ABSTRACT

The academic buildings of the Richard Stockton College of New Jersey are heated and cooled by a large-scale, closed-loop, ground-coupled, heat pump system. Heat is exchanged in a borehole well field that is traversed by three aquifers. The system has been in operation since 1994 and a thermal buildup has occurred since more heat is rejected by the system than extracted. The well field was designed with monitoring wells which allow access to the underground environment, and studies have been conducted to determine how groundwater quality and aquifer microbiota have been affected by the temperature increase. The temperature increase is as much as ten degrees Celsius within the well field and the thermal effects have spread downstream. The temperature fluctuations are in a range that is critical for the optimum growth of several broad groups of bacteria. While no significant differences were observed for groundwater pH or conductivity, preliminary work indicates that there are changes to the aquifer microbial community. Recent addition of a cooling tower to the system is expected to correct the thermal imbalance and bring the temperature back to ambient conditions. The temperature fluctuation range that is critical for the optimum growth of several broad groups of bacteria. While no significant differences were observed for groundwater pH or conductivity, preliminary work indicates that there are changes to the aquifer microbial community. Recent addition of a cooling tower to the system is expected to correct the thermal imbalance and bring the temperature back to ambient conditions. The specific changes in the aquifer microbiota suggested by our work provide a basis to evaluate whether the aquifer microbial community will recover once the thermal imbalance of the well field is corrected. This work highlights the need to consider the overall thermal balance in system design to maximize efficiency and minimize the environmental impacts.

1. INTRODUCTION

The usage of ground source geothermal energy has had a significant impact on the environment via the reduction of greenhouse gas emissions. The installation at Richard Stockton College of New Jersey (RSC) has had a 16% in CO₂ emissions during the 10 year period of this study (Stiles, 2004). Studies have shown that approximately 70 percent of the energy used in a geothermal heating and cooling system is renewable energy from the ground, the remainder is clean, electrical energy which is employed to concentrate and transport heat (GAO/RCED, 1994). However, the impact on the earth surrounding the geothermal fields and the aquifers that absorb much of the heat has only been begun to be explored (Sowers, et al. 1997). In 1993, Richard Stockton College of New Jersey (RSC) installed what was at the time the largest geothermal well field in the world under a 5.7 acre campus parking lot. This installation is used to heat and cool the main academic building composed of 14 academic wings and 440,000 sq ft of floor space. Water is circulated through a closed loop system using over 65 miles of piping in a vertical field. Water in the system is neither discharged nor recharged only thermal energy is exchanged between the surface and underground environment. The geothermal well field traverses three aquifers; the Upper and Lower Cohansey and the Rio Grande water bearing zone. The College is located in the New Jersey Pinelands, a federal reserve where unrestricted development is not permitted and growth is monitored by the Pineland Commission. With the development of the casino industry in Atlantic City, significant changes in land use have occurred in the last several years in the region, and the need for more housing has overflowed into surrounding communities. Many of these communities in coastal and southern Jersey rely on the Cohansey aquifer for their drinking water. The Cohansey and Kirkwood aquifers have an estimated reserve of 17 trillion gallons of water (Pinelands Guide). This study is motivated in part by concerns about potential impacts on the quality of the groundwater which serves as an important source of drinking water for the region.

At the geographic location of the College there is a net cooling load resulting in a slow increase in the temperature of the well field. As predicted in earlier studies (Pal, et al. 1998) the overall temperature of the well field has
increased at the rate of about 1° C/year resulting in as much as a 11 °C change in some areas of the field over the 10 year period of operation (Epstein/Sowers 2006). There is very little known about how this heat deposition and thermal buildup may affect water quality. In this work, we have studied the chemistry and microbiology of the aquifers, comparing previous results (Sowers, et al. 1997, York, et al. 1998) with recent data spanning the 10 year period that the geoexchange system has been in operation.

2. METHODS

Monitoring Wells:

The RSC installation was designed with monitoring wells in and around the field enabling measurements of temperature and aquifer sampling for water chemistry and microbiology studies. Figure 1 shows the location of the wells used in this study. Groundwater flow in the region as a whole is from west to east (Epstein et al. 1996). Thus the East well is located downstream of the well field; the Center well is in the center of the field and the West well is upstream of the field. Additional wells for sampling are located within and surrounding the field. Samples for water quality were drawn from all of these sites. The microbiology work focused on the West (upstream) the Center and the East wells (downstream). During the initial 1994 studies the College Drive well which is located outside of the well field, but downstream from the field was used as a control site. However, it was predicted (Epstein et al, 1996; Epstein, 1998; Sowers et al, 1997) that the heat deposited in the field would travel to these wells in as few as 632 days. This effect actually occurred in 677 days, thus limiting the usefulness of the College Drive site as a control. A USGC well located further away from the field was used as a control in 2005 for the chemistry studies. Comparison of temperature data collected in 1995 vs. 2005 for both the USGS well and the up field West well (Figure 2) shows the temperature profiles are superimposable. Since the West well temperature has remained relatively constant and has not been affected by the thermal buildup, this site was used as a control for the microbiology study.

Sample Collection

Temperature monitoring was done using a Solinst/Canada Model 210 water level/temperature meter. Temperatures were taken every five feet from the surface to the bottom of each well. Water samples were taken from the monitoring wells after each of the wells was purged for 15 minutes. For the chemical analysis, samples...
were collected in polyethylene containers and taken to the laboratory for immediate analysis of pH and conductance. Samples were refrigerated and anions analyzed later using Dionex ICS 2000 Ion Chromatograph.

For the microbiology studies samples were collected into a sterile 50 mL conical tube. Three independent samples were collected for each aquifer, at each site. Three subsamples were fixed immediately in phosphate buffered glutaraldehyde and processed for direct enumeration of bacteria using epifluorescent microscopy as previously described (York et al. 1998) following the method of Kepner and Pratt (1994). For a determination of viable counts (numbers of culturable bacteria) the aquifer samples were stored on ice in the field then transported to the laboratory for plating onto a nutrient agar media. Triplicate plates were grown at 14°C, 23°C, or 37°C for 4 to 6 days. The number of bacterial colonies, each presumably arising from a single cell, was recorded. The colony forming units (or cells) per milliliter of the original sample was calculated for comparisons. The colony morphology of cultured bacteria was also examined. Pure cultures of bacteria with apparently different colony morphology were isolated and purified for further characterization.

**Molecular genetic identification of microbes**

Bacteria were isolated in pure culture from the Upper Cohansey Center well samples, then stored frozen at -70°C in 15% glycerol. Chromosomal DNA was obtained from cultured bacteria and a portion (880 base pairs) of the 16S ribosomal RNA (rRNA) gene was amplified by polymerase chain reaction (PCR) (Weisburg, 1991). PCR products were ligated into the pGEM-T Easy vector (Promega) and transformed into *E. coli*. Plasmid DNA clones containing the rRNA genes were isolated and DNA sequences were determined by automated DNA cycle sequencing (Beckman-Coulter CEQ 8000). Preliminary identification of microbes were determined by comparing DNA sequences to the GenBank database using BLAST (Basic Local Alignment Search Tool) or the Ribosomal Project Database II (RPD) (Altschul, et al. 1997, Cole et al. 2005).

**3. RESULTS**

**Chemical Parameters**

The Safe Drinking Water Act requires that water approved as potable have selected chemical parameters remain within required limits. Monitoring of some of these basic parameters such as pH, conductivity and selected cation and anion concentrations were performed and data from 1994/5 was compared to that of 2005 to see if the increase in temperature had any effect on these gross measures of water quality. In addition, the availability of newer equipment enabled the concentration of additional anions to be determined in recent samples.

With the exception of the Center well (Upper Cohansey) most wells show only a small change in the conductance of the water as can be seen in Figure 3. Values of the conductance are similar or slightly lower, but all are still safely within the required limits. The Center well (Upper Cohansey) shows a significant spike, however, it was noted that this well had poor drainage around the top of the well pipes. Although each pipe was capped, it was suspected that parking lot run-off contaminated the sample.

Similarly a comparison of pH measurements for the aquifer samples do not appear to be significantly different. While the data depicted below is typical a given month, the

![Conductance graph](image-url)  
**Figure 3. 2004 vs. 1995 comparison of conductivity measures in aquifer samples from at various sampling sites.**
individual values from each year are well within a standard deviation of the yearly average and \( \pm \Phi \). These changes are shown in Figure 4.

![Graph showing changes in bacterial counts](image)

Figure 4. 2004 vs. 1995 comparison of pH measurements in aquifer samples from at various sites.

In 2005, ion chromatography was used to determine chloride, fluoride and nitrate levels in the West, Center and East Wells. As can be seen in Table 1, these levels were well within required levels for potable water.

<table>
<thead>
<tr>
<th>Well</th>
<th>West Upper</th>
<th>Center Upper</th>
<th>East Upper</th>
<th>West Lower</th>
<th>Center Lower</th>
<th>East Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>F(^-)</td>
<td>4.59</td>
<td>5.04</td>
<td>4.61</td>
<td>3.52</td>
<td>3.62</td>
<td>N/A</td>
</tr>
<tr>
<td>Cl(^-)</td>
<td>35.6</td>
<td>130.6</td>
<td>38.9</td>
<td>60.0</td>
<td>38.0</td>
<td>N/A</td>
</tr>
<tr>
<td>NO(_3^-)</td>
<td>5.11</td>
<td>9.02</td>
<td>7.33</td>
<td>3.94</td>
<td>6.21</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 1 ppb anion concentration

The chemistry measurements taken together indicate that the temperature changes from the thermally unbalanced field do not cause significant changes in the water chemistry of the aquifers involved.

Microbiology

Microbes that live in the underground environment are adapted to a relatively constant temperature. Although microbes can live in a range of different temperatures, the temperature changes in the well field, from 14°C to as much as 23°C, are in a critical range for broad groups of bacteria. Research conducted from 1995 through 1997 indicated changes in both the numbers and types of bacteria found in groundwater samples from the well field compared to a control site outside the well field (York et al. 1998). During summer 2004, similar experiments were repeated and the results compared to previous data to get a snapshot of changes that had occurred in the intervening

![Graph showing bacterial counts](image)

Figure 5. 2004 vs. 1995 comparison of Total bacterial counts from Upper Cohansey aquifer.
period as the groundwater temperature had continued to rise. Figure 5 shows that the total number of bacteria in the Upper Cohansey aquifer was significantly lower in 2004 compared to numbers determined in 1996. Paradoxically, no significant differences were observed in total bacterial numbers from the different sampling sites despite the gradient of temperatures across the well field (Epstein & Sowers, 1996).

When samples from the Upper Cohansey aquifer were plated to determine the number of culturable bacteria (viable count), greater numbers of culturable bacteria were recovered from samples from the Center and East well that have the warmest temperature when compared to samples from West (upstream) and College Drive (outside well field-downstream) (Figure 6). Note that only a fraction of the total bacteria can be grown in the laboratory, but the observations that samples from within the well field have more culturable bacteria while the total number of bacteria is similar at the different sites suggests that there may be different types of bacteria in the different samples. There is also a pattern that the bacteria from the Center well apparently have a temperature preference for growth at the higher temperatures of 23 or 37 °C compared to growth at 14 °C since the same sample produces more colonies at the higher temperatures. Although this pattern is not consistently observed (East well). Furthermore, the bacterial types are apparently different based on their appearance on culture media. These observations taken together suggest changes in the microbial community structure.

Identification

In order to understand the changes in bacterial community in greater detail, we sought to identify some of the bacteria that had been cultured from the Upper Cohansey aquifer Center sampling site. A molecular genetic strategy was used, which is based on obtaining DNA sequencing for the 16S ribosomal RNA gene, a highly conserved gene found in all organisms. This gene has been used extensively to determine phylogenetic relationships between organisms, and robust databases of DNA sequence for this gene are available (Altschul, et al. 1997, Cole et al. 2005). To date thirty-three microbes have been identified. Table 2 shows preliminary genus level identification of twenty microbes isolated from Upper Cohansey aquifer samples in 1997 and thirteen isolated in 2005. There are some genera that were found among both the 1997 and 2005 samples (black lettering). Others that were found in one sampling set, but not the other. Blue lettering indicates those found only in 1997 while red lettering indicates those isolated in 2005 only. This suggests specific changes that may have occurred in the microbial community, and suggests specific organisms to focus on in further investigations.

4. DISCUSSION

Geoexchange is an environmentally friendly technology which has been shown to reduce CO₂ emissions. Only thermal energy is exchanged with the underground environment. Stockton’s system as initially installed was not thermally balanced and a thermal buildup occurred. This provided a unique opportunity to study the impact of the thermal buildup on groundwater chemistry and aquifer microbiota. While this thermal imbalance has been recently addressed by the installation of a cooling tower, these studies were conducted as the temperature in the well field was increasing and at a point prior to the installation of the cooling tower when the temperature was
maximally disturbed. While chemical measures of water quality did not show any significant changes, microbiological studies suggested changes in the microbial community. Overall there was a reduction in the total number of bacteria in the 2004 samples and preliminary identification of microbes suggests specific types of bacteria that might be particularly sensitive to temperature changes.

While it is well known that some bacteria can cause disease, it is not as widely appreciated that many bacteria often have important beneficial roles, including acting as primary producers in the environment, and recyclers of nutrients. Despite the fact that microbes play key roles in the environment estimates are that roughly 1% of the bacterial species have been identified. Many of the microbes identified in the Upper Cohansey aquifer samples have previously been isolated from aqueous environments. Some of these genera (Rhodococcus, Pseudomonas and Acidovorax) contain species of bacteria with degradatory metabolism, which may provide a natural mechanism for maintaining water quality.

In the summer of 2005 a 750 ton cooling tower was added to the RSC GHP in order to thermally balance the system. Models predict that the cooling tower will restore the temperature to ambient levels within 100 days once equilibrium is restored. It may take five or more years to bring the average temperature of the well field back to its original values. Identification of microbes which may be particularly sensitive to thermal changes can provide a basis to evaluate whether the aquifer microbial community will recover once the thermal imbalance of the well field is corrected. Finally, this work highlights the need to consider the overall thermal balance in system design to maximize efficiency of the system and minimize the potential environmental impacts.

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REFERENCES


