GEOLOGY AND ENERGY UTILIZATION OF THE KLAMATH FALLS KNOWN GEOTHERMAL RESOURCE AREA

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ABSTRACT

Klamath Falls, Oregon, is located on a geothermal hot springs area which has been used by residents, principally in the form of hot water for space heating, at least since the turn of the century. Approximately 400 shallow-depth wells ranging from 90 to 1,900 feet in depth are used to heat approximately 500 structures. This utilization includes the heating of residences, schools, a college campus, businesses (including a creamery for milk pasteurization), heating swimming pools and melting snow from pavements. It is felt that only a small portion of the area's potential is being utilized, with speculation that a high temperature stream area exists below the known shallow reservoir.

Well water, which ranges from 100^{0}F to 230^{0}F, has been used directly in heating and drinking water systems; however, present practice is to use down-hole, hair-pin, heat exchanger (locally termed a coil) with city water as the circulating fluid. Even though at present only about one quarter of the city uses this geothermal resource, investigations are being made into district heating and the heating of large apartment units from a single well.

INTRODUCTION

Klamath Falls, Oregon, is located on a Known Geothermal Resource Area (KGRA) (Ref. 1), and the residents have made use of the resource, principally in the form of hot water for space heating, at least since the turn of the century. The local use appears to be somewhat unique and is the most successful attempt at using geothermal hot water for space heating in the United States (Ref. 2).

It is estimated that Klamath Falls has approximately 400 hot water wells for space heating of approximately 500 structures. These include single-family residences, several residences sharing a single well, apartment houses, commercial buildings, swimming pools, and for process utilization.

HISTORICAL DEVELOPMENTS (Ref. 3)

Surface hot springs and mud pots were present before the settlement of Klamath Falls and had been used by Indians and sheepherders before the turn of the century. Five specific spring areas were known during this time; the most noted ones were the "Big Springs" located in the present Modoc Field adjacent to the high school and "Devil's Teakettle" located in the present Ponderosa field behind the City School Administration buildings. Other locations were one on either side of Main Street in the vicinity of the present City swimming pool and Klamath Medical Clinic and one between Mills School and the railroad passenger depot. The latter area was a swamp and excellent duck hunting area for many years. Today these areas are the location of artesian or near surface artesian wells. These natural spring areas were used by residents for scalding hogs and poultry and as temporary residence for many transients. Figure 1 gives the locations of the above areas.

Today most of the eastern portion of the city of Klamath Falls is heated by hot water. The principal heat extraction system is the closed loop down-hole heat exchanger (locally called a "coil") utilizing city water in the heat exchangers.

Most of the present wells for residences vary between 90 and 900 feet in depth with 200 to 300 feet being most common. Commercial establishments and schools, requiring a greater heat output, increase the well depth to over 1,800 feet with 1,000 to 1,300 feet common. Depth to the water surface varies from artesian (surface) to 350 feet with 50 to 100 feet most common. Down-hole heat exchangers will generally extend to near the well bottom with a minimum of 100 feet below the water surface.

Four "streamers" are located along the middle of Hillside Avenue. These are sources of natural steam that were encountered during the course of drilling at very shallow depths (approximately 90 feet). Due to the high temperature gradient in this area, grass and wildlife (frogs and quail) can be seen all winter, and at one location, a subtropical Mimosa tree is growing. No water is present in these wells, thus the stream is used to heat the city water in the heat exchangers.

Present uses of the hot water heat include residences, almost all of the city schools, Oregon Institute of Technology, a creamery (for heating and milk pasteurizing), melting snow from a state highway pavement, keeping a floor from freezing and frost heaving in a cold storage plant, accelerated curing of concrete, direct use in a laundry, and for heating swimming pools. Several locations make use of waste hot water discharged into storm sewer lines.

GEOLOGY (Ref. 4 and 5)

The Klamath Falls KGRA is located near the east side and center of Klamath Basin, a northwesterly oriented graben approximately 50 miles long and 10 miles wide extending from Medicine Lake highland to the south to the Crater Lake caldera to the north. The area is typical of the basin and range country of horst and graben structure located to the east, with Upper Klamath Lake being the largest body of water in this basin. The area is drained by the Klamath River to the south into California. The Cascade Mountains are located to the immediate west and the high desert country to the east. Evidence of recent volcanic activity is shown by Mt. Lassen to

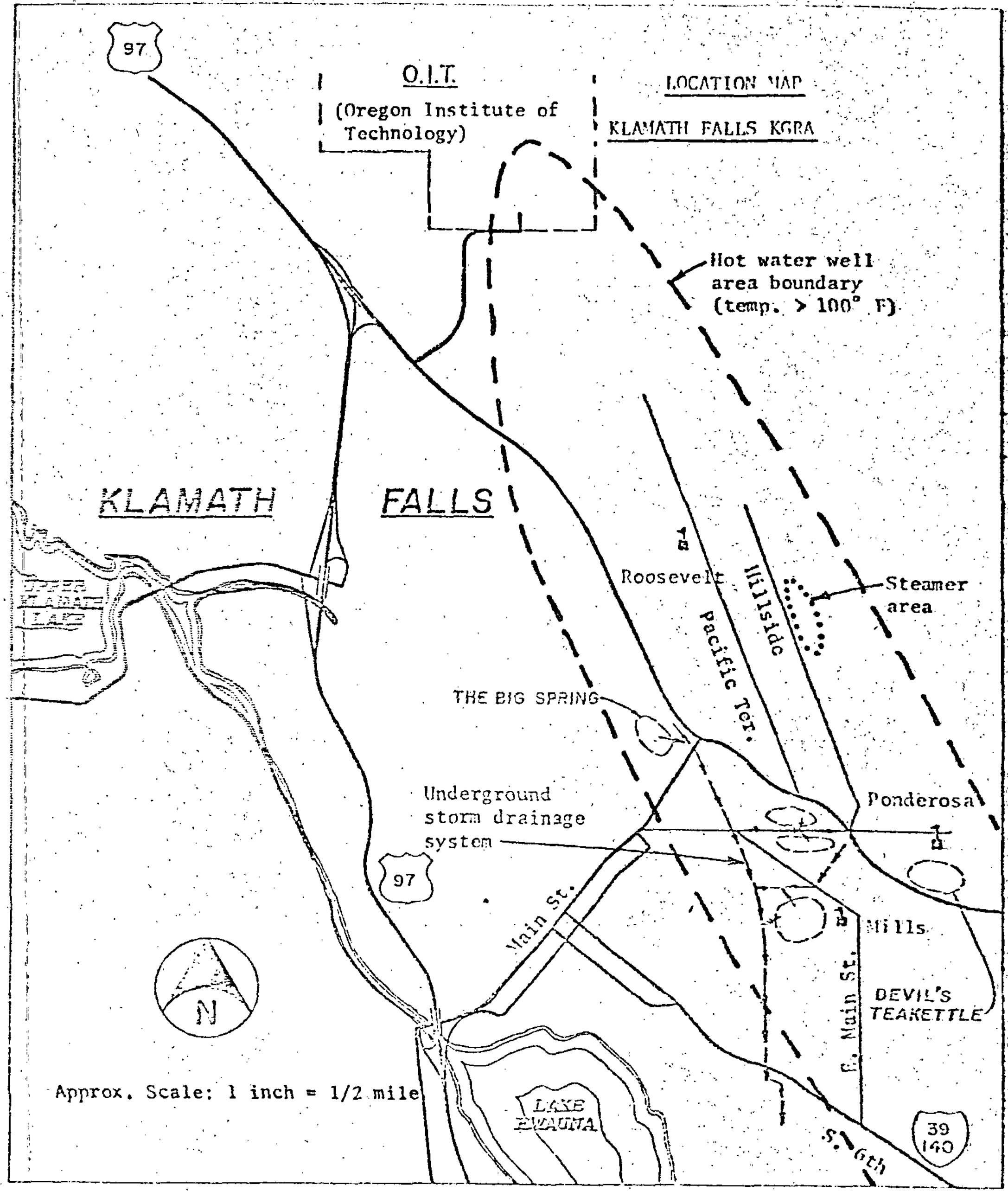


FIGURE 1. General Location Map of the Klamath Falls Known Geothermal Resource Area

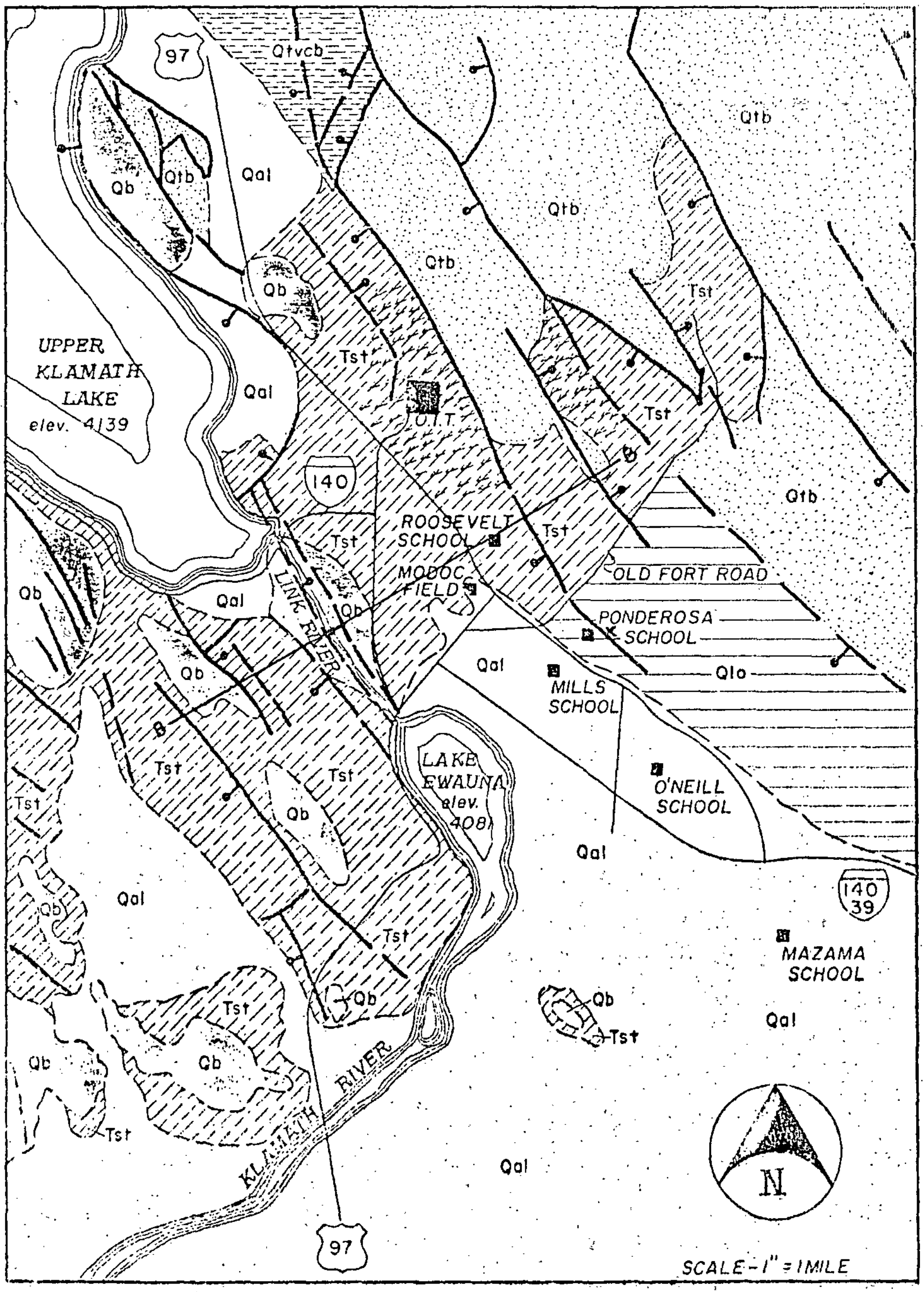
the south (erupted in 1914-1917), Mt. Shasta (a composite volcano), Crater Lake (formerly Mt. Mazama which erupted approximately 6,500 years ago), and Lava Beds National Monument (with lava flows as recent as 500 years ago).

The steeply dipping normal faults that form the graben have estimated vertical movements of 1,600 feet with several of the fault scarps being exposed in the basin (i.e., Rattlesnake Point and Stukel Mountain). The main hot water well area is located adjacent to the fault scarp over fault blocks that are slightly tilted and raised above the central portion of the graben. The principal geologic formations are lava flows, volcanic breccia including lapilli, locally designated "cinders", and extensive deposits of lacustrine diatomite and tuffaceous siltstones and sandstone. Many of the above deposits are intermixed making divisions difficult to define. All of the above are underlain by Cascade lava flows of andesites and basalts. All deposits are Pliocene or more recent. Figures 2 and 3 illustrate the geology of the area.

In general, the fractured basalts and cinders are highly porous, being capped by a nearly impervious zone of diatomite and tuffaceous sediments locally called "chalk rock" (Tst on the geologic map) which varies from 30 to 150 feet thick in the area. In very localized areas (as seen behind the new hospital), this "chalk rock" has been hydrothermally altered to various siliceous deposits, locally called "hot springs agates."

The hot water probably originates as seepage from the Cascades to the west, Crater Lake to the north and in part as seepage from Upper Klamath Lake and the "hog backs" to the east. These latter two sources probably contribute most of the cold water near the surface of the area. Two main geothermal reservoirs probably exist, a lower area with temperatures in excess of 250^{0}F, with heat and water being transferred by convection cells to the upper reservoir in the form of steam and hot gases along fault zones. The upper reservoir has temperatures less than 250^{0}F with the upper portions of this zone being cooled by the downward seepage of cold ground water. Wells generally intercept the hot water in specific stratas of porous material (fractured basalts, andesites and cinders). Water generally flows in these layers and can be identified by the lack of drilling cuttings when bailing a well. These layers can be from 2 to 20 feet thick with impervious layers in between. The general circulation pattern in both the upper and lower reservoirs is probably along fault zones vertically and porous layers horizontally. No well drilling has encountered the lower reservoirs, thus its existence and the associated live steam can only be the subject of speculation and interest for future drilling.

The permeable layers of hot water appear to be somewhat channelized, as in several cases a well drilled in the vicinity of several "good" wells with active flowing zones, was unable to intercept these zones. These latter wells often have high rock temperatures; however, without the free flowing water to provide an adequate transfer medium, additional depth is required to allow for added heat exchanger pipe length. These wells are



GENERALIZED GEOLOGIC MAP
OF KLAMATH FALLS & VICINITY

GEOLOGIC MAP EXPLANATION

Holocene

Qal — Alluvial deposits including diatomite and peat

Pleistocene

Qlo — Fluvial terrace and lacustrine deposits

Qb — Basalt flows

Qtb — Basalt flows, pyroclastic breccia, and agglomerate; of uncertain stratigraphic relationships; may in part be contemporary with Tst, Tb, and Qb.

Pliocene

Tst — Lacustrine & fluviatile tuffaceous siltstones, sandstone, ashy diatomite, basaltic tuffs and breccias, few thin basalt flows.

Tertiary-Quaternary

Qtvcb — Basalt eruptive centers

SYMBOLS

—•— Known fault location, ball on downthrow side

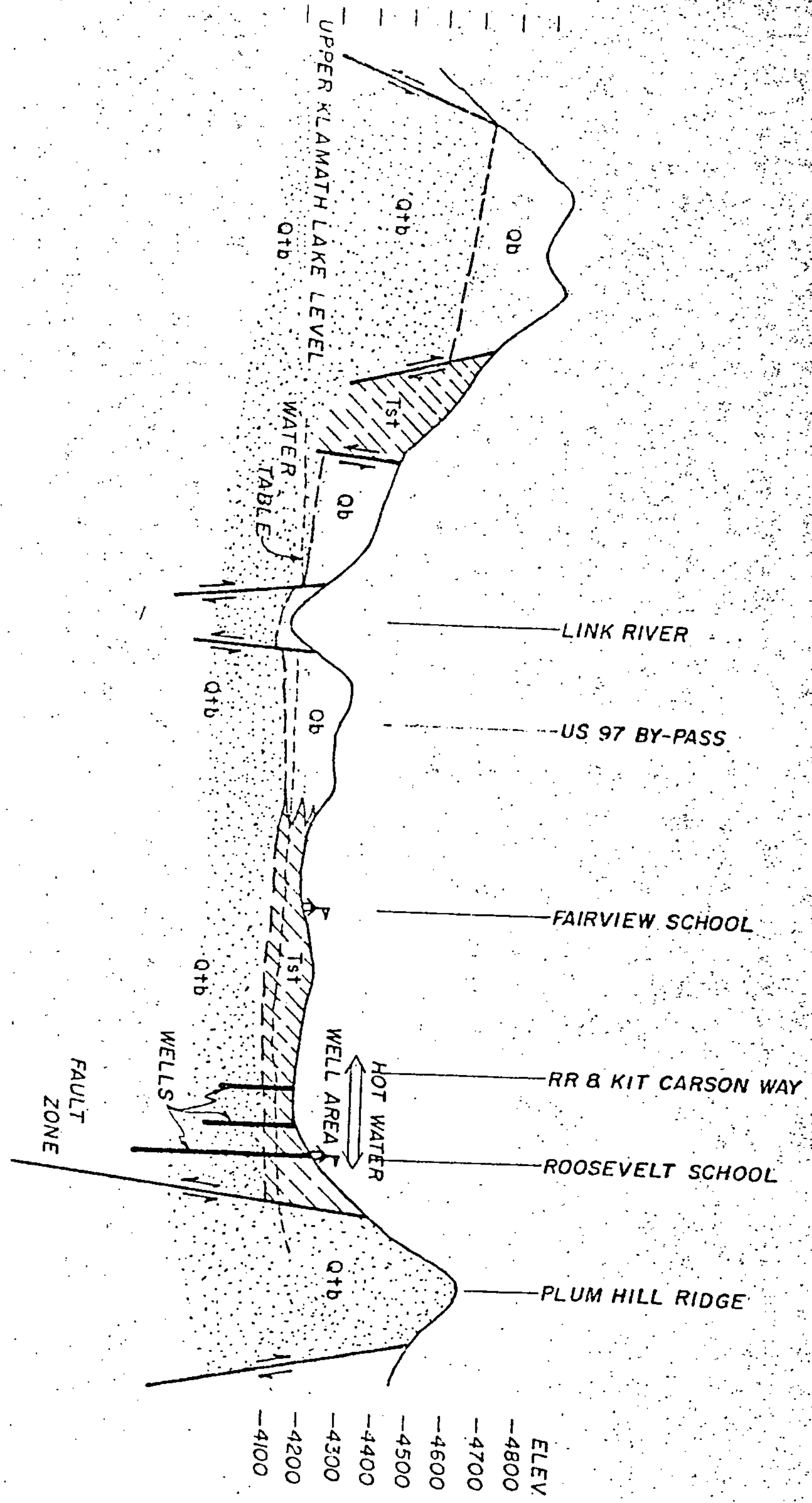
— — — Approximate or inferred fault location

- - - - Contact location

▨ Zone of hydrothermal alteration

Reference:

1. Peterson, Norman V. and Edward A. Groh, "Geothermal Potential of the Klamath Falls Area, Oregon - A Preliminary Study, The Ore Bin, Vol. 29, No. 11, State of Oregon Department of Geology and Mineral Industries, Portland, November 1967.
2. Peterson, Norman V. and James R. McIntyre, "The Reconnaissance Geology and Mineral Resources of Eastern Klamath County and Western Lake County, Oregon," Bulletin 66, State of Oregon Department of Geology and Mineral Industries, Portland, 1970.
3. Personal contacts with Dr. Murray C. Gardner, Geothermex, Berkeley, California, 1974.



GEOLOGIC CROSS SECTION B-B

VERTICAL SCALE: 1" = 400'
HORIZONTAL SCALE: 1" = 2000'

FIGURE 3

known locally as "mud" wells. At one location a well over 1,000 feet deep was drilled within 250 feet of one only 220 feet deep. This well was essentially dry, even after attempts to fracture the rock at the bottom with dry ice and explosives.

DETAILS OF THE UTILIZATION

A. Well Construction Characteristics

Most of the wells in Klamath Falls are drilled with cable tool drilling equipment. Early wells were relatively shallow mainly because of the location in the better geothermal areas. Casing of these early wells was only deep enough to case off surface cold water and to prevent caving near the surface. The casing length was around 30 feet and in many cases only 1/8 inch wall thickness. As a result caving would often occur below the casing, filling in the lower portion of the well and causing the temperature of the water to cool. Cleaning was required every eight to ten years, and casing life was extremely short, estimated less than 15 years. Electrolysis would develop between the down-hole heat exchanger and the well bore below the casing causing replacement of the heat exchanger pipe in less than ten years.

Recent well drilling practice is to still use cable drilling rigs or to use rotary drilling rigs to depths near expected live water flows and then finish the drilling with cable drilling tools. Drillers feel that there is some danger of sealing off the flow of live water with the rotary drills (Ref. 7).

The usual construction of newer wells is to make the well bore 12 inches in diameter and to install casing 8 inches in diameter. Well depth is determined by a sufficient section of free flowing water, high temperature, and the length of coil required to supply heat for the structure. Heating system contractors consider 24 inches of free flowing water near 190°F (88°C) as the minimum to provide sufficient heat for a typical 1,600 to 1,800 square foot home, with longer sections more desirable.

Once a sufficient length of free flow at satisfactory temperature is obtained, drillers prefer to continue drilling 10 to 25 feet even though the extra depth may not be required for the heat exchanger pipe. This extra depth provides space for a mud leg and a volume to hold debris that may otherwise slough into the well and cover the lower flow.

Once the well bore is complete, casing is started down the hole. Perforations are cut in the casing as it is lowered so that free flowing water can enter the casing. The casing extends to the bottom of the bore and, by Oregon law, must be set in a solid formation. If required, a packer may be installed to block off cold water flows. Packers are generally made by securing burlap to the casing in the desired position as the casing is lowered. After the casing is set, grout is placed above the burlap to provide a permanent seal.

Since the bore is larger than the casing, live water flows at several depths are usually encountered, and the perforations allow circulation; it is believed that a convection cell is established within the well. How effective this cell is in providing good circulation after many years is open to some question.

Present casing thickness is 1/4 to 5/16 inches and the expected life is well over 50 years.

Well water temperatures vary from 70°F (21°C) at the top to over 220°F (105°C) at the bottom The low surface temperatures are generally caused by cold surface water cooling the surrounding formations. Rock temperatures in drill holes have been measured as high as 250°F (127°C) but once water enters the hole, the temperature will drop to the 220°F range. Average water temperatures in the hot water area vary from 100°F to over 210°F. Temperatures below 100°F are generally not considered to be adequate for space heating. Water temperatures outside of this area vary from 100°F to 70°F as the location is further removed from the hot water region.

B. Heat Exchange Systems

Since the turn of the century, geothermal well water has been piped through space heating systems in Klamath Falls. Even though the water in the area is unusually pure for geothermal water, it corroded and scaled plumbing systems of the area so, that in a relatively short time, systems had to be repaired or replaced. About 1930, the first down-hole heat exchanger, locally known as a coil, was installed in a geothermal well. The heat exchanger coil consists of two strings of pipe connected at the bottom by a reverse bend. The temperature of the well water and the predicted heat load determine the length of pipe required. Based on experience, local heating system contractors estimate approximately one foot of coil per 1,500 BTU per hour required. The coil pipes are connected to the supply and return of the distributing piping and the entire system filled with city water. Figure 4 illustrates a typical system. The "thermo-syphon" (or gravity feed in standard hot water systems) process circulates the domestic water, picking up heat in the well and releasing the heat in the radiators. Circulation pumps are required in cooler wells or in larger systems to increase the flow rate. Thermo-syphon circulation will provide 3 to 5 psi pressure difference in the supply and return lines to circulate 15 to 25 gallons per minute with a 10° to 20°F temperature change.

There are several older and/or cooler wells that are pumped directly into the storm sewers or canal. In most cases the well is pumped in order to increase the flow of geothermal waters and raise the temperature of the well to a level locally considered satisfactory for use in space heating, about 140°F (60°C). In a few instances, mostly in the artesian area, well water is pumped directly through the heating system.

TYPICAL HOT WATER DISTRIBUTION SYSTEM

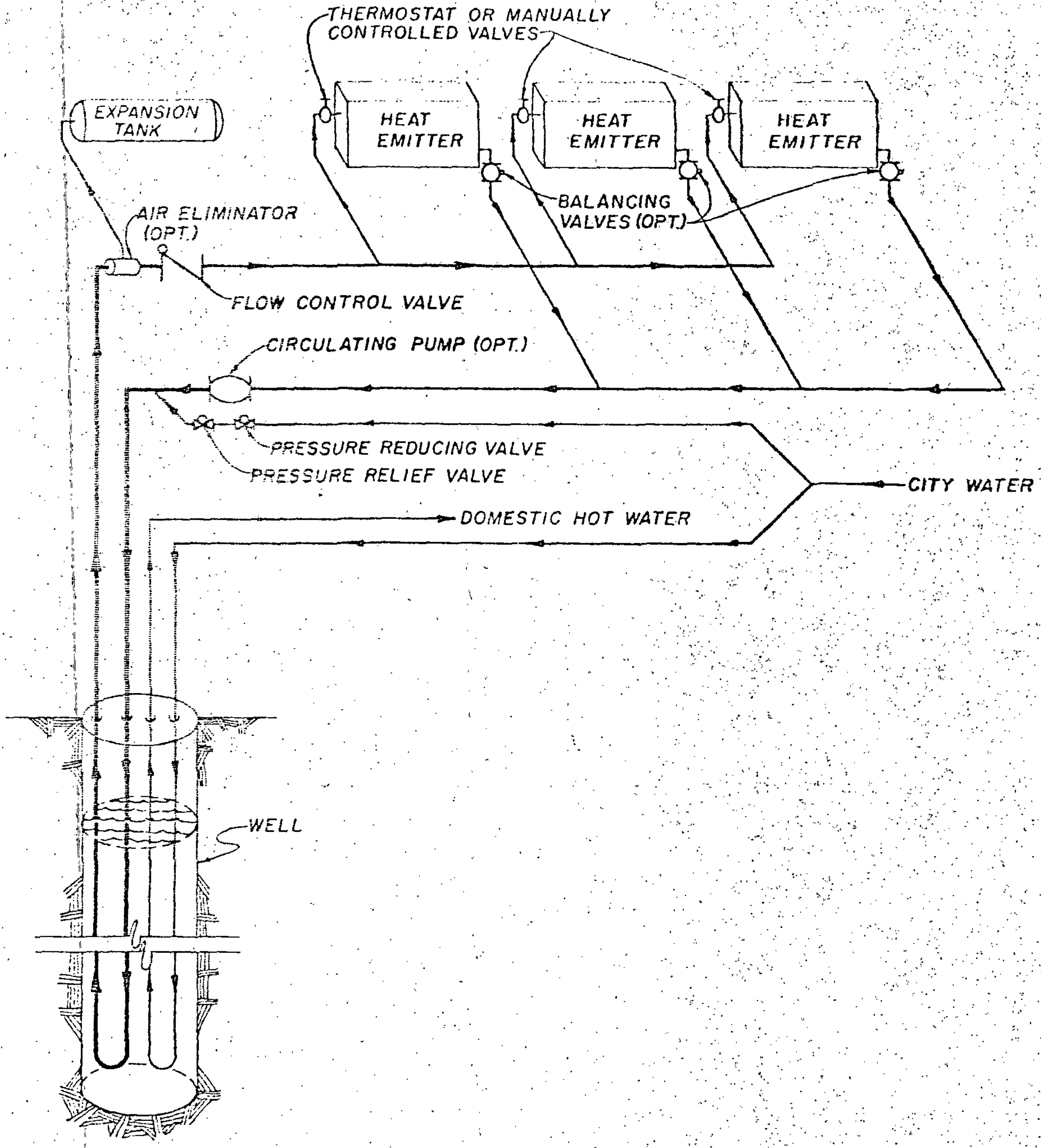


FIGURE 4

The down-hole heat exchanger system is economical, minimizes corrosion problems, probably conserves the resource, and eliminates the problem of waste water discharge. The most common failure of these systems is corrosion of the heat exchanger pipe at the air-water interface. Other areas of failures are where pipes touch the side of the casing or due to twisting where they rub or touch each other. Most heat exchanger pipes are standard black iron pipe, although a few are double strength near the top in deep wells to reduce stresses, or at the water line to provide longer corrosion resistance. The average life of standard black iron pipe in the wells investigated was about 14 years. Other materials have been tried for use at the waterline including brass and lead; and based on limited information, these appear to extend the life of the system. The most common, economical, and apparently effective method of reducing corrosion is to pour used motor oil or paraffin in the well. These materials either reduce evolved gases and water vapor, or provide a protective coating on the coil surface, or both. Several types of corrosion resistant paints have been tried with questionable results.

C. Specific Utilization Examples

1. Residence. The author's residence is typical of many of the space heating and domestic hot water usages of a geothermal hot water well in the community. Located south of the OIT campus and adjacent to Roosevelt School (see Figure 1), the home consists of 2,500 square feet of floor space on one level. The well is 150 feet deep with 68 feet to the static water level. The temperature of the water varies from 190°F at the top to 197°F at the bottom, with very little variation in temperature occurring over the 25 years since the well was drilled. The well was drilled 12 inches in diameter and then cased with 8-inch diameter casing. Two heat exchanger loops (or coils) extend to the bottom of the well, one at 2 inches in diameter for the space heating requirements and one at 3/4 inch in diameter for domestic hot water. No circulation pump is required as the hot water "thermosyphons" naturally. Space heating is provided by running the closed system heated water through a series of radiators under the house, and then a normal forced air system is used to heat the house. The tap water, using city water in the "coil", reaches a temperature of 185°F at the tap. Sections of the heat exchange pipe have corroded at the water surface, thus they have been replaced twice in 25 years. Space heating requirements are 1.8×10^8 BTU per year with approximately 250,000 BTU per hour required during peak usage.

2. Oregon Institute of Technology Campus (Ref. 6). The OIT campus consists of seven buildings covering approximately 440,000 square feet of floor space. Three hot water wells have been drilled adjacent to campus varying from 1,288 to 1,800 feet in depth. These wells vary from 14 inches in diameter at the top to 8 inches in diameter at the bottom with casing varying from 12 inches to 6 inches in diameter. These wells can be individually pumped up to 450 gallons/minute at 192°F. Centrifugal pumps, located at a depth of 550 feet are used to pump the water from the wells. Up to two

wells are used at one time during the heaviest demands, while the third well stands by. The well water is pumped from the well and used in most cases directly in the heating system in each building (see Figure 5). Both hot water radiators and forced air systems are used for heating. The water is finally discharged at approximately 125°F. The average heat utilization rate is 2.8 million BTU per hour with over 30.1 million BTU per hour available for cold weather.

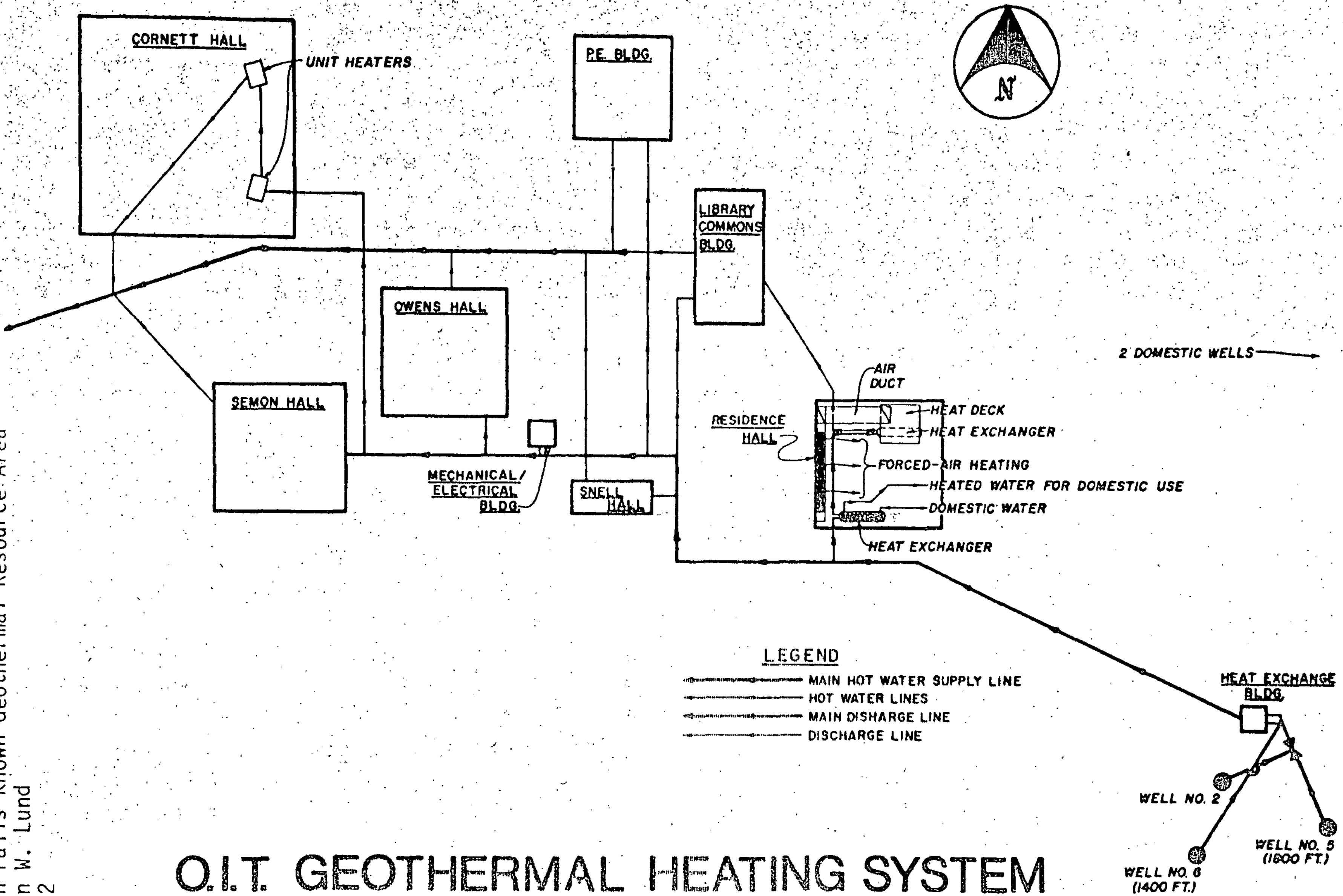
3. Medo-Bel Creamery. This creamery, located just south of Modoc Field ("Big Springs") uses hot water from a 765-foot deep well for a variety of applications. The most unusual is for pasteurizing milk. Water is available from the well at 181°F and is pumped directly into the pasteurizing equipment. The milk is heated at 161°F for 15 seconds and then quickly cooled to 36°F to retain flavor. More than 500,000 pounds of milk are treated each month. The building is also heated by direct use of the well water. The waste hot water is then pumped directly into the city storm sewer system. A 7-1/2 horsepower jet pump is used extending approximately 30 feet down into the artesian well.

4. Klamath Ice and Storage Company. This company has seven cold storage warehouses kept at below freezing temperatures. To prevent the soil under the floor slabs from freezing and frost heaving, a closed-loop system of heating coils is placed approximately three feet below the floor slab under cork insulation and some soil. The system consists of 2-inch diameter pipes placed four feet apart and filled with oil. The oil is heated through a 125-foot "coil" heat exchanger in a 6-inch diameter cased hot water well approximately 1,100 feet deep under artesian conditions. Over 1.19×10^6 BTU per hour is utilized in this unique system.

5. Pavement Heating by the State Highway Department. The heat from a 419-foot deep well is used to remove snow and ice from a critical section of highway pavement approaching a busy intersection. The stretch of pavement is on a steep grade approaching a stop light. Since it is a major truck route, it is extremely important that the snow and ice be clear from this pavement during bad weather. One-inch diameter pipe placed in the concrete pavement on 18-inch centers form a grid under the pavement. Antifreeze is circulated in a closed system through the well and into the grid system. The antifreeze enters the grid at a temperature of 120°F and leaves at 103°F and will keep the pavement sufficiently clear of snow and ice to provide free travel at temperatures of 10°F below zero and under conditions of three-inch per hour snowfall.

SUMMARY AND CONCLUSIONS

The Klamath Basin KGRA has been utilized primarily for space heating for over 70 years. The most popular method of extracting the heat from the ground is by down-hole heat exchangers in hot water wells. A secondary method is to pump the water from the ground and pass it through a heat ex-



O.I.T. GEOTHERMAL HEATING SYSTEM

FIGURE 5

changer above ground and then waste or reinject the water. In some cases the water is used directly in the heating system and wasted to the storm sewer system.

The extent of the near surface hot water can be fairly well delineated with the area with temperatures greater than 100^{0}F shown in Figure 1. The temperatures of the near surface water appear to gradually diminish as the location gets farther away from this 100^{0}F boundary. Based on well drilling logs and conversations with local residents, the temperatures of the water outside this area decrease from 100^{0}F to about 70^{0}F within half a mile to the east and west. The typical cold water well has a temperature of 70^{0}F in the basin. In the cold well water area of the city several businesses and residences have used heat pumps for heating and cooling. These have worked very successfully, as the water temperature remains constant throughout the year. The main disadvantage is that the initial installation of the system is expensive. The cost of hot water well operation in Klamath Falls also appears to be somewhat expensive for an individual homeowner. Initial investment of from $7,000 to $10,000 appears to be usual at the present time. The annual operating cost, including maintenance, is quite low, amounting to less than $100 per year. In many instances in the community, to reduce the initial investment cost of a new well, several homeowners have shared one well with good success.

The obvious conclusion is to consider some sort of district heating similar to that in Iceland. Alternatives that could be considered are a minimum of four homes sharing a well, an entire block sharing a well, or an entire subdivision sharing a well. The greater the number of homes on one well, the larger and deeper the well will probably have to be and the greater the overhead cost for maintenance and administration will be. Four homes to a well appear to be near optimum for cost and efficiency.

The total heat utilization from hot water wells estimated for Klamath Falls is approximately 1.7×10^{11} BTU/year or 5.6 megawatts. This is the average utilization for the entire year with up to 56 megawatts being used during peak periods. It is obvious that only a small portion of the total potential of this resource is being tapped. At the present time, studies are being initiated at the Geo-Heat Utilization Center established at Oregon Institute of Technology to further study the basin and to optimize the utilizations and to explore additional methods of energy utilization such as greenhouses, soil warming, food processing and use in the forest products industry.

ACKNOWLEDGMENTS

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REFERENCES

1. Koenig, James B., "Worldwide Status of Geothermal Resources Development", Geothermal Energy, edited by Paul Kruger and Carel Otte, Stanford University Press, Stanford, California, 1973, pp. 15-58.

2. Koenig, J. B., "Geothermal Exploration in the Western United States", Geothermics, Pisa Conference, Vol. 2(1), 1970, pp. 1-13.

3. Culver, G. Gene, John W. Lund, and Larsen S. Svanevik, Klamath Falls Hot Water Well Study, (performed for Lawrence Livermore Laboratory, P. O. #6373305), Oregon Institute of Technology, Klamath Falls, Oregon, October, 1974.

4. Peterson, Norman V. and Edward A. Groh, "Geothermal Potential of the Klamath Falls Area, Oregon--A Preliminary Study", The Ore Bin Vol. 29, No. 11, State of Oregon Department of Geology and Mineral Industries, Portland, November, 1967.

5. Peterson, Norman V. and James R. McIntyre, "The Reconnaissance Geology and Mineral Resources of Eastern Klamath County and Western Lake County, Oregon", Bulletin 66, State of Oregon Department of Geology and Mineral Industries, Portland, 1970.

6. Purvine, W. D., Utilization of Thermal Energy at Oregon Institute of Technology, Klamath Falls, Oregon, presented at The International Conference on Geothermal Energy, Oregon Institute of Technology, Klamath Falls, Oregon, October 7, 1974.

7. Storey, David M., Geothermal Drilling in Klamath Falls, Oregon, presented at The International Conference on Geothermal Energy, Oregon Institute of Technology, Klamath Falls, Oregon, October 8, 1974.

8. Lund, John W., G. Gene Culver, and Larsen S. Svanevik, Utilization of Geothermal Energy in Klamath Falls, presented at The International Conference on Geothermal Energy, Oregon Institute of Technology, Klamath Falls, Oregon, October 7, 1974.