Reconnaissance Study of Age and Recharge Temperature Of Groundwater Near Moab Utah

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Introduction

At the request of the Moab Mesa Land Company LLC I performed a reconnaissance study of groundwater in the vicinity of Moab Utah. The objective of the study was to evaluate the age, recharge temperature and recharge elevation of groundwater discharging from springs and wells. Samples were collected from the following sites:

1. Moab City Spring #3 (Somerville Spring #3);
2. Lloyd Somerville Spring;
3. Pioneer Spring;
4. George White Well 4;
5. George White Well 5.

The samples were analyzed for tritium, dissolved noble gases, and the stable isotopes of hydrogen and oxygen. Collectively the results of these analyses can be interpreted in terms of the age of the water, and the approximate elevation at which the water was recharged. This report describes the collection and analysis of these samples and presents the results. It also provides background information regarding the use of these analyses as hydrologic tracers.

Samples from the Moab City Spring #3 (Somerville Spring #3), Lloyd Somerville Spring, and George White Wells 4 and 5 were collected because these represent significant discharge points for the Glen Canyon Group Aquifer that is assumed to be recharge in or on the flanks of the La Sal Mountains. The sample from Pioneer spring was collected as
a control as it is assumed to be recharge to the west of Spanish Valley where groundwater
flows northeastward toward the Valley.

Background

Tritium

Tritium \(^{3}\text{H}\) is a radioactive isotope of hydrogen with a half-life of 12.4 years. Tritium is
produced naturally in the atmosphere and prior to 1950 the concentration in continental
precipitation was about 2 to 5 TU (1 TU is equal to 1 \(^{3}\text{H}\) atom per \(10^{18}\) atoms of \(^{1}\text{H}\)).
Beginning in the early 1950s, \(^{3}\text{H}\) concentration in precipitation in the northern
hemisphere rose dramatically due to aboveground testing of thermo-nuclear weapons.
Because \(^{3}\text{H}\) is incorporated into the water molecule, it is geochemically conservative
(apart from its well-known radioactive decay).

The \(^{3}\text{H}\) concentration of precipitation in Salt Lake City from 1963 to 1984 is shown in
Figure 1. Some of the same data are shown in Figure 2 for the period 1971 to 1988 with
an expanded scale on the vertical axis. Although direct measurements of \(^{3}\text{H}\) in
precipitation in Utah were not made prior to 1963, the concentration prior to 1950 was
less than about 5 TU as determined by comparison of modern precipitation in Utah with
stations having longer records.
Figure 1. Tritium concentration in precipitation at Salt Lake City for 1963 to 1984.

As seen in Figure 1, peak concentrations in Salt Lake City were approximately 9000 TU. Precipitation that fell after 1950 that then recharge groundwater will have a tritium concentration that is greater than about 3 TU at the present point in time. Thus, the concentration of $^3$H in groundwater is a guide to whether or not the water was recharged before or after 1950.
Figure 2. Tritium concentration in precipitation at Salt Lake City for 1971 to 1984.

**Noble Gases**

The atmosphere contains well-known concentrations of noble and other gases such as neon (Ne), argon (Ar), and krypton (Kr), and nitrogen (N₂). The solubility of these gases in recharging water is a function of the temperature and pressure (elevation) when the water was in final contact with the atmosphere (i.e. just above the water table.) Studies of noble gas concentrations in groundwater indicate the presence of an additional amount of dissolved gas, termed excess air that probably results from trapping air bubbles when the water table rises. Because the production of these gases within aquifers is insignificant, the dissolved concentrations in groundwater are indicators of the
temperature and pressure that existed at the water table when the water was recharged. Because the temperature-pressure relationship of the solubility is unique for each gas, it is theoretically possible to determine the recharge temperature and pressure and the amount of excess air (three unknowns) by measuring the concentration of at least three different gases in groundwater. However, this is only possible if “perfect” measurements of dissolved gas concentrations can be made. Since there is uncertainty associated with all analytical results, it is not generally possible using only dissolved gas concentrations to determine all three unknowns. In most dissolved gas studies, the recharge elevation is relatively well known. Solving for only two unknowns generally leads to a recharge temperature that has an uncertainty of ± 1 °C. In order to solve for all three unknowns using real data (i.e., data that contain uncertainty) it is necessary to include additional information. Manning and Solomon (2001) have shown that in the Wasatch Mountains the relationship between recharge temperature and elevation is similar to the atmospheric lapse rate for adiabatic cooling. Air temperature data from 4 stations were obtained in order to determine the atmospheric lapse rate in the Moab area. The mean annual temperature at Moab is 13.2 °C and decreases by just over 6 °C per 1000 m into the La Sal mountains. By assuming that the recharge temperature also decreases by about 6 °C per 1000 m, it is possible to obtain recharge temperature, elevation, and excess air values for samples in which a suite of noble gas analysis is obtained.

Stable Isotopes

The stable isotopic composition of water depends on numerous processes, but mostly the temperature of condensation and the history (origin and trajectory) of an atmospheric
water mass. Because temperature decreases with increasing elevation (atmospheric lapse rate), the stable isotopic composition of water is indirectly a function of elevation. However, because of variability in storm histories and temperature, along with other fractionation processes (e.g. sublimation of snow or evaporation of rain) the isotopic composition of individual precipitation events can be variable. Generally a time-series of precipitation values along with a statistically significant number of groundwater samples is needed to interpret stable isotope data in terms of recharge elevations. Samples for stable isotopes in this study were collected as a general check on noble gas thermometry.

**Sample Collection and Analysis**

Samples were collected during a two-day period from December 21 to 22, 2000. Field measurements included water temperature, dissolved oxygen, barometric pressure, and the total dissolved gas pressure. These measurements were made using probes calibrated at the University of Utah.

Samples for $^3$H were collected in 1L glass bottles with polyseal caps. Samples for stable isotopes were collected in 500 ml glass bottles and were also sealed using polyseal caps. In both cases care was taken to minimize the amount of headspace present in the bottles. Samples for dissolved gases were collected using two different methods. The most reliable method for collecting dissolved gas samples makes use of diffusion samplers that were custom fabricated at the University of Utah. These devices consist of silicon rubber tubing attached to a short length of 3/16" OD soft copper tubing. The samplers were submerged in discharging spring waters for approximately 24 hours. Dissolved gases in the groundwater permeate the silicone rubber tubing causing the gas inside the samplers
to equilibrate with dissolved gases in water. After equilibration, the samplers were removed and the copper tube was sealed using a cold-welding crimping device. While this method is considered the most reliable, it could not be used on George White Well #4 and #5 because the wells could not be operated continuously for a 24-hour period. Samples for dissolved gases from these wells were collected by directing well discharge through 3/8" OD copper tubing, and then sealing these tubes with high-pressure refrigeration clamps.

Tritium analyses were performed at the University of Utah Noble Gas Laboratory using the \( ^3 \)He in-growth method. This technique has the lowest detection limit (<0.1 TU) of all possible methods. The uncertainty in \(^3\)H values varies according to the concentration and is approximately ±5% for values greater than 1 TU. Noble gases were also analyzed at the University of Utah Noble Gas Laboratory using a custom-built cleanup system connected to an MAP 215 sector-field mass spectrometer. An air standard was used for calibration that was performed after approximately every 3\(^{rd}\) sample. The analytical precision for noble gases is approximately ±0.5 % for \(^3\)He and \(^4\)He, 1% for \(N_2\), and \(^{40}\)Ar, and less than 3% for \(^{20}\)Ne and \(^{84}\)Kr. Stable isotope analyses were performed at the Stable Isotope Ratio For Ecological Research (SIRFER) laboratory at the University of Utah. The uncertainty in the stable isotope values is approximately ± 1 per mil for deuterium and 0.1 per mil for oxygen.
Results

The results of $^3$H, noble gases, and stable isotope values are shown in Table 1. Also shown are values measured during sampling such as dissolved O$_2$, and the temperature of the water.

Table 1. Results of noble gas, $^3$H, stable isotopes, and field values of groundwater.

<table>
<thead>
<tr>
<th></th>
<th>Pioneer Spring</th>
<th>Moab City Spring 3 (Somerville Spring #3)</th>
<th>Lloyd Somerville Spring</th>
<th>George White Well 4</th>
<th>George White Well 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^4$He (ccSTP/g)</td>
<td>1.14E-02</td>
<td>1.16E-02</td>
<td>1.23E-02</td>
<td>1.42E-02</td>
<td>1.33E-02</td>
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<td>$^{40}$Ar (ccSTP/g)</td>
<td>2.93E-04</td>
<td>3.00E-04</td>
<td>3.11E-04</td>
<td>3.64E-04</td>
<td>3.43E-04</td>
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<tr>
<td>$^{84}$Kr (ccSTP/g)</td>
<td>3.91E-08</td>
<td>4.00E-08</td>
<td>4.24E-08</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>$^{20}$Ne (ccSTP/g)</td>
<td>1.51E-07</td>
<td>1.50E-07</td>
<td>1.58E-07</td>
<td>1.86E-07</td>
<td>1.76E-07</td>
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<tr>
<td>$^4$He (ccSTP/g)</td>
<td>4.00E-08</td>
<td>5.11E-08</td>
<td>6.27E-08</td>
<td>9.24E-08</td>
<td>7.68E-08</td>
</tr>
<tr>
<td>R/Ra $^*$</td>
<td>0.985</td>
<td>0.811</td>
<td>0.680</td>
<td>0.571</td>
<td>0.656</td>
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<tr>
<td>$^3$H (TU)</td>
<td>0.3</td>
<td>0.72</td>
<td>0.4</td>
<td>1.2</td>
<td>1.7</td>
</tr>
<tr>
<td>±</td>
<td>0.1</td>
<td>0.05</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
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<td>$\delta^{18}$O (%)</td>
<td>-14.3</td>
<td>-14.6</td>
<td>-14.3</td>
<td>-14.6</td>
<td>-14.5</td>
</tr>
<tr>
<td>$\delta^D$ (%)</td>
<td>-110</td>
<td>-112</td>
<td>-112</td>
<td>-112</td>
<td>-112</td>
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<tr>
<td>Collection Date</td>
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<td>12/22/00</td>
<td>12/21/00</td>
<td>12/21/00</td>
<td>12/21/00</td>
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<tr>
<td>Water Temp. when Collected (°C)</td>
<td>16.4</td>
<td>16.5</td>
<td>16.5</td>
<td>17.0</td>
<td>16.8</td>
</tr>
<tr>
<td>Field measured O$_2$ (ppm)</td>
<td>7.6</td>
<td>8.7</td>
<td>7.0</td>
<td>7.6</td>
<td>8.2</td>
</tr>
</tbody>
</table>

$^*$ R is the $^3$He/$^4$He ratio of the sample, Ra is the $^3$He/$^4$He ratio of air (1.384 X 10$^{-6}$)

NA = Not Available

The results shown in Table 1 have been interpreted in terms of the age and approximate recharge elevation as discussed in the following sections.
Age

The data shown in Table 1 provide several measures of the age of the samples. By age I refer to the elapsed time between recharge and sample collection. As discussed in the background section, $^3$H values below about 3 TU in Utah indicate water that was recharged prior to the peak of thermo-nuclear weapons testing in the early 1960s. The highest $^3$H observed was 1.7 TU and thus in a general sense all of the waters are thought to be older than about 40 years. The $^3$H values are consistent with the helium isotope ratios that are all less than 1 indicating the presence of little (if any) tritiogenic $^3$He (which is the daughter product of $^3$H decay).

Another measure of age is provided by the concentration of $^4$He in the samples. Helium-4 is one of the final stable products of the radioactive decay of naturally occurring uranium and thorium. A base amount of $^4$He is present in groundwater as a result of atmospheric $^4$He being dissolved in precipitation. If the production of $^4$He is assumed to be uniform in the subsurface, then the $^4$He concentration in groundwater (above the base amount from the atmosphere) will reflect the amount of time the water has been in contact with the aquifer. In this study I have not determined the $^4$He production rate (this is a significant amount of work far beyond the scope of this reconnaissance study) and thus the $^4$He data cannot be used to precisely estimate ages. However, based on values reported in the literature (Solomon, 2000) the $^4$He production rate is likely to be such that a significant concentration in groundwater will not occur until the contact time has been about 1000 years. The base amount of $^4$He in groundwater (that is recharged at an elevation of 1600 m) is about $4.0 \times 10^{-8}$ ccSTP/g which is precisely the amount.
measured in Pioneer Spring. However, elevated values exist in all other samples with the maximum being $9.2 \times 10^{-8}$ ccSTP/g in George White Well 4. I interpret this to mean that Pioneer Spring water is between about 40 and 1000 years old, whereas the other waters could be older than 1000 years. It is interesting to note that $^4$He concentrations (and the related helium isotope ratio) vary systematically with space. The highest $^4$He values occur to the south in George White Well 4 and George White Well 5, and then decline to the lowest value in Pioneer Spring to the northwest.

Figure 3 shows the measured $^3$H values plotted as a function of the $^4$He concentration. While some scatter exists, there is a positive correlation between $^3$H and $^4$He. At first glance this appears to contradict the interpretation that the higher the $^4$He concentration the older the water. However, the highest $^3$H values occur in the wells and represent an integration of water collected over the length of the well screen. It seems likely that majority of water collected by the well is old but that this is being mixed within the well bore with a small amount of younger water. Mixing of waters of different ages in well bores has been observed in many studies. To confirm this interpretation (i.e. mixing a small amount of young water with a large amount of old water) I calculated the $^3$H/$^3$He age of the samples collected from George White Wells 4 and 5. A detailed discussion of the $^3$H/$^3$He dating procedure is beyond the scope of this report, but suffice it to say that when tritium free water is mixed with tritiated water, the apparent $^3$H/$^3$He age of the mixture will be the age of the young fraction (even if only a small amount of young water is added to a large amount of old water.) The $^3$H/$^3$He age of these samples is about 18 to 20 years. Assuming that precipitation near Moab had a similar $^3$H value as Salt Lake
City, the average concentration in 1980 (i.e. 20 years ago) was 31 TU. Radioactive decay during 20 years would reduce this concentration to about 10 TU, but dilution with older water is required to lower this to the observed values of 1.4 TU (average of wells 4 and 5.) The approximate amount of dilution required is 14 parts young water to 86 parts old water.

Figure 3  Relationship between $^3$H and $^4$He in groundwater.

Recharge Temperature and Elevation

The concentration of dissolved gases is shown in Table 1. I have evaluated the recharge temperature by first assuming a recharge elevation, and then solving an over-determined set of solubility equations representing each of the gases listed in Table 1 (except $^4$He because it is generated in the subsurface). This procedure results in a value the recharge
temperature and excess air that best fits the observed data. A new recharge elevation was then assumed and the set of solubility equations was resolved to provide another estimate of the recharge temperature. This produces a family of solutions for each sample that represent the recharge temperature versus the recharge elevation. These curves are shown in Figure 4.

![Graph showing temperature as a function of recharge elevation.](image)

Figure 4  Recharge temperature as a function of recharge elevation. Also shown is the atmospheric lapse rate. The slope of the lapse rate curve is consistent with air temperature values in the Moab area. The intercept was adjusted such that the Pioneer Spring sample has a recharge elevation (assumed) of about 1600 m.

The curves shown in Figure 4 are truncated at an elevation of about 1250 m since this is the approximate elevation of the sample collection points and it is highly unlikely that the
recharge elevation is lower than the discharge elevation. Thus, the temperature that corresponds to the lowest elevation on these curves represents the maximum possible recharge temperature.

Also shown in Figure 4 is a curve that represents the lapse rate for recharging water. The slope of this curve is consistent with the atmospheric lapse rate, but the intercept has been adjusted such that the lapse rate curve and the temperature-elevation curve for Pioneer Spring intersect at an elevation of about 1600 m. In other words, I have assumed that the recharge elevation for Pioneer Spring is 1600 m. Pioneer Spring is located on the western slope of Spanish Valley and recharge to this spring is not likely to be derived from the La Sal Mountains, but rather from the western flank of the valley. In a more complete study an empirical lapse curve could be developed by sampling springs that discharge at various elevations. The uncertainty in the lapse rate curve represents the primary uncertainty associated with assigning precise recharge elevations based on dissolved gases. Although this uncertainty is difficult to estimate, it is probably such that the uncertainty in recharge elevations that are derived from this curve are about ± 300 m.

Using the lapse rate curve described above, estimates of the recharge elevation for Moab City Spring 3 and Lloyd Somerville Spring are 2200 m and 2450 m respectively. Similar estimates for George White Wells 4 and 5 were not made because it was not possible to obtain dissolved Kr values from these wells. (The analytical method used at the University of Utah does not provide Kr values for water samples collected in copper
tubes. It was not possible to use diffusion samplers on these wells because they could not be operated for a continuous 24 hour period that is required to equilibrate the samplers.)

The consistency between the age and recharge temperature-elevation results was evaluated by plotting the He isotope ratios versus the dissolved N\textsubscript{2} concentration. The He isotope ratio should be completely independent of recharge temperature or elevation, but is proportional to groundwater age. Dissolved N\textsubscript{2} concentrations are a function of recharge temperature and elevation, but should not depend on age (or contact time) because only insignificant amounts of N\textsubscript{2} are likely to be derived from the aquifer. The relationship between the He isotope ratio and dissolved N\textsubscript{2} is shown in Figure 5. In all cases as the dissolved N\textsubscript{2} concentration increases the He isotope ratio decreases. Lower He isotope ratios correspond to older groundwater ages. Higher dissolved N\textsubscript{2} concentrations could result from either lower recharge temperatures, or lower recharge elevations. The relationship shown in Figure 5 makes sense if the higher N\textsubscript{2} values result from colder recharge temperatures because water that was recharged at higher elevations (at colder temperatures) would be older at the discharge point. In contrast the relationship shown in Figure 5 makes little sense if the higher N\textsubscript{2} values result from recharge occurring at a lower elevation that would be closer to the discharge points. In other words, I interpret the relationship shown in Figure 5 to be strong evidence in support of the interpretation of recharge elevation derived using an assumed (and therefore uncertain) lapse rate. The older the water at the discharge point, the higher the recharge elevation.
Figure 5. Relationship between the He isotope ratio (R/Ra) and dissolved N₂. Higher values of R/Ra correspond to younger ages. Higher values of N₂ represent colder recharge temperatures that occur at higher elevations. These data support the concept that the older the water at the discharge point, the higher the recharge elevation.

A final check on the recharge temperature and elevation can be made using the stable isotope data shown in Table 1. A precise use of stable isotope data to determine recharge elevation requires extensive sampling of precipitation at various elevations at various points in time to establish an empirical elevation curve. Although this curve has not been generated, the general relationship should be for higher elevation recharge to have lower (more negative) stable isotope values. An examination of Table 1 shows that this is generally the case. However, there is less variability in the stable isotope values than I
expected. Until more precipitation values are available, I can only conclude that the stable isotope ratios are consistent with the dissolved gas data, but do not at this time provide an independent check on the elevation of recharge.

Conclusions

Summary

Five samples were collected from springs and wells in the Moab area for the analysis of dissolved gases, tritium, and stable isotopes. These measurements were used to interpret the age and the temperature/elevation of recharge.

Tritium values range from 0.3 to 1.7 TU. These values suggest water that is generally older than 40 years. Dissolved $^4$He values indicate that some waters may be older than about 1000 years, but a precise date using $^4$He would require a more extensive analysis of the $^4$He production rate within the aquifer. The data provide little doubt that the majority of water sampled is older than 40 years, but an upper limit on the age cannot be determined precisely.

There is a general trend of decreasing $^4$He (and hence decreasing age) moving northwestward from George White Wells 4 and 5 to Pioneer Spring. Also, small amounts of $^3$H exist in discharge from George White Wells 4 and 5. These values are interpreted to result from the mixing of around 10% young water (that is about 20 years old) with 90
% older water (that is older than 40 years and may be older than 1000 years) within the well bore.

The concentration of dissolved gases indicates that the maximum possible recharge temperature is around 13 to 15 °C. By combining the dissolved gas data with an assumed curve for the recharge lapse rate, the recharge elevation of water discharging from Moab City Spring 3 and Lloyd Somerville Spring are estimated to be 2200 and 2450 m respectively. The uncertainty in recharge elevation is estimated to be about ± 300 m. The recharge lapse rate curve was developed by assuming that the recharge elevation of Pioneer Spring was 1600 m, and that the slope of this curve is equal to that of the atmospheric lapse rate. The dissolved gas temperature-elevation results are consistent with trends in the age of water. The older the water at the discharge point, the higher the recharge elevation. Stable isotope ratios are generally consistent with the dissolved gas data, but show less of a relationship with other parameters (age and dissolved gas temperatures) than expected. Nevertheless, the stable isotope data do not contradict the dissolved gas results, but do not at this time provide an independent estimate of the recharge elevation.

**Implications**

The general conclusion that water discharging from springs and wells is old and derived from recharge that occurs at high elevations (ca. 2000 to 2500 m) has implications regarding the location of the recharge area. For the area southeast of Moab, Blanchard (1990) indicates that the direction of groundwater flow in the upper groundwater system of the Glen Canyon Group Aquifer is to the west-northwest. Figure 6 shows areas
(shaded in blue) that are up gradient from the sampling locations (Moab City Spring 3, Lloyd Somerville Spring, and George White Wells 4 and 5) and where land surface is at an elevation between 2000 and 2500 m. This area represents the most probable recharge area for waters discharging at the collection sites considered in this study. This conclusion assumes that the water table in the shaded area of Figure 6 is moderately close to land surface. The depth to water in this area has not been considered in this study. If the depth to water were substantially greater than a few hundred meters, then the most probable recharge area (i.e. the shaded area in Figure 6) would be moved eastward. The probable location of recharge shown in Figure 6 is consistent with the conclusions of Steiger and Susong who state that “these areas, called upper mesas in this study, are recharge areas for the Glen Canyon aquifer because water that infiltrates the top of the mesas could eventually reach the underlying Glen Canyon aquifer and because the mesas receive the largest amount of precipitation in the study area.”

**Important Note**

It is important to emphasize that this was a reconnaissance study that consisted of a very small number of samples that were analyzed for only a selected number of parameters. Although the analyses presented appear to be internally consistent, it is not possible to evaluate how representative these results are of the entire system. The results of this study should be used mostly as a guide to the general nature of the groundwater flow system.
able recharge area (blue shading) for samples collected in this study.
References


