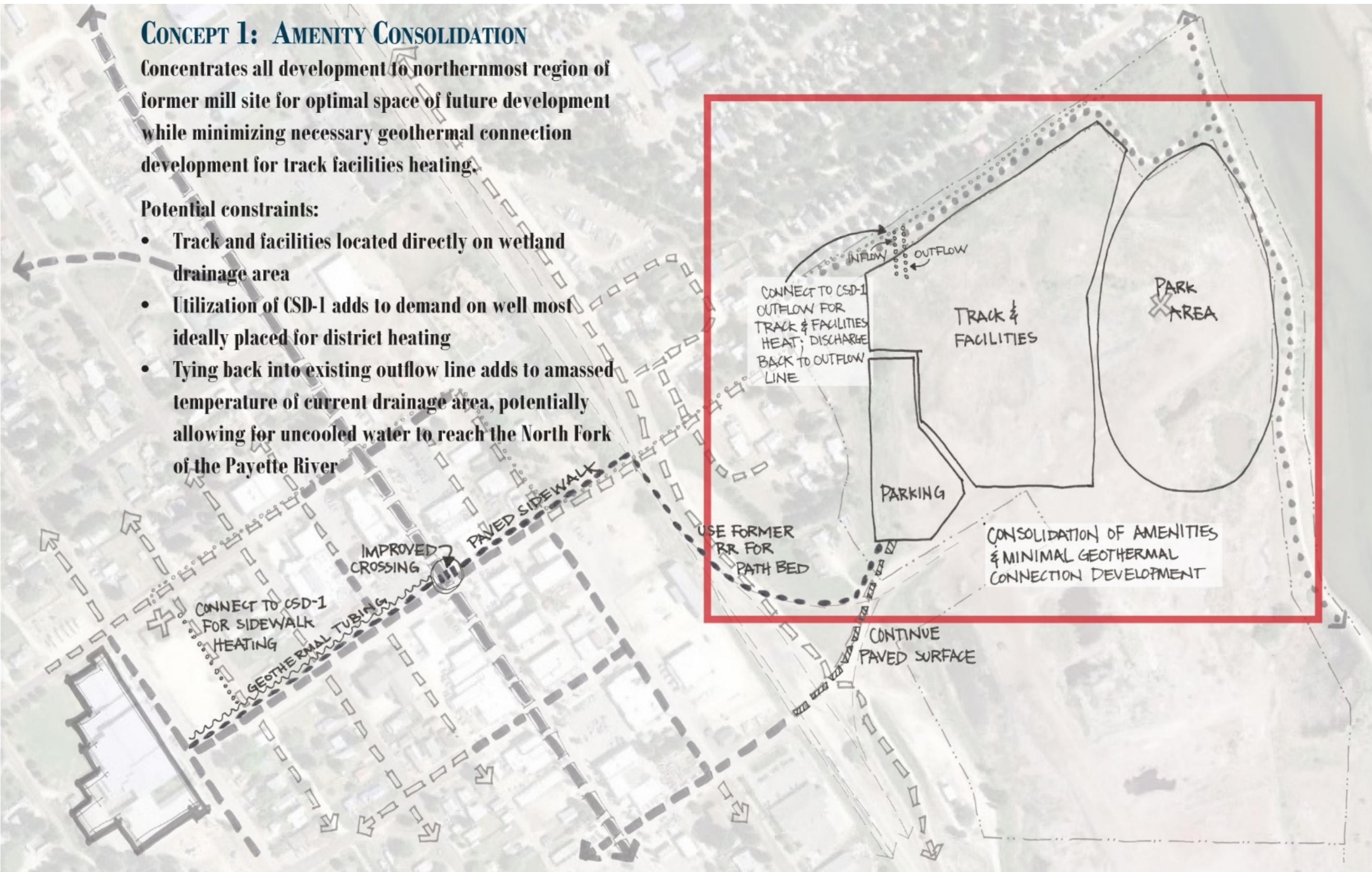


Figure 15 *Chosen Project Development focus; See following conceptual designs*



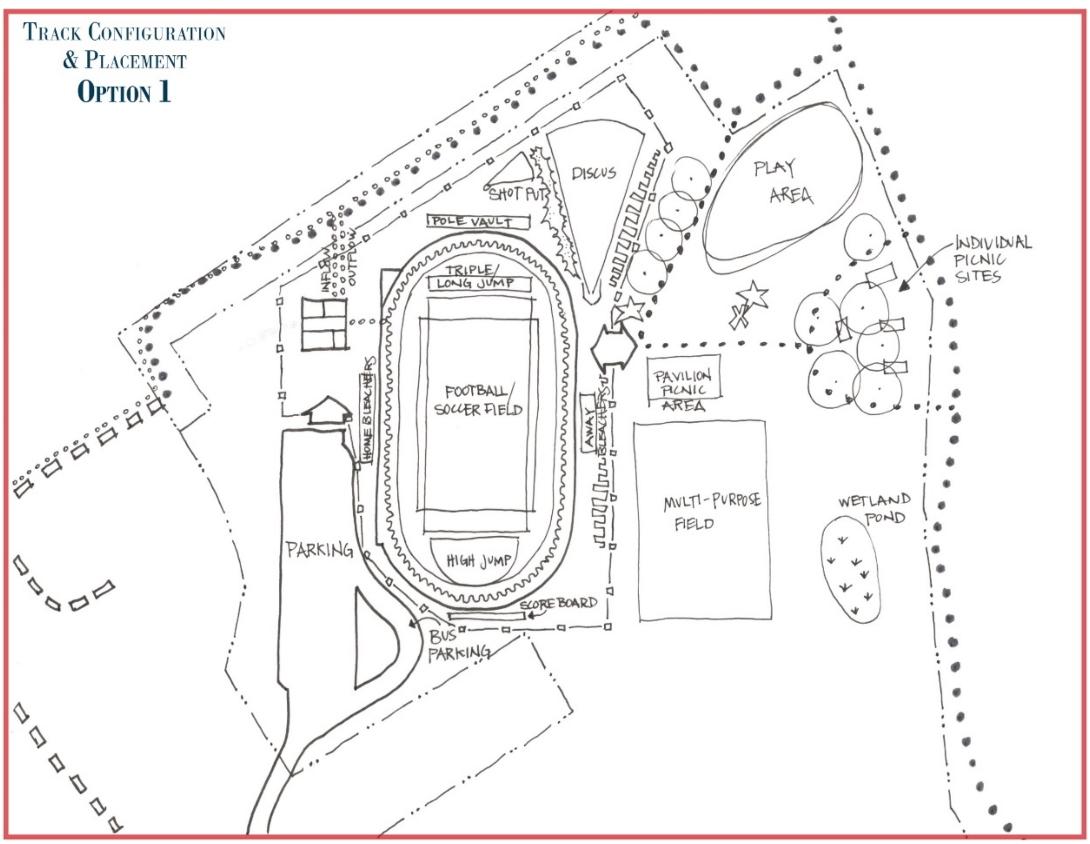
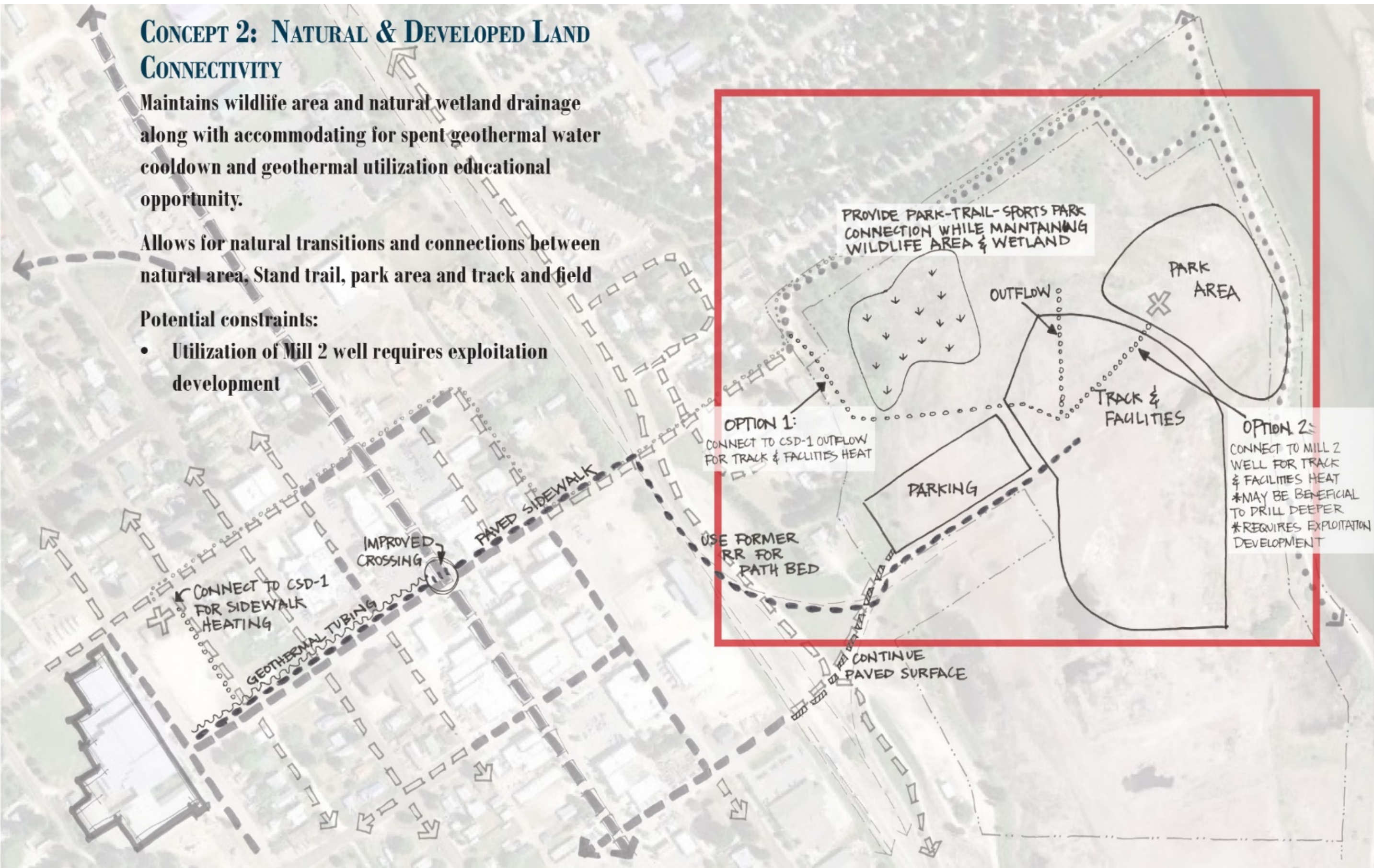


Figure 16
Conceptual Development for Design, Option 1. Detailed concept to left.



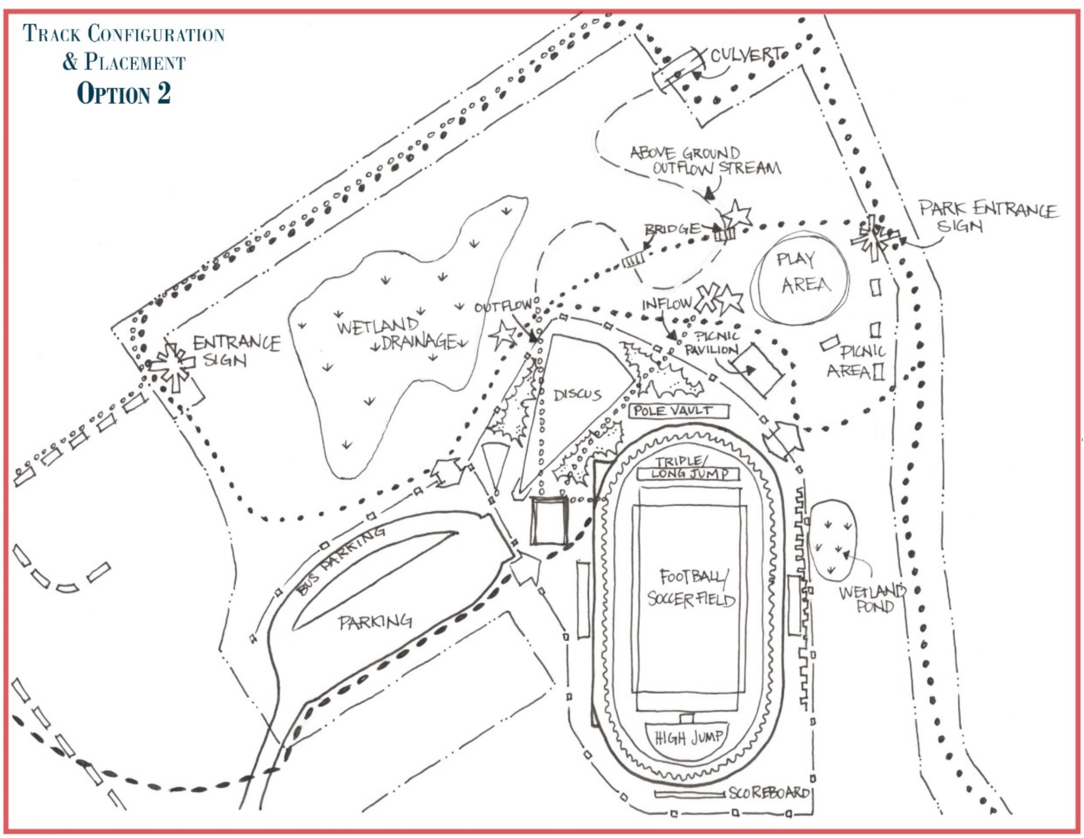


Figure 17
Conceptual Development for Design, Option 2. Detailed concept to left.

MASTER PLAN

GEOTHERMAL WELL APPLICATION

The following design utilizes two existing geothermal wells in Cascade—CSD-1 well located near the school and Mill 2 Well located at the north end of the former mill property.

CSD-1: A new inflow line traverses the school lot from the current pump house to bring geothermal water to the new sidewalk along Pine Street from School Street to Main Street. The four block expanse of geothermally heated sidewalk provides a safe and year-round accessible passage from the school to downtown Cascade, along with providing a trial run for sidewalk heating application within the city.

In addition to the expanded use of the well, the outflow line is redirected from a wetland adjacent to the North Fork of the Payette River to a seasonal wetland farther inland from the river. The new drainage sight for the geothermal water then flows into a drainage creek designed to continue to eliminate any contaminants and cool the water. The creek empties into the secondary wetland adjacent to the river. Readjustment of the outflow will allow for expanded use of CSD-1 in the future without introducing thermal and other pollutants to the North Fork of the Payette River.

Mill 2 Well: Currently unutilized, an inflow line brings geothermally heated water from Mill 2 Well to a newly built pump house that is a multi-use building for the track and field. The water is then directed to the track allowing for year-round usage and early season training. Additional uses of the geothermal heat could include onsite walkway heating and handicap parking space heating. The outflow line is directed to the head of the designed stream to join the water from CSD-1.

Figure 18 *Master Plan*

DESIGN ELEMENTS

Streetlights: While streetlights exist along Main Street, new streetlights are added to Pine Street, placed strategically along the new path to the track and field facility, and included in the track and field parking lot design.

Crosswalk: A raised crosswalk with material change will increase safety at the Pine Street/Main Street crossing. Additionally, a Rectangular Rapid Flashing Beacon (RRFB) will accompany the pedestrian crossing.

Pathways: Along with a paved 10' wide path to the track and field that follows the former railroad bed, a defined path extends along Pine Street to connect to the existing city property trail that ties into Strand Trail. At the point of connection, a new trail will link to the track and field complex and continue on to Geothermal Park and Strand Trail.

Geothermal Park: Designed as an educational and recreational amenity, Geothermal Park incorporates educational placards throughout the design. The park consists of a pathway system, a dispersed picnic area, a playground inspired by the history and culture of the town, and a pavilion picnic area that can serve as an eating area for participants and visitors at a sports event.

Track and Field: An 8-lane, 400 meter track encircles a field that can host both football and soccer. All Idaho field events are present including high jump, long jump, triple jump, pole vault, discus and shot put. Additionally there is a scoreboard, home and away bleachers, and a multi-purpose building with locker rooms, restrooms and concessions. The entire area is fenced with access from the parking lot and from Geothermal Park. The parking lot accommodates 110 vehicles plus 6 handicap spaces and bus parking. It is designed to hold and treat stormwater runoff.

Wildlife: The area north of the track that is inclusive of the wetland is preserved for wildlife. Development within Geothermal Park is kept minimal to maintain a wildlife corridor along the river that maintains at least 200' spacing.

Figure 19 *Site perspective 1: Bird's eye view*

Figure 20 *Site perspective 2: Track and field entrance*

Figure 21 *Site perspective 3: Track access to pavilion and Geothermal Park*

Figure 22 *Site perspective 4: Geothermal Park playground, looking toward Payette River*

Figure 23 *Site perspective 5: West bridge over cooling stream*

PINE STREET SNOWMELT DESIGN

Figure 24 *Site perspective 6: Pine Street sidewalk*

The Pine Street sidewalk heating has about 6,090 ft^2 of snow melting surface. The required heat load varies with air temperature, wind, snowfall rate and snow accumulation. The design objective is to provide adequate performance while limiting installation and operation costs. The variables in snowmelt design are climate, available geothermal temperature and flow, tube depth, and tube spacing. The desired outcome would maintain a slab surface temperature of 38°F at 15°F air temperature with a 5mph wind speed. These conditions require 85 Btu/hr/ft^2. The same variables would apply to heating of the track, with consideration to the difference of a rubberized surface.

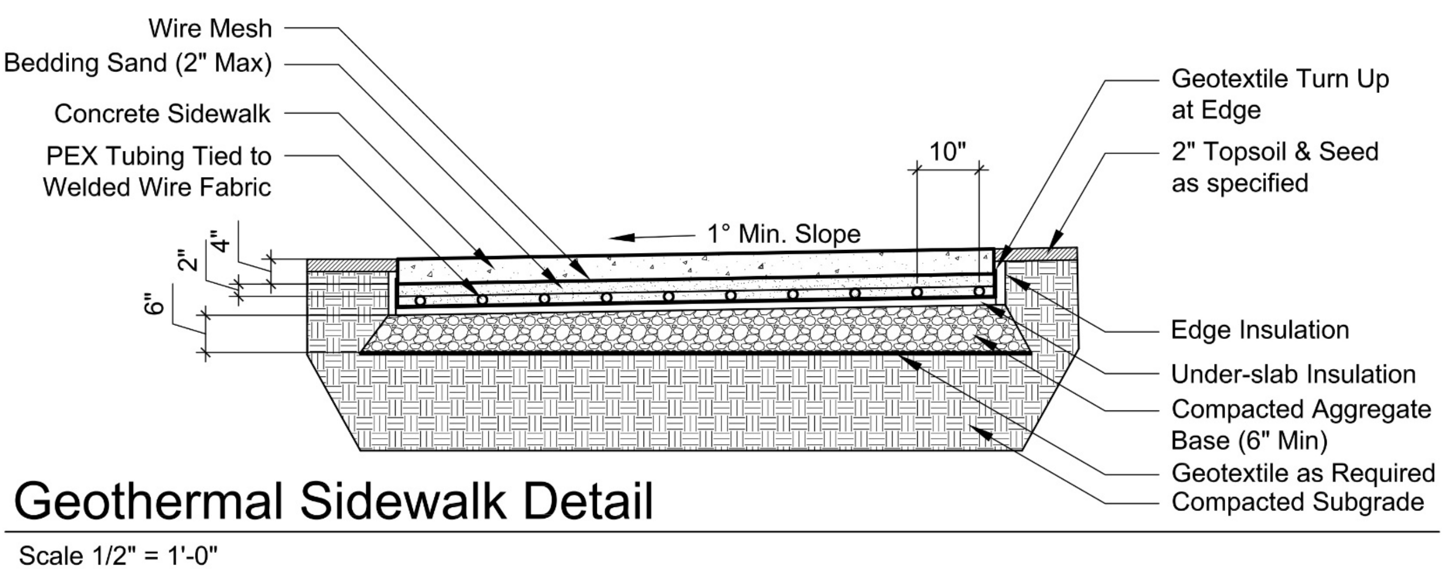


Figure 25 *Geothermal sidewalk detail *Note: scale inaccurate because of resizing*

The benefits of a snowmelt system in Cascade include:

- Elimination of cost and inconvenience of snow and ice removal
- Reduced liability exposure during the winter
- Elimination of damage to sidewalks from freeze-thaw cycles
- Safe connection from the school to the downtown Cascade area
- Option of future sidewalk heating expansion

Figure 26 *Geothermal sidewalk construction; Pictured at right, a manifold box allows for individual control of sidewalk sections. Left; http://geothermal.marin.org; Center and Right: Tanya Boyd, Geo-Heat Center, 2003*

PINE STREET CROSSWALK DESIGN

Figure 27 *Site perspective 7: Pine Street crosswalk*

TRACK AND FIELD PARKING LOT

Stormwater Flow & Treatment: The goal of the parking lot design is to provide adequate parking for students, spectators and busses and allow for safe pedestrian transit, while addressing treatment for stormwater runoff. The total area dedicated to the 116-vehicle parking lot is about 1.5 acres, 1.2 of which are an impermeable surface. The remaining .3 acres consists of a long, narrow island separating rows of parking and a larger semi-circular area that separates bus parking and turnaround from the rest of the parking lot. These areas must be of sufficient size and depth to hold and treat stormwater runoff from the parking lot for a minimum of a 1" design storm, the capture of which controls roughly 90% of annual runoff.

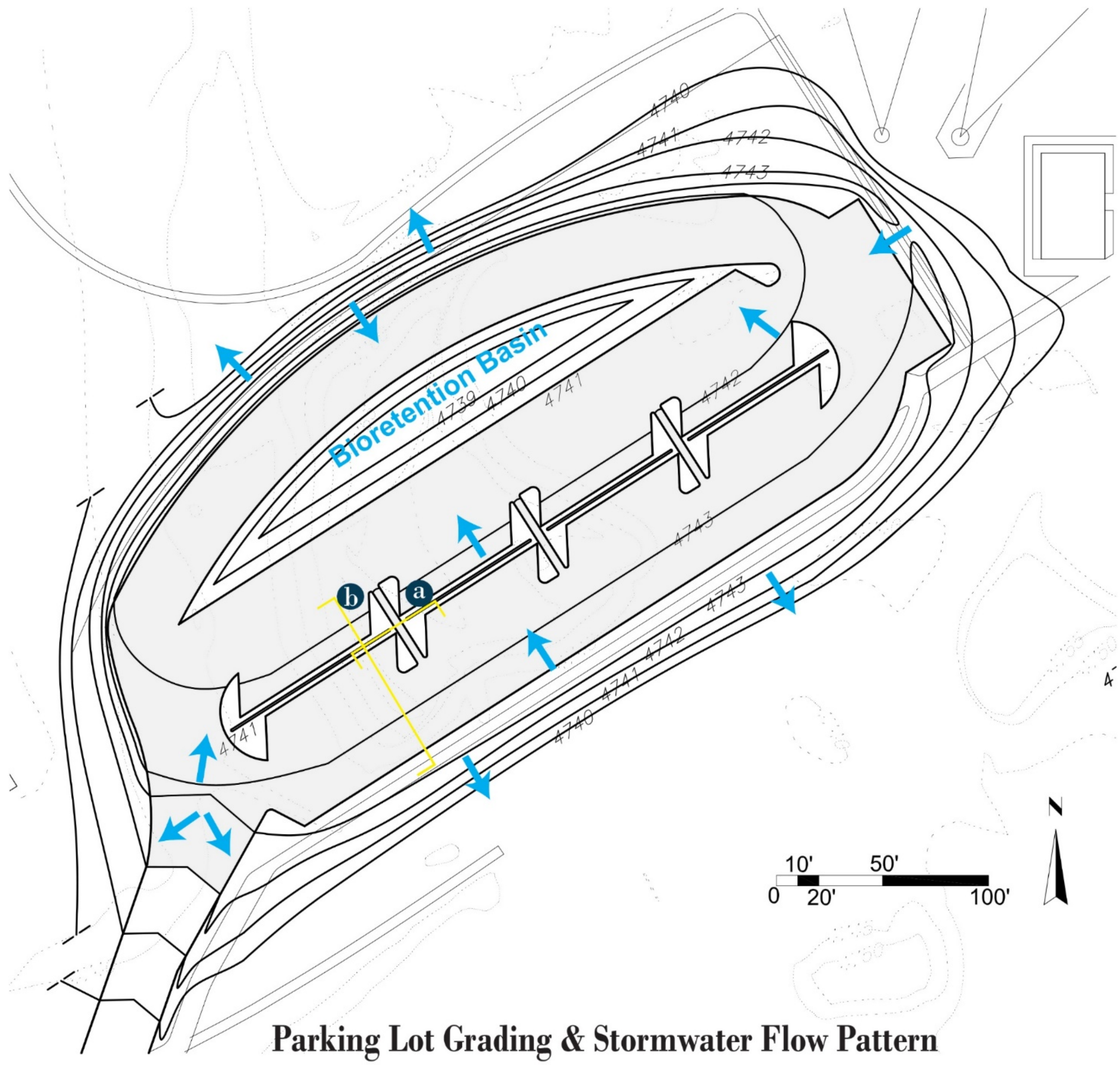


Figure 28 *Parking lot grading*

The center island allows for directed flow from the parking lot through curb cutouts with gravel channels to the lined vegetated channel that runs through the middle. Culverts connect the island sections beneath the three pedestrian sidewalks to direct flow to the low point where an overflow structure connects this area to the bioretention basin.

Figure 29 *Parking lot island cross section*

Figure 30 *Parking lot cross section*

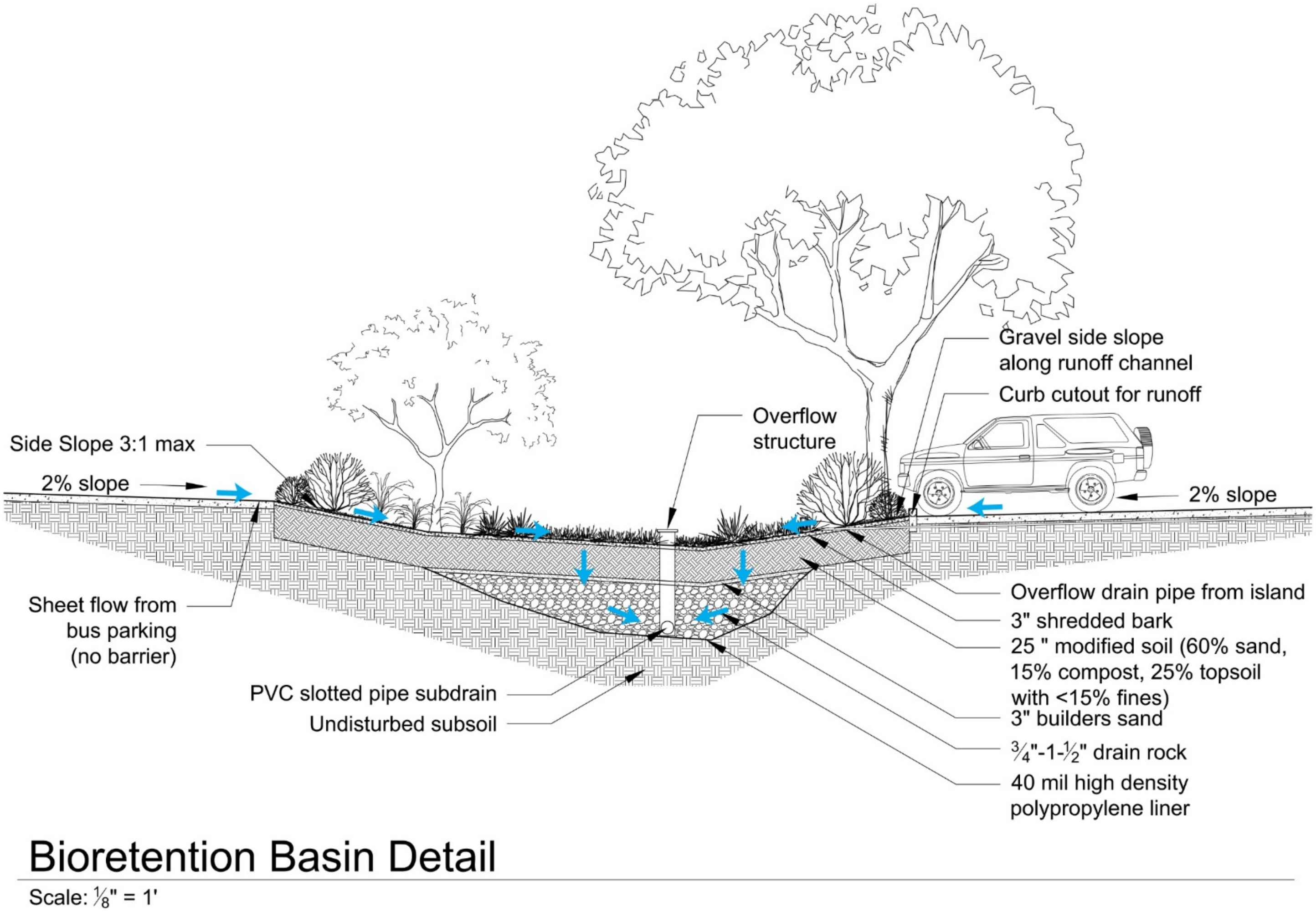


Figure 31 *Bioretention basin detail *Note: scale inaccurate because of resizing*

The bioretention basin is designed to treat all parking lot runoff in excess of a 2-year, 24-hour storm, a volume of runoff more than three times that of a 1" design storm. The lined vegetated basin is layered with filtering material to remove impurities from the runoff. A slotted pipe subdrain releases the treated stormwater back to the hydrologic system. An overflow structure allows for the release of stormwater in the event of a larger storm.

Beyond functional value, bioretention basins and other permeable green areas can be used to provide shade and add to the aesthetic value of the landscape, existing as natural planting beds through both wet and dry periods.

GEOTHERMAL PARK

Figure 32 *Site perspective 8: Geothermal Park*

Design Cohesiveness: Geothermal Park is the cohesive element of the design that brings together the track and field complex, Strand Trail, and the area serving dual duty as preserved wildlife space and spent geothermal water treatment—all while giving homage to the town's history and heritage. This is accomplished with several simple elements:

Access: the park has entrance points from the parking lot on the west side of the track and field facility, from the east side of the track, and directly from the Strand Trail.

Amenities: a covered pavilion accommodates both park functions as well as providing an eating area for groups of spectators and athletes at an event. The dispersed picnic area offers a resting point for those along the Strand trail and more secluded eating options away from the sports area. The playground encourages use of the Strand trail to gain access and focuses on the concept of nature play, bringing in elements from the town's culture to develop play structures.

Signage: Interpretive signs are placed around the park describing different aspects of the natural environment, the town's history and the role of geothermal resources in Cascade. Additionally, welcome and wayfinding signs invite and explain the layout of the path system, inclusive of Strand trail.

Natural Features: The stream created from disposal of spent geothermal water provides an element of interest along the path system of Geothermal Park, allowing for the intermingling of people and nature.

Open Space: The park remains largely in its naturalized state without manicured appearance in order to maintain a viable corridor for wildlife along the river and into the wetland area.

Park Signage

W1 Welcome sign with city trail map and space for pavilion reservation information

W2 Welcome sign with city trail map

S1 Educational Sign: Mill 2 Well depth, temperature and function

S2 Educational Sign: Description of positioning of play equipment to mimic layout of the geothermal wells drilled throughout town accompanied with a map of the town and well location

S3 Educational Sign: History of the site as a lumber mill and the significance of log playground structures

S4 Educational Sign: Role of the geothermal stream for fluid cooling and treatment

S5 Educational Sign: Role of wetland in geothermal fluid treatment and its significance for wildlife

Figure 33 *Geothermal Park layout and signage*

Figure 34 *Playground Elements: Nature play area with inspiration taken from Cascade's logging culture.*

Clockwise, Westmoreland Park (Sarah Roop, 2016); Custom designed structure (http://www.bowerhouseconstruction.co.uk); Westmoreland Park (Sarah Roop, 2016); Stepping round example (http://www.naturesinstruments.com)

GEOTHERMAL COOLING STREAM

Figure 35 *Site perspective 9: Geothermal cooling stream*

Spent Geothermal Surface Disposal: Affecting the economic feasibility of geothermal development is the disposal of spent geothermal fluids. Creating wetlands and waterways that are designed to cool waters and remove trace elements from geothermal fluids can be both an economical and environmental method of water treatment. Wetlands are self-perpetuating, aesthetically appealing, productive systems that provide valuable habitat for wildlife. An open channel can be used in conjunction with wetlands to increase heat loss efficiency from a geothermal source and further remove trace elements from the fluid. If the effluent is of sufficient quality, the channel can remain unlined.

Figure 36 *Geothermal disposal map*

The principle chemical present in the geothermal waters around Cascade is sodium. While current treatment involves surface disposal to a small wetland adjacent to the Payette River, expanded use of the geothermal resource may require more extensive treatment. The redirection of the existing CSD1 outflow to a seasonal wetland that connects to the formerly used wetland via a naturalized channel not only allows for adequate water treatment, but maintains and enhances the existing wildlife habitat.

Riparian Planting Zones

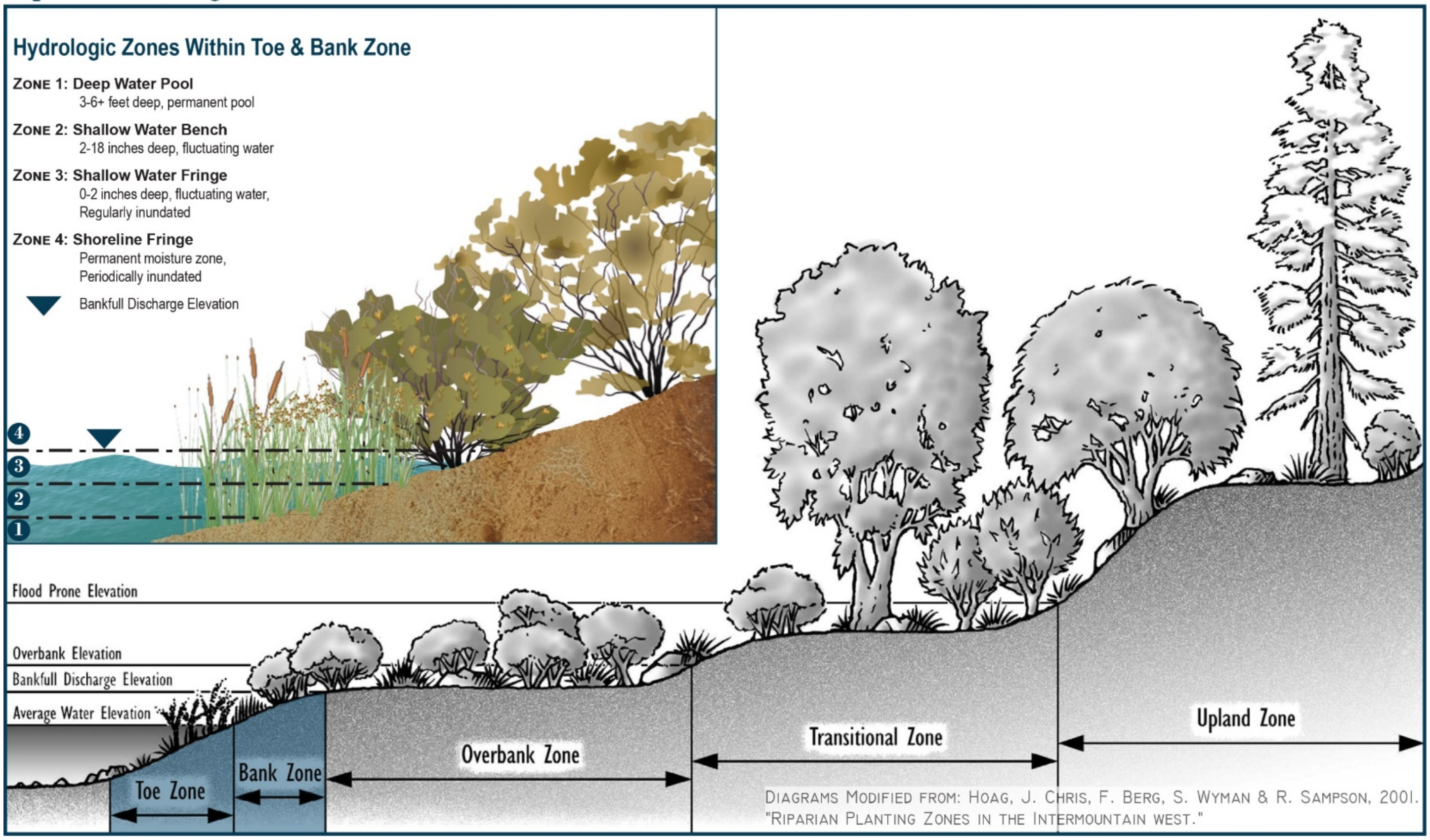


Figure 37 *Riparian planting zone chart*

The Riparian Planting Zones shown above represent species relation to the waterline. The inset diagram focuses on Zones 2 through 4 within the Toe and Bank Zones as these areas will most greatly influence treatment of geothermal waters. Selected plants should be native or naturalized to the region, have the ability to thrive in and treat sodium-rich water, and add to the functional and aesthetic qualities of the water features.

Species	Hydrologic Zone	Salinity Tolerance	Availability In Field	Commercial Availability	Wildlife Value	Notes
Herbaceous Grasses and Grass-Like Species						
Carex nebrascensis Nebraska Sedge	2,3,4	Medium	Common	Seed & Plugs	Waterfowl food & cover, small mammal cover	Tolerates heat if provided with adequate moisture
Deschampsia cespitosa Tufted hairgrass	3,4	Medium	Common	Seed	Small mammal cover	
Eleocharis palustris Spikerush	2,3,4,5	Medium	Very Common	Seed & Plugs	Waterfowl food	Excellent soil stabilizer
Juncus balticus Baltic rush	2,3,4,5,6	Medium	Very Common	Seed & Potted	Waterfowl food	Tolerates wide range of hydrolic conditions
Pascopyrum smithii Western wheatgrass	4,5,6	Medium	Common	Seed		Excellent soil stabilizer
P. spicata XE repens Newhy hybrid wheatgrass	3,4,5,6	Very High	Introduced	Seed		Tolerates high salinity
Puccinellia nuttalliana Alkali grass	3,4,5,6	High	Common	Seed & Plugs	Small mammal cover	Tolerates high salinity
Scripus acutus Hard-stem bulrush	2,3,4	Medium	Very Common	Seed & Plugs	Waterfowl food & cover, small mammal cover	Excellent soil stabilizer
Scripus maritimus Alkali bulrush	2,3,4,5	High	Common	Seed & Plugs	Waterfowl food & cover	Tolerates high salinity
Scripus pungens Three-square bulrush	2,3,4	Medium	Very Common	Seed & Plugs	Waterfowl food & cover, small mammal cover	Tolerates some hydrologic drawdown
Spartina pectinata Prairie cordgrass	2,3,4,5	Medium	Fairly Common	Seed & Plugs	Small game cover	Not palatable for livestock
Typha latifolia Cattail	2,3,4	High	Very Common	Seed & Plugs	Water & small mammal food & cover	Can be invasive
Native Willows						
Salix alba White/Golden Willow	4	Low	Common	Yes		Good rooting ability from cuttings
Salix geyeriana Geyer willow	2,3	Low	Very Common	Yes-limited		Good rooting ability from cuttings
Salix lemmonii Lemmon willow	2,3	Low	Fairly Common	No		Good rooting ability from cuttings
Salix lutea Yellow willow	2,3	Medium	Very Common	Yes-limited		Good rooting ability from cuttings
Salix scouleriana Scouler willow	5 (upland willow)	High	Fairly Common	Yes		Need to be treated with hormone
Riparian Shrubs and Trees						
Alnus sinuata Sitka alder	2,3	Low	Fairly Common	Yes	Big game browse & upland bird food	Poor rooting ability from cuttings
Alnus incana spp.Tenuifolia Thinleaf alder	2,3	Low	Common	Yes	Big game browse & upland bird food	Poor rooting ability from cuttings
Betula occidentalis Water birch	2,3	Low	Fairly Common	Yes	Big game browse	Poor rooting ability from cuttings
Cornus sericea Redoiser dogwood	2,3,4	Low	Fairly Common	Yes	Game & small mammal browse & bird food	Moderate rooting ability from cuttings
Crataegus douglasii Black/Douglas hawthorn	3,4	Low	Fairly Common	Yes	Browse & cover for many species	Poor rooting ability from cuttings
Pentaphylloides floribunda Shrubby cinqefoil	3,4	Unknown	Very Common	Yes	Big game browse	Poor rooting ability from cuttings
Populus tremuloides Quaking aspen	4	Medium	Very Common	Yes	Big game browse	Poor rooting ability from cuttings
Populus trichocarpa Black cottonwood	4	Unknown	Very Common	Yes	Big game browse	Very good rooting ability from cuttings
Prunus virginiana Chokecherry	4,5	Low-Medium	Common	Yes	Birds & small mammals eat fruit	Good rooting ability from cuttings
Ribes aureum Golden current	3,4,5	High	Common	Yes	Birds & small mammals eat fruit	Good rooting in greenhouse
Rosa woodsii Wood's rose	2,3,4,5	Low	Very Common	Yes	Rosehips eaten by many species	Good rooting in greenhouse
Sambucus coerulea Blue elderberry	4,5	Low	Fairly Common	Yes	Fruits important for birds	Poor rooting ability from cuttings

Figure 38 *Plant species list suitable for geothermal stream*

A Vision for Direct Use Geothermal Application Expansion in Cascade

The potential for expansion of direct use geothermal utilization exists in Cascade. The current applications within the city prove its viability and further opportunity analyses have confirmed the unrealized capacity of the natural resource within the city.

As Cascade transitions from its former economic ballast of timber production, the full utilization of the town's tapped geothermal resources can provide unique opportunities that go beyond the present cost savings and reduced emissions of district heating that the town currently experiences.

The following illustration presents a scenario of expanded geothermal use. Included is the proposal laid out in this presentation as well as the proposed expansion of the city's district heating system as detailed in the *City of Cascade Geothermal Feasibility Report.* Lastly, a plan is suggested for continued expansion of direct use applications, including expanded downtown sidewalk heating, community and commercial greenhouses, and aquaculture facilities.

Exploring the full range of direct use geothermal applications can result in unexpected benefits that radiate throughout the town. Through gains such as job creation, promotion of commercial growth, expansion of the tourist industry, improvement in quality of life, and incitement of community cohesiveness, geothermal projects can effect a high level of resiliency for the residents of Cascade as they play an active role in adapting with their changing circumstances and environment. Whether it is through agriculture, fisheries, snow melting, heating and cooling requirements or other uses, geothermal resources can not only reduce a community's carbon footprint, but transform a community environmentally, economically and socially.

Potential Benefits from Direct Use Geothermal Applications

- Energy security and price stability
- Long term environmental sustainability
- Improved agricultural productivity
- Increased food security
- Educational opportunity
- Job creation
- Promotion of commercial growth
- Expansion of tourist industry
- Stimulus for community cohesiveness
- Improved quality of life

Figure 39
Cascade geothermal application expansion map

CONCLUSION

The outcome of this project seeks to discover solutions for low temperature geothermal fluid utilization and its disposal. As with all geothermal resource projects, aspects of its utilization are unique to this specific area and its resource. The implications of this project can benefit the City of Cascade as a projection for sustainable, forward-thinking community development that has potential for both economic and community-strengthening returns.

Additionally, while aspects of every geothermal development project are unique, there are also aspects that can be applied elsewhere. Every project utilizing geothermal resources adds to the much needed base knowledge for geothermal applications. Through each project's successes and failures, expertise is gained on an individual basis, and communities have examples to follow.

The path to direct use geothermal utilization exists, it just needs to be more travelled. By focusing design for addressing community needs on geothermal utilization, the resource is brought to the forefront of design, rather than being a component of design. In this way, the sustainable resource is the celebrated emphasis, bringing attention and attraction to its benefits, with the hope of inspiring further geothermal based projects within this community and other communities with similar opportunity.

As Cascade celebrates its 100 year anniversary, it will be a time to reflect upon the past and look toward to the future, envisioning not just how the town will grow and change, but how the greater community and region will contribute to the future. This project is a conception of what that future could look like: a sustainable, healthy, resilient town that is fully integrated with beauty of Idaho.

Part II:

Applications of Low Temperature Geothermal Resources and Considerations for Sustainable Community Direct Use Development in the United States

APPLICATIONS OF LOW TEMPERATURE GEOTHERMAL RESOURCES AND CONSIDERATIONS FOR SUSTAINABLE COMMUNITY DIRECT USE DEVELOPMENT IN THE UNITED STATES

By Sarah Roop

INTRODUCTION

In the past, geothermal resources were largely viewed in two ways: as a high temperature energy resource or as a low temperature amenity used on an individual basis. [1] Likewise, utilization is generally categorized as indirect use (power generation derived from high temperature resources), or direct use (both moderate and low temperature resources used as direct heat without conversion). [2] While the division of the two categories largely stands, the uses and the scale at which lower temperature resources are being used has changed.

Utilization of direct use resources has grown slowly throughout the United States as applications and technologies for these resources have increased. Though many stumbling blocks remain in place for greater expansion of the renewable resource—including site-specific conditions, legal hurdles, high start-up costs and substantial risk in development—exploitation of this resource is starting to gain a foothold in small communities for a myriad of applications throughout the western United States.

Contributing to the motivation to develop geothermal resources is the worldwide push toward clean energy. According to the Intergovernmental Panel on Climate Change, carbon policy is believed to be a driving force for future geothermal development.[3] As a sustainable resource, geothermal energy contributes insignificantly to atmospheric pollution, requires minimal land use, is widely available and is indigenous in its nature. [4]

In addition to environmental sustainability, development of direct use geothermal resources can expand a community's economic base directly, indirectly and through induced effects. With increased knowledge of an available resource and applications for that resource, communities can thrive, adapting with a changing environment and actively seeking greater economic stability. The following paper provides a general synopsis of geothermal resources and their development followed by basic

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[1] Lund, "Geothermal Direct-Heat Utilization," 6.
[2] Ogola, Davidsdottir, and Fridleifsson, "Opportunities for Adaptation-Mitigation Synergies in Geothermal Energy Utilization- Initial Conceptual Frameworks," 509.
[3] Intergovernmental Panel on Climate Change and Edenhofer, *Special Report on Renewable Energy Sources and Climate Change Mitigation*, 79.
[4] Elíasson and Björnsson, "Multiple Integrated Applications for Low-to Medium-Temperature Geothermal Resources in Iceland," 446.

parameters for design elements of selected applications and how these applications can transform a community to become more resilient environmentally, economically and socially.

Sources of Geothermal energy

Geothermal energy is the internal heat of the earth, a heat generated predominantly from the decay of naturally occurring radioactive isotopes of uranium, thorium and potassium.[5] It is this energy that powers many of the large scale processes of the earth as the heat is redistributed from the earth's internal heat to cooler outer regions. Taken as a whole, the earth's temperature increases with depth and the heat from the center of the earth flows steadily outward and is lost into space by radiation, though the temperature throughout the layers is unevenly distributed.[6]

For human utilization, geothermal energy is defined as our resource base, which is made up of all accessible and inaccessible heat. Geothermal resources are the portion of the resource base that is technologically accessible, regardless of economic viability.[7] These resources have three common components: 1) a heat source, 2) fluid to transport the heat energy from inner rock to the surface, and 3) permeability in the rock.[8] Areas of geothermal significance[9] will have all of these characteristics to lesser and greater extents and will display higher water and/or mineral temperatures at much shallower depths than is typical.[10]

Heat sources for geothermal areas are generally derived from one or more of five circumstances. The first is the intrusion of molten rock from far below the surface of the earth. This results in high temperature geothermal resources. Secondly, there can be a higher than average surface heat flow. Less commonly, exceptional heating of shallow rock can occur by the decay of radioactive elements. Another instance of geothermal heat occurs because deeper rocks are thermally blanketed by rocks with low thermal conductivity, such as shale. Lastly, the ascent of groundwater that has circulated to depths

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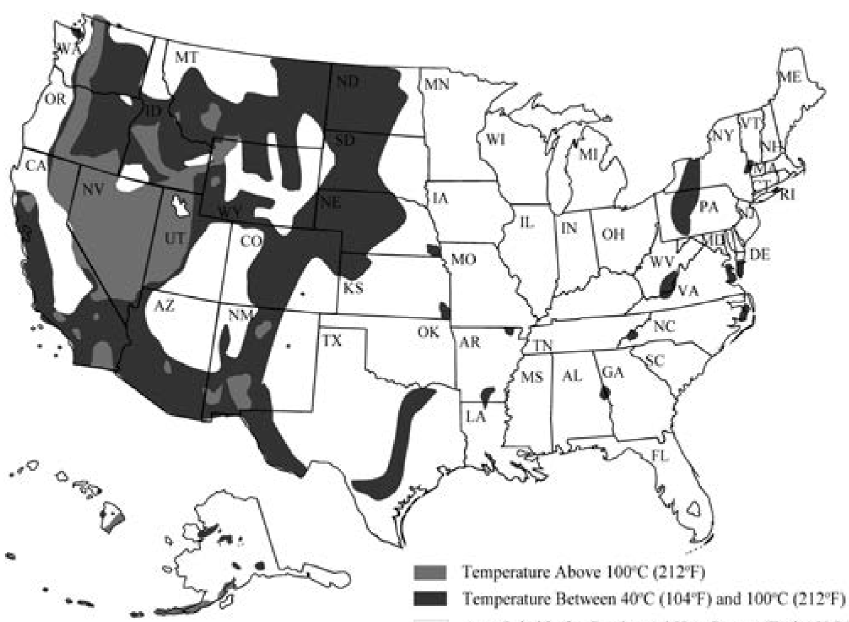
[5] Lund and Boyd, "Geothermal Energy Uses. Geo-Heat Center Quarterly Bulletin, Vol. 28, No. 2 (Complete Bulletin), A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 1.
[6] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 23.
[7] Glassley, *Geothermal Energy: Renewable Energy and the Environment*, 121.
[8] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 24.
[9] *This does not include ground-source heat pumps, which will be discussed later, nor does it take into account Enhanced Geothermal Systems (EGS) which is not discussed in this paper. EGS is a relatively new technology that involves drilling thousands of feet into the earth and then pumping water down to fracture the hot rock to create reservoirs. This method is not site specific and the resulting energy could be used to produce electricity. However, the major hurdle with this method is its potential to create earthquakes.*
[10] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 24.

of 1 to 3 miles can create geothermal areas. The last two circumstances usually result in low to moderate temperature resources.[11]

GEOTHERMAL CLASSIFICATIONS

Geothermal resources have been arbitrarily divided into Low (<194°F), Intermediate (194-302°F) and High (>302°F) temperature classifications,[12] sometimes broken down further with a Very Low temperature classification (<120°F).[13] There are many more occurrences in the United States and around the world of lower temperature resources than high temperature areas, as seen in the fact that almost every country in the world has some low-temperature systems, but only a handful have access to high temperature systems. In the United States, 5 percent of identified geothermal systems carry temperatures above 300°F, while 85 percent of those systems are below 200°F.[14] With some exceptions, resources above 300°F are used for power generation while those below are applied to direct use projects.[15]



[16]

[11] Ibid.
[12] Ibid., 27.
[13] Ibid., 3.
[14] Lund, "Geothermal Direct-Heat Utilization," 6.
[15] Lund and Boyd, "Geothermal Energy Uses. Geo-Heat Center Quarterly Bulletin, Vol. 28, No. 2 (Complete Bulletin), A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 1.
[16] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 2.

There are both convective hydrothermal resources and conduction dominated resources. Convective resources are further broken down into vapor dominated systems, water dominated systems and hydrothermal reservoirs.[17] Conductive resources occur in sedimentary basin and beneath sedimentary coastal rocks.[18] Of geothermal resources identified, most are available through reservoirs in hydrothermal convection systems for low temperature geothermal resource areas.[19]

Classification of Geothermal Resources

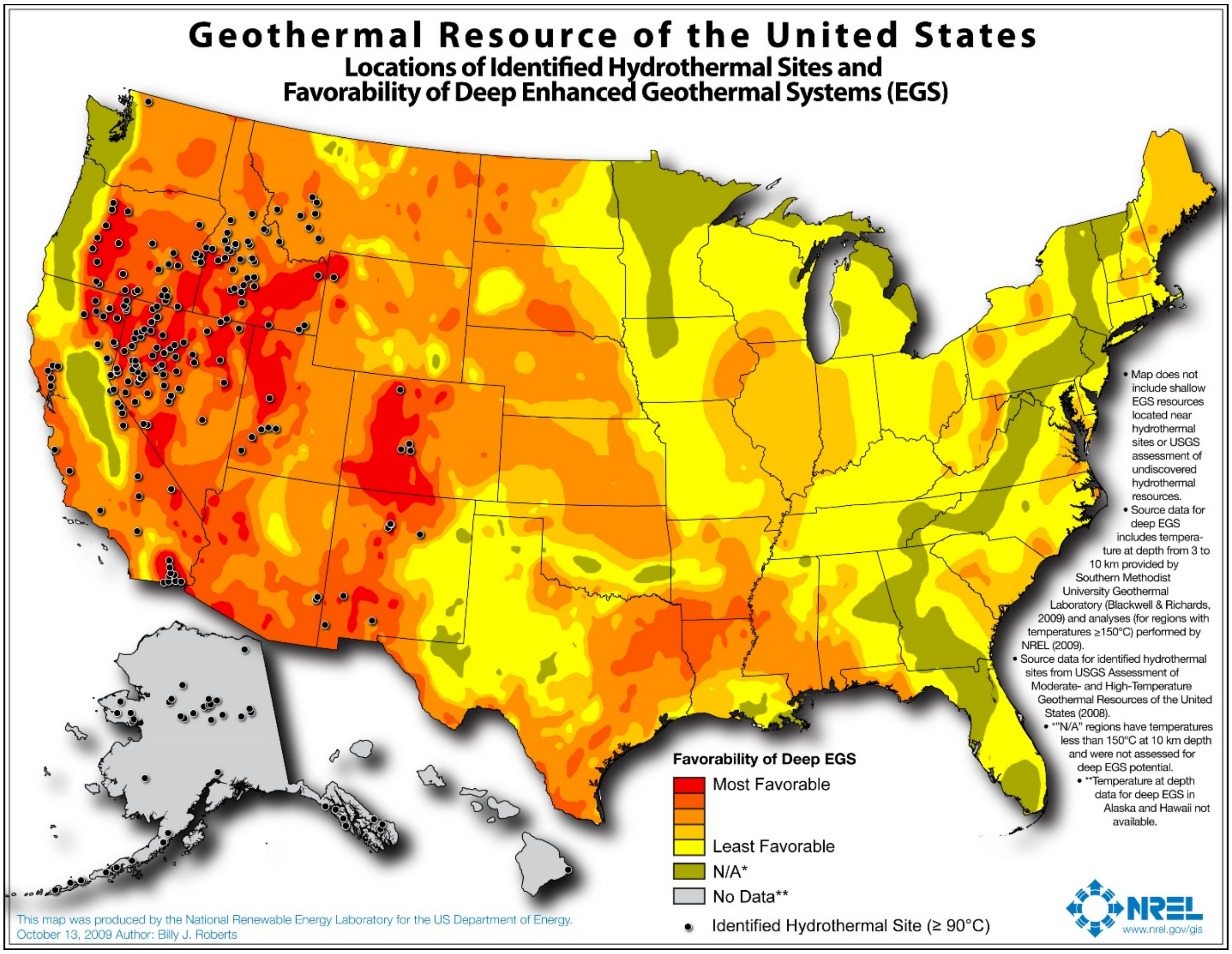
Resource Type	**Characteristics**	
	°C	**°F**
Convective Hydrothermal Resources		
Vapor dominated	240	464
Hot water dominated	30-350+	86-662
Other Hydrothermal Resources		
Sedimentary basin/regional aquifers *(hot fluid in sedimentary rocks)*	30-150	86-302
Geo-pressured *(hot fluid under pressure that is greater than hydrostatic)*	90-200	194-392
Radiogenic *(heat generated by radioactive decay)*	30-150	86-302
Hot Rock Resources		
Part still molten (magma)	>600	1112
Solidified (hot, dry rock)	90-650	194-1202

White and Williams, 1975 [20]

AREAS OF GEOTHERMAL SIGNIFICANCE

Much of the Western United States has areas of unusually high heat flow in conjunction with an unusually high geothermal gradient, with geological evidence suggesting that the curst is thinner in this region. However, heat is not the only factor to consider. In order for development of geothermal resources to be economically feasible, a fluid needs to bring heat to the surface.[21] It is in these areas where groundwater meets permeable rock—either between pores of mineral grains or along open fault zones, fractures and fracture intersections—that the use of geothermal resources can be an economic and environmental boon to individuals and communities.

[17] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 28.
[18] Ibid., 33.
[19] Ibid., 41.
[20] Ibid., 27.
[21] Ibid.



[22]

There are over 1,300 hydrothermal convection and conduction geothermal systems identified in the United States, and though thought of as a Western state resource, improving technology is allowing for space conditioning and district heating to be an economically feasible option with lower and lower temperatures.[23]

With continued awareness, development and application of ground-source heat pumps, geothermal energy is now available where it was previously considered uneconomical to develop. Ground-source heat pumps are high efficiency heat pumps that use the earth's inherent thermal energy as a heat source for heating or a heat sink for cooling. Unlike conventional geothermal resource development, ground-source heat pumps are not site-specific.[24] These units are installed in almost every state in the

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[22] Roberts, "Geothermal Resources of the United States."
[23] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 3.
[24] Fridleifsson, "Direct Use of Geothermal Energy around the World," 6.

United States, but especially in the mid-western and eastern states,[25] with over one million installed units as of 2010.[26] The United States is a leader in installed units, along with China, Sweden, Germany and the Netherlands.[27]

It is hypothesized that the heat energy flowing beneath the United States could theoretically "provide most of the future low temperature energy needs of this nation."[28] How much geothermal energy actually contributes to the United States' energy needs will be determined by how much research and money is devoted to development and demonstration programs of the resource as well as the cooperation and contributions of the various actors, including federal, state and local governments along with industry and universities in addition to the interest of the general population.[29]

HISTORICAL USES AND DEVELOPMENT

Direct use of geothermal resources is one of the oldest, most common, and versatile ways to use geothermal energy.[30] Exploited throughout the world for centuries, geothermal resources were mainly utilized in the form of spas and bathing, cooking, washing of clothes, and heating and therapeutic treatments.[31] Today, however, a myriad of uses have arisen across the world, with the largest energy use and capacity occurring in the area of ground-source heat pumps.[32] Trends in the United States are similar with ground-source heat pumps accounting for 84 percent of direct use energy use, with a 13 percent annual growth rate in 2010. The next largest direct use application is in aquaculture and swimming pool heating, however, these uses and others have remained relatively static between 2005 and 2010 with fluid gains and losses of direct use developments. [33]

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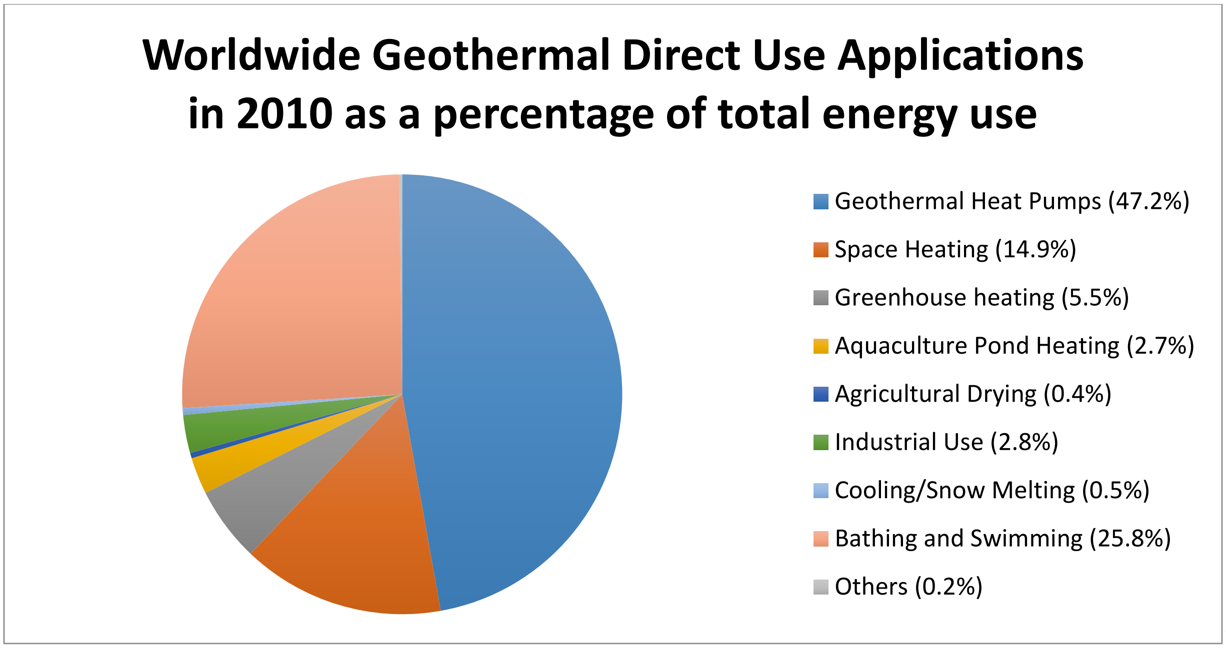
[25] Lund, "Direct Heat Utilization of Geothermal Resources Worldwide 2005," 9.
[26] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 9.
[27] Lund, "Development of Direct-Use Projects," 162.
[28] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 6.
[29] Ibid.
[30] Lund, "Development of Direct-Use Projects," 159.
[31] Oldmeadow et al., "Low Temperature Geothermal Applications as Enablers of Sustainable Development," 3054.
[32] Lund, "Development of Direct-Use Projects," 162.
[33] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 2.



[34]

Utilization of geothermal resources in the United States remained relatively undeveloped until the oil price shock in the 1970s exposed the United States' dependence on foreign energy supplies, a gap between energy consumption and production that had been growing steadily since the late 1950s.[35] This led to a renewed interest in alternative forms of energy. Starting in 1977, the United States Department of Energy initiated programs to aid in industry growth. These included technical assistance to developers, preparation of project feasibility studies, cost sharing demonstration projects, resource assessments and loan guarantees. Accompanying these programs were various tax credit programs offered from both federal and state entities.[36] The cost sharing demonstration projects started in 1978 generated a list of key factors that play a role in the success or failure of geothermal development:

- Every project is unique
- Simplicity is the key to operational success
- A strong promoter is needed to develop each project
- Customers are needed for district heating systems
- Funding and costing methods can affect development
- Legal and institutional considerations play a major role
- Qualified personnel are needed
- Direct use projects can be economical
- Cascaded uses can improve economics
- Well siting affects resource development
- Spent geothermal fluid disposal can be a significant consideration

[34] Lund, "Development of Direct-Use Projects," 161.
[35] Peterson, Widner, and Nelson, "Estimated Impacts of Proposed Idaho Geothermal Energy Projects," 12.
[36] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 3.

- Piping and production system needs are unique to each project
- Direct use projects can operate satisfactorily[37]

With this compilation of lessons learned, developers had a starting point. Though legalities remained an obstacle at times, the door had been opened for the use of low temperature geothermal resources in the United States.

One of the more important factors for the continued development of direct use geothermal energy is expanding demand for the resource. One of the advantages of low temperature resources is its relative abundance and the lower cost of development compared to high temperature resources.[38] Additionally, support for advanced technology in direct use applications is attainable because its utilization is understood and accepted by the public, in contrast to more public concern for larger applications such as geothermal power plants which are perceived to have much greater societal and economic impacts.[39] Lastly, along with continued advancement in technology for low temperature resources and the use of ground-source heat pumps, direct use applications can also take advantage of conventional technologies that have a long history of use.[40]

As witnessed by projects that both got off the ground and others that fell flat, development of a geothermal site is an extensive and risky process involving experts from many fields for resource exploration, drilling and well construction and fluid piping. In the end there is no guarantee that the resource will be able to provide the needed energy, or that the resource is even accessible due to rock and soil composition. Risks can be lessened by amassing a knowledge base of the individual resource, hiring experienced project leads and teams, and taking advantage of appropriate technology and equipment.[41] And though all projects are unique, flow charts of typical activities exist to aid in implementing a phased approach to further minimize risks.[42]

LEGALITIES OF GEOTHERMAL DEVELOPMENT

The legalities of geothermal development in the United States have been addressed on both national and state levels and may also have further regulations on local levels. Major differences in legislation is

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[37] Ibid., 9–13.
[38] Oldmeadow et al., "Low Temperature Geothermal Applications as Enablers of Sustainable Development," 3055.
[39] Romanach, Carr-Cornish, and Muriuki, "Societal Acceptance of an Emerging Energy Technology," 1145.
[40] Barbier, "Geothermal Energy Technology and Current Status: An Overview," 47.
[41] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 40.
[42] Lund, "Development of Direct-Use Projects," 1.

largely attributed to how geothermal resources are defined and characterized, which in turn affects other related resource definitions and as a result, all aspects of regulation.[43]

Geothermal resources are both surface and subsurface entities, and are related to water, gas and minerals. To define these resources, the first task is to differentiate geothermal resources from other natural resources to establish what is subject to geothermal leasing (providing access and securing rights to resource exploration and development), taxation and development regulations. Secondly, geothermal resources must be related to groundwater, subsurface minerals and other natural resources. The clarity and wholeness of the definition of geothermal resources will influence the amount of future conflicts in development.[44]

The first attempt to define geothermal resources was the California Geothermal Resources Act of 1967.[45] It was followed by the Federal Geothermal Steam Act of 1970. Both definitions described in detail the physical properties of geothermal resources that *distinguish* them from other natural resources but did not *relate* these resources to other natural resources.[46] Other states with known geothermal resources followed in suit, developing their own take on geothermal resources, each state establishing a division of responsibility, assigning regulatory responsibility to an appropriate agency according to definition. The inconsistency in definitions can cloud the issues of ownership, access and authority. The following exemplify the wide variety of definitions:

- Alaska characterizes geothermal resources as water and all ownership of the resource is by the state, regulated by the Department of Natural Resources, Division of Oil and Gas.[47]
- Arizona characterizes geothermal resources as steam, hot water or mineral and ownership is included with ownership of the land.[48]
- Idaho characterizes geothermal resources as *Sui generis* (neither water nor mineral) which fails to clearly characterize the resource. The state claims ownership underlying all state and school lands. The regulating agency is the Idaho Department of Lands.[49] Idaho has a separate definition altogether for low temperature resources, defined as greater than 85°F and less than 212°F, characterizing these as ground water and regulated by the Department of Water Resources.[50]

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[43] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 361.
[44] Ibid.
[45] Ibid.
[46] Ibid., 362.
[47] Ibid., 367.
[48] Ibid., 377.
[49] Ibid., 381.
[50] Lyons, "A Regulatory Guide to Geothermal Direct Use Development," 2.

- Geothermal resources in Utah, Wyoming and Montana are public domain because they are characterized as water.[51]

The Energy Policy Act of 2005 amended the Geothermal Steam Act of 1970 by modifying how royalties are calculated and how land is leased, among other things. The Act also included provisions to make geothermal energy more competitive with fossil fuels by providing tax incentives and loan guarantees.[52]

In general, regulations are directed toward large scale electrical generation projects, giving less attention to low temperature direct use application.[53] Since there is no single set of regulations for direct use geothermal development, it is important to be familiar with and contact all appropriate regulating agencies according to location early in the planning process.

ENVIRONMENTAL CONSIDERATIONS

Beyond the obligatory regulation process, potential developers should consider all environmental factors that may arise during exploration, development and operation of a direct use project. Generally the environmental impacts of geothermal development are proportional to the scale of development,[54] but as all projects are unique, environmental impacts may be as well. The main factors that may apply include:

- Airborne effluents
- Water pollution
- Land subsidence
- Induced seismicity
- Noise
- Water availability
- Solid waste
- Land use
- Vegetation and wildlife
- Economic and cultural factors[55]

Proper planning and procedure address most environmental issues, but special attention to design of the landscape around geothermal resource infrastructure in the areas of water pollution, solid waste, and vegetation and wildlife can result in a more sustainable outcome.

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[51] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 364.
[52] *Energy Policy Act of 2005*, 660–74.
[53] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 393.
[54] Ibid.
[55] Ibid., 396.

Geothermal fluids contain varying quantities of dissolved volatile compounds and dissolved solids, specifically nitrogen, carbon dioxide and hydrogen sulfide, with smaller amounts of ammonia, mercury, radon and boron.[56] High concentrations of salt are also commonly present in geothermal fluids.[57] The concentrations of these pollutants depend upon the geological conditions of the area. Though the pollutant content of low temperature geothermal resources are generally inconsequential, all emissions should be analyzed and monitored.[58] In addition, thermal pollution to surface waterways is a concern if the spent fluids are discharged on the surface, having several adverse affects including decreased dissolved oxygen in the water, damage to aquatic wildlife, migration of organisms and undesired vegetative growth.[59]

There are three basic options when it comes to disposal of spent fluids in order to avoid both thermal and solid waste pollution to land and water: subsurface injection, disposal to surface waters, and/or disposal to the ground.[60] Determining whether to employ a surface or subsurface discharge is done on a site-to-site basis according to the quality of the discharge water, hydrological conditions, environmental regulations and local requirements. [61] Regardless of the chosen approach, careful management of the water cycle is paramount to ensure the long term sustainability of the resource. Extraction without replenishment can decrease productivity due to diminished pressure and flow rates, tap out the resource or draw down water from other resource reservoirs.[62]

Subsurface disposal is accomplished through reinjection, an option that helps to maintain reservoir pressure and can replenish the reservoir, thus improving upon the sustainability of the resource. This is often the method chosen or required for geothermal power projects.[63]

However, the high cost and complexity can be prohibitive for smaller direct use developments so alternative lower cost options may be considered.[64] Should surface discharge be the chosen method, it is generally preferable to discharge to ground rather than surface waters because it minimizes the chance of degrading water quality, and also keeps the water resource within the same geographic

[56] Fridleifsson, "Direct Use of Geothermal Energy around the World," 7.
[57] Shortall, Davidsdottir, and Axelsson, "Geothermal Energy for Sustainable Development," 396.
[58] Fridleifsson, "Direct Use of Geothermal Energy around the World," 7.
[59] Shortall, Davidsdottir, and Axelsson, "Geothermal Energy for Sustainable Development," 396.
[60] Lyons, "A Regulatory Guide to Geothermal Direct Use Development," 7.
[61] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 397.
[62] Glassley, *Geothermal Energy: Renewable Energy and the Environment*, 242.
[63] Barbier, "Geothermal Energy Technology and Current Status: An Overview," 51.
[64] Schmitt, "Agriculture, Greenhouse, Wetland and Other Beneficial Uses of Geothermal Fluids and Heat," 2.

area.[65] Ground surface discharge is accomplished through the creation of cooling ponds to hold spent geothermal water prior to mixing with surface waters, or spent fluids can be redirected to other uses, known as cascading and addressed in a later section.

Another method of spent fluid treatment is the creation of wetlands designed to remove dissolved solids and trace elements, using the same ideology as that for sewage treatment. Not only can wetland systems provide habitat for wildlife, but they are a self-perpetuating system that is productive and aesthetically appealing.[66] Several species of aquatic macrophytes have proven adept at bioaccumulation of trace elements common in geothermal water. They are as follows:

> *Aquatic macrophytes will be planted with a high enough density t o allow maximum purification of the geothermal water.*
>
> > *Upper Section of wetland (deepest part): EGERIA, COONTAIL, WATER MILFOIL, PONDWEED, and DUCKWEED.*
> >
> > *Lower Section of pond (shallower): BULRUSH, CATTAILS, COMMON REED and ARROWHEAD.*
> >
> > *Around the berm of the wetland (Riparian species): SANDBAR WILLOW, SAMPHIRE, and SALT GRASS.*[67]

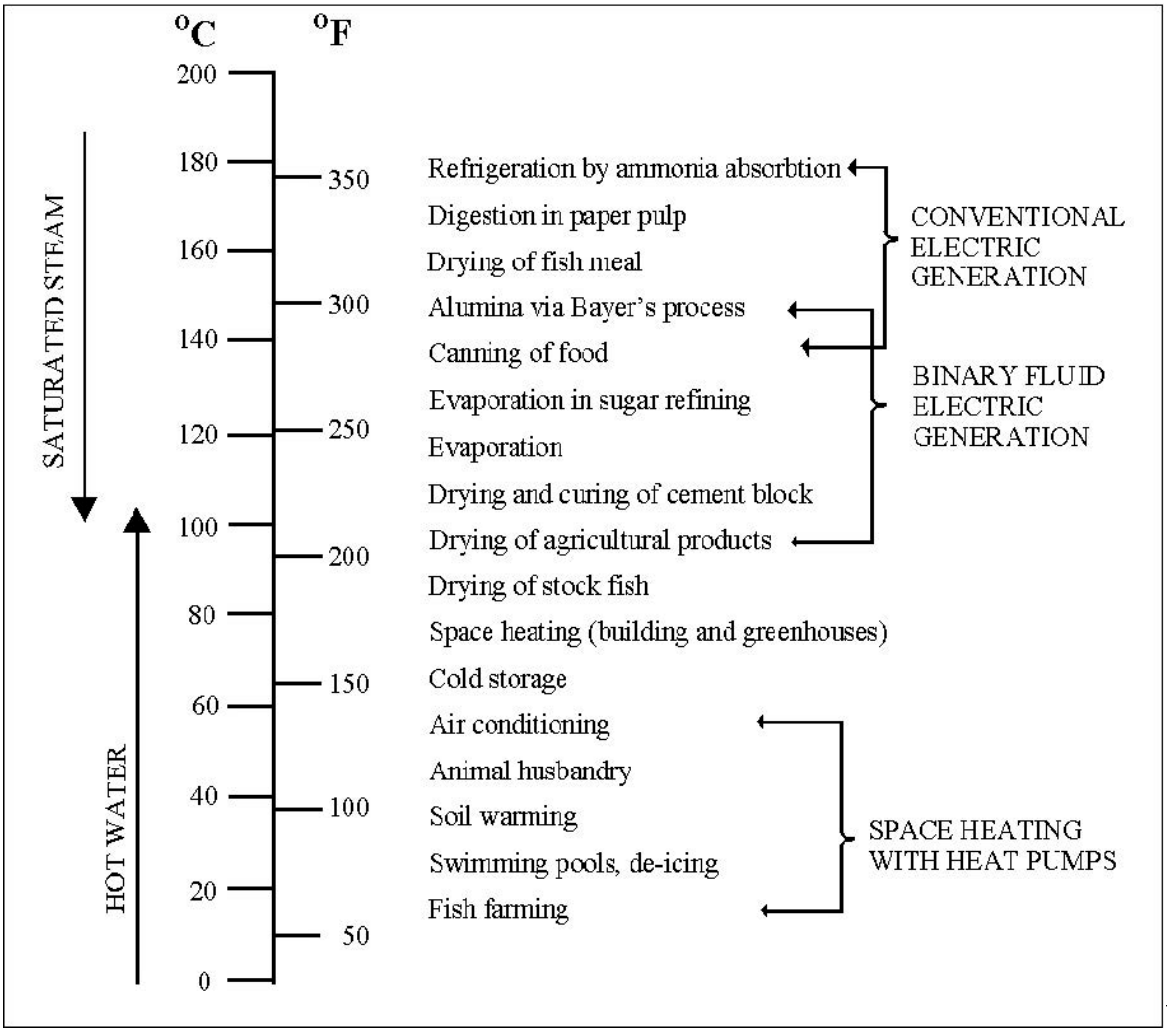
Additionally, the introduction of several species of fish can benefit the wetland, such as Mosquito Fish (Gambuzia affinis) for mosquito control, Tilapia (T. nilotica or T. aurea) for algae consumption, and a possible predator, such as large mouth bass.[68]

GEOTHERMAL APPLICATIONS

Direct use applications of geothermal resources fall into five basic categories for low temperature resources: agriculture (greenhouses and soil warming), aquaculture (fish, prawn and alligator farming), balneology (hot spring and spa bathing), industrial applications (such as mineral extraction, food and grain drying), and space heating and cooling (inclusive of district energy systems).[69] A sixth utilization sometimes categorized separately is ground-source heat pumps, used for heating and cooling.[70] These

[65] Lyons, "A Regulatory Guide to Geothermal Direct Use Development," 9.
[66] Schmitt, "Agriculture, Greenhouse, Wetland and Other Beneficial Uses of Geothermal Fluids and Heat," 9.
[67] Ibid., 11.
[68] Ibid.
[69] Peterson, Widner, and Nelson, "Estimated Impacts of Proposed Idaho Geothermal Energy Projects," 28.
[70] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 2.

uses fall in a range of resource heat requirements, from very low to moderate temperatures, as seen in the Lindal diagram below.



[71]

The Lindal Diagram was named for the Icelandic engineer Baldur Lindal, who first proposed the temperature ranges that were suitable for various direct use activities.[72]

Greenhouses

The use of geothermal resources has allowed for the economical operation of commercial greenhouses in cold climate areas where such operations were previously not a financially viable option.[73] Not only can this type of application take advantage of the lower end of the geothermal temperature range,[74] but

[71] Fridleifsson, "Direct Use of Geothermal Energy around the World," 4.
[72] Lund, "Geothermal Direct-Heat Utilization," 7.
[73] Lund, "Development of Direct-Use Projects," 2.
[74] Lund, "Geothermal Direct-Heat Utilization," 8.

plant growth can also be stimulated by the CO_2 present in geothermal fluids, which can increase yields up to 15 percent and improve crop quality.[75] Additionally, geothermal heating allows for better humidity control.[76]

As of 2010, the United States had 44 operating greenhouses heated by geothermal resources. Top crops include potted plants and cut flower for local markets, with some operations growing tree seedlings and vegetables. Generally vegetable crops cannot compete with foreign markets unless grown organically.[77]

Recently, operations continuing through the winter have proven to be profitable investing in fast growing crops. Though still a relatively small enterprise, greens including baby kale, arugula, lettuce mixes and Asian greens have found receptive local markets in cold climate areas. Several factors have seemed to play in a role in the success of a winter greenhouse. They are 1) Maximizing the use of space: by utilizing eighty percent of the growing space or more by using the floor as well as vertical space with hanging baskets, the higher cost of winter growing can be better offset; 2) Pursuing direct-to-consumer marketing channels: participating in Community Supported Agriculture (CSA) programs has proven to be more profitable than marketing to local grocers and deliveries can be supplemented with longer lasting fall crops such as winter squash, potatoes and root vegetables; and 3) Keeping start-up costs as low as possible: a matter of keeping materials, labor and design elements efficient and effective, but not excessive.[78]

Successful operation of a cold climate greenhouse is not only a function of crop choice, but depends upon many variables including climate, resource temperature, local market and type of structure.[79] There are two main components to consider in the design of greenhouses that affect its functionality: construction materials and heating systems.

The construction materials used will determine the heating requirements for the greenhouse, so it is necessary to decide upon these elements in order to determine the parameters for the heating system. There are several options, all with strengths and weaknesses. Choice of materials may be dictated by

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[75] Ogola, Davidsdottir, and Fridleifsson, "Opportunities for Adaptation-Mitigation Synergies in Geothermal Energy Utilization- Initial Conceptual Frameworks," 526–27.
[76] Schmitt, "Agriculture, Greenhouse, Wetland and Other Beneficial Uses of Geothermal Fluids and Heat," 7.
[77] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 9.
[78] Pesch, "Deep Winter Greenhouse Enterprise Analysis," 1–2.
[79] Lund, "Development of Direct-Use Projects," 2.

the type of crop intended for the space (such as a crop needing high light quality), the need for high efficiency (especially in colder areas), or possibly it may be influenced by aesthetic values if functional factors are less of an issue. There are four general transparent materials used in greenhouse construction—glass, plastic film, fiberglass and polycarbonate panels—all of which have benefits and drawbacks and are associated with a general style of architecture. Combinations of these materials is also common.[80]

Building Material: Struts	Advantages	Disadvantages	
PVC Pipe	Inexpensive Easy to work with Commonly available Pipe ends can become connectors Resists bugs, rot and moisture	High ecological cost Brittle over time from cold and UV	
Steel Pipe	Durable, strong and easily worked Resists bugs, rot and mold No connectors needed	Medium ecological cost Heavy Expensive Need specialized tools Can rust	
Bamboo	Light, strong and renewable	Hard/impossible to find locally Can be expensive Need specialized skill Does not resist bugs	
Wood	Universally available Can be green and renewable Durable, strong and easily worked	Needs to be treated to resist rot May split, break or otherwise fail Does not resist bugs	
Building Material: Transparent Panels	**Advantages**	**Disadvantages**	**Building Style**
Glass	Highest light quality Durable and strong	Expensive Poor energy efficiency (unless double glazed)	Peaked design 36-42' widths/ 20' length increments
Polyethylene film	Very energy efficient Relatively easy to install Inexpensive	Reduced light transmission Requires replacement 3 year intervals	Arched roof design 30' widths/ 100'-150' lengths
Fiberglass	Requires less structural support	Poor energy efficiency	Similar to Glass
Polycarbonate Panels	Stong Excellent insulation Easy to cut and install lightweight	Moderately reduced light transmission	Similar to Glass

There are six basic types of heating systems: finned pipe, unit heaters, finned coil, soil heating, cascading and bare tube. While the choice of heating system may be partially dictated by weighing the pros and cons of a chosen system, the final decision is often influenced by the grower's preference and familiarity to a certain type of heating system rather than engineering or economical considerations.[81] In addition to a heating system, most geothermal applications require a heat exchanger, which separates the

[80] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 271.
[81] Ibid., 274.

heating equipment from the geothermal fluid. With the use of a heat exchanger, some loss of temperature must be factored in depending on type of heat exchanger chosen. For a plate-type heat exchanger, a loss of 5°F to 10°F can be expected. A shell and tube heat exchanger, generally not used in direct use applications, loses around 15°F to 20°F. Homemade configurations can see as much as 20°F to 40°F losses. [82] Some general rules of thumb for resource temperature are as follows:

- *Minimum supply air temperature = space temperature + 25°F*
- *Minimum supply water temperature for air heating coil = supply air temperature + 15°F*
- *Minimum geothermal temperature entering isolation heat exchanger = coil supply water temperature + 10°F*

The same temperature differences apply to the leaving side of the heat exchange equipment.

- *Minimum air coil leaving water temperature = space + 15°F*
- *Minimum geothermal temperature leaving isolation heat exchanger = coil leaving temperature + 10°F*[83]

Aquaculture

Among the simplest of geothermal applications when allowed to flow directly into the pond, aquaculture pond heating has found its way into the United States fish industry. [84] In the past couple decades, the United States has shifted from consuming wild-caught fish to eating more and more farm-raised fish and seafood.[85] Despite recent trends of a decline in the aquaculture industry because of market saturation and competition from imports, fifty-one aquaculture sites heated by geothermal fluid exist in 11 states, the largest concentrations of which are in Southern California and along the Snake River in Idaho.[86]

Both water quality and disease control are important factors when directly using geothermal fluids in an aquaculture pond. [87] There a several water quality factors that affect fish survival and growth in a controlled setting. These include temperature, dissolved oxygen, nitrogenous wastes, pH, alkalinity, hardness, carbon dioxide, salinity, chlorine and hydrogen sulfide.[88] All of these factors need to be

[82] Rafferty, “Direct-Use Temperature Requirements,” 2.
[83] Ibid., 3.
[84] Ibid., 1–2.
[85] Boyd and Rafferty, *Aquaculture Information Package*, 1.1.
[86] Lund and Boyd, “US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources,” 9.
[87] Lund, “Development of Direct-Use Projects,” 3.
[88] Boyd and Rafferty, *Aquaculture Information Package*, 2.1.

measured and managed, the frequency of which generally coinciding with the intensity and density of the fish.[89]

One of the first steps in planning a geothermal aquaculture project is determining the heat available from the resource which will set parameters for the size of the project. This step is closely followed by choosing the species to be raised. Each aquaculture species has tolerable temperatures for survival and optimum temperatures for growth (see chart below). The species selection will determine the temperature at which the water must be maintained.[90]

Species	Tolerable Extremes (°F)	Optimum Growth (°F)	Growth Period to Market Size
Oysters	32-97 typ	76-78 typ	24
Lobsters	32-88	72-75	24
Penaeid Shrimp			
Kuruma	40-?	77-87	6 to 8 typ
Pink	52-104	75-85	6 to 8
Salmon (Pacific)	40-77	59	6 to 12
Freshwater Prawns	75-90	83-87	6 to 12
Catfish	35-95	82-87	6
Eels	32-97	73-86	12 to 24
Tilapia	47-106	72-86	-
Carp	40-100	68-90	-
Trout	32-89	63	6 to 8
Yellow Perch	32-86	72-82	10
Striped Bass	?-86	61-66	6 to 8

Behrends, 1978 [91]

In order to maintain specific temperatures in a fish pond, it is important to know the heat exchange processes that affect it. In a non-covered body of water, heat exchanges occur with the atmosphere through evaporation, convection, radiation and conduction, in order of greatest heat loss component to least.[92] Formulas can be applied to each of these processes to determine peak heat loss, with final calculations taking local temperature variations, wind, humidity and solar heat gain into account.[93]

There are several methods for reducing peak heating requirements. A surface cover can greatly reduce heat requirements by eliminating heat loss by evaporation. While extremely effective, a floating cover is

[89] Ibid., 2.3.
[90] Ibid., 4.1.
[91] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 291.
[92] Boyd and Rafferty, *Aquaculture Information Package*, 4.1.
[93] Ibid., 4.2-4.4.

not a practical option for commercial applications. A pond enclosure can cut down on evaporative, convective and radiation losses, the extent of which depending on the type of enclosure, materials used, and the presence or absence of ventilation. Lastly, thermal mass supplied by the water itself can help to maintain pond temperature as water is an excellent heat storage medium.[94]

Once the peak heating demand is established, the flow requirements are determined as a function of the temperature difference between the pond water and the resource temperature. As this would provide for the peak heating demand, the hot water would have to be mixed for all other times. This can be done in two ways: a flow-through system or a recirculating system. The flow-through system mixes geothermal water with cold water prior to its introduction to the pond.[95] Circular tanks are the most common tank shape as they tend be self cleaning. The length to width to depth ratio for a rectangular tank should be 30:3:1 for a good flow pattern.[96] If cold water is unavailable, recirculating pond water with or without aeration can provide the desired effect.[97] These systems recycle 90 to 99 percent of the water and require a clarifier to remove solid waste and a biofilter to remove ammonia and nitrite produced by the fish.[98]

General guidelines for aquaculture heating are:

- *Minimum acceptable heating water temperature = pond temperature + 15°F*
- *Maximum available heating water temperature = geothermal temperature – 10°F*
- *Minimum achievable leaving geothermal temperature = pond temperature + 10°F*[99]

Balneology and Swimming Pools

An application that has gained more recognition in the United States with a 'return to nature' movement, [100] hot springs are one of the more difficult geothermal heat utilizations to evaluate because

[94] Ibid., 4.4.
[95] Ibid., 4.5.
[96] Ibid., 3.1.
[97] Ibid., 4.5.
[98] Ibid., 3.2.
[99] Rafferty, "Direct-Use Temperature Requirements," 2.
[100] Lund, "Geothermal Direct-Heat Utilization," 7.

many owners do not know flow rates or inlet and outlet temperatures. In 2010, there were 242 documented facilities in 17 states.[101]

Hot springs have long been used for bathing as well as therapeutic purposes. In China, hot springs have been used medically for over 500 years and today are used in the treatment of high blood pressure, rheumatism, skin disease, diseases of the nervous system, and surgery recuperation. [102] In the United States, many hot spring sites were originally used by Native Americans for bathing and recuperation from battle.

When used therapeutically, oftentimes temperatures are closely monitored. When used for other purposes, such as a swimming pool, temperatures can fluctuate more liberally. Generally, about 80°F is the preferred temperature, with a 9°F acceptable variance. With resource heat that is too warm, geothermal water can be mixed or cooled by aeration or in a holding pond, or pool water can be on the receiving end of a cascaded use system. Another consideration is whether there will be direct or indirect use of the resource. The former requires regularly replacing the used water and is not conducive to sanitary methods such as chlorine inclusion. Oftentimes it is more economical to provide heat through a heat exchanger, keeping geothermal fluids within a closed loop system. [103] General heating requirement guidelines for swimming pools are the same as that for aquaculture ponds, given in the previous section.

Industrial Uses

Compared to greenhouses, space heating and aquaculture, most industrial application require higher temperatures,[104] and although there are many potential industrial applications of geothermal energy, the actual uses remain limited. [105] There are nine industrial facilities in three states which include two biodiesel plants in Oregon and Nevada, a laundry facility in California, and a brewery in Klamath Falls, Oregon, using heat from the existing district heating system both for building heat and the brewing

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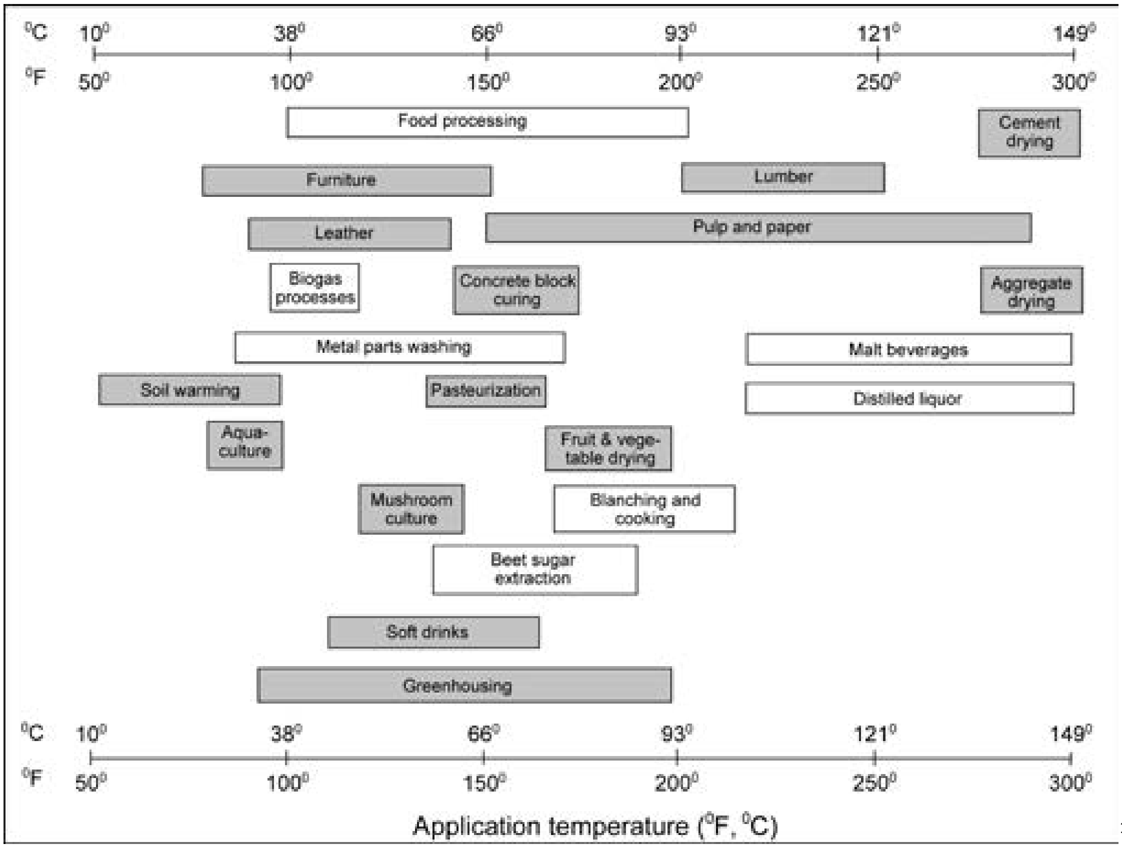
[101] Lund and Boyd, “US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources,” 9.
[102] Lund, “Geothermal Direct-Heat Utilization,” 7.
[103] Lund, “Development of Direct-Use Projects,” 2.
[104] Ibid., 3.
[105] Lund, “Geothermal Direct-Heat Utilization,” 8.

process. [106] The following chart expands upon the Lindal diagram to include more specific industrial uses in relation to their temperature requirements.



[107]

Space and District Heating

The difference between district heating and space heating is simply that district heating distributes water through a network of pipes to homes and/or blocks of buildings from a central location where space heating is usually limited to one geothermal well per structure. [108] In 2010 in the United States it was estimated that there were over 2,000 homes in 11 states using a space heating system[109] and 20 geothermal heating districts, most of which are limited to just a handful of buildings. [110]

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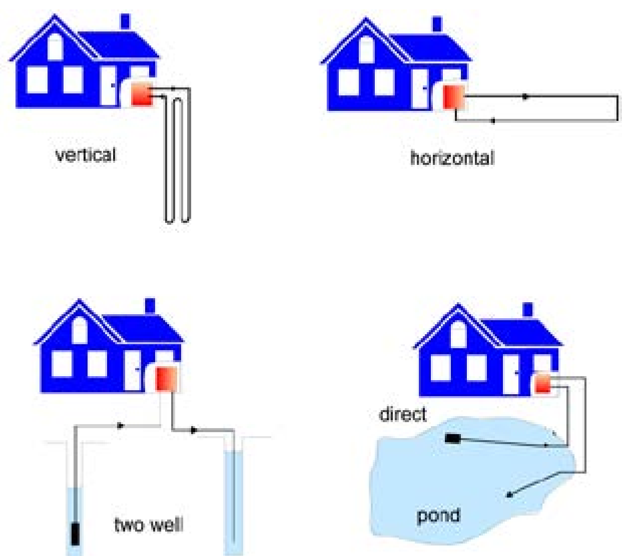
[106] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 9.
[107] Lund, "Development of Direct-Use Projects," 2.
[108] Ibid.
[109] Lund et al., "The United States of America Country Update 2010," 6.
[110] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 8.

Space heating is relatively straight forward, generally involving shallow wells that often use downhole heat exchangers to supply the heat. This method conserves geothermal water and has minimum impact. Geothermal heat pumps can also be above ground and used in both open and closed loop systems, as illustrated below.[111] The main concentration of space heating in the United States is in Klamath Falls, Oregon, where about 600 wells deliver heat to individual businesses, apartments and homes. [112]



[113]

District heating involves significantly more capital with the majority of the costs going to initial investment in production and injection wells, downhole and circulation pumps, heat exchangers, pipelines and distribution network, flow meters, valves and control equipment, and building retrofit.[114] These costs may add up to several million dollars in contrast to a conventional fossil fuel system which amounts to the cost of a central boiler and distribution lines. The two systems are comparable in the cost of annual maintenance, but the difference shows in the fuel for the fossil fuel systems which continues to add up at an ever-increasing rate while the cost of geothermal fluid remains stable. [115] The

[111] Lund and Boyd, "Geothermal Energy Uses. Geo-Heat Center Quarterly Bulletin, Vol. 28, No. 2 (Complete Bulletin), A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 6.
[112] Lund et al., "The United States of America Country Update 2010," 6.
[113] Lund and Boyd, "Geothermal Energy Uses. Geo-Heat Center Quarterly Bulletin, Vol. 28, No. 2 (Complete Bulletin), A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 7.
[114] Lund, "Development of Direct-Use Projects," 2.
[115] Lund, "Geothermal Direct-Heat Utilization," 8–9.

average savings to the consumer when using geothermal district heating compared to the cost of natural gas ranges from 30 to 50 percent per year.[116]

Another aspect of district heating projects is the thermal load density, which is the heat demand divided by the area of the district.[117] As discovered in the demonstration projects started in the late 1970s in the United States, without the customer base, district heating is not economically viable. A written commitment to retrofit buildings within the district as well as an obligation of funds to perform the retrofits should be obtained early in the project.[118] To further improve efficiency and economic viability of the project, district heating projects are often hybrid systems, relying on fossil fuel peaking during the coldest periods.[119] This eliminates the need to drill additional wells or pump more fluids from the existing well.[120]

Snow Melting

The first pavement snow melting system was installed in 1948 in Klamath Falls, Oregon, to improve safety at an 8 percent grade traffic light approach.[121] Since then, methods of heating pavement with geothermal fluids has been tested and utilized in other northern regions throughout the world. [122]

Geothermal energy can be used to melt snow on paved surfaces by using one of four methods: (1) through heat pipes, (2) through the direct use of geothermal water to circulating pipes, (3) through a heat exchanger at the well head, or (4) by allowing the water to sprinkle over the surface of the pavement.[123] Of these, the first two are the most common. Though not as efficient as using geothermal waters directly because of lower temperature circulating fluid, heat pipes are the most universal because they can be used with normal ground temperatures.[124]

The heating requirements for a system depend on the rate of snowfall, air temperature, relative humidity and wind velocity. The system can be applied to sidewalks, roadways and bridges and brings the expected benefits of added safety for pedestrians and vehicles and the elimination of snow

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[116] Lund, "Development of Direct-Use Projects," 2.
[117] Ibid.
[118] Lienau and Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 10.
[119] Lund, "Geothermal Direct-Heat Utilization," 8.
[120] Lund, "Development of Direct-Use Projects," 2.
[121] Lund, "Pavement Snow Melting," 17.
[122] Ibid., 16.
[123] Ibid.
[124] Ibid., 19.

removal.[125] In addition, the negative impacts of deicing chemicals, including concrete corrosion and environmental pollution, can be lessened or eliminated.[126]

Piping material can be either metal or plastic. Polyethylene pipe is now more commonly used because it is non-corrosive and easier with which to work.[127] Portland cement or asphalt concrete are both conducive for a snow melting system, though asphalt concrete has a lower thermal conductivity and so will differ in pipe spacing and temperatures. Unlike asphalt concrete, placing the pipes within Portland cement is an option. However, it can be advantageous to lay the piping below, as is usually the case for sidewalks, because utility cuts and repairs can be accomplished without damaging the pipes. Naturally, it is important to have appropriate base and subbase thicknesses along with proper drainage to protect from frost heave.[128] Many standards for construction can be found in the ASHRAE Handbook.

Geothermal tail water of about 104°F can be used for melting ice and snow on paved surfaces. This application of melting snow and ice with low temperature geothermal spent fluids can be a significant method toward achieving efficient energy cascading utilization in northern climates.[129]

Cascaded Use

Until recently, geothermal application had been largely determined by resource temperature and short-term financial gains, leading to single purpose resource exploitation.[130] Cascaded use refers to a multi-stage utilization, using lower and lower water temperatures in successive steps.[131] As an example, first-stage use could be space heating or district heating, flowing into a second-stage use of floor heating, soil heating for greenhouses, aquaculture, animal husbandry or snow melting.[132] Agricultural irrigation is an additional option with low salinity geothermal water, and can work especially well for salt tolerant crops such as barley, forage and sugar beets.[133]

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[125] Ibid., 12.
[126] Wang, Zhao, and Chen, "Experimental Investigation of Ice and Snow Melting Process on Pavement Utilizing Geothermal Tail Water," 1538.
[127] Lund, "Pavement Snow Melting," 12.
[128] Ibid., 16.
[129] Wang, Zhao, and Chen, "Experimental Investigation of Ice and Snow Melting Process on Pavement Utilizing Geothermal Tail Water," 1545–46.
[130] Elíasson and Björnsson, "Multiple Integrated Applications for Low-to Medium-Temperature Geothermal Resources in Iceland," 448.
[131] Lund, "Geothermal Direct-Heat Utilization," 9.
[132] Elíasson and Björnsson, "Multiple Integrated Applications for Low-to Medium-Temperature Geothermal Resources in Iceland," 442.
[133] Schmitt, "Agriculture, Greenhouse, Wetland and Other Beneficial Uses of Geothermal Fluids and Heat," 1.

An interesting use of cascaded geothermal waters is that of downstream aquaculture facilities from geothermal greenhouse operations. This can be accomplished in two ways: first, the geothermal water cascaded from the greenhouse would be used only for heating and temperature control; second, the geothermal water would be used both for heating and as a culture medium. A facility at New Mexico State University successfully used spent geothermal water from greenhouses for both heating and as culture water, but found that highly sophisticated temperature control systems were necessary involving both direct flow of the water into the tank as well as heating water indirectly with a heat coil. A sedimentation tank and artificial wetland filter processed water prior to inclusion in the fish tank to remove suspended solids and nitrogen, followed by a blending tank for recycled culture water and the cascaded water.[134]

The numerous advantages of cascaded use and possible disadvantages are as follows:

Main advantages

- *Greater versatility and flexibility in marketing the energy and adjusting the energy facility to changes in demand.*
- *Better overall energy efficiency and use of the energy resource and, hence, better resource and environmental sustainability.*
- *Possibility of adopting stepwise development, which also means stepwise capital investment and an early return in project earnings. There is thus more time for market promotion and long-term planning becomes easier.*
- *Great socio-economic potential through creation of new jobs.*
- *Ideal for small community development.*

Main disadvantages:

- *Increased complexity of the development and increased risk.*
- *Increased complexity of the control and management systems.*
- *Greater total capital investment.*
- *Profitability risk.*[135]

To broaden the scope of cascaded use, integrated use is also an option. Integrated use means "the integration of geothermal resources with other types of resources (whether conventional or alternative renewable energies) in a single efficient and economical energy supply system that meets modern sustainability criteria better than stand-alone developments ever could."[136] An example of this is in Akureyri, Iceland, where five tapped geothermal reservoirs feed into an energy system that heats the

[134] Zachritz, Polka, and Rudi Schoenmackers, “Potential for Intensive Aquaculture Production Cascaded from Geothermal Greenhouse Operations,” 77–81.
[135] Elíasson and Björnsson, “Multiple Integrated Applications for Low-to Medium-Temperature Geothermal Resources in Iceland,” 450.
[136] Ibid., 448.

business district then the water is recirculated and reheated by electric heat pumps. Electric and oil-fueled boilers also serve to boost the system during peak loads and emergencies. Part of the return water is reinjected while the remaining hot water produced is used for space heating, heating for sports facilities and swimming pools, snow melting and industrial uses.[137]

SUSTAINABILITY OF GEOTHERMAL RESOURCES

As of 2010, the United States saved the equivalent to 13.3 million barrels of oil per year (amounting to 1.76 million tons of carbon savings annually) with its direct utilization of geothermal energy. An additional equivalency of 6.9 million barrels of oil was saved annually just in savings in the cooling mode of geothermal heat pumps. [138]

Geothermal energy is viewed as a renewable, sustainable energy. [139] To describe geothermal energy as renewable has been explained in the process from where geothermal resources come: the tapped heat from an active reservoir close to the earth's crust that is continuously restored as geothermal fluids are extracted by natural recharge, reinjection, or a combination.[140] The term sustainable is more controversial. Simply stated in a report from the Intergovernmental Panel on Climate Change, "sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future."[141] This definition is expounded upon specific to geothermal energy by Hahnlein, et al. as follows:

> *For the sustainable thermal use of shallow geothermal energy, technical, economical, environmental and also social aspects should be integrative considered. We conclude that a shallow geothermal system is sustainable, if the following aspects are principally fulfilled:*
>
> *From technical aspects:*
>
> - *The system operates without any major technical failures;*
> - *Other adjacent systems are not impacted;*

[137] Ibid., 448–49.
[138] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 10.
[139] Hähnlein et al., "Sustainability and Policy for the Thermal Use of Shallow Geothermal Energy," 915.
[140] Intergovernmental Panel on Climate Change and Edenhofer, *Special Report on Renewable Energy Sources and Climate Change Mitigation*, 71.
[141] *Report of the World Commission on Environment and Development*, 39.

From economical aspects:

- *The system implies no main financial disadvantage in comparison with other renewable or conventional heating and cooling systems;*

From ecological aspects:

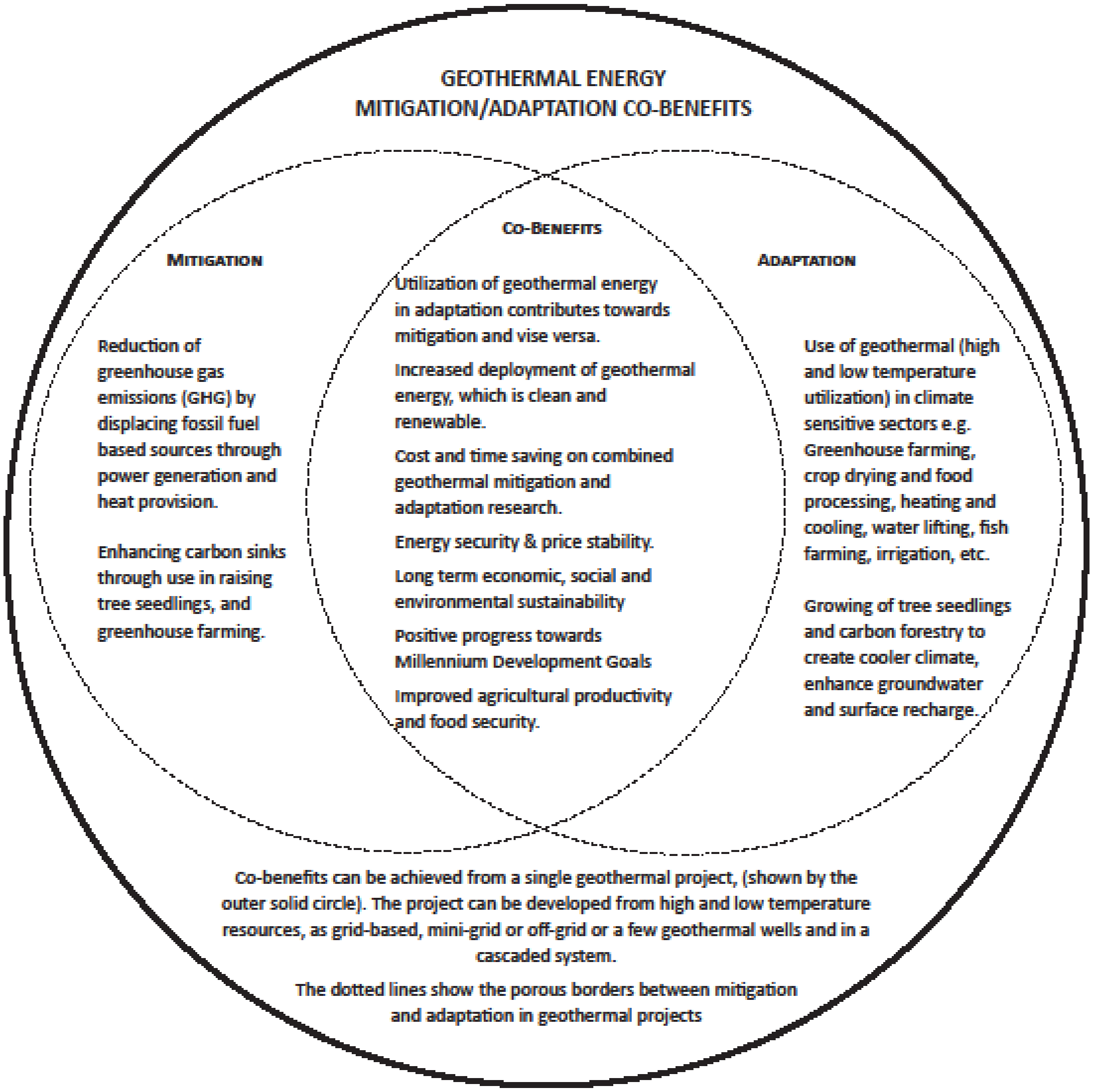
- *The generated energy is mainly renewable energy;*
- *CO^2 emissions and particulate matter emissions are saved or even reduced;*
- *Impacts on groundwater quality, quantity and ecology are negligible;*
- *Temporary changes during the operation are reversible;*

From social aspects:

- *The owner has a user-friendly and controllable heating system;*
- *The system contributes to environmental protection and climate change;*
- *The user obtains or feels a social prestige;*
- *No interferences with adjacent installations exist (e.g., possible conflicts with the neighbor).*[142]

Geothermal projects that can fulfill these sustainability parameters can also be used as both a mitigation and an adaptation method concerning global warming. The goal of mitigation is to reduce greenhouse gas emissions and create carbon sinks. Adaptations aim to adjust the way people live to continue to thrive in our changing environment. Geothermal projects can simultaneously reduce emissions while providing new opportunities than can reduce vulnerability and enhance resilience. The method with which geothermal energy contributes to adaptation is time, region and impact specific.[143] Ogola, et al. developed the following diagram that illustrates the relationship between the use of geothermal resources and its role in both mitigation and adaptation and the shared benefit potential.

[142] Hähnlein et al., "Sustainability and Policy for the Thermal Use of Shallow Geothermal Energy," 923.
[143] Ogola, Davidsdottir, and Fridleifsson, "Opportunities for Adaptation-Mitigation Synergies in Geothermal Energy Utilization- Initial Conceptual Frameworks," 518.



[144]

To further increase the benefits of geothermal projects, and considering both mitigation and adaptation approaches, environmental strategies may be incorporated into projects. In the Philippines, forestry projects have accompanied government-led geothermal projects. Such a marrying of schemes within the geothermal field has served to improve groundwater recharge along with increasing the availability of ground and surface water for the community, creating carbon sinks and reducing erosion. [145]

There is much to gain from direct utilization of geothermal energy—environmentally, economically and socially—but the project has to meet the sustainable criteria in the implementation phase as well as the

[144] Ibid., 529.

[145] Shortall, Davidsdottir, and Axelsson, "Geothermal Energy for Sustainable Development," 402.

development phase. Given this criteria, the Geo-Heat Center predicts that future development will most likely occur in these areas:

- *Collocated resource and uses (within 10 km apart)*
- *Sites with high heat and cooling load density (>36 MWt/sq km)*
- *Food and grain dehydration (especially in tropical countries where spoilage is common)*
- *Greenhouses in colder climates*
- *Aquaculture to optimize growth—even in warm climates*
- *Ground-coupled and groundwater heat pump installations (both for heating and cooling)*[146]

COMMUNITY & GEOTHERMAL RESOURCE DEVELOPMENT

Communities that take on geothermal development, whether it be high or low temperature, stand to gain benefits beyond those apparent in cost savings and reduced emissions. Through gains such as job creation, promotion of commercial growth, expansion of the tourist industry, improvement in quality of life,[147] and incitement of community cohesiveness,[148] geothermal projects can result in a high level of resiliency for the communities that chance the risks in development of the resource.

In regard to our changing climate, vulnerabilities of communities vary greatly along with their adaptive capacity to address those vulnerabilities. The role of geothermal development in communities that have access to geothermal resources is that of helping both natural and human systems adapt to climate change. [149] Whether it is through agriculture, fisheries, snow melting, heating and cooling requirements or other uses, geothermal resources can not only reduce a community's carbon footprint, but improve resiliency with a more efficient energy technology.

The potential economic impact of the development of geothermal resources can further boost resiliency. This may be direct, such as through the creation of jobs, or indirect, as in the additional activity that is spurred to supply goods and services to the development. There may also be induced effects, which is the circulation of the money that is brought in by direct and indirect effects. Known as the multiplier or ripple effect, the economic activity that can occur from an initial expenditure can substantially influence the economic well-being of a community.[150] An example of this is in Klamath Falls, Oregon, where the development of a geothermal district heating system along with geothermally

[146] Lund, "Geothermal Direct-Heat Utilization," 9.
[147] Nealon, "The Economic, Environmental, and Social Benefits of Geothermal Use in Idaho," 1–3.
[148] Merrick, "Adventures in the Life of a Small Geothermal District Heating System (or) The Little Project That Could," 5.
[149] Ogola, Davidsdottir, and Fridleifsson, "Opportunities for Adaptation-Mitigation Synergies in Geothermal Energy Utilization- Initial Conceptual Frameworks," 518.
[150] "Buried Treasure: The Environmental, Economic, and Employment Benefits of Geothermal Energy," 11.

heated sidewalks led to downtown revitalization. The availability of geothermal energy was also attributed with attracting a large scale nursery that provides both employment for the community as well as tree seedlings for local reforestation projects.[151]

When it comes to the development of the resource (initial financial and geological assessments, environmental permitting, drilling and technological assistance) both state and the federal governments are needed to overcome the inevitable setbacks communities will face.[152] At this time in the United States, direct use receives little attention and less financial support as the government looks to promote high temperature resources. Consequently, most direct use projects are small and developers and investors are hard to find.[153] For this reason, the community is seen as the best possible promoter of geothermal developments, both because it takes full community moral and financial support to complete[154] as well as having the advantage of not needing to realize an immediate high capital return on investments.[155]

CONCLUSION

The benefits of a developed direct use geothermal resource are undeniable; the barrier to its widespread application lies in the development process. Confusing legalities, innumerable catastrophic risks and high initial costs are major obstacles in the exploration and development of low temperature geothermal resources for communities. However, both larger and smaller scale developments have been successful, and once established, can contribute to a community's overall resilience. With greater attention to climate change, it is possible that governmental assistance in funding and research will increase along with incentives to develop renewable energy sources, thus opening a channel for greater sustainable development in the area of low temperature geothermal resources. In the meantime, communities can choose to take cautious steps forward in their resource exploration, or set out to be a leading force in direct use geothermal development with the existing technology and expertise.

[151] Lund and Boyd, "Geothermal Energy Uses. Geo-Heat Center Quarterly Bulletin, Vol. 28, No. 2 (Complete Bulletin), A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 15.
[152] Merrick, "Adventures in the Life of a Small Geothermal District Heating System (or) The Little Project That Could," 1.
[153] Lund and Boyd, "US Geothermal Projects and Resource Areas. Geo-Heat Center Quarterly Bulletin, Vol. 29, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources," 10.
[154] Merrick, "Adventures in the Life of a Small Geothermal District Heating System (or) The Little Project That Could," 5.
[155] Lund, "Geothermal Direct-Heat Utilization," 7.

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