PROBLEMS WITH DISPOSAL OF THERMAL EFFLUENT THEIR INFLUENCE ON DEVELOPMENT OF LOW-TO-MODERATE TEMPERATURE GEOTHERMAL RESERVOIRS

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Editor's Note: A number of communities are having to deal with disposal of geothermal fluids from direct use projects. This article provides insight into disposal regulations and four case histories of communities dealing with disposal of geothermal fluids. The GHC acknowledges William E. Nork, Inc. and the Geothermal Resources Council for permission to reprint this article from the 1990 International Symposium on Geothermal Energy, GRC Transactions, Vol. 14, pp. 661-668.

ABSTRACT

The exploitation of low-to-moderate geothermal aquifers is similar to development of non-thermal aquifers in some respects. However, there are some problems which are peculiar to these resources. Although the hydrostratigraphic unit may be areally extensive, the thermal reservoir itself is typically of limited areal extent. So, in addition to being constrained by the physical attributes of the system, resource development can be inhibited by regulations which have their origins removed from these types of systems. Examples of how the regulations for disposal of heat-spent thermal effluent via Class V injec-tion wells influenced development of four low-to-moderate temperature geothermal reservoirs are discussed below.

BACKGROUND

Space heating is a common use of low-to-moderate temperature (less than 250° Fahrenheit) geothermal resources. This heat resource is exploited by individual home owners, industry, and heating districts. In the United States, direct usage for space heating amounts to 1.56 x 10^{12} kJoules annually (Culver, 1990).

The development of low-to-moderate temperature geothermal aquifers as a source of heat follows a pattern. Similarities in the evolution of development of these resources exist for diverse locales. In the earliest stage of development, the extraction of heat via shallow wells or the capture of natural discharge from thermal springs is relatively simple, cost effective, and well within the reach of individual home owners and small-scale commercial users. Where the resource temperature is high and the heat flow in the aquifer is sufficient, withdrawal of fluids from the reservoir may not be required. The heat can be extracted via downhole heat exchangers (DHEs). A typical DHE system is depicted in Figure 1.

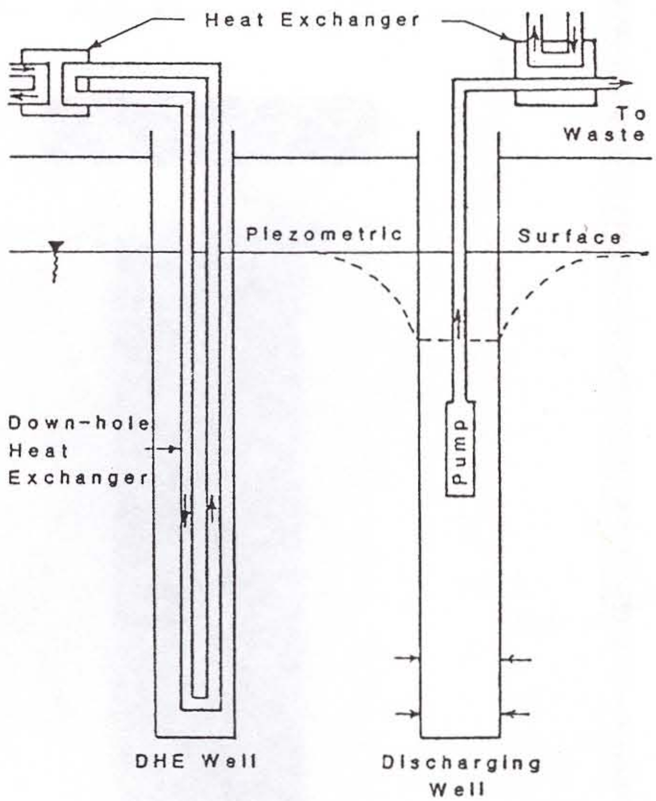

Figure 1. Typical well construction.

Another type of simple system employed in the early stages of development utilizes a flowing artesian well. The fluid is either partially consumed through in-house domestic use or is discharged to waste with no further traditional beneficial use. The discharge from these flowing wells (a type of "pump and dump" system, also depicted in Figure 1) may affect a minor decrease of the hydrostatic head of the geothermal aquifer and/or the natural discharge of thermal springs.

As exploitation of the geothermal reservoir progresses, the hottest areas become built out and development spreads toward the margin of the resource. These fringe areas are usually not as hot nor do they exhibit the flowing artesian conditions found in the core resource area. As a consequence, the simple methods used in the earliest stage of development are not effective. Where there is no artesian flow, wells are fitted with pumps to bring the water to the surface. Where heat flow is insufficient to naturally replenish heat extracted from a well equipped with a DHE system, a pump may be installed to draw off the cooler water and induce flow of hotter water into the well from the aquifer. Also at this stage, geothermal use becomes attractive to large-scale commercial and institutional users. The overall effect is to increase the discharge from and decrease the pressure in the aquifer.

To a degree, this increased discharge is beneficial to the system in that it allows utilization of heat which might otherwise not be captured. So long as the artificial discharge from the aquifer is small compared to the natural discharge, a short-circuit in the system is effected and the aquifer achieves a new hydrologic equilibrium. The decline in the artesian pressure and decrease in the natural discharge may be more noticeable than in the initial stage of development; but, these conditions have yet to adversely impact the users. However, they are harbingers of things to come. Up to this point, the benefits derived from the use of geothermal energy such as reduced consumption of fossil fuels and lower emissions from wood burning stoves offset the impacts on the aquifer.

Problems begin to surface in the next stage of evolution. By now, withdrawals have increased to the point where natural surface discharge is substantially reduced. Still, so long as the withdrawals do not exceed the natural discharge, the rate of decline is ultimately arrested as the aquifer adjusts to the new equilibrium condition. However, isolated problems start to occur, particularly in the areas where artesian wells no longer flow. This leads to a chain reaction as the rate of discharge is accelerated as formerly artesian wells are equipped with pumps and the increased pumpage further accelerates the decline in artesian head. Eventually mining of the water commences as the aquifer enters an overdraft condition.

The sheer volume of the thermal effluent begins to create disposal problems by this stage. Until now, small discharges were tolerated; but, the large aggregate discharge generated by the sum of the pump and dump systems can no longer be ignored by the regulatory agencies. Although the thermal effluent from low-to-moderate temperature reservoirs can be of reasonably good chemical quality, it may violate local surface-water discharge standards.

Once the problem of the overdraft of the aquifer is recognized, the "obvious" solution is to reinject the heat-spent thermal effluent to the aquifer. In many, but not all cases, it is no more difficult to drill a well capable of accepting the requisite discharge from an individual system than it was to complete the production well. However, because injection is incorporated into the resource exploitation scheme at a late date, a large number of production wells are already in existence by the time reinjection becomes a necessity. Each of these preexisting wells is potentially impacted by the breakthrough of cooler thermal effluent from neighboring injection wells. The hunt for injection well sites begins.

The ideal reinjection well site is one which is hydraulically connected to the exploited aquifer in order for the injectate to maintain the reservoir pressure and at the same time is sufficiently removed from production wells to inhibit temperature breakthrough. However, in neighborhoods where everyone on the block owns their own geothermal well, one person's solution becomes another one's pollution.

Many low-to-moderate temperature geothermal systems are relatively small in areal extent. The hot water typically upwells along localized conduits such as faults. As the geothermal fluid moves away from the source area, it cools and mixes with other waters. Because the temperature and chemistry change away from the source area, delimiting the extent of the gradually evolving geothermal reservoir becomes somewhat arbitrary. The boundaries in a physical and regulatory sense become even less distinct when the same hydrostratigraphic unit is exploited as a source of drinking water a short distance down gradient.

A successful reinjection well not only maintains the aquifer pressure without adversely impacting adjacent production wells, it must comply with state and federal controls relative to discharges into the groundwater system. Unfortuantely, the very regulations which were conceived to safeguard drinking water supplies can constrain the beneficial development of the resource and by doing so, create a problem as difficult to solve as completing the injection well.

Underground Injection Control

Reinjection of heat-spent thermal effluent is regulated under the Underground Injection Control (UIC) Program established by the Section 1421 of the Safe Drinking Water Act. The UIC Program is administered by states whose pro-grams meet United States Environmental Protection Agency (EPA) guidelines. At present, 39 states operate UIC programs.

EPA established five classifications of injection wells. Geothermal injection wells come under the broad category of Class V wells. This class essentially encompasses all wells not covered under Classes I through IV. The UIC programs for Class V wells in the states of California, Oregon and Nevada are highlighted below.

The state of California UIC program is, in principle, administered by Region IX of the U.S. Environmental Protection Agency. In practice, it is administered by the California Division of Oil and Gas (CDOG) which regulates permitting, construction, operation, monitoring, and abandonment of all geothermal wells including Class V injection wells. The regional offices of the State Water Quality Control Board do not regulate underground injection per se, but monitor the impacts on the chemical quality of the receiving waters whether they are surface or groundwater sources.

California adopted EPA's definition for an underground source of drinking water (USDW) as " . . . an aquifer . . . which . . . contains less than 10,000 mg/l total dissolved solids . . ." (40 CFR 144). CDOG mandates that injection does not result in the increased risk of degradation of a USDW. Existing and potential uses of the water and integrated use of the resource are considered in defining degradation. On the other hand, the Water Quality Control Board defines degradation as any increase in one or more constituent. These opposing points of view by the two principal regulatory agencies can lead to a myriad of difficulties in planning an injection strategy.

Underground Injection Control in the state of Oregon is administered by the Department of Environmental Quality (DEQ).

The Water Resources Department (OWRD) is responsible for managing the low-to-moderate temperature (<250°F) geothermal resource and regulates the construction, operation, maintenance, and abandonment of injection wells as well as the appropriation of the water. Through memoranda of agreement, OWRD regulates low-to-moderate temperature geothermal injection (Class V) wells.

Consistent with California and EPA, the state of Oregon defines an underground source of drinking water as "an aquifer . . . which supplies drinking water for human consumption, or . . . in which the groundwater contains fewer than 10,000 mg/l total dissolved solids . . ." (OAR 30-40-010). However, degradation of the chemical quality of the water is treated differently from California. Reinjection is permitted provided injection does not result in a violation of state and federal drinking water standards at designated compliance points.

In addition to the state controls, the city of Klamath Falls, Oregon, exerts local control over geothermal usage within their jurisdiction. Quite simply, the Geothermal Resource Act of 1985 requires all geothermal fluids discharged from the aquifer be reinjected as of July 1, 1990.

Within the state of Nevada, Underground Injection Control is administered by the Nevada Division of Environmental Protection (NDEP). NDEP regulates the permitting, construction, operation, and abandonment of all Class V injection wells. The Department of Minerals overlaps the jurisdiction of NDEP in that they permit construction, operation, abandonment of all geothermal wells (production and injection). Where the geothermal aquifer is exploited as a source of drinking water supply or where development might directly impact a drinking water supply, the State Division of Health also reviews injection permits to ensure that these supplies are not endangered even though they have no UIC jurisdiction.

Nevada went a step farther than California and Oregon, adopting a stricter definition of an underground source of drinking water which classifies all groundwaters within the state as USDW " . . . regardless of chemical quality . . . " (NAC 445.42335). NDEP's definition of degradation, however, allows for abroad interpretation which takes into account current and future beneficial use of the water. In the special case where the geothermal fluid meets state and federal drinking water standards, the NDOH utilizes zero degradation of the aquifer as the standard.

Each of the three states allows for an aquifer to be exempted as an underground source of drinking water.

California, Oregon and Nevada are similar in their approach to Underground Injection Control for Class V wells in that there are at least two agencies in each state which directly or indirectly share some aspect of UIC. The most significant difference is in the approach each state takes in defining and addressing degradation of the chemical quality of the receiving aquifer. In general, Oregon's approach is the most flexible in that some impacts on receiving waters are tolerated by both of the agencies involved. California and Nevada are similar to each other in that the lead agencies (CDOG and NDEP) take a flexible and practical approach to reinjection. In contrast, the zero-degradation policy of the California Regional Water Quality Control Board and the Nevada Division of Health is very rigid. As a result, in addition to the obvious technical problems associated with exploitation of the resource, there are the problems dealing with various regulatory agencies with different agendas.

There is a consensus among the lead agency for each of these three states that the UIC regulations were drafted specifically for Class I through IV wells and, therefore, do not account for the special case of the Class V geothermal injection wells. A specific example is the requirement for a widespread confining layer to prevent migration of the injectate into sources of drinking water supply. In almost every case, such a confining layer does not exist and the injection horizon qualifies as an USDW. The inability to meet this single criterion would effectively eliminate development of the resource.

EXAMPLES

Four case histories are discussed below which briefly describe the variety of problems associated with developing low-to-moderate temperature geothermal aquifers. The solutions to the technical and regulatory problems associated with disposal of the thermal effluent for each project have not been entirely satisfactory.

Figure 2. Location map.

Klamath Falls, Oregon

The geothermal aquifer at Klamath Falls, Oregon, is the classic low-to-moderate geothermal aquifer. More than 500 geothermal wells are used to extract heat from the aquifer. Development there closely parallels the evolutionary sequence proffered above. The aquifer is presently in the later stages of evolution and an overdraft condition exists. Declines in reservoir pressure beginning in the early 1970s have resulted in a reduction in artesian well discharge and, in extreme cases, may have caused subsidence of the land surface. These problems prompted passage of the Geothermal Resource Management Act of 1985 which requires reinjection of all thermal effluent by July 1, 1990.

Compliance with the state of Oregon UIC regulations at Klamath Falls is easier than the technical problems associated with reinjection. The aquifer is highly transmissive, the chemical quality is generally good and relatively uniform, and it is apparently not directly coupled with sources of drinking water tagged by wells. However, the large number of producing wells makes it difficult to site injection wells which will arrest the rate of decline while minimizing adverse impacts on the numerous individual systems already in existence.

The aquifer at Klamath Falls has been extensively studied. The work of Sammel, et al., (1984), and Benson and Lai (1984) provide considerable insight into the aquifer. Additional work, based in large part on these studies (William E. Nork, Inc., 1985) suggest that the overdraft of the aquifer is in the range of 500 acre-feet per year.

The largest institutional users are the city of Klamath Falls and the Oregon Institute of Technology. The city has reinjected their thermal effluent as long as the system has been in operation. Work by Nork (ibid.) suggests that the injection by the city does have a positive impact on the aquifer. That is, the rate of pressure decline would be greater in its absence. OIT, which until recently discharged its thermal effluent to waste, is presently pursuing a reinjection program. This project has not been totally successful to date, however, and there is some question whether reinjection at this locale will have a significant positive impact in the area where the problems are most acute because of the distance between OIT and the main hot well area.

In addition to these programs, the city collects thermal effluent from a number of individual wells and extracts heat at their central heat exchanger system before reinjecting it at the city's injection well. The potential to collect and utilize more waste geothermal fluids and reinject them at the city's injection well exists; but at present, it is not economically feasible to do so.

While the geothermal energy users in Klamath Falls support the Geothermal Resource Management Act of 1985, there has been no stampede to comply with the provisions of the ordinace. The cost to the individual users to complete individual injection wells is simply too great and most people have adopted a "wait and see" stance, assuming that the larger users will be successful in arresting the water level declines.

Susanville, California

The geothermal aquifer at Susanville, California is a classic low-to-moderate temperature geothermal aquifer. Hot water with a temperature of approximately 190°F upwells along faults along its western margin. The water flows laterally in a southeasterly direction within permeable zones associated with basaltic lava flows (Benson, et al., 1980). As distance from the conduits increases, the temperature declines and the chemical quality of the water changes significantly. Total Dissolved Solids (TDS) of the water in the hottest part of the reservoir ranges from 700 to 900 milligrams per liter (mg/l). Within one mile from the source, the TDS decreases several hundred parts per million.

Utilization of the aquifer differs from that of Klamath Falls in that there is minimal utilization of the resource by individual property owners. The city of Susanville, California, one of only a few developers and operates a district space heating system which produces from the low-to-moderate temperature geothermal aquifer. The district provides heat to 77 users and facilities from two wells. The combined yield of the two wells is approximately 900 gallons per minute of 180°F water. Current production is about 500 gpm and expansion of the system is contingent on resolution of problems associated with disposal of the heat-spent thermal effluent. At present, one-half of the water is reinjected to the reservoir and the other half discharges into agricultural drains which ultimately empty into the Susan River.

The problem at Susanville has little to do with an overdraft of the aquifer. To date there has been no measurable decline in the artesian pressure of the reservoir. In this respect it differs from the evolutionary model discussed above. Susanville's problems stem from the fact that the discharge from the system does not meet the discharge standards for the Susan River, despite the fact that the impact on the chemical quality of the river is minimal. The city's discharge permit is due for renewal and there is doubt that continued surface discharge will be acceptable to the Water Quality Control Board - Lahontan Region (LRWQCB).

The city has expended considerable effort in its attempts to locate and complete injection wells. One well is utilized to inject approximately one-half of the thermal effluent. The well is incapable of accepting the balance because it suffered extensive formation damage during construction (Geothermex, 1984). Because of its location in a residential neighborhood and proximity to the Susan River, chemical rehabilitation to enhance its injectivity is impractical. In addition, it is relatively close to existing production wells and its impact on them at higher injection and production rates is uncertain.

Other attempts have been even less successful. A second injection well was drilled at a promising site more remote from the production wells. While the well intercepted the target geologic formation, it was less permeable at this locale than in the vicinity of the production well sites and the well was a failure (William E. Nork, Inc., 1989).

Other disposal schemes included injecting into a shallow horizon within the geothermal aquifer. However, aquifer stress tests showed this zone to be in hydrologic connection with overlying aquifers which serve as sources of drinking water to individual homes. Increased pressure due to injection would have increased upward leakage to this shallow aquifer.

The problems at Susanville are exacerbated by the fact that the hottest and most transmissive part of the aquifer tapped by supply wells is too small to allow adequate separation between injection and production wells to prevent thermal breakthrough at high production rates. Because the chemical quality of the geothermal fluid improves with distance from the production wells, reinjection outside of the core area may be perceived by LRWQCB as a source of contamination to the geothermal aquifer in this area. A dilemma ensues because LRWQCB will not approve of an injection plan until hard data are obtained through the drilling of a well and funds for drilling may not be available until after the injection strategy is approved.

A possible solution is for CDOG to grant an exemption for the aquifer but this will put them in direct conflict with LRWQCB. The problem at Susanville has yet to be resolved and it is evident the city will expend considerably more effort to reach a solution. At present, the city has appealed to LRWQCB to relax their discharge standards for the Susan River under the pretext that the minimal "degradation" of the chemical quality of the river is offset by the improvements in the overall environmental quality at Susanville.

Reno, Nevada

Development of the low-to-moderate geothermal resource in the Moana area at Reno, Nevada, closely parallels that of Klamath Falls. In both cases, the initial use of the resource centered around an historical area of hot springs discharge and migrated outward as the area was built out. The geothermal fluid upwells along faults in volcanic rocks west of the spring discharge area and moves laterally toward the east in overlying alluvial deposits, cooling as it does so (Bateman and Scheibach, 1975). The temperatures in wells range from 208°F along its western margin near the faults, 160-170°F near the historical discharge area, to as low as 120°F to the east. Farther to the east, these alluvial deposits are exploited as a source of drinking water from wells. At present, more than 300 individual wells are used for space heating purposes. Most are utilized by individual home owners, but there are two commercial heating districts, numerous institutional users, and several large commercial users.

The geothermal aquifer in Reno is in an overdraft condition as a result of the cumulative effects of a large number of individual domestic "pump and dump" systems. Water from these wells is both extracted directly for use in the home because of its overall good chemical quality and from wells equipped with DHEs for the purpose of "exciting" the wells to maintain their temperature. This fluid is discharged either to the storm or sanitary sewer. As a result, natural hot spring discharge has ceased completely and numerous formerly flowing artesian wells no longer flow.

The larger users do not appear to contribute to the overdraft because they currently reinject heat-spent thermal effluent. This is a relatively recent development, however, since many of these users previously discharged to an irrigation ditch network. This practice ceased when the ditches were defined as part of the Truckee River system. The Truckee has some of the most stringent discharge standards of any river system in the world.

The concentration of the large number of producing wells in a small area presents problems in locating injection well sites which will not adversely impact the existing wells. Because of the low hydraulic gradient and moderate aquifer transmissivity, the horizontal separation between pumping and injection wells is necessarily large. In order to prevent recirculation of the fluids, the injection wells for the large-scale users would be required be placed at the periphery of the geothermal area. This presents a problem in that the chemical quality of the receiving waters in those areas would be better than the thermal effluent and degradation of the aquifer would be a problem. As a consequence, most injection wells have been completed at horizons in the geothermal system which differ in depth from the production zones.

This scheme represents some conflicts with a literal interpretation of UIC regulations. The geothermal reservoir is a complex aquifer system with various degrees of communication between the different units. NDEP recognizes this fact and allows a fair degree of freedom in injection programs so long as the effluent is injected within the "geothermal system." One problem with this approach is that it has yet to be demonstrated whether or not this program effectively maintains the reservoir pressure. Another problem is that injection wells can be considerably deeper, hence, more costly than production wells.

The ultimate solution to the overdraft problem at the Moana area relates to regulating the discharge from the numerous domestic heating wells. However, the domestic well users are too close together to prevent them from impacting one another or themselves. One possible solution is to require collection of the waste discharge and reinjection through communal wells. The political, economical and technical aspects of this program have yet to be explored.

Elko, Nevada

Geothermal development at Elko, Nevada, more closely parallels development at Susanville, California, than the other two examples. The principal users are one commercial geothermal space heating district (Elko Heat Company) and one institutional district space heating system (Elko County School District) in addition to a few individual users near an area of hot spring discharge on the edge of town.

The school district system derives its source of hot water from a 1,972 feet deep flowing artesian well (William E. Nork, Inc., 1985c). Reinjection to the deep aquifer was not considered because of the high cost of injecting at pressures required to overcome the artesian pressure of the reservoir. Initial disposal schemes targeted permeable zones in a shallow alluvial aquifer. Modeling of the alluvial aquifer (William E.

Nork, Inc., 1986) indicated that one of the principal sources of recharge to the alluvial aquifer was upward leakage from the geothermal aquifer. Disposal of the effluent in this zone was viewed as a "short-circuit" of the natural system.

The program was vetoed by the NDOH on the grounds that the effluent would degrade the chemical quality of the alluvial aquifer which serves as the source of water supply to the city. This action was taken despite the fact that the water from the geothermal well was similar to the alluvial water and met drinking water standards except for elevated concentrations of iron. NDEP concurred with this opinion despite arguments that the concentration of iron in the city's wells would not measurable increase.

A solution to the disposal problem for the school district system was ultimately reached. Their effluent was added to that of the Elko Heat Company which was used for golf course irrigation in combination with secondary treated sewage effluent and to provide heat to the city's sewage treatment system to enhance the treatment process. Thermal fluids not consumed in this way are permitted to infiltrate into the shallow aquifer near an area of historical spring discharge. It was perceived that this disposal method was simply of short-circuit in the system and that the aquifer would ultimately adjust to a new equilibrium condition as the natural discharge of the hot springs was intercepted by the geothermal wells.

The disposal system has performed well to date. There have been no decline in the artesian flow from the school district wells.

A potential problem may surface in the near future, however. The Elko area has experienced phenomenal growth in population in response to an upsurge in the mining industry. As a result, the"excess" capacity of the rapid infiltration basins which was allotted for disposal of the geothermal effluent may be used to meet the demands for sewage treatment. This may require the heating districts provide an alternate means of disposal, or at the very least, amend the existing permits to account for the total volume of effluent from all sources.

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