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Hydrochemical Data from Perennial Springs in the PR Spring Area of the Southern Uinta Basin, July 2013

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1. *Purpose of this document*

The purpose of this document is to examine the hydrochemistry of perennial springs (those flowing during July, 2013) in the PR Spring area of the southern rim of the Uinta Basin (Figure 1). This area is noteworthy for its potential tar sand development.

A recent court decision (No. WQ PR-11-001) permitted US Oil Sands (USOS) to conduct mining, processing, and disposal at the site (Figure 1) without liners in disposal pits, and without monitoring groundwater or spring quality. This decision reflected arguments made by expert witnesses testifying on behalf of US Oil Sands, which were that: 1) no ground water exists on the site; and 2) no potential for water recharge exsits at the ridge top (where the mining/processing/disposal site is situated) to reach springs in the adjacent canyons.

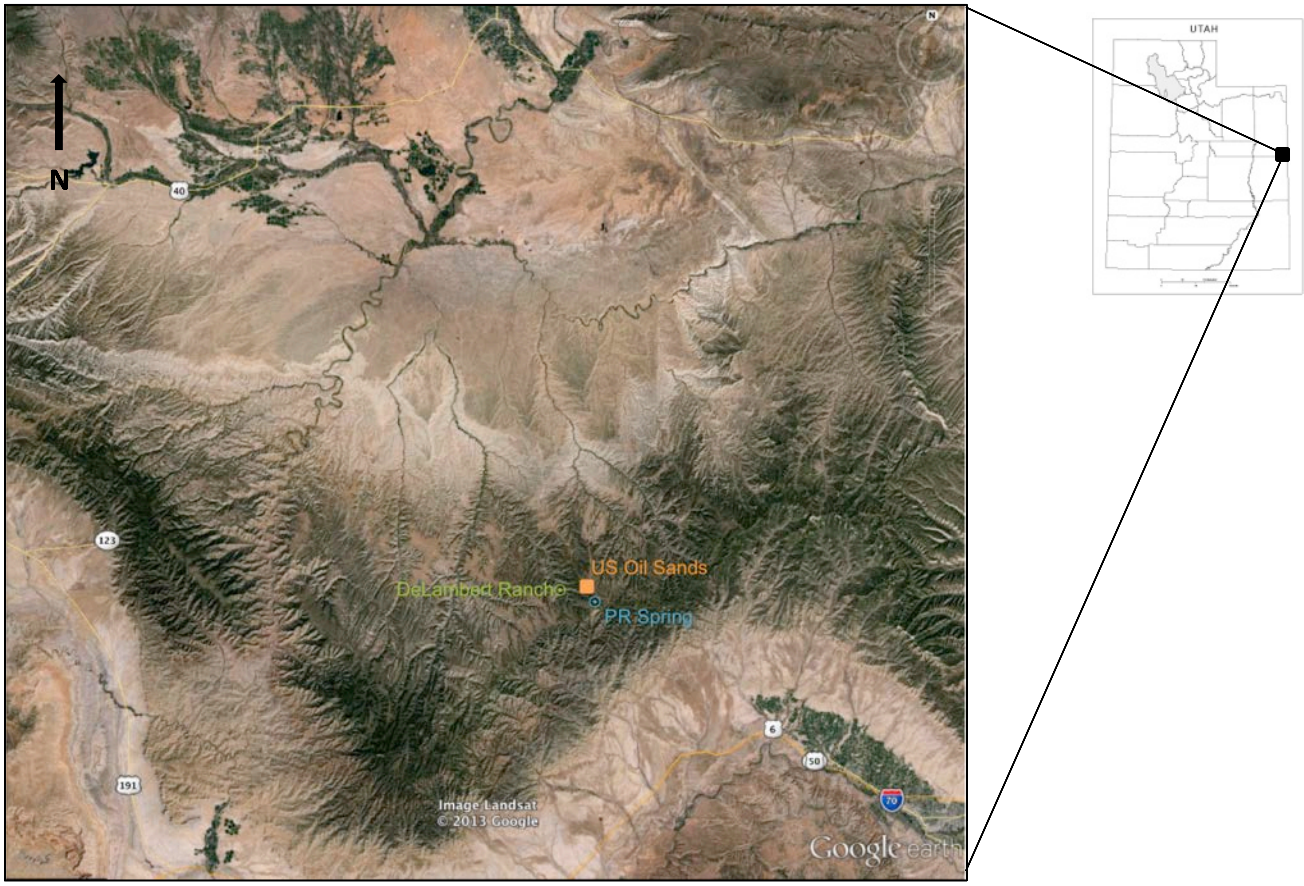

Figure 1. Google Earth image of the location of the PR Springs area in the southern rim of the Uinta Basin. US Oil Sands is located on Seep Ridge, north of Main Canyon. The DeLambert's Ranch is lcoated in Main Canyon. PR Spring is located in PR Spring Canyon, which intersects Seep Ridge to the north.

The results presented here indicate the existence of a groundwater flow system that is recharged on the ridge tops and flows downward to springs in the adjacent canyons. This finding raises concern for impairment of the springs and seeps in the canyons due to mining/processing/disposal activities at the ridge top sites if mitigation measures are not implemented to protect groundwater. The results of this investigation of perennial springs run counter to statements made by USOS expert witnesses regarding lack of a groundwater system and lack of a hydrologic connection between ridgetop recharge and the springs in the adjacent canyons. However, further consideration of USOS' underlying support for their statements shows that their findings are consistent with the new data indicating that a hydrologic connection exists between recharge at the ridgetops and springs in the adjacent canyons.

2. *Introduction*

The study area is located in the Tavaputs Plateau of the Book Cliffs on the southeastern rim of the Uinta Basin, 90 miles south of Vernal, UT (Figure 1). The mining/processing/disposal site lies on Seep Ridge, which trends northwest-southeast, and which is bounded on the southwest by Main Canyon (Figure 2). Several perennial springs are present even in dry seasons, and are a subset of a larger number of springs that are present during wet seasons. While previous testimony describes Seep Ridge as "dry and dusty" and therefore devoid of groundwater, nearby valleys only 500 ft below the ridge; e.g. Main and Horse Canyons, are lush, and contain Apsen trees and grassy meadows suggesting otherwise (Figure 2).

The DeLambert Ranch in Main Canyon is approximately three miles southwest from the mining/processing/disposal site (Figure 1). Here groundwater seepage in Main Canyon supports ranching families, livestock, wildlife, and vegetation. Notably, the homes in Main Canyon use the spring water from a horizontal pipe driven into the hillside at the fork of Main and Horse Canyon for drinking, cooking, and the support of a perrennial lake. Addtionally, livestock in the meadows utilize the spring water in all of Main Canyon.

Whereas the lake and homes at DeLambert Ranch are three miles from the mining/processing/disposal site, the meadows in Main Canyon extend up-valley toward the site. Additionally, multiple perrennial springs exist at different elevations in Main Canyon immediately below the mining/processing/disposal area on the ridge (Figure 3). Existing reports from the USGS and the University of Utah (Price and Miller, 1975, pgs 27-28; Byrd, 1970 page 17 top) specifically describe Seep Ridge as a recharge zone for water to the shallow unconfined aquifer below. In contrast, testimony related to the USOS permit decision indicates a lack of groundwater to a depth of approximately 2000 feet below the ridge. A critical question, therefore, is whether recharge of precipitation at Seep Ridge is connected to (hydrologically upgradient of) the seeps and springs that exist below the ridge.

Figure 2. Photograph of Main Canyon, looking up-canyon, east (approximately) toward DeLambert ranch houses (left middle ground).

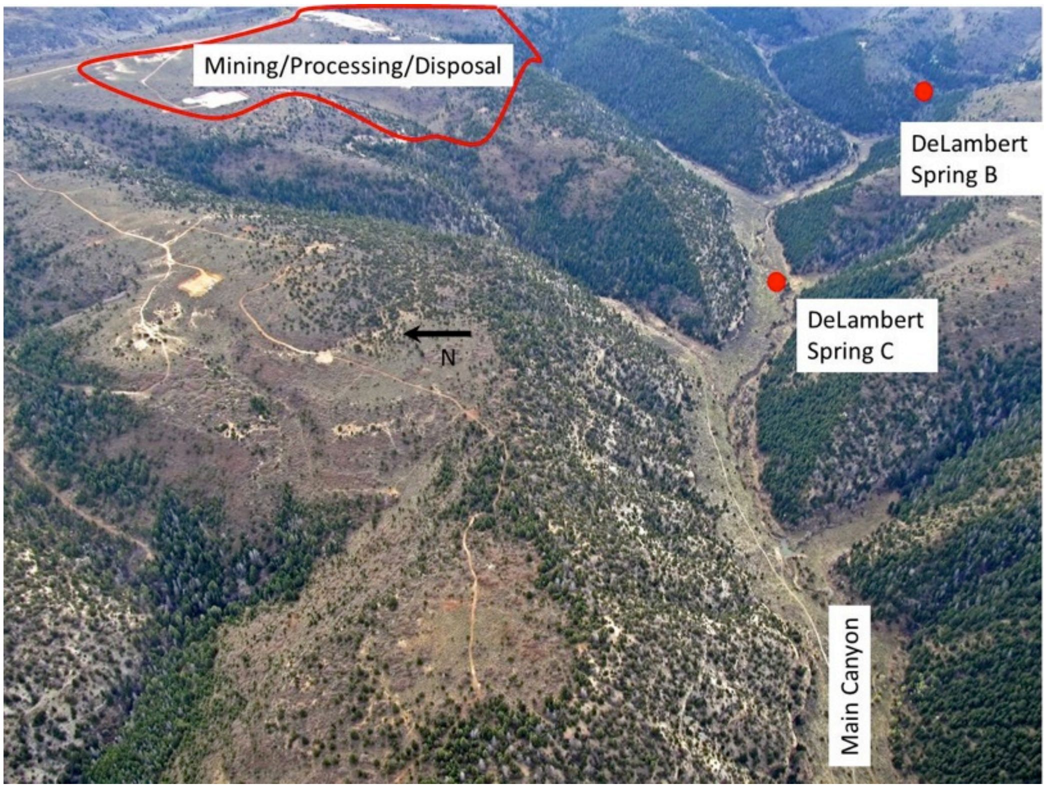

Figure 3. Aerial photograph of Main Canyon looking east (approximately). Approximate outline of mining/processing/disposal site is given in red. North arrow is approximate.

3. Materials and Methods

3.1. Background of Study area

The USOS area is located on the eastern section of the Roan Cliffs, of the Uinta Basin in South Eastern Utah. According to several studies in the late 1980s investigating the viability of Oil Sand production, the Roan Cliffs include outcrops of both the Eocene Douglas Creek member of the Green River Formation and Eocene Renegade Tongue of the Wasatch Formation (Kimball 1981, Lindskov and Kimball 1985, Holmes and Kimball 1987). The Douglas Creek and Renegade Tongue outcrops are significant because both formations contain a large freshwater aquifer, the Douglas Creek aquifer, where they exist at depth to the north (Holmes and Kimball 1987). The Douglas creek aquifer is recharged via precipitation and stream infiltration at an average rate of ~20,000 acre-feet per year and are responsible for the transfer of 20,000 acre-feet per year (Holmes and Kimball 1987).

The Uinta Basin climate zone is bounded by the Uinta Mountains to the north and the Tavaputs Plateau of the Book Cliffs to the south. The Uinta Basin is a semi-arid environment that ranges in elevation from approximately 5,000 to 10,000 ft. In its entirety, the Uinta Basin has an annual normal precipitation of less than 8.5 inches (Fuller 1994, Jensen et. al 1990). The study area is at a higher elevation (~7,000 to 9,000 ft) and has higher annual normal precipitations of 8 to 20 inches (Appendix A). The annual maximum, minimum, and mean annual temperatures for the study area are 14^{o}C, 1 ^{o}C, and 7 ^{o}C, respectively (Appendix B). During the months of May and June of 2013 the total amount of precipitation was 1.52 inches (Western Regional Climate Center, 2013).

3.2. Collection of samples

During mid-summer, July 15 & 16, 2013, water samples were taken from six sites in the PR Springs area (Figure 4). Westwater was sampled from the low flowing stream, Westwater Creek, located 12 miles south of the PR Spring area. DeLambert A was sampled from a horizontal well driven into the hillside at the confluence of Main and Horse Canyons at the DeLambert Ranch. DeLambert B was sampled from a seep in the canyon wall in upper Main Canyon on the north side of the valley stearm. DeLambert C was sampled from slow flowing water in a narrow stream just down stream of emergence from a dry meadow in a lush flood plain. PR Spring was sampled from a stand pipe well connected by pipe to cistern in hillside collecting spring water approximately 150 yards from stand pipe. USOS Well 4 was sampled from a pumped well screened at a depth of approximately 2,200 ft below the ridge. The method used to collect water samples from the six sites depended on the flow characteristics of the water and are described in the following section.

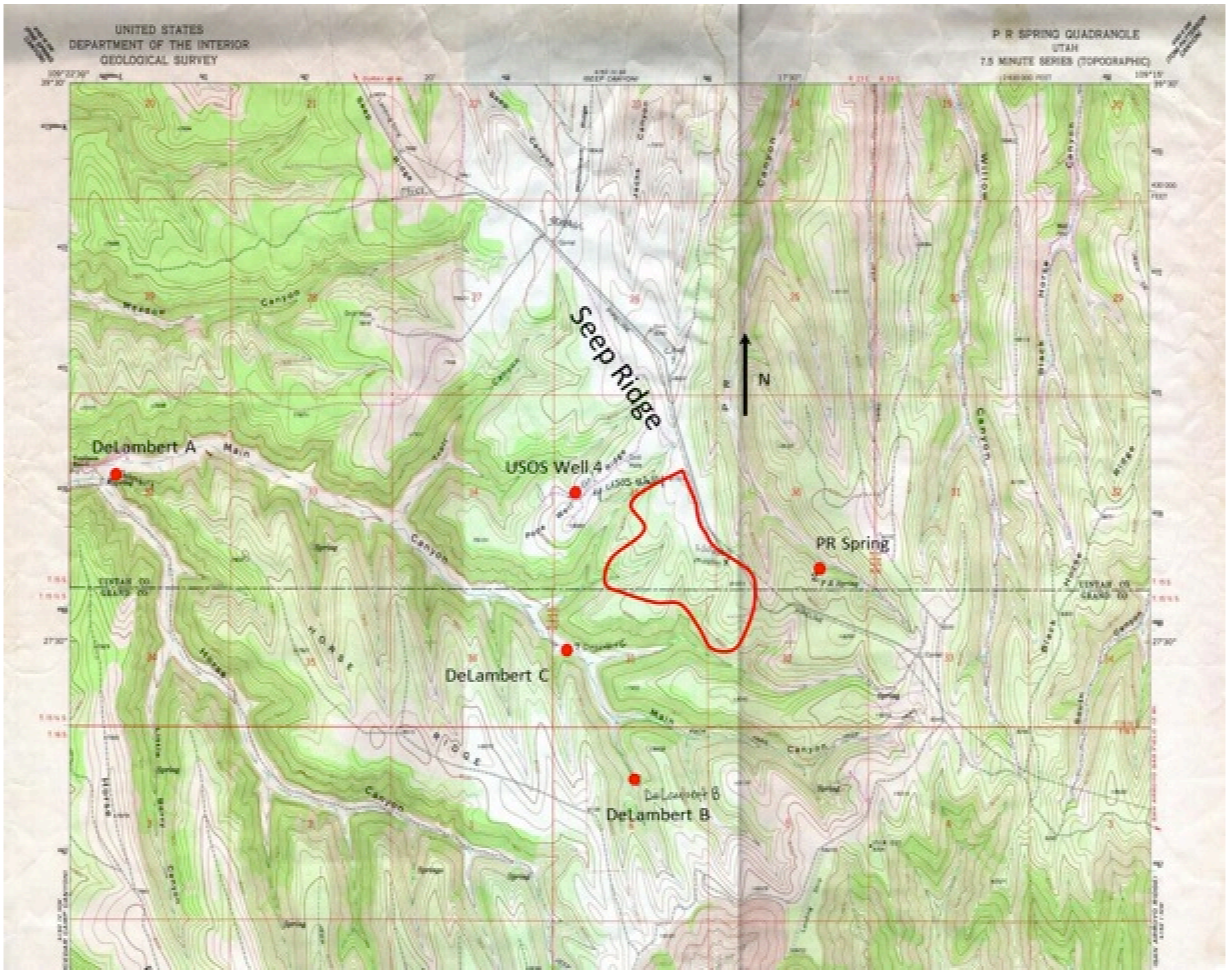

Figure 4. Topographic map of the sampled area with approximate locations (red dots) of springs and wells sampled. The approximate area of mining/processing/disposal site is also outlined in red.

3.3. Hydrochemistry

3.3.1. Field Parameters

The springs, seeps, and wells were characterized for temperature, barometric pressure, conductivity, dissovled oxygen (DO) and pH in the field using a multi-parameter water-quality probe (YSI Inc.). Elevation for each sampling site was taken from the PR Spring topographic map (Figure 4). The field parameters were compared with elevation to examine trends and hydrologic evolution with depth. Equilibration with the atmosphere in cisterns (PR Spring) and pump energy (Well 4) can sensitively affect pH and temperature, therefore trends with elevation for temperature and pH were not examined for these sites. Measurements were performed by placing the probe in a 1-liter (L) bottle while continuously pumping water (overflowing) into the bottle using a geopump. All parameters were recorded upon stabilization of patameters to a constant values.

3.3.2. Sulfur Hexafluoride

Sulfur Hexafluoride (SF_6) is predominantly an anthopogenicly produced gas, for which atmospheric concentration have steadily increased over the last 5 decades (Busenberg and Plummer, 2000). Trace amounts of SF_6 gas dissolved in water can be used to date the age of recharge (transfer from the unsaturated zone to the saturated zone). SF_6 samples were taken at PR Spring, DeLambert A and C, and USOS Well 4 to determine groundwater age. Duplicate samples were taken in 1-L sized amber bottles. A copper tube connected to a geopump was placed in the bottom of the bottle to displace air with water. The bottles were closed with a polyseal cone lined cap and sealed with electrical tape for storage and transport. The sampling methodology used was performed in accordance with the USGS The Reston Chlorofluorocarbon Laboratory guidlelines (U.S. Geological Survey, 2013). Samples for excess air were not collected. The Westwater site was not sampled for SF_6 because in stream settings, surface water may be mixed with the atmosphere, thereby re-setting the SF_6 content. SF_6 analysis was performed at the Dissolved and Noble Gas Laboratory, Geology & Geophysics Department, University of Utah in Salt Lake City, Utah. SF_6 was measured by the Shimadzu GC8A electron-capture gas chromatography with headspace calibarations as described by Busenberg and Plummer (2000). Calibration was performed using a 150 parts per trillon SF_6 standard. Inaccuracy of recharge elevation of approximently 1000 ft introduces an error of about 0.5 years in the SF_6 age model, with overestimation of the recharge elevation resulting in a younger apparent age (Busenber and Plummer, 2000). The detection limit of SF_6 concentrations is 0.01 femtomole (fmol)/L in water or lower.

3.3.3. Diesel Range Organics/Gas Range Organics - Field Measurement

All springs, seeps and wells were sampled for diesel range organics (DROs) and gas range organics (GROs). DRO/GRO samples were collected in 340 mL glass vials containing a preservative. DRO/GRO samples were sealed with a teflon-lined cap and stored in ice-packed coolers in the field and in transport. All samples were submitted for analysis at Chemtech-Ford Laboratories (Sandy, Utah). The detection limits for GROs is 0.24 mg/L and DROs is 5.0 mg/L.

3.3.4. Diesel Range Organics/Gas Range Organics - Lab Sample

A sample of the consolidated tar sands was collected from the PR Spring area to test the dissolution of DRO/GRO from tar sands into water in a controlled experiment. The tar sand sample was divided into two 150 g portions. Each sample portion was placed in a glass beaker, filled with 350mL of milli-q water, and left for one week under ambient conditions. The pH and tempterature were monitored daily. After one week, the equilibrated water was collected in three 40-mL glass vials containing a preservative, sealed with a teflon-lined cap and stored in ice-packed coolers in the field and in transport. Both samples were submitted for DRO/GRO analysis at Chemtech-Ford Laboratories in Sandy, Utah.

3.3.5. Strontium

Strontium is a divalent cation that readily substitutes for Ca^{2+} in carbonates, sulfates, feldspars and other rock-forming minerals. Water-rock interaction yields Sr as a minor component of most groundwater. Strontium isotopes ($^{87}Sr/^{86}Sr$) have proven to be a useful indicator of water-rock interaction, and as a tracer for groundwater movement and the origin of salinity. Samples collected from all six sites were filtered though 0.5-micron and 0.25-micron acid-washed filters with a sterile syringe emptied into a 100 mL acid-washed bottle. The analysis was performed at the ICP-MS Laboratory at the Geology & Geophysics Department, University of Utah. Strontium concentrations were measured by a Agilent 7500ce quadrupole inductively coupled plasma mass spectrometer (ICPMS). The detection limit is ±0.3 parts per billion (ppb). The isotopic analysis of strontium was measured by a Thermo Neptune multi-collector CP-MS. The detection limit is ±0.39 ppb.

4. Results

4.1. Field Parameters

The hydrochemistry of spring, seep, and wells measured in the field are presented in Table 1.

Table 1. Hydrochemical parameter values measured in the field.

Location	**Elevation (ft)**	**Temperature (°C)**	**Barometric Pressure (mmHg)**	**Dissolved Oxygen (%)**	**Dissolved Oxygen ($^{mg}/_{L}$)**	**Conductivity ($^{\mu s}/_{cm}$)**	**pH**
P R Spring	8040	15.0	-	88.5	9.20	636	7.66
USOS Well 4	6290	27.2	570	0.5	0.04	1427	8.91
DeLambert A	7040	10.1	594	30.4	3.75	996	7.42
DeLambert B	7600	10.6	581	80	9.40	640	7.85
DeLambert C	7400	8.6	585	33.8	3.83	750	7.41
Westwater	6070	-	-	-	-	-	-

The mid-level meadow springs (DeLambert A & C) showed slightly higher conductivity (900 uS/cm) (classified as fresh) and lower dissolved oxygen (30% saturation) than the higher elevation springs such as PR Spring. The water at the deep-level USOS Well 4 (drawn from depths between 2000 and 2300 feet below the ridge from a known lower aquifer in the Mesaverde Formation) has even higher conductivity (1500 uS/cm) (brackish), and is devoid of oxygen (Figures 5 & 6). USOS Well 4 is chemically more evolved (greater water-rock interaction) than the springs and seeps at higher elevations.

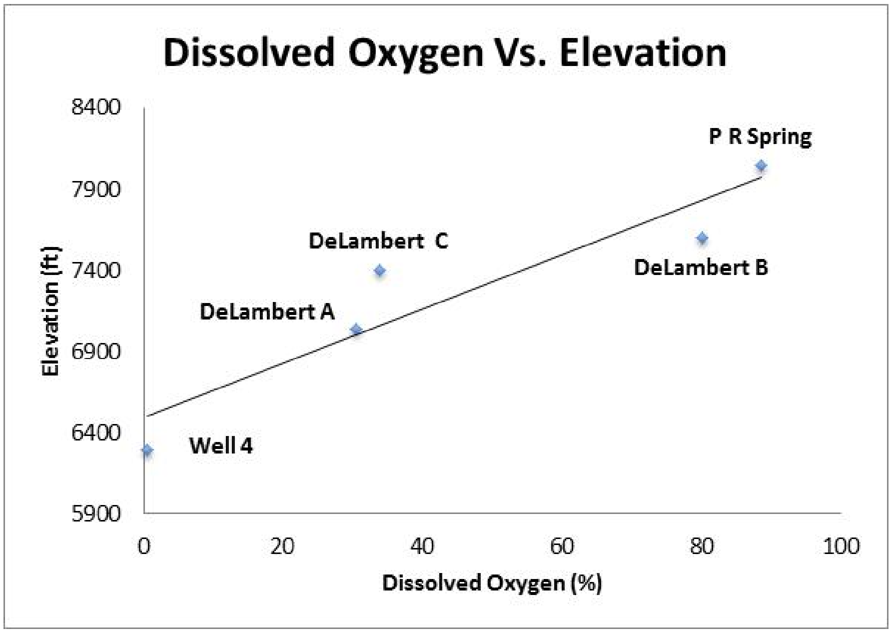

Figure 5. Measured dissolved oxygen (relative to saturation) as a function of elevation. A linear trend line is shown in black.

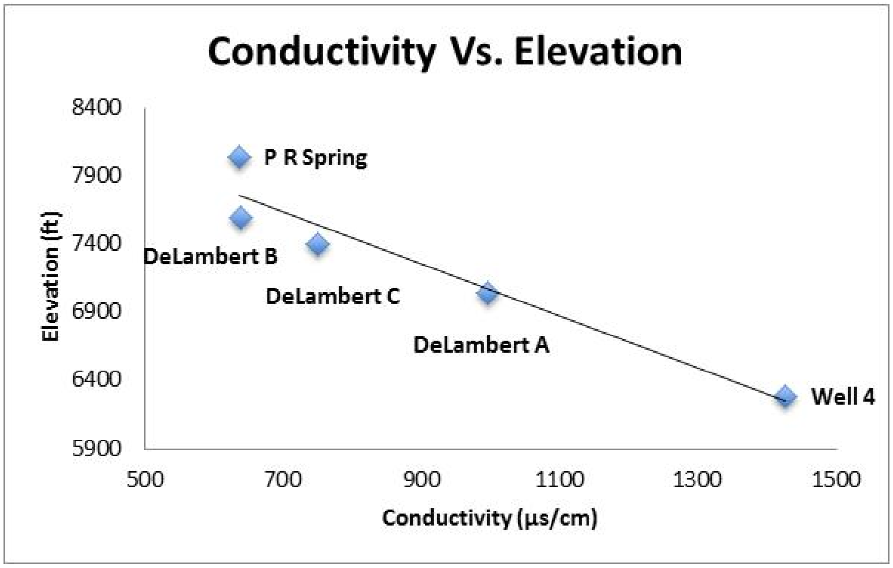

Figure 6. Measured conductance (µS/cm) as a function of elevation. A linear trend line is shown in black.

4.2. *Sulfur Hexafluoride*

The SF_6 data are presented in Table 2.

Table 1. SF6 concentration and age model data.

Location	Estimated Recharge Elevation (ft)	SF_6 ($^{fmol}/_{Kg}$)	SF6 Recharge Year	SF6 Recharge Age (Years)
P R Spring	8200	1.56	2008	5.5
USOS Well 4	8200	0.22	1983.5	30.0
DeLambert A	8200	1.23	1998	16.0
DeLambert B	-	-	-	-
DeLambert C	8200	1.48	2000	13.5
Westwater	-	-	-	-

SF_6 age data are consistent with the dissolved oxygen and conductance data, showing that the lower dissolved oxygen-higher conductivity water tends to be older (Figure 7). It is important to note that all spring samples indicated young ages (a few years at most since recharge). Even the deep well indicated an age in the range of two to three decades.

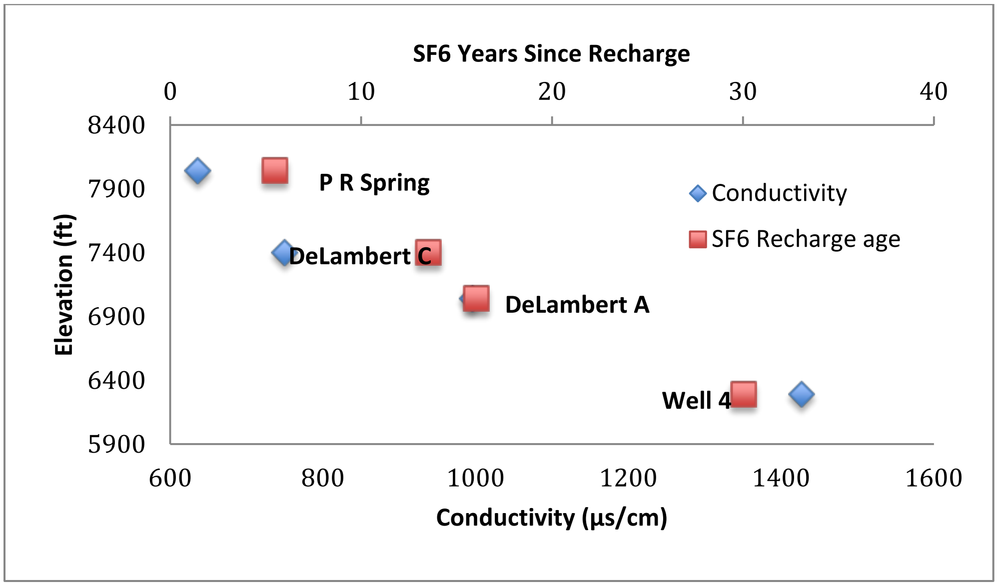

Figure 7. SF_6 recharge age (years since recharge) on secondary (upper) y-axis, with conductivity results (lower y-axis) for comparison.

4.3. Diesel Range Organics/Gas Range Organics in Spring/Well samples

All samples showed non-detection for both DROs and GROs, with detection limits of 0.24 mg/L (GROs) and 5.0 mg/L (DROs). These results demonstrate that under ambient conditions, the concentration of organic compounds in the groundwater samples were less than the above reporting limits for both size ranges. The results will serve as a useful baseline for assessment of potential impairment due to mining/processing/disposal activities.

4.4. Diesel Range Organics/Gas Range Organics Tar Sand-Equilibrated Water

All tar sand-equilibrated water samples showed non-detection for GROs with detection limits of 0.24 mg/L. The tar sand-equilibrated water samples yielded 9 mg/L DROs with a detection limit of 5.0 mg/L. The low measured DRO concentration for tar sand-equilibrated samples relative to detection limit (less than a factor of two) demonstrates that any DRO dissolved into groundwater in contact with tar sand would easily be driven below detection by dispersion and sorption during transport. Hence, the absence of measureable DRO and GRO concentrations in spring and well water does NOT indicate a lack of contact of these waters with tar sand during infiltration.

4.5. Strontium

Plotting in a $^{87}Sr/^{86}Sr$ vs. 1/Sr diagram (Figure 9) is classically used to evaluate two-component mixing and end-member water compositions (Negrel & Petelet-Giraud, 2010). The springs show a clear trendline indicating a relationship among them that is distinct from the groundwater from USOS Well 4 (Figure 8).

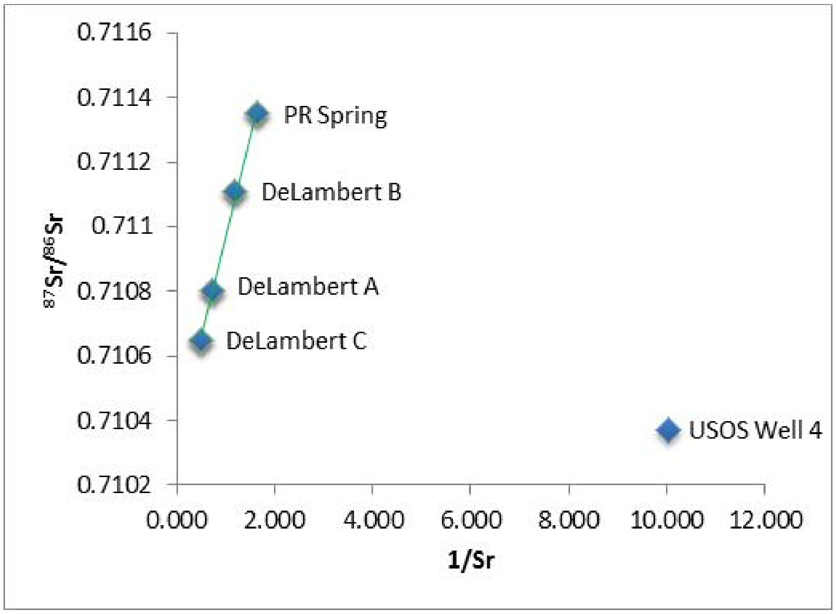

Figure 8. The 87Sr/86Sr graph shows the evolution of 87Sr content in the water that increase with of water/rock interaction.

Notably, the trend among the springs is similar when elevation is substituted for 1/Sr (Figure 11), which (along with the field and SF_6 data) strongly suggests that the mixing line represents downward-flowing groundwater in the hydrologic system. As groundwater flows downward and increases in age (Figure 9), the Sr concentration increases and the $^{87}Sr/^{86}Sr$ decreases (Figures 8 and 9).

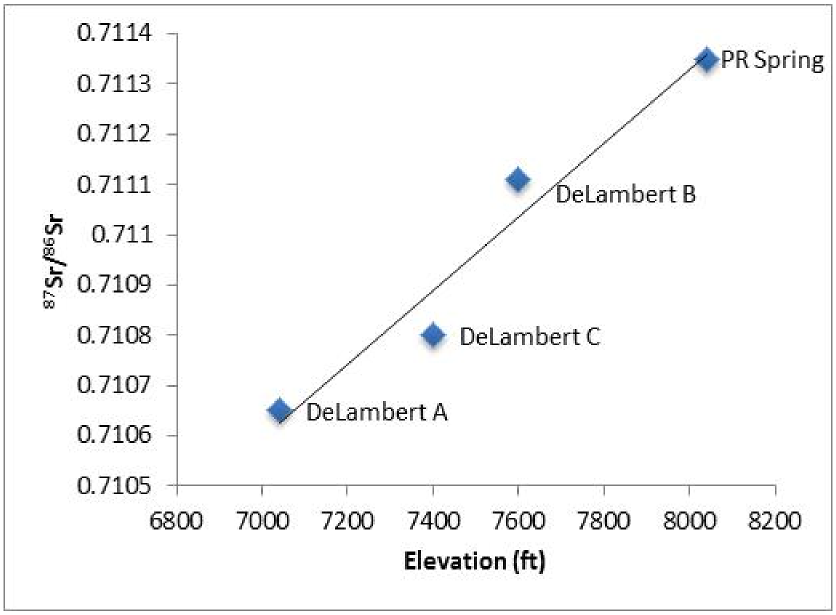

Figure 9. Sr isotope ratio versus elevation for sampled springs.

5. Discussion

The source of the springs located in Main Canyon is an important question. If recharge at nearby ridges is the source of the springs, then the potential impact of tar sand development on spring water quality and flow should be evaluated as ranching families rely on springs in Main Canyon for their livelihood.

The field parameters (Table 1, Figures 5 & 6), SF_6 age (Figure 7), and Sr isotopes data (Figures 8 & 9) all indicate that higher elevation springs are less chemically evolved than the water at lower elevations. This indicates that the perennial springs in Main Canyon are sourced from local recharge at the ridgetops. The data are consistent with the expectation that, as the groundwater moves deeper, a greater amount of water-rock interaction occurs, yielding greater dissolved solids concentrations, greater depletion of oxygen, increasing Sr concentration, and decreasing $^{87}Sr/^{86}Sr$ isotope ratios.

6. Relationship with USOS Expert Witness and DWQ Testimony

The conclusion that Main canyon springs are sourced from recharge at nearby ridgetops lies in stark contrast to the previous conclusion (Mark Novak, personal communication) that springs in Main canyon are sourced via recharge to the local alluvium. The alluvial fill in Main Canyon is restricted to the valley floor. Approximately, 100 acres of alluvium fills the canyon from the DeLambert Ranch spring (DeLambert A) to the eastern reaches of Main Canyon (Figure 10). The Canyon walls consist of consolidated sandstone outcrops from the Douglas Creek Member (400 to 600 ft thick) with interbedded shale and tar sands units. The predominately flat valley floor is likely the top of a consolidated sandstone unit of the Renegade Tongue covered with a thin layer of unconsolidated alluvium in the streambed.

Figure 10. The black line outlines approximately 100 acres of alluvial fill over the sandstone unit of the Renegade Tongue Member in Main Canyon directly below the mine site.

The assertion by DWQ personnel that recharge directly to the alluvium drives the observed perennial flow within Main Canyon springs runs counter to the data presented above, and therefore needs to be investigated. The assertion on the part of DWQ needs to be supported with data and calculations.

Direct recharge to the alluvium should reflect average air temperature, which was 18 to 19 °C for the months of June and July 2013 (Western Regional Climate Center, 2013). However, the measured water temperatures in the springs (DeLambert A, B, C) were 8 to 10 °C, far lower than the average temperature of the preceding two months. The measured temperatures were similar to the annual mean temperature, 7 °C, indicating that the water in the springs reflects longer residence time associated with groundwater, specifically flow through bedrock (NGWA, 1999). Given the measured temperatures, it is unlikely that these spring waters are sourced from direct recharge to the alluvium.

The indication via hydrochemical data, of a groundwater system recharged at the ridgetops, is at first glance, inconsistent with the USOS expert witness testimony (http://www.deq.utah.gov/locations/prsprings/), which argued that: 1) no ground water exists under the site; and 2) no potential exists for water recharged at the ridge top (where the mining/processing/disposal site is situated) to reach springs in the adjacent canyons. Below we further examine these arguments to reconcile them with the data presented above.

The first argument (lack of groundwater under the site) is based on more than two hundred boreholes drilled at the site. Drillers and observers were instructed to report the presence of signifcant groundwater during drilling and coring activities. The absence of usable quantities of water was argued to indicate a lack of groundwater under the site. Reconciling the observation of a lack of significant groundwater in the boreholes with the hydrochemical results occurs via the fact that recharge through the subsurface occurs through discrete fissures, cracks, and bedding plains, and therefore is spatially non-homogenous. The volume through which fluid travels within any given volume of rock in a recharge area is small, and therefore one cannot conclude the absence of a groundwater system based on the apparent absence of water in rock cores. Because recharge may be discrete and diffuse within the rock mass, the science of groundwater resource characterization goes far beyond visual examination of water in boreholes, and instead focuses on the determination of hydraulic heads and rock permeabilities (e.g. Freeze & Cherry, 1979).

As is evidenced in groundwater textbooks, the significance of a groundwater resource is determined NOT through visual examination of water in holes, but rather through permeability testing of the rock cores, and through measurements of hydraulic heads in boreholes. While boreholes were in fact drilled at the site, the resulting cores and boreholes were not used in a manner consistent with typical groundwater resource evaluation. Such an evaluation would have involved two types of measurements:

1) Measurement of hydraulic head (water level) after an equilibration time (to allow water level to stabilize) within the borehole.
2) Measurement of permeability within the retrieved core.

Both measurements are absent from the record regarding the significance of the recharge area to the observed springs and wells. The direct examination of cores and cuttings for water is an insufficient basis from which to determine the significance of Seep Ridge to the springs and seeps in the valleys below. According to the coring program memorandum

(303LayneChristensenMemoCoringProgramRFQ110218) the majority of the drilled cores stopped 100 ft or more above the level (7600 ft) of the highest elevation spring in Main Canyon, thereby futher decreasing any expectation of finding visible saturation of core material.

A rationale for plugging the coreholes immediately following electrical logging was not provided, but is not consistent with efforts to evaluate the groundwater resource, and determining the signficance of recharge at Seep Ridge to the springs and seeps below. Notably, the coring program memo (303LayneChristensenMemoCoringProgramRFQ110218) states that electrical logs would be obtained prior to plugging the coreholes. The electrical logs (if available) may provide valuable information regarding water within the system.

The hydrologic connection between recharge at the ridgetop and the perennial springs in the adjacent Main Canyon (as demonstrated by the hydrochemical data), lies in apparent contradiction of statements made by a USOS expert witness that the regional dip of the rock strata (to the north) prevents groundwater recharged at Seep Ridge from reaching springs in Main Canyon.

Department of Water Quality believes that water in the perennial springs is sourced from direct precipitation to the valley alluvium. The extent of the alluvium is very limited, hence groundwater travel times in the alluvium would be rapid. This is not consistent with the perennial nature of the springs during dry periods, the cold temperatures of the water, the fact that the highest elevation spring is in bedrock, and the regular progression from high to low elevation springs in terms of chemistry.

The assertion that the northward dip of strata prevents a hydrologic connection between recharge at Seep Ridge and springs in Main Canyon assumes that the direction of flow is controlled solely by bedding planes. Such is true only if the fracture permeability is less than the bedding plane permeability, which is highly unlikely given that the regional northward dip is subtle (a few degrees).

More critical is the fact that the USOS expert is incorrect regarding the dip of the strata at the site. The strata do NOT dip significantly to the north in the area of Main Canyon and Seep Ridge. Instead the strata in this vicinity are horizontal to south dipping. While the regional dip of the strata in the southern Uinta basin is to the north, the local dip is zero or to the south depending on location. The local dip differs from the regional dip in the vicinity of Seep Ridge and Main Canyon due to the Main Canyon anticline that runs through this area creates flat or south dipping beds from Seep Ridge to Main Canyon (Byrd, 1970 plate 4, and pages 16-17).

Visual examination of Main Canyon demonstrates that the strata are horizontal to south-dipping (Figure 11).

Figure 11. Looking east up Main Canyon from the DeLambert Ranch. North is left, south is right. The strata are nearly horizontal, with a slight dip to the south.

Furthermore, the topographic gradient is higher from Seep Ridge to Main Canyon than it is to the north (Figure 3), which would also tend to drive flow southward from the ridge. The combination of horizontal to south-dipping strata and a steeper topographic gradient to Main Canyon suggest that recharge on Seep Ridge is hydrologically connected to the perennial springs in Main Canyon, and is consistent with the hydrochemical data demonstrating this hydrologic connection. Notably, spring DeLambert B, located on the north side of Main Canyon, emits from south-dipping rock strata (Figure 12).

Figure 12. Photo looking northeast at the spring (DeLambert B). In the overexposed portion one can see the southward dipping beds.

7. Summary

New findings from hydrochemical sampling demonstrate the existence of a hydrologic system linking recharge at Seep Ridge with the perennial springs that exist in Main Canyon. While this finding lies in stark contrast to USOS expert witness testimony, we found that the observations that underlie this testimony either: 1) are insufficient grounds for determination of the significance of groundwater at the site; or 2) are factually incorrect.

Given these new hydrochemical findings it seems prudent to consider implementation of mitigation measures (lined disposal pits, monitoring of spring chemistry and flow, among other possible measures) to protect the quality of the groundwater system, and to conduct further hydrologic studies to determine the hydrologic relationship between recharge at Seep Ridge and springs in the canyons below in greater detail, as well as the hydrologic relationship between the mid-level springs and deep-level groundwater. These preventative measures will protect the wellbeing and livelihood of the ranch and families in proximity to the proposed tar sands site.

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9. *Appendix A*

Records of Annual Precipitation

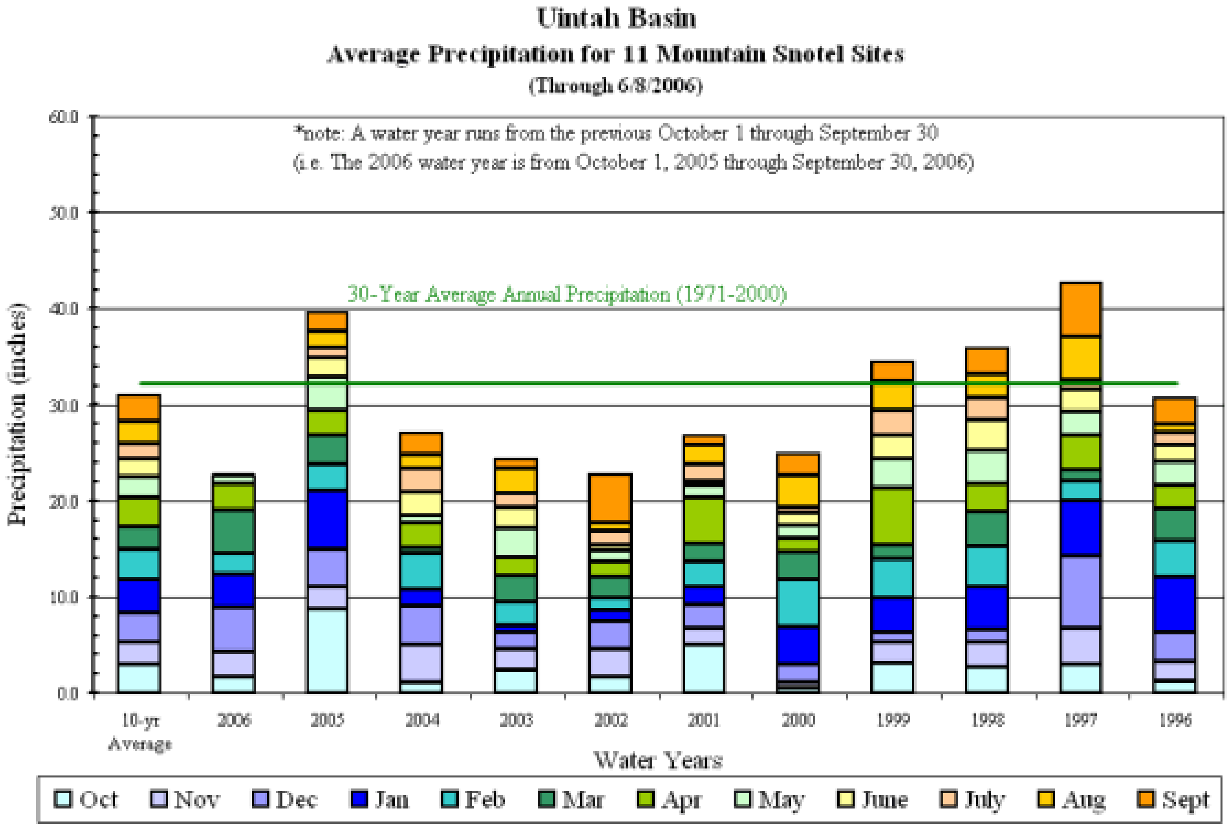
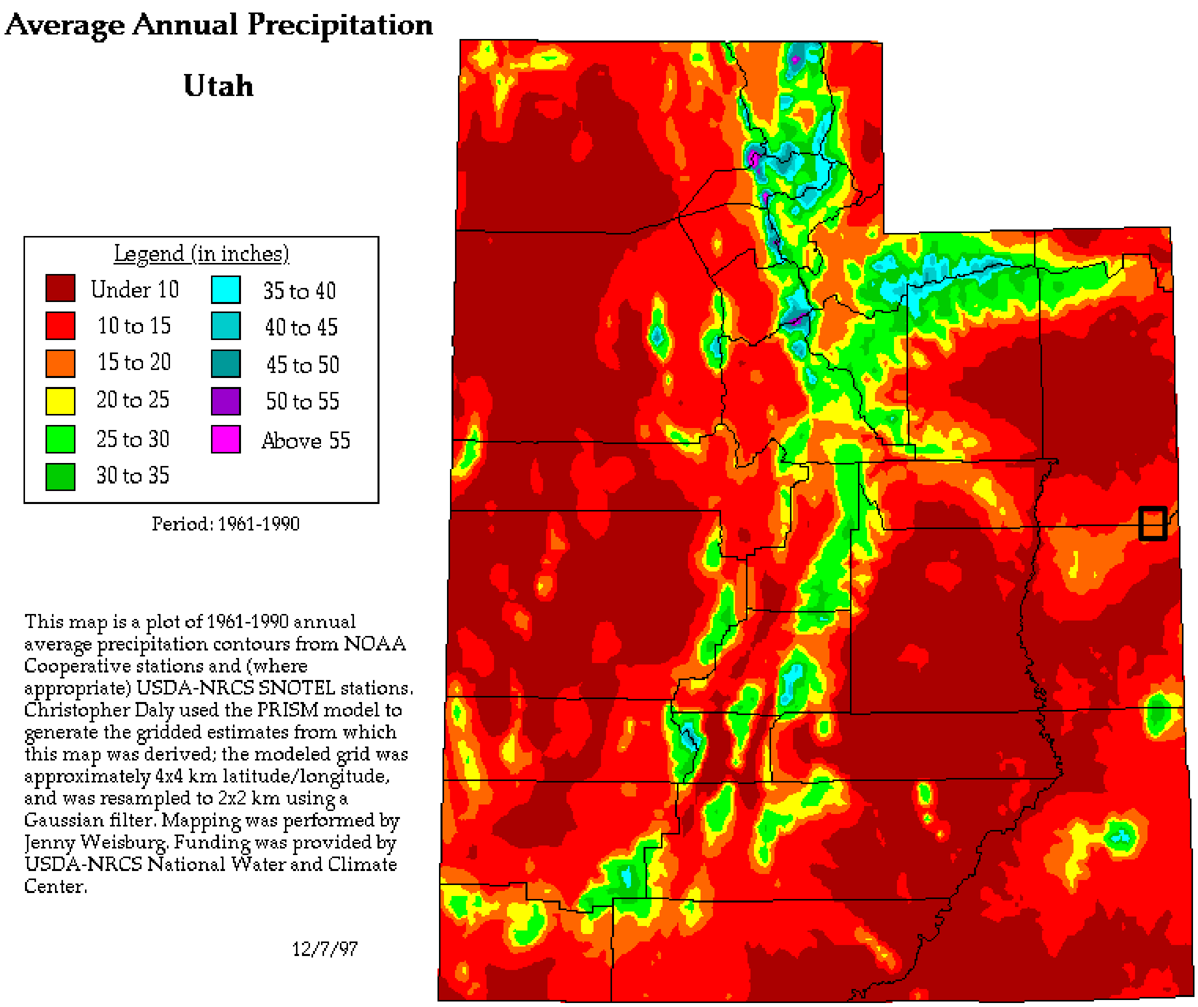


Figure 1. Average Precipitation for the Uintah Basin reported by the state of Utah. The sited 30-year average annual precipitation is ~32 inches (Utah Division of Water Resources 2006)



This map is a plot of 1961-1990 annual average precipitation contours from NOAA Cooperative stations and (where appropriate) USDA-NRCS SNOTEL stations. Christopher Daly used the PRISM model to generate the gridded estimates from which this map was derived; the modeled grid was approximately 4x4 km latitude/longitude, and was resampled to 2x2 km using a Gaussian filter. Mapping was performed by Jenny Weisburg. Funding was provided by USDA-NRCS National Water and Climate Center.

Figure 2. Average Annual Precipitation for the state of Utah. Tar Sands site is located on the boarded of Uintah and Grand County, outlined with a black box. The average annual precipitation is 15-20 inches (WRCC 1997).

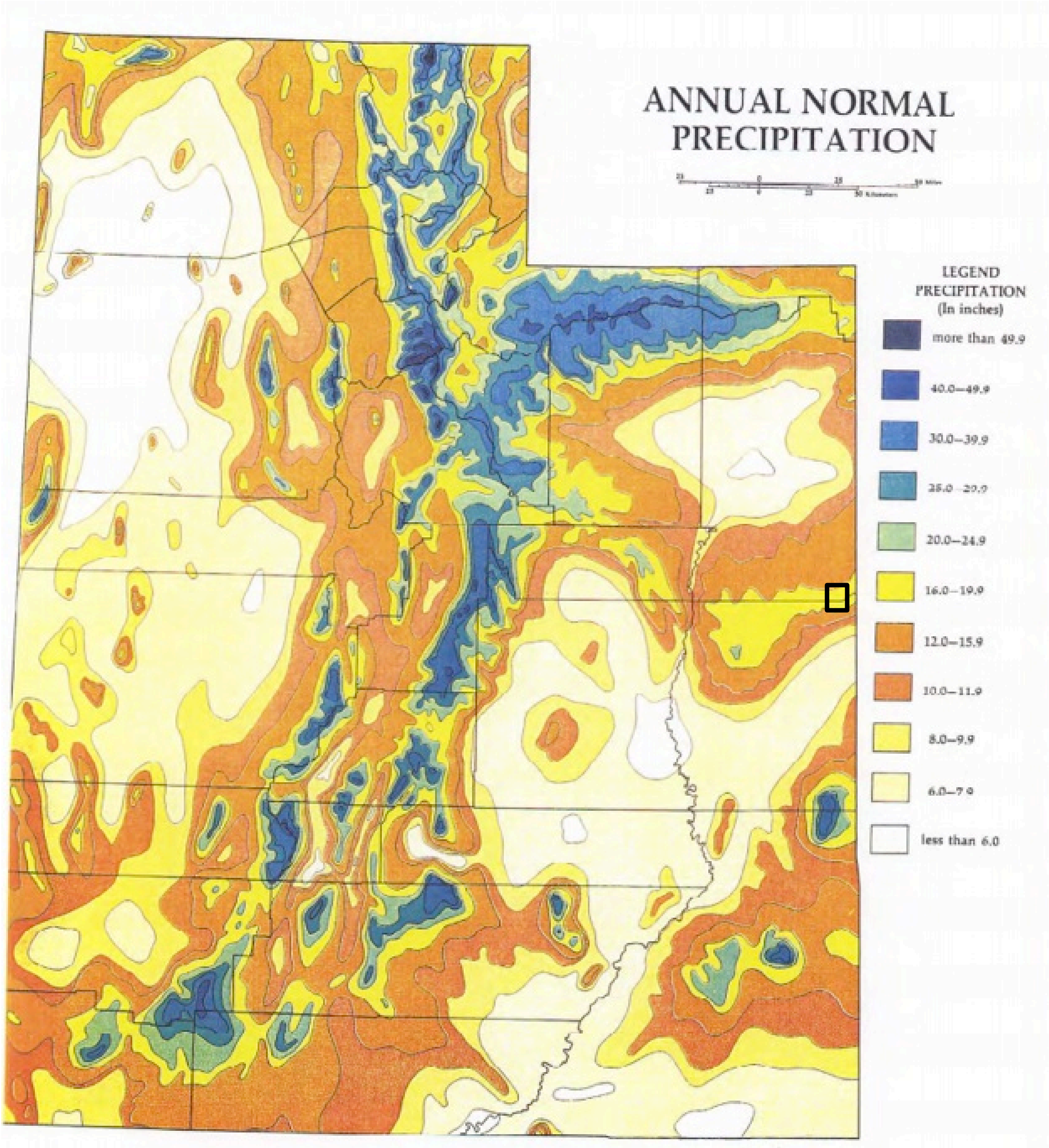


Figure 3. Annual Normal Precipitation, Utah (after Greer et al., 1981)

Figure 3. The annual normal precipitation for the state of Utah. This study area is outline in black and has an annual normal precipitation of 16.0 to 19.9 inches. The areas of higher elevations within the Uinta Basin have higher annual precipitation rates. (Jensen et al., 1990)

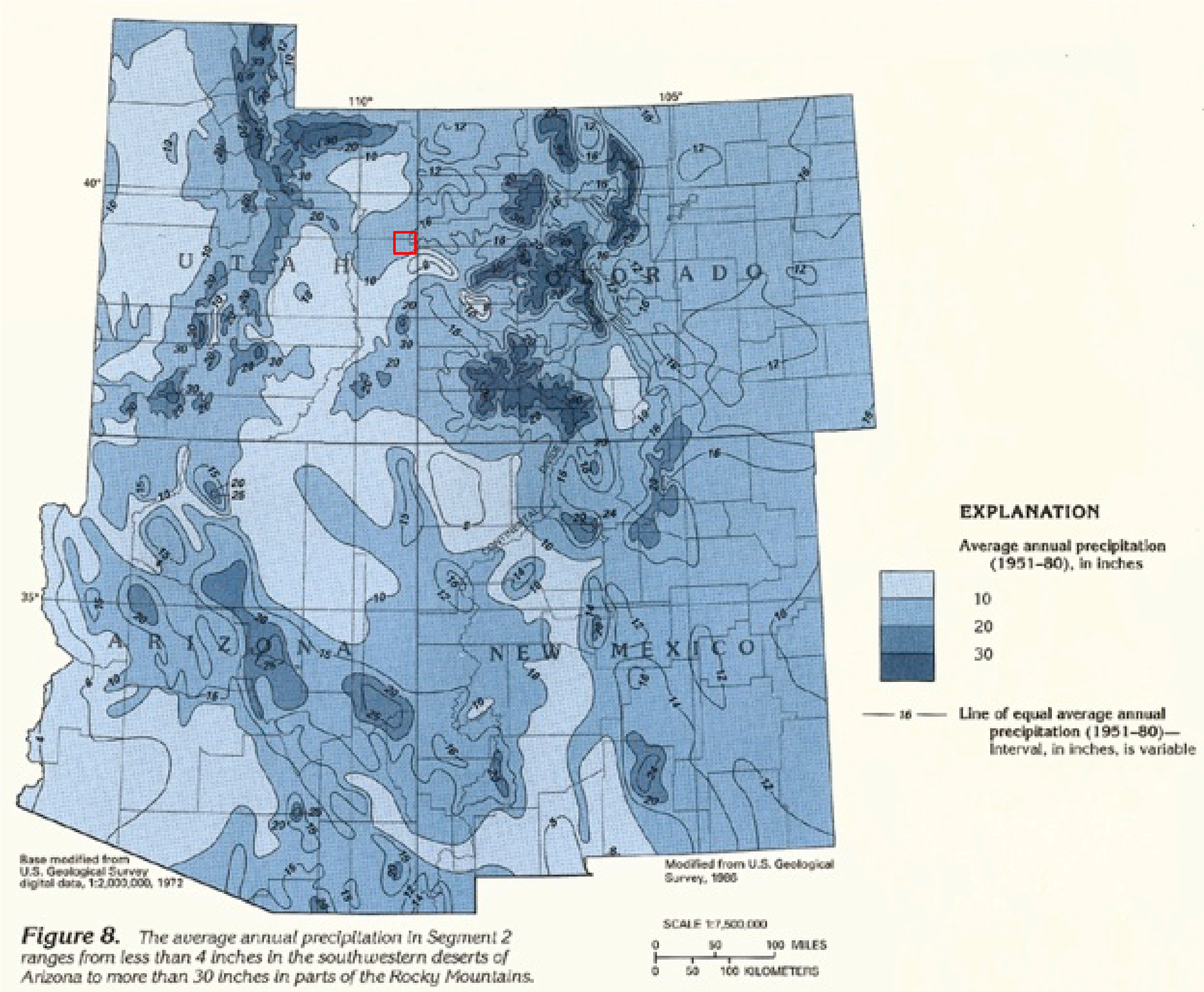


Figure 4. Average annual precipitation in the Tars Sands area is 10 to 20 inches according to the color-coding system. More specifically the area is located near the 16 inches line of equal average annual precipitation (Robson and Banta 1995).

10. Appendix B

Temperature Records

Table 1. Maximum, Minimum, and Annual Temperatures (in Fahrenheit) for the years 1971 to 2000 (PRISM Climate Group, 2013)

POR:	1971-2000
Grid Resolution:	30-arcsec (~800m)
Units:	English(degrees F / In.)
Longitude:	-109.097
Latitude:	39.569

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Tmax	34.05	38.30	44.94	53.51	63.66	75.47	81.16	78.93	70.21	58.08	42.48	35.15	56.34
Tmin	14.09	16.30	24.57	30.47	39.07	47.79	54.90	53.29	44.71	34.65	23.31	15.78	33.24