

**Geothermal Energy Exploration Study
Final Technical Report**

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Any findings, opinions, and conclusions or recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of the Department of Energy.

Executive Summary

This project promoted the goal of developing geothermal energy capacity in geographic areas beyond the traditional and well-developed areas in California and Nevada. Snohomish County PUD (the District) has a growing service load and is required by the Washington State renewable portfolio standard to provide 15% of its load from new, renewable energy resources by 2020. The District believes that geothermal energy has the potential to contribute significantly towards meeting this challenge and aspires to develop geothermal capacity in or near its service territory by 2020. Washington State currently has no geothermal electricity production online or in development. Additionally, no significant geothermal exploration had been conducted in the region prior to this effort.

Supported by funds from this award, the District thoroughly explored the feasibility of a hydrothermal geothermal development within its service territory. The District successfully planned and drilled six exploratory geothermal wells and added significantly to the knowledge of the geology of the area. The Straight Creek Fault region, which was the sole location that showed significant potential for hydrothermal development in the District's service territory, was determined not to be feasible for development.

The District subsequently expanded its search for geothermal development locations to include all of Washington State. Mount Baker has been identified as the area of the state with the greatest potential for geothermal development. Having gathered additional information about the Mount Baker region with support from this award, the District is actively pursuing exploration and development in the area.

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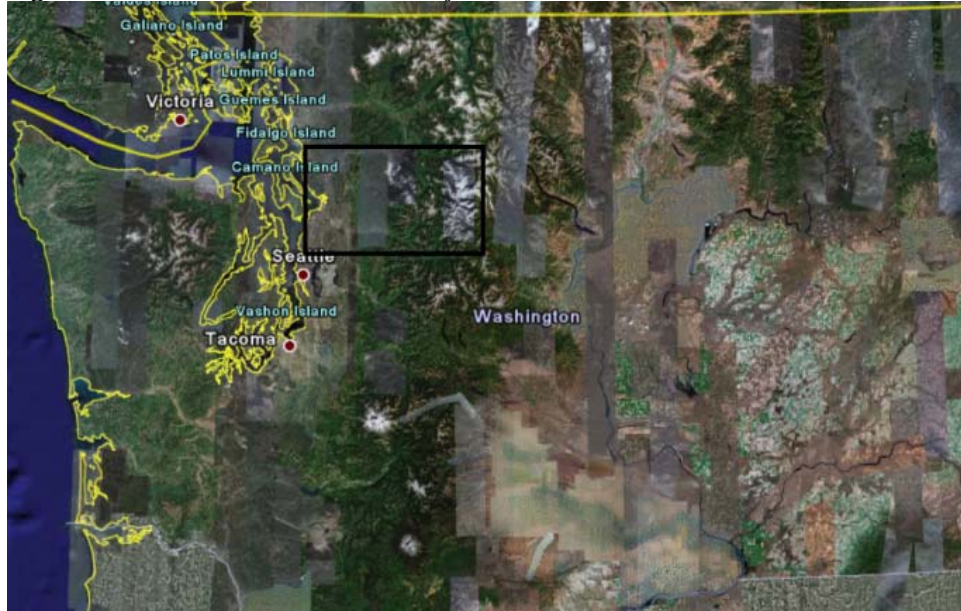
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1. Introduction

Snohomish County PUD (the District) has a growing service load and is required by the Washington State renewable portfolio standard to provide 15% of its load from new, renewable energy resources by 2020. The District believes that geothermal energy has the potential to contribute significantly towards meeting this challenge and aspires to develop geothermal capacity in or near its service territory by 2020 (see Figure 1). Washington State currently has no geothermal electricity production online or in development. Additionally, no significant geothermal exploration had been conducted in the region prior to this effort.

Figure 1. Location of Snohomish County



This project built on the District's prior efforts to identify and evaluate potential geothermal resources in or near the Snohomish County region. The first objective of this project was to assess the potential for geothermal development along the Straight Creek Fault south of Glacier Peak in Snohomish County, which was identified as the most promising location for development within the District's service territory. The second objective of this project was to identify the top locations for potential development in a larger geographic area of Washington State if the assessment of the Straight Creek Fault region indicated that geothermal development was not feasible.

2. Results and Accomplishments

2.1 Exploration and Assessment of the Straight Creek Fault Region

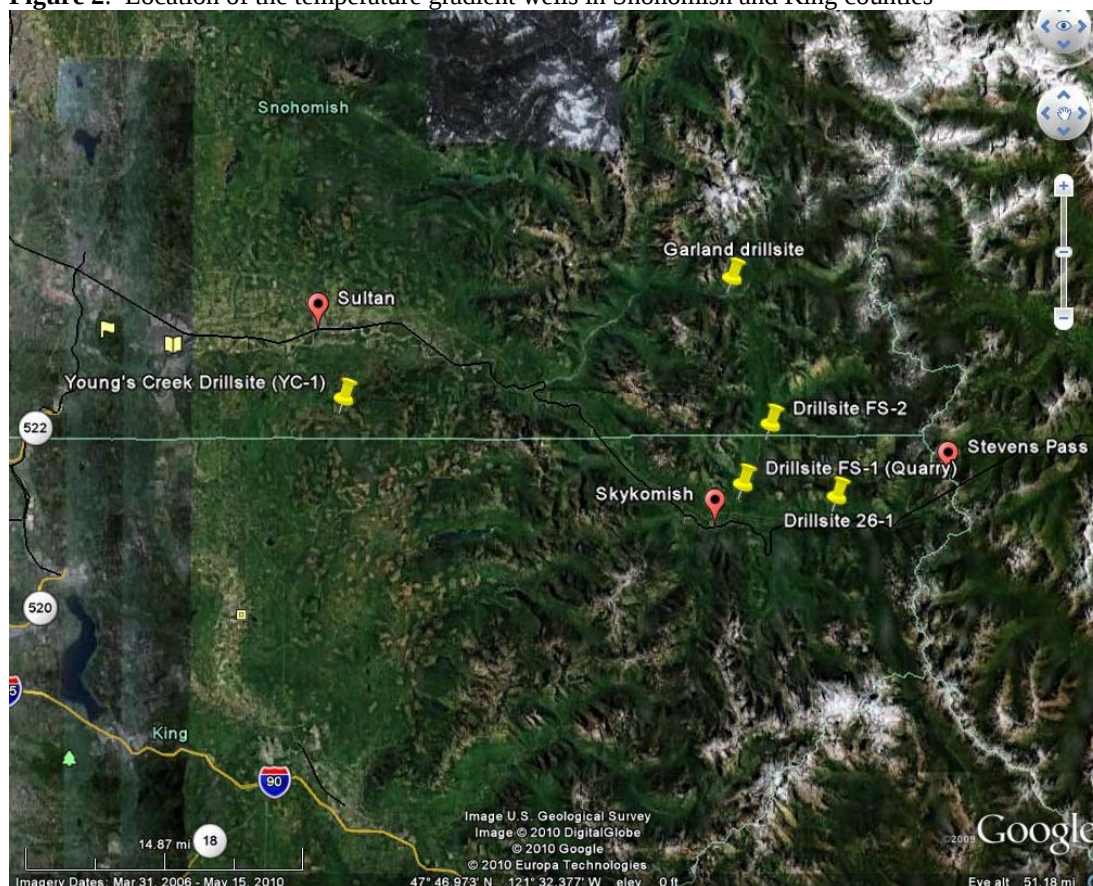
As a result of a geothermal development study conducted by the District prior to receipt of this award, the District identified the Straight Creek Fault region as the most promising area within its service territory for geothermal development. The decision was based on a review of existing data, an analysis of the geological map of the region, geochemical studies, and an assessment of land-use limitations in the region.

The District collaborated with its technical consultants at GeothermEx and geologic personnel in the Washington State Department of Natural Resources to identify five locations on which to drill shallow temperature gradient wells to assess the feasibility of geothermal development in the region. The selection criteria for locations were to choose sites that:

- Were accessible from existing roads
- Would minimize environmental impact by virtue of being previously developed sites
- Would minimize drilling expense and difficulty through the presence of shallow bedrock
- As a group, would represent a geographic distribution that covered the Straight Creek Fault region as well as possible

The District acquired permissions for drilling from the owners of the lands on which the proposed wells were located. Landowners included the United States Forest Service, the Washington Department of Natural Resources, and one private landowner. The District obtained Washington State geothermal drilling permits for five temperature gradient wells as well as land disturbance permits from Snohomish County and King County. The locations of the temperature gradient wells are shown in Figure 2.

Figure 2. Location of the temperature gradient wells in Snohomish and King counties

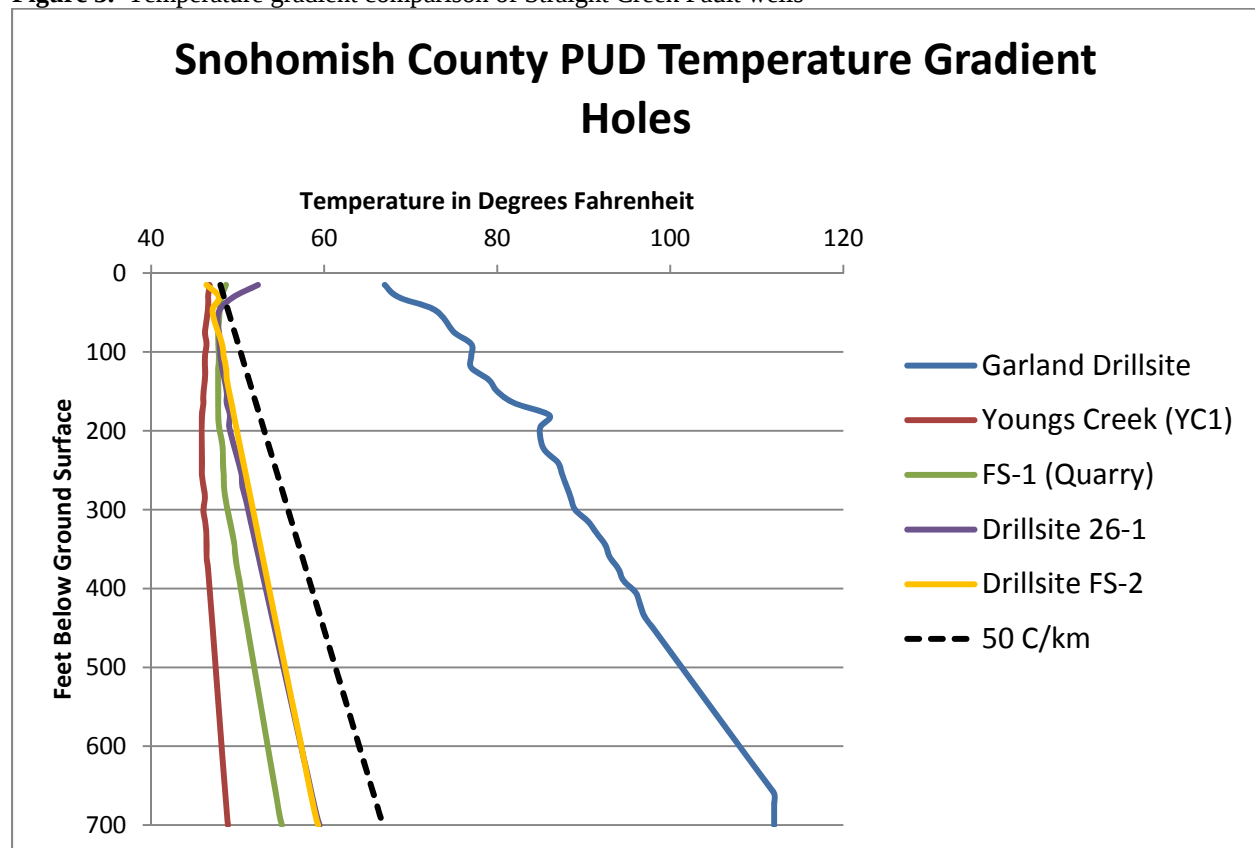


The District contracted with Boart Longyear, Inc to drill five 700-foot-deep temperature gradient wells on locations throughout the Straight Creek Fault Region in fall, 2010. In keeping with the District's communication and outreach plan, multiple news stories covering the effort appeared in

regional newspapers and on regional television. Those were the first geothermal temperature gradient wells drilled in Washington State in more than three decades.

After reviewing the resulting drilling logs and temperature gradients with its technical consultants for the project, AltaRock Energy, the District determined that one of its temperature gradient well locations, Garland Mineral Springs, indicated that additional effort was warranted to study the feasibility of geothermal development at the location. Only Garland Mineral Springs displayed a temperature gradient greater than the minimum expectation for an economically feasible development of 50 degrees Celsius per kilometer. (See Figure 3)

Figure 3. Temperature gradient comparison of Straight Creek Fault wells



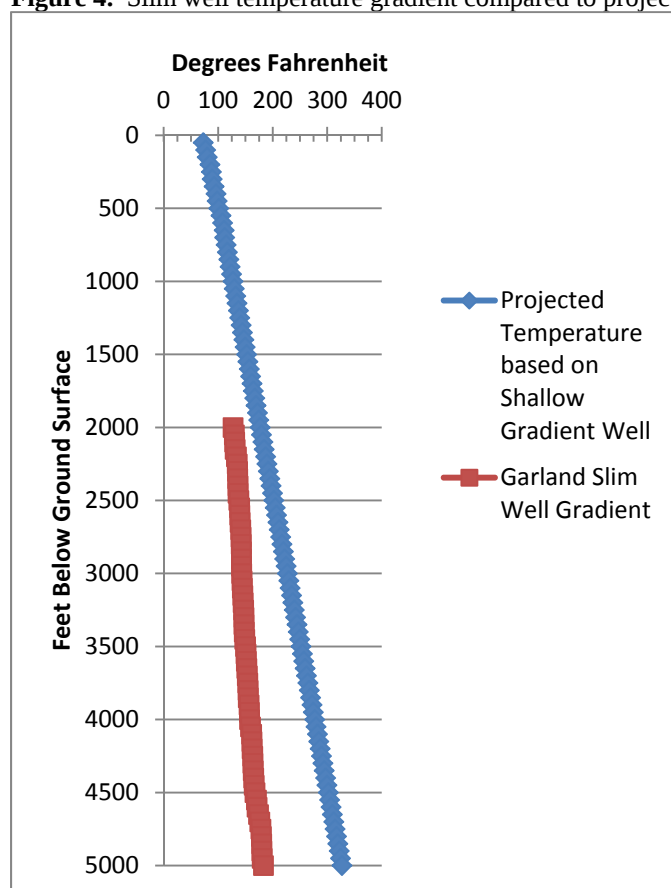
The District worked with GeothermEx to develop the well plan and drilling program for a 5,000-foot-deep slim well at the Garland Mineral Springs location. The purpose of the well was to explore the temperature gradient in the area at depth and to allow permeability testing of the geothermal reservoir if one was encountered in the drilling. GeothermEx assisted the District in identifying a drilling engineer to represent its interests and ensure successful completion of the drilling.

In work conducted outside the scope of this award, the District completed the drilling of the 5,000-foot-deep slim well in the fall of 2011. The District conducted temperature and permeability testing on the slim well during the winter of 2012. GeothermEx delivered a report in March, 2012, assessing the development potential of Garland Mineral Springs based on the results of that testing.

While the slim well was being drilled, the District contracted with the Washington Department of Natural Resources to conduct geologic mapping in the area surrounding Garland Mineral Springs. The mapping effort was suspended due to the onset of winter weather.

As can be seen in Figure 4, the elevated temperature gradient and flowing geothermal waters that had made Garland Mineral Springs an area of focus did not continue at depth in the slim well. Rather, the temperature gradient observed at depth was consistent with the general background heat signature in the region. A common rule of thumb is that a geothermal system must have a temperature gradient of at least 50 degrees Celsius per kilometer to be economically feasible to develop. The shallow temperature gradient well had a temperature gradient of approximately 110 degrees Celsius per kilometer. The deeper slim well gradient was only 34 degrees Celsius per kilometer.

Figure 4. Slim well temperature gradient compared to projected temperature



While geology and geochemistry suggest that there is a deep geothermal reservoir with waters of sufficient temperature to develop a plant, the limited land access in the area constrains exploration significantly on areas at a distance from the surface springs. Garland Mineral Springs is on a private parcel of approximately 40 acres that is located in the middle of the Wild Sky Wilderness. (See Figure 5.) The District believes that successful development at the location required that the geothermal resource be readily accessible from the private parcel.

Figure 5. Garland Mineral Springs and the surrounding Wild Sky Wilderness.



2.2 Planning Exploration Beyond the Straight Creek Fault Region

Based on the slim well results and the report from GeothermEx, the District determined in spring, 2012, that development of a hydrothermal geothermal plant was not feasible at Garland Mineral Springs. As a result the District terminated its exploration effort in the Straight Creek Fault Region and expanded the geographic scope of its location search to include the rest of Washington State. In August, 2012, GeothermEx delivered a preliminary feasibility study of geothermal development in Washington State. Based on the report, the District determined that the region around Mount Baker in northwest Washington held the greatest potential for successful development.

District personnel visited the Mount Baker region with GeothermEx personnel in fall, 2012, in order to identify geologic structures, gather geochemical samples and scout access and land use. GeothermEx used the information gathered from this visit and feedback from the District to develop a site-specific evaluation of Mount Baker as a geothermal development prospect, delivered in January, 2013. It identified primary areas of interest, estimated the geothermal potential of the resource, and offered the outline of a preliminary exploration plan. The preliminary exploration plan details steps to further refine the assessment of the geothermal resource and identify prime locations for exploratory drilling sites. The plan includes geologic mapping of the region as well as magnetotelluric and gravity surveys. The District is actively pursuing these steps in the Mount Baker region.

3. Conclusions

With the help of the funds from this award, the District thoroughly explored the feasibility of a hydrothermal geothermal development within its service territory. The District successfully planned and drilled six exploratory geothermal wells and added significantly to the knowledge of the geology of the area. The Straight Creek Fault region, which was the sole location that showed significant potential for hydrothermal development in the District's service territory, was determined not to be feasible for development.

The District has expanded its search for geothermal development locations to include all of Washington State. Mount Baker has been identified as the area of the state with the greatest potential for geothermal development. GeothermEx performed a site-specific evaluation of the Mount Baker area for the District which concluded with recommended steps to further refine the assessment of the geothermal resource and identify prime locations for exploratory drilling sites. The plan includes geologic mapping of the region as well as magnetotelluric and gravity surveys. The District is actively pursuing these steps in the Mount Baker region.

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