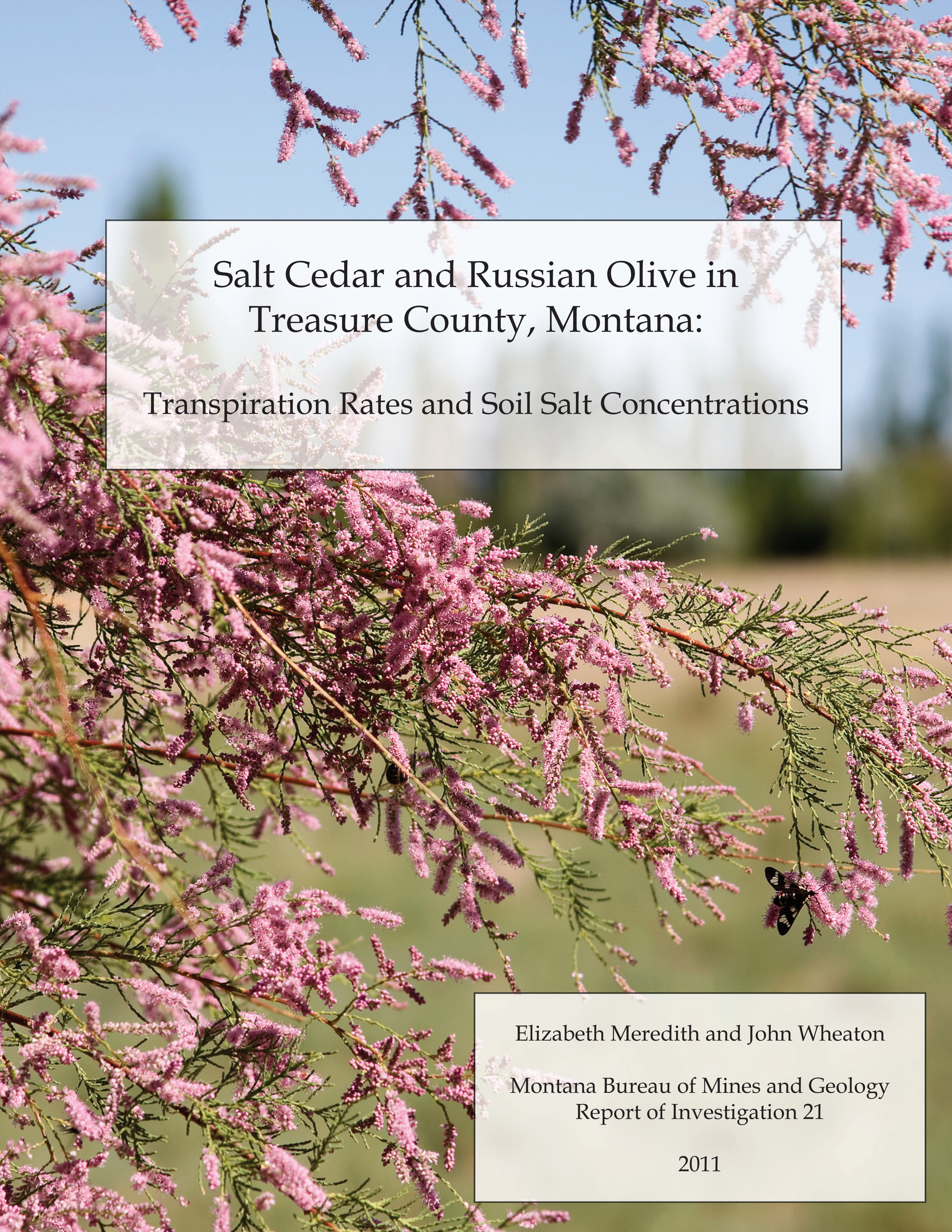

# Salt Cedar and Russian Olive in Treasure County, Montana:

## Transpiration Rates and Soil Salt Concentrations

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## ABSTRACT

This preliminary study evaluated a relatively inexpensive and low-maintenance method for measuring transpiration in an area impacted by Salt Cedar and Russian Olive trees. Additionally, soil salinity in an area surrounding a large Salt Cedar tree was evaluated and the salt composition analyzed. Salt Cedar (genus *Tamarix*) stands have the potential to significantly impact watersheds throughout Montana due to the reported high transpiration rates of the plants and their tendency to concentrate soluble salts near the soil surface. Impacts to riparian areas from increased groundwater salinity and lowered groundwater flow rates include: lower in-stream flow rates, higher surface-water temperatures, and higher surface- and groundwater salinity. Higher soil salinity can hinder native plant growth and reduce important plant diversity in the riparian zone.

Three wells were installed in and near a stand of Russian Olive and Salt Cedar trees near the town of Hysham in Treasure County, Montana. These wells were used to monitor the water level of the near-surface alluvial aquifer. Water levels were monitored with dataloggers every hour for approximately 11 months to establish natural water-level variation when all trees are present. After that initial period, the Russian Olives were cut; 1 month later the Salt Cedar trees were cut.

Numerous previous studies have looked at the water consumption of Salt Cedar and other phreatophytes; however, almost all have concentrated on Salt Cedar in desert ecosystems. The method used in this study involved closely monitoring the groundwater level on an hourly basis. Using the rate of recovery from diurnal oscillations and the difference between daily readings, it is possible to calculate how much water has been used by the plant. A 10-day period with minimal precipitation was selected for each of the three variables: all trees present, only Salt Cedar, and no trees. In the situations where all the trees were present and only Salt Cedar were present, the two wells in the stand of trees had a higher evapotranspiration (ET) rate than the baseline well, which was surrounded only by grasses and small shrubs. Cutting the Salt Cedar (no trees present) resulted in all wells having very similar ET rates.

The difference in ET between the wells near the Salt Cedar and Russian Olive trees and the baseline well gives a rough approximation of the ET that is attributable to the trees as opposed to the surrounding vegetation. The calculated ET values of approximately 1 mm/day are consistent with previous studies that found ET rates for Salt Cedar range from about 1 mm/day to as much as 15 mm/day (annual rates of 70 to 140 cm/year). Desert ecosystems have both higher temperatures and lower humidity than the studied watershed: both factors contribute to higher rates of transpiration in the desert. As all previously identified studies took place in desert ecosystems, it is not unusual that the rates estimated here are on the low end of that range.

Samples collected for saturated paste (soil) analysis show different distributions of cations and anions in peak (high) salinity samples and background (low) salinity samples, not simply higher concentrations. In milliequivalents per liter, a unit that takes into account the charge and mass of the ion, the two background samples have balanced cations; that is, the calcium, magnesium, and sodium concentrations are approximately equal. However, in the peak samples, the amount of sodium in the sample increased substantially—to over twice the amount of the other cations. This is particularly important because sodium can cause soil to lose structure and fertility. The anions in the background samples were dominated by sulfate, which is also true in the peak samples but to a much greater extent. This study supports other research that has shown Salt Cedar concentrates salts on the soil surface. The work done for this project has shown that much of that salt is present as highly soluble sodium sulfate (such as thenardite).

# INTRODUCTION

## Background

Salt Cedar (genus *Tamarix*) stands have the potential to significantly impact watersheds throughout Montana due to the reported high transpiration rates of the plants and their tendency to concentrate soluble salts near the soil surface. Impacts to riparian areas from increased groundwater salinity and lowered groundwater flow rate include: lower in-stream flow rates, higher surface-water temperatures, and higher surface- and groundwater salinity. Higher soil salinity can hinder native plant growth and reduce important plant diversity in the riparian zone.

Phreatophytes such as Salt Cedar increase groundwater salinity levels by transpiring salt-free groundwater, which elevates the salt concentration of the remaining water. Surface water that is in communication with the higher salinity groundwater is also affected by the increased salt levels. Capillary action can bring this higher-salinity groundwater near the surface, potentially impacting the soil quality. Additionally, Salt Cedar is known to concentrate salts in its leaves that, when shed in the fall, increase the salinity of the soil beneath and surrounding the Salt Cedar stand. This makes the environment hostile to all but halophytes; in Montana these are generally non-native plants. The type of salt concentrated in the soil by Salt Cedar needs to be understood in order to evaluate potential changes in soil structure that could lead to reduced fertility and higher erosion rates. Sodium ions, in particular, can cause soil to de-flocculate, thereby reducing soil pore space and field capacity. Soluble salts in the shallow soil can be carried to surface-water bodies by overland flow during rainstorms or flooding events.

Salt Cedar and other deep-rooted plants, such as Russian Olive, have the potential to transpire a great deal of water because their roots can penetrate the saturated zone in the aquifer known as the water table. In contrast, transpiration from shallow-rooted plants is limited by the amount of water in the soil pore space. Transpiration rates from Salt Cedar have been reported [in terms of evapotranspiration (ET)] to range from less than 1 mm/day to more than 15 mm/day in desert ecosystems in Arizona and New Mexico (Cleverly, 2002; Dahm, 2002; Robinson, 1965; Wyman, 2007). The transpiration rate for Salt Cedar in a semi-arid zone such as is found in eastern Montana will be somewhat less than the extreme transpiration rate measured in the desert. Accurately determining the water consumption of Salt Cedar in Montana watersheds is important to fully understand the extent of the potential impact Salt Cedar may have upon the watershed.

Damage to riparian environments in eastern Montana can be particularly severe given the relatively limited water resources. A mixed Salt Cedar and Russian Olive stand near the Yellowstone River just east of Hysham, in eastern Montana, was selected for this study; however, the methods used in this project will be applicable to other watersheds. Non-native phreatophyte species present in this area include two Salt Cedar species: *Tamarix ramosissima* and *T. chinensis*, and hybrids of these two, and Russian Olive: *Elaeagnus augustifolia*.

## Project Overview

This study was a collaborative effort between the Treasure County Weed District (TCWD) and the Montana Bureau of Mines and Geology (MBMG). Funding for this project was through the State of Montana, Department of Environmental Quality 319 program. The effort and cost of controlling Salt Cedar needs to be evaluated in the context of the potential damage to a water system. The results from this study will be used to make decisions on controlling the spread of Salt Cedar, to develop watershed restoration plans, and to educate landowners on the impacts of Salt Cedar.

## Purpose

Determining the water consumption of Salt Cedar in Montana watersheds will help determine the potential impact of the species on riparian areas. However, transpiration studies are generally extremely time-intensive and costly. This preliminary study evaluated a relatively inexpensive and low-maintenance method of measuring transpiration in an area impacted by Salt Cedar and Russian Olive trees. Additionally, soil salinity in an area surrounding a large Salt Cedar tree was evaluated and the salt composition analyzed to determine the potential for soil degradation.

### Study Design

Three wells were installed in and near a stand of Russian Olive and Salt Cedar trees; two within the stand of trees and one outside the stand surrounded by only grasses and small shrubs. These wells were used to monitor the water level of the near-surface alluvial aquifer. A meteorological station was also installed near the stand. Water levels were monitored with dataloggers every hour for approximately 11 months to establish natural water-level variation when all trees are present. After that initial period, the Russian Olive trees were cut and the stumps treated with Remedy™ from Dow Agro Sciences. One month later, the Salt Cedar trees were cut and the stumps also treated with Remedy™. During this time, aquifer water levels continued to be monitored every hour by dataloggers. Drawdown in aquifers can be correlated to the transpiration rate of the ecosystem using a method first outlined by White (1932). By removing the trees one species at a time, we attempted to differentiate, in relative and absolute terms, between the water use of the two species and the surrounding vegetation.

To investigate the nature and extent of Salt Cedar's accumulation of salt near the surface, two salinity transects were measured around a large Salt Cedar tree. Samples from the locations of the peak salinity and background salinity were collected and analyzed for soluble salts.

### Acknowledgments

This project was funded with a Montana Department of Environmental Quality EPA 319 grant (DEQ contract 207051) through the Treasure County Weed District, Jennifer Cramer, Weed Coordinator. This project would not have been possible without cooperation from Milmine Ranch, who allowed us to install wells and cut trees on their property. The good spirits and plentiful energy of Simon Bierbach, Grant Sinclair, and Faith Thompson made cutting a great deal of Russian Olive manageable, and perhaps even fun. Clay Schwartz downloaded dataloggers and assisted Jennifer Cramer in taking water-level measurements, which added to the accuracy of the water-level study. Faith Thompson and Joe Friez did a great deal of background research for this study, and Kevin Chandler identified excellent references for drawdown to transpiration calculations. The MBMG and the TCWD thank all who helped improve the quality of this study.

## LITERATURE REVIEW RESULTS

Numerous previous studies have looked at the water consumption of Salt Cedar and other phreatophytes. An extensive bibliography of these studies has been compiled as a part of this report (appendix 1). A chart summarizing the findings of a selection of these reports is presented in appendix 2. Irrespective of the method used to measure transpiration, the units are generally in mm/day or a similar unit. This unit is used because it normalizes differences between plant size and leaf area. The length/time unit can refer to leaf area or affected groundwater area depending upon the transpiration/ evapotranspiration measurement method used.

### Evapotranspiration Measurement Methods

*Water Level*

The method used in this study involves closely monitoring the water level on an hourly basis for several days to weeks. Using the rate of recovery from diurnal oscillations and the difference between daily readings, it is possible to calculate how much water has been used by the plant (Butler and others, 2007). The original method was published by White (1932) and was found to be accurate to within 20% for sands and gravels by Loheide and others (2005).

*Bowen Ratio Methodology*

The Bowen ratio–energy balance (BREB) method is based on the flux-profile relationships for energy and mass exchange, and is used to estimate ET over vegetated or bare soil (Perez and others, 1999). The Bowen ratio is generated by dividing the sensible heat flux by the latent heat flux. This method for ET estimation has been found to be very accurate during daylight hours, with less than a 5% margin of error (Fritschen, 1965). The equations for this method measure short-term flux; these short-term results can then be summed to produce long-term data. This method is reliant on accurate data, therefore accurate and precise instruments and measurements must be used. When flux measurements approach the minimum resolution of the instruments, the data may provide flawed ET estimates and therefore be unusable.

*Blaney–Criddle Method*

The Blaney–Criddle method for estimating water consumption ($U$) uses evaporation, rain, effluent flow, and pond leakage for its basic model. Of interest for transpiration calculations are the plant water consumption equations. These equations use a seasonal coefficient ($K$) times a monthly consumptive use factor ($F$). The monthly consumptive use factor is derived from the mean monthly temperature in Fahrenheit ($t$) times the mean monthly percent of daytime hours ($p$), divided by 100:

$$U = K * F$$
$$F = t * p / 100$$

The seasonal coefficient is obtained from known water use for specific species (Arizona Department of Envrionmental Quality, 1998).

*Lysimeters*

Lysimeters extract or measure water in the soil. Several types of lysimeters can be used in ET studies (Lister, 2003):

- A pan lysimeter is an open container buried with its top lip even with the ground surface. The water that percolates through the soil to the bottom of the lysimeter is collected and compared with the known rainfall/watering event to calculate ET.
- A gravimetric lysimeter weighs the soil and calculates evaporative loss through changes in total weight.
- A suction lysimeter uses a vacuum to pull water from the soil through a porous material for collection and comparison to the water added to the system to determine ET.

*Eddy Covariance*

The eddy covariance method of calculating ET measures the latent heat, sensible heat, and water vapor content of the small, circularly moving eddies that form when wind moves over a rough surface, such as tree canopies and ground clutter. By observing the heat and moisture content of an eddy rotating toward the object being studied and comparing it to the eddy heat and moisture when it is rotating away, the net change can be determined. The vapor fluctuation measurements are used to calculate latent energy and the temperature fluctuation measurements are used to calculate sensible heat (Dahm and others, 2002).

*Remote Sensing*

The remote sensing method uses ground measurements of ET, meteorological variables, and vegetation indices (VI) determined by satellite sensors to project plant water use. Vegetation indices were created by correlating data on foliage density and transpiration. The formula to calculate crop transpiration on a ground area basis ($E_G$) using this method is:

$$E_G = ET_o * k * VI$$

$ET_o$ is the daily potential or reference crop ET, VI is one of several possible VIs scaled between 0 (no vegetation) and 1 (full cover vegetation), and k is a constant determined by linear regression of measured $E_G$ with VI. In communities of phreatophytes in arid regions, precipitation is low, and the top meter of soil is often dry; therefore, accurate calculation of soil evaporation is often a negligible component of the ET equation (Nagler and others, 2009).

*Xylem Sap Flux*

The xylem sap flux method of determining transpiration utilizes a heating element to send a pulse of heat into the sap. Temperature probes are placed above and below the point of heating; the lower probe is commonly placed 0.5 cm below the heat source, and the upper probe 1 cm above the heat source. When the temperature at both probes equalizes, the heat pulse has moved 0.25 cm, and the time elapsed is used to calculate sap flow rate. Total sap flow can then be calculated by the product of sap velocity and cross sectional area of conducting sapwood (Stephen and others, 2000).

*Water Budget*

A water budget uses known values such as amount of irrigation, runoff, capillary rise from the water table, precipitation, evapotranspiration, and deep percolation to groundwater to account for the total water cycle (California Irrigation Management Information System, 2009). If one of these values is unknown, it can be obtained with the consideration of the other variables. Transpiration can then be estimated by subtracting known evaporation for the given surface from the evapotranspiration total.

### *Penman-Monteith Equation*

The Penman-Monteith equation estimates ET using the equation:

$$\lambda \mathrm{ET} = \frac{\Delta(Rn - G) \ + \ \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)},$$

where $R_n$ is the net radiation, $G$ is the soil heat flux, $(e_s - e_a)$ is the vapor pressure deficit of air, $\rho_a$ is the mean air density at constant pressure, $c_p$ is the specific heat of the air, $\Delta$ represents the slope of the saturation vapor pressure temperature relationship, $\gamma$ is the psychrometric constant, and $r_s$ and $r_a$ are the (bulk) surface and aerodynamic resistances (AgSystems, 2007).

## LOCATION

### Geologic Description

The study site is on modern (Holocene) alluvium of the Yellowstone River watershed to the east of the town of Hysham in Treasure County, Montana (fig. 1). It is near bluffs composed of Judith River sandstone (Upper Cretaceous) and hills capped by alluvial terrace deposits (Holocene and Pleistocene). The Bearpaw shale (Upper Cretaceous and stratigraphically above the Judith River formation) is exposed where modern fluvial erosion has excavated through the terrace deposit (Vuke, 2002).

The alluvium is composed of well-rounded gravels, sand, siltm and clay derived from local Cretaceous sandstone and shale bedrock (Lopez, 2000). The Judith River Formation is a fine- to medium-grained sandstone interbedded with silty shale. The Bearpaw Formation is a dark gray shale interbedded with siltstone and fine-grained sandstone (Vuke and others, 2000).

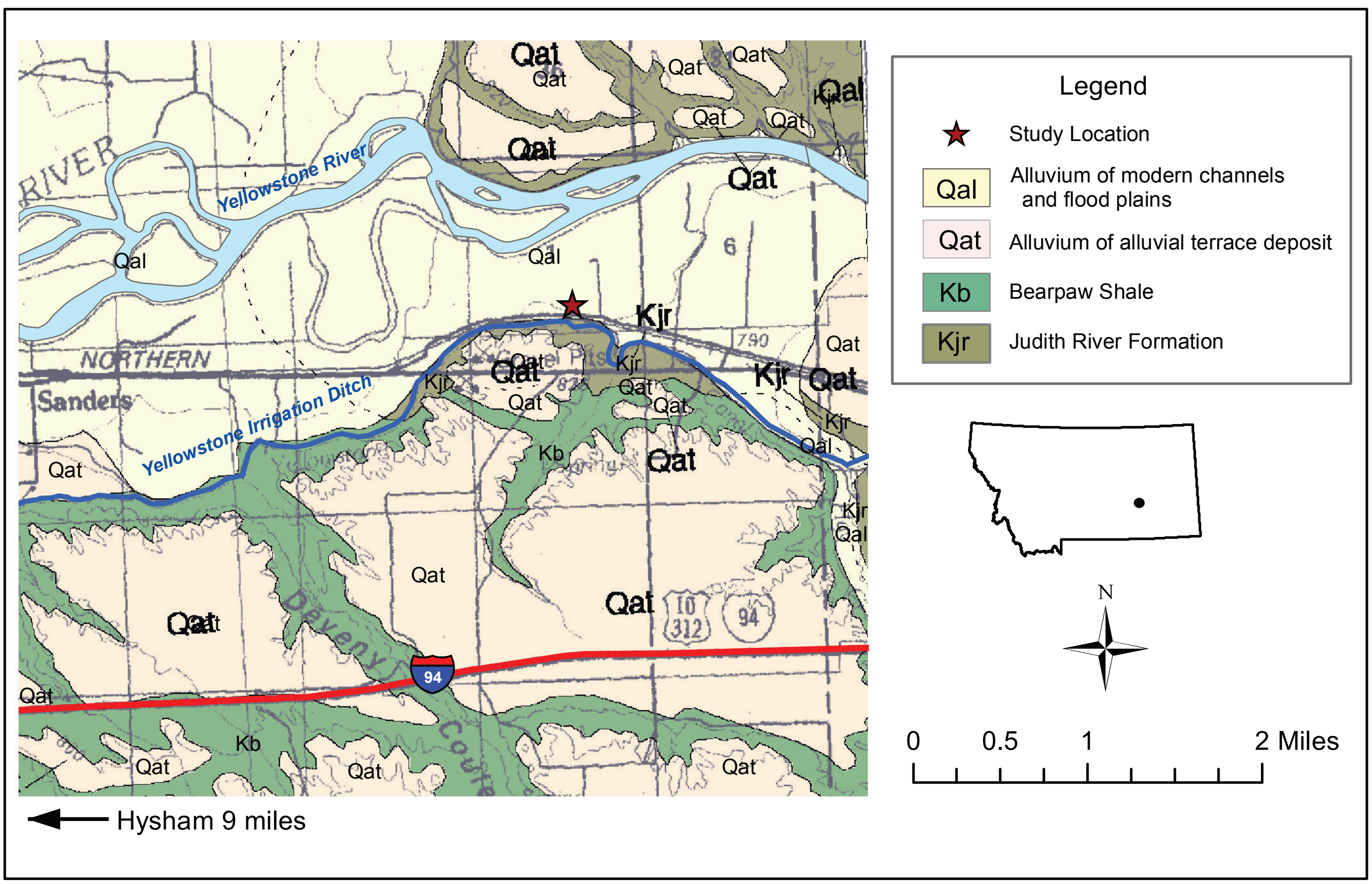


Figure 1. The study site location is approximately 9 miles east of the town of Hysham in Treasure County, Montana. The alluvial valley is flanked by Judith River sandstone and Bearpaw shale. The Yellowstone Irrigation Ditch is 80 meters upgradient of the study site.

The lithologic logs constructed from the well cuttings give specific information to the nature of the aquifer at this particular point in the valley (see appendix 3). At each of the three well sites, there is approximately 2 inches of soil and clay/clay loam. The next 8 to 10 inches is fine-grained, well-sorted, unconsolidated sand. There is a sharp contact between the sand and the underlying well sorted gravels. The gravel aquifer is composed of small, well-rounded cobbles (approximately 2 cm in diameter), with few fines present. These gravels are continuous to at least 13.8 ft, the depth of the deepest monitoring well.

The geologic structure of the Yellowstone River valley near Hysham, Montana is dominated by shallow anticlines and synclines. Overall, the sedimentary beds dip downward to the west-southwest; however, the shallow alluvial groundwater system is dominated by the surficial topography.

## Hydrogeologic Description

Modern alluvial deposits along rivers are good aquifers in this area, generally providing abundant, good quality water. Terrace deposits can serve as aquifers; however, because their recharge source is usually very local, terrace aquifers can be sensitive to drought. Additionally, water quality can be low because the water in terrace aquifers can have a long residence time. The Bearpaw shale is a poor aquifer in the area, producing small amounts of poor quality water, whereas the Judith River sandstone is a good producing aquifer, where present (fig. 1).

Groundwater in the alluvial aquifer of the Yellowstone River generally flows parallel to, and slightly toward, the river. The Yellowstone River alluvium is typically very wide, 1 to 4 miles across. The Yellowstone River valley is about 3.5 miles wide just upstream (west) of the study site and narrows to about 0.75 miles at the study site; the alluvial aquifer becomes thinner as bedrock also becomes shallower at the study site. The horizontal and vertical valley constriction at the study site causes an increased hydraulic gradient and hence a much greater amount of groundwater discharges to the river in this area.

Another factor controlling the movement of groundwater at the study site is the presence of the Yellowstone Irrigation Ditch (YID) approximately 80 m (260 ft) upgradient from the wells (fig. 1). The ditch is constructed in the Judith River outcrop and sandstone can be seen exposed in the ditch (fig. 2). The trees lining the bank below the ditch and the standing water below the ditch suggest that the ditch leaks water while in operation and provides recharge to the shallow alluvium and bedrock aquifers in this area.

Figure 2. Yellowstone Irrigation Ditch with exposed sandstone.

# METHODS

## Groundwater Investigation

### *Well Installation*

Three monitoring wells were installed in a pasture that had a distinct stand of Russian Olive and Salt Cedar trees. This allowed all wells to be in the same aquifer, while still placing one well outside the stand of trees and two wells in the midst of several Russian Olive trees and several Salt Cedar trees. A schematic illustrating the spatial relationships between the wells and trees is shown in figure 3. Wells were installed with a portable Winkey Drill using a rotary auger (fig. 4). Wells are constructed with 1.25 inch schedule-40 PVC. Information specific to each well can be found in appendix 3.

### *Tree Removal*

To isolate the effect of the individual tree species (Salt Cedar and Russian Olive) on the aquifer, each species was removed in turn. After monitoring aquifer water levels for 11 months, all Russian Olive trees in the study area were removed on July 30, 2009. Approximately 30 trees were cut and placed in a slash pile as per the landowner's direction (fig. 5). The Salt Cedar trees, about 5 trees, were cut on September 3, 2009. Both Russian Olive and Salt Cedar tree stumps were treated with Remedy™ from Dow Agro Sciences immediately upon being cut to prevent regrowth.

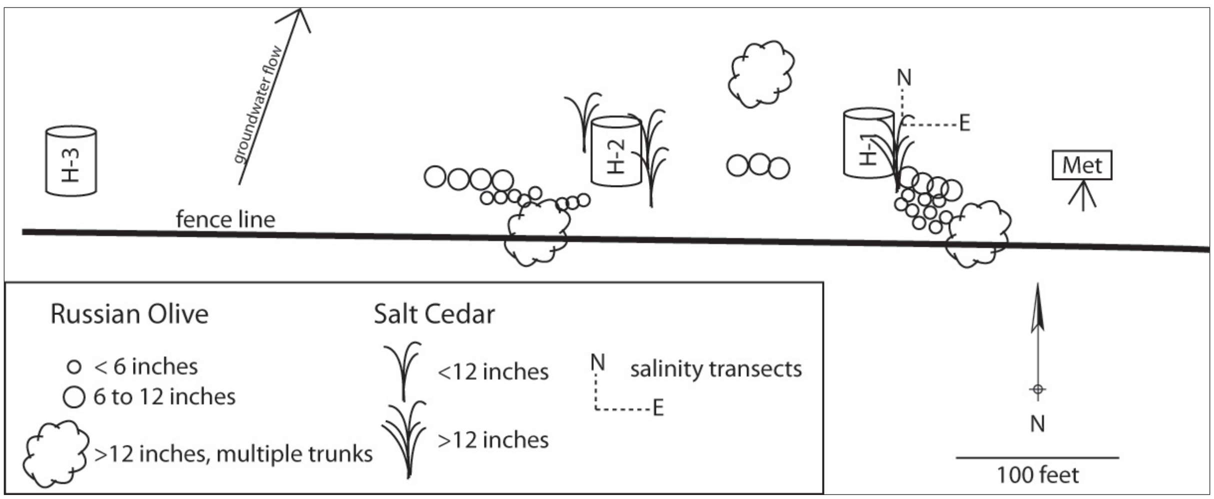


Figure 3. A schematic of the study site including the three monitoring wells (not to scale), the met station, and the placement of the trees relative to the wells.

### *Water-Level Measurements*

Water levels in monitoring wells were measured using a hand-held electronic tape (sounder) approximately monthly, when personnel were available. In addition to these sounder measurements, each well was equipped with a real-time, groundwater-level datalogger. These loggers collect water-level data measured to the 0.01 ft and have factory-reported errors less than 0.3%. Water levels collected by loggers are corrected for barometric changes using a nearby barometer running concurrently with the water-level loggers. Detailed water-level data were collected every hour for 1 year.

Figure 4. Drilling monitoring wells with a portable Winkey Drill.

Figure 5. Russian Olive slash pile.

## Soil Salinity Investigation

*Soil Salinity Transect*

Soil salinity was measured along two transects away from the largest Salt Cedar tree near well H-1: to the north and east. Soil salinity was measured every 2 ft for the first 10 ft, then every 5 ft until consistently low salinity levels were measured (interpreted to be background salinity). Sample salinity was measured by collecting soil samples from the first 3 inches of soil, placing approximately 200 to 300 grams of soil in a clean plastic container, and adding an equal amount by volume of distilled water. The soil and water were mixed and allowed to sit for 30 minutes prior to measurement with a specific conductance meter.

*Soil Sample Collection*

Based on the results from the salinity transects described above, 3.5-liter samples for soluble salt analyses were collected from the first salinity peak nearest the tree trunk and from the lowest salinity level that was interpreted to represent background salinity levels, for a total of four samples. Collection techniques conformed to EPA publication EPA/600/R-92/128 (Mason, 1992), but did not include the statistical requirements for this preliminary study. The four samples collected serve as an example of soluble salts present rather than a statistically significant survey. Samples were collected using a clean hand trowel from the first 3 inches of soil, taking care to avoid including surface vegetation. Samples were stored in clean, resealable, 1-gallon, plastic, food storage bags. Soil samples were kept sealed and cool until they were delivered for analysis the following day. Saturated paste extraction analyses were done by Energy Labs of Billings, Montana. Energy Labs follows the Saturated Paste extraction method ASA Mono. #9, Part 2, Method 10-2.3.1 (Rhoades, 1982). Performing a saturated paste extraction includes drying and passing the soil through a sieve before adding deionized water to just reach field capacity. The wetted soil sits overnight at 25$^{o}$C, after which the water is extracted from the soil under vacuum. The extracted water is then analyzed for pH, conductivity, alkalinity, and calcium, magnesium, sodium, bicarbonate, carbonate, sulfate, and chloride concentrations.

## STUDY RESULTS AND DISCUSSION

### Groundwater Investigation

Water levels in the alluvial aquifer strongly reflect the influences of transpiration and precipitation (fig. 6). Even small precipitation events of a few tenths of an inch result in almost immediate and measureable increases in groundwater level. The sensitivity of the aquifer to precipitation means that the effects of transpiration are often overwhelmed by the aquifer response to precipitation. The large rain event in May 2009 had a much greater impact on the water level than did the larger rain event in August 2009 because the greater biomass present in late summer mitigated the effect of the precipitation on the water table (fig. 6). Additionally, the nearby irrigation ditch, the YID, started carrying water in late May. The rising aquifer water level in June is probably related to leaking from the ditch.

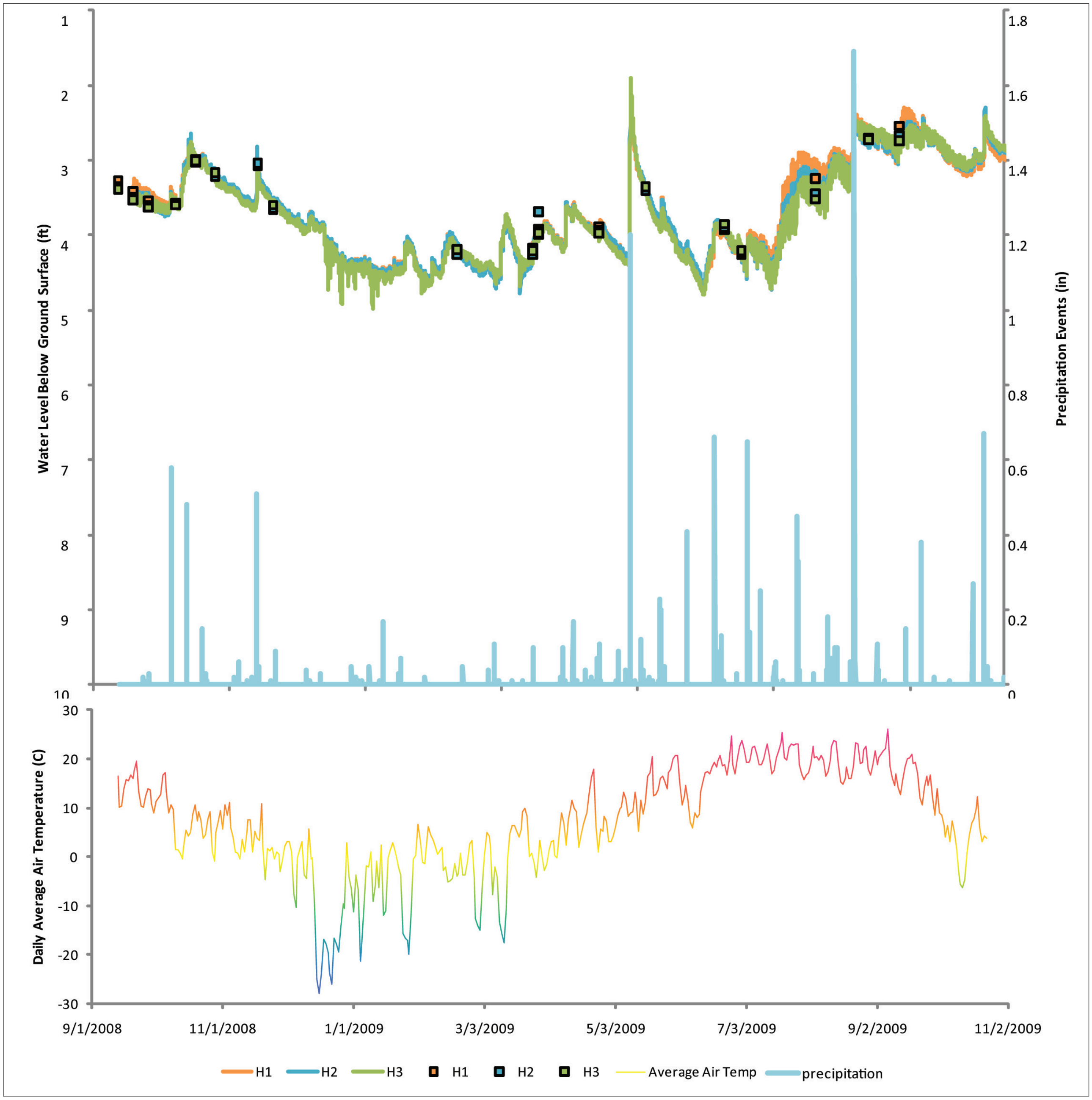


Figure 6. Hourly water levels for wells H1, H2, and H3 (orange, dark blue, and green lines), electronic tape measurements of water level (squares), precipitation events (separated by more than 3 hours), and average daily temperature at the Salt Cedar study site. Note that the water level drops in December 2008 are most likely caused by the extreme cold temperatures introducing error to the loggers.

Diurnal fluctuations of water level result from plants transpiring water during daylight hours (water-level drawdown) and shutting down transpiration at night (water-level recovery). The magnitude of these fluctuations is greatest during the summer months, when transpiration is at its peak, and minimal during the winter, when plants are mostly dormant. Diurnal fluctuations reach their minimum immediately after the first killing freeze of the season. The shallow nature of the water table (between 2 and 4 ft below ground) likely allows for direct evaporation from the water table as well. The small diurnal fluctuations that persist after the killing frost may be caused by this direct evaporation. Therefore all calculations presented here represent a combination of evaporation and transpiration (evapotranspiration or ET). The overall drawdown that occurs between rain events is caused by the aquifer's inability to recover the transpired water fully before transpiration begins again the next day. It is this overall drawdown that can be used to estimate the transpiration rate of the plants using the aquifer.

The method to estimate water use through diurnal fluctuations proposed by White (1932) states:

$$ET = S_Y(r \pm s)$$

Where ET is the evapotranspiration consumption of groundwater expressed as a daily rate, $S_Y$ is the specific yield of the aquifer, $r$ is the water-level recovery rate, and $s$ is the net change in water table elevation over 1 day where positive values represent drawdown (fig. 7). Specific yields for well-sorted fine gravels

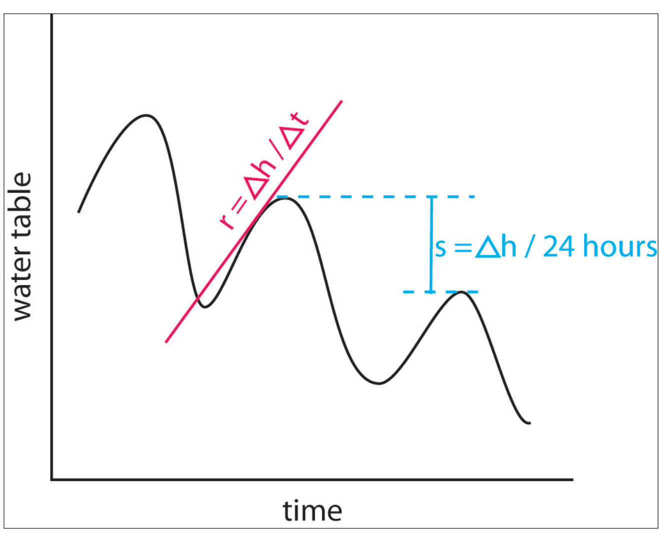


Figure 7. Depiction of White's equation variables *r* and *s*.

such as those that compose the alluvial aquifer of the study site range from 0.13 to 0.40 (arithmetic mean 0.28; Weight and Sonderegger, 2001).

A 10-day period with minimal precipitation was selected for each of the three variables: all trees present, only Salt Cedar (Russian Olive cut), and no trees (Russian Olive and Salt Cedar cut; table 1 and fig. 8). The water level at 23:00 each day was used to fit a line to estimate overall aquifer drawdown (variable *s* in the above equation). The slopes of the best-fit lines are the change in water table over 24 hours (Δh/24 hours). The best-fit line averages the drawdown per day, giving less weight to the outliers (fig. 8; note that the drawdown per day on the figure is in feet/day). Table 1 summarizes the slopes (the *s* variable) and *r* (recovery rate) for each of the wells for each time period (wells H1 and H2 are amid Russian Olive and Salt Cedar trees; well H3 is the baseline well).

Table 1. Variables in White's equations in mm/day.

| | *r* | *s* | | |
|---|---|---|---|---|
| | | H1 | H2 | H3 |
| All trees present | 105 | 8.50 | 7.62 | 5.49 |
| Salt Cedar only | 78 | 9.70 | 5.52 | 4.91 |
| No trees | 63 | 9.36 | 8.69 | 8.84 |

The variable *r* is difficult to measure because there can be quite a bit of human-introduced interpretation and error. To minimize this, 15 measurements were made for *r* for each time period; five measurements for each of the three wells. The average *r* for each time frame is presented in table 1. The recovery rate is related to upgradient influences and the amount of recent precipitation.

The ET consumption of the study area was calculated using the White equation. The range of ET values is presented in table 2, assuming the maximum range of $S_Y$ (0.13 to 0.40) and the mean $S_Y$ (0.28). In all situations, except after all trees had been cut, the two wells in the stand of trees (H1 and H2) had a higher ET rate than the baseline well (H3). During the period when all trees were in place and in good health, the highest rate of ET was near well H1, followed by H2, and the lowest rate of ET was near the baseline well H3. After the Russian Olive trees were cut, the highest rate of ET was still near well H1; however, the rates of

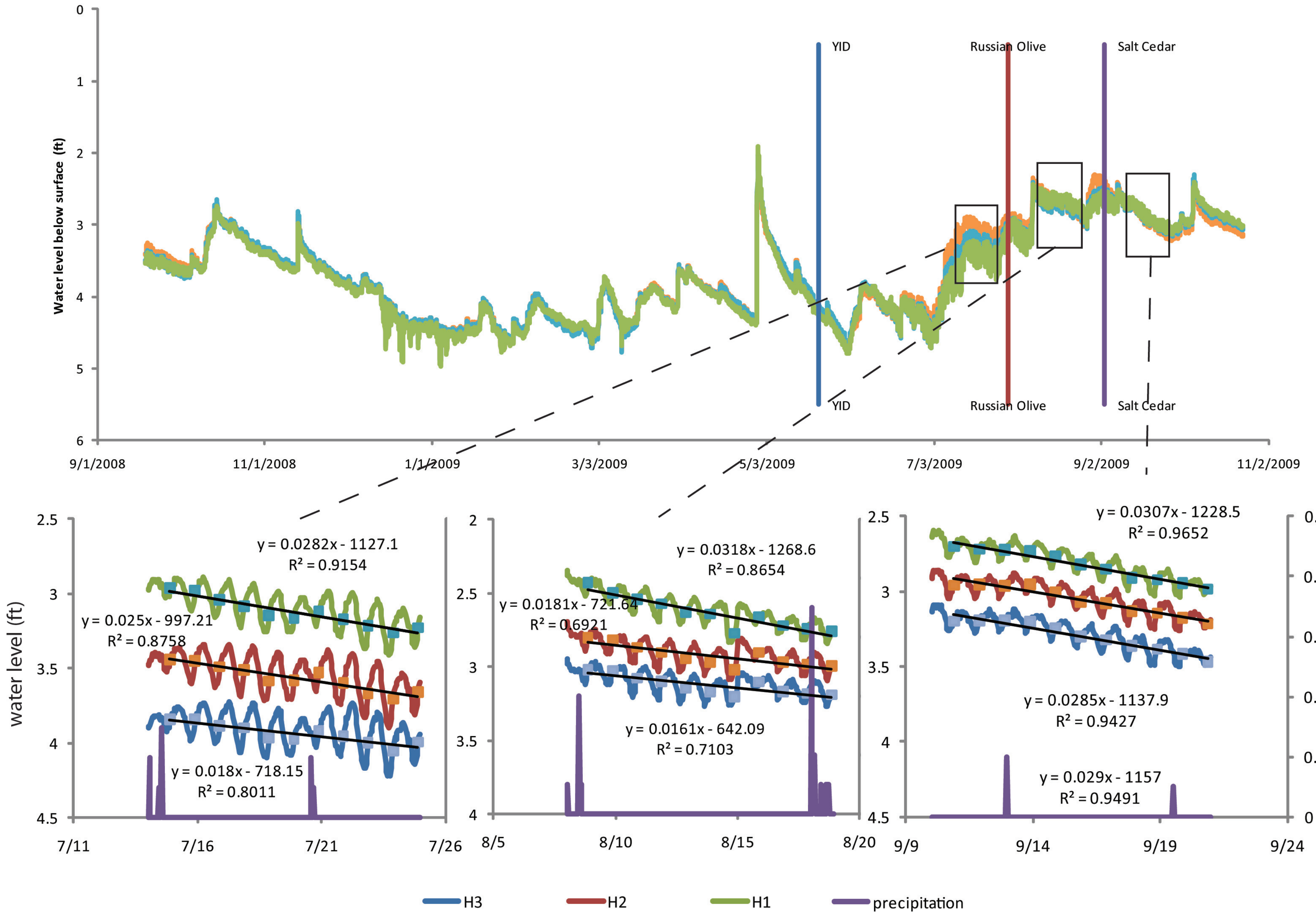


Figure 8. Diurnal detail showing water levels before cutting any trees, after cutting Russian Olive, and after cutting Salt Cedar. The slope of the line fit (by the least squares method) to the water levels at the same hour each day represents the average drawdown in feet/day over 10 days. The water levels were offset to show detail.

Table 2. Calculated values of $ET_G$ in mm/day.

| | H1 | | | H2 | | | H3 | | |
|---|---|---|---|---|---|---|---|---|---|
| $S_Y$ | 0.13 | 0.28 | 0.40 | 0.13 | 0.28 | 0.40 | 0.13 | 0.28 | 0.40 |
| All trees present | 14.75 | 31.77 | 45.38 | 14.62 | 31.49 | 44.99 | 14.34 | 30.89 | 44.14 |
| Salt Cedar only | 11.40 | 24.56 | 35.09 | 10.86 | 23.39 | 33.42 | 10.78 | 23.22 | 33.17 |
| No trees | 9.38 | 20.20 | 28.86 | 9.29 | 20.01 | 28.59 | 9.31 | 20.06 | 28.65 |

ET near wells H2 and H3 were very similar. Groundwater consumption near well H2 may have been primarily controlled by the large Russian Olive trees nearby, rather than the smaller Salt Cedar trees, causing the ET rate to be similar to the baseline well once the Russian Olive trees were removed. Cutting the Salt Cedar (no trees present) resulted in all wells having very similar ET rates.

The difference in ET between the wells near the trees and the baseline well (table 3) gives a rough approximation of the ET that is attributable to the trees as opposed to the surrounding vegetation (for this exercise the ET values at $S_Y = 0.28$ were used). As applied here, this method is only an approximation because the vegetation surrounding the baseline well is not a perfect representation of the vegetation surrounding the trees. Tall grasses, wild asparagus, and a few shrubs surrounded the baseline well. For most of the year, especially a wet year like 2009, these plants were healthy and green. Salt Cedar and Russian Olive trees (and all trees to some extent) suppress other vegetation such as grasses and shrubs. Therefore, subtracting the baseline well ET provides a minimum ET value for the trees studied. The actual ET for the trees would likely be higher than calculated here. The relative ET rate may have increased in well H1 because the surrounding vegetation was using less water. For example, if the grasses had been grazed recently the relative contribution of the grasses to ET would be less.

The calculated ET values ranging from 0.17 to 1.34 mm/day (table 3) are consistent with previous studies that found ET rates for Salt Cedar ranging from about 1 mm/day to 5 mm/day, up to as much as 15 mm/day (0.003 to 0.016 ft/day, up to 0.049 ft/day; appendix 2). As all previously identified studies took place in desert ecosystems with much higher evaporation rates, it would be expected that the rates estimated here are on the extreme low end of that range. Annual ET rates published in previous studies, which account for the lower transpiration rate in the winter, vary from approximately 70 cm/year to over 140 cm/year (2.3 to 4.6 ft/year). We would expect that ET rates of Salt Cedar in Montana would be on the low end of this range.

Table 3. Difference in $ET_G$ values (mm/day) in wells near phreatophites as compared to the baseline well using $S_Y$ = 0.28.

| | H1 | H2 |
|---|---|---|
| All trees present | 0.87 | 0.60 |
| Salt Cedar only | 1.34 | 0.17 |
| No trees | 0.15 | -0.04 |

Given the approximate water consumption calculated here of 1 mm/day, 1 acre of Salt Cedar canopy in eastern Montana will use approximately 0.003 acre-ft of water per day or 0.6 acre-ft of water in a 6-month growing season.

### Soil Salinity Investigation

The results from the soil salinity transect are presented in figure 9. For each transect, a dual peak was present. Samples for saturated paste analyses were collected from the location of the first salinity peak, as that was taken to represent the soil salinity directly related to the presence of the Salt Cedar tree. The first peak on each transect occurred just at and just outside the outer range of the Salt Cedar canopy, which corresponds to salinity levels on the transects of 1.6 millisiemens per centimeter (mS/cm; or 1606 microsiemens per centimeter [µS/cm]) to the north and 2.0 mS/cm (2,030 µS/cm) to the east. We interpret this to mean the accumulation of the leaf litter is most concentrated at the outer edge of the canopy. The second peak for each transect appeared to be related to the presence of several Russian Olive trees. To the north, a small Russian Olive tree was present, but the canopy did not intersect the transect line. In contrast, the eastern transect line passed under the canopy of a large Russian Olive tree. The proximity of the transect lines to the canopy of the other

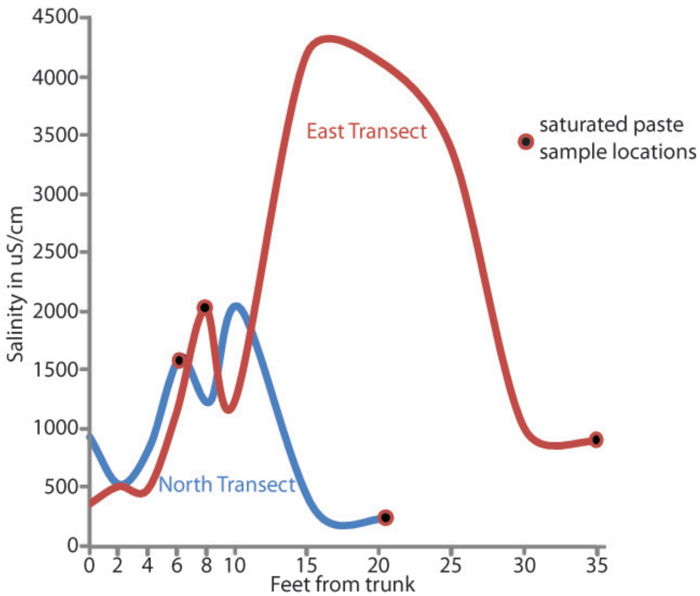


Figure 9. Soil salinity transects of distance from a large Salt Cedar tree. The canopy of a large Russian Olive was 15 to 20 ft to the east of this Salt Cedar. The Russian Olive may have influenced the salinity along the transect,causing a second large spike in the transect.

trees may explain the difference in the magnitude of the salinity peaks. Background soil samples, which were defined as soil outside the influence of Salt Cedar and Russian Olive trees, were collected from soil with a consistent, low overall salinity as compared to the salinity peaks. Along the north transect, the background condition was 226 µS/cm (0.23 mS/cm) at 15 to 20 ft from the base of the tree; however, the background was much higher along the eastern transect: 900 µS/cm (0.90 mS/cm). This could be caused by natural soil heterogeneity or the presence of several Russian Olive trees that were present along the transect.

Results from the soil saturated paste extraction are available in table 4 and appendix 4. The pH of all samples was approximately neutral (7.3 to 7.7). The conductivity of the saturated paste analyses reflected the measurements made in the field along the transects, but were higher overall because of the different measurement methods: along the north transect the peak was 9.5 mS/cm and the background was 2.45 mS/cm; along the east transect the peak was 9.15 mS/cm and the background was 5.09 mS/cm.

The cation and anion analyses were modeled using a geochemical modeling program developed by the United States Environmental Protection Agency, MINTEQA2 (Allison and Brown, 1992). The speciation and saturation index results from the MINTEQA2 modeling are in appendix 4. The speciation table gives a rough idea of the mineral species present in solution and the saturation index provides the species that will precipitate out of solution, with the higher index species precipitating first.

For the saturated paste extraction samples, both transects show higher concentrations in every analyte in the peak sample as compared to the background sample, as would be expected (table 4). More important is the distribution of species. In milliequivalents per liter (meq/L), a unit that takes into account the charge and mass of the ion, the two background samples have calcium, magnesium, and sodium concentrations that are approximately equal. However, in the peak samples the amount of sodium in the sample increased substantially relative to calcium and magnesium, such that sodium composed the majority of cation species. This is particularly important because sodium, because of its large hydrated radius, can cause soil to lose structure by deflocculating clay and organic matter. Additionally, sodium can displace plant nutrients, such as calcium, from soil cation-exchange sites, diminishing soil fertility.

Table 4. Saturated paste analysis of soil samples.

| | North Transect | | East Transect | |
|---|---|---|---|---|
| | 6 ft peak | 20 ft background | 8 ft peak | 35 ft background |
| pH | 7.7 | 7.3 | 7.7 | 7.7 |
| Conductivity mS/cm | 9.5 | 2.45 | 9.15 | 5.09 |
| $Ca^{2+}$ mg/L (meq/L) | 442.9 (22.1) | 248.5 (12.4) | 501 (25.0) | 539.1 (26.9) |
| $Mg^{2+}$ mg/L (meq/L) | 452.1 (37.2) | 108.5 (8.93) | 481.2 (39.6) | 224.8 (18.5) |
| $Na^{+}$ mg/L (meq/L) | 2271 (98.8) | 184.1 (8.01) | 2007 (87.3) | 609.2 (26.5) |
| $HCO_3^-$ mg/L (meq/L) | 538 (8.8) | 406 (6.6) | 638 (10.5) | 306 (5.0) |
| $CO_3^{2-}$ mg/L (meq/L) | 55 (1.8) | 34 (1.1) | 38 (1.3) | 27 (0.9) |
| $SO_4^{2-}$ mg/L (meq/L) | 7430 (154.7) | 1080 (22.5) | 7110 (148) | 3260 (67.9) |
| $Cl^-$ mg/L (meq/L) | 264 (7.4) | 54 (1.5) | 514 (14.5) | 146 (4.1) |

The anions in the background samples were dominated by sulfate, which is also true in the peak samples, but to a much greater extent. This study supports other research that has shown Salt Cedar concentrates salts in the soil surface. The work done for this project has shown that much of that salt is in the highly soluble form sodium sulfate (such as thenardite).

## CONCLUSIONS

The water-level drawdown method used to measure ET in this study has proven to be useful in measuring Salt Cedar evapotranspiration rates in Treasure County, Montana; however, the results are not site-specific. This method will work throughout eastern Montana in areas with Salt Cedar or other plant populations of concern.

This study evaluated the effectiveness of using the aquifer drawdown method (White's equation) to measure the evapotranspiration of phreatophytes such as Salt Cedar and deep-rooted plants, such as Russian Olive. While this study was limited in scope, we learned some valuable information for future studies.

This study showed it is possible to use this method to determine evapotranspiration rates for Salt Cedar and Russian Olive; however, future studies will be improved by:

- selecting a site that is more homogeneous, with a majority of the species being either Salt Cedar or Russian Olive, depending upon the focus of the study.
- studying an aquifer that has a deeper water table to minimize direct evaporation, but still demonstrates sensitivity to recharge and discharge.
- combining indirect transpiration measurements, such as water table drawdown, with direct transpiration measurements.
- selecting a site that has a well-defined, isolated population of phreatophytes in order to install a baseline well that is unaffected by phreatophytes.
- creating a stable baseline by removing or reducing extraneous species, such as mowing grasses and removing shrubs.
- locating the study site such that upgradient influences are minimized or controlled; no (or few) trees or irrigation ditches.

The evapotranspiration rate calculated for this stand of Salt Cedar is a minimum, because the plants around the baseline well did not perfectly represent the grasses and shrubs near the trees. However, the calculated rate of approximately 1 mm/day is on the low end of published results from high desert ecosystems, and may therefore be roughly representative of the actual evapotranspiration rate.

The soil analysis supports previous studies that indicate that Salt Cedar trees concentrate salt on the soil surface. Saturated paste extraction shows elevated levels of sodium and sulfate over background.

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# APPENDIX 2
## Summary Charts of Previous Investigations

| Reference (last, date) | Plant species (Scientific) | Plant name (Common) | Location City/Area | State | Climatic Region |
|---|---|---|---|---|---|
| Owens, 2007 | Acer rubrum | red maple | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Wullschleger, 2001 | Acer rubrum | red maple | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Young, 1985 | Betula occidentalis | birch | Sally Creek, Medician Bow Mts. | WY | Mountainous-Semiarid |
| Owens, 2007 | Liriodendron tulipifera | yellow poplar | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Wullschleger, 2001 | Liriodendron tulipifera | yellow poplar | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Nagler, 2008 | Medicago sativa | alfalfa | HayDay Farms, Inc.-Blythe | CA | Desert |
| Owens, 2007 | Nyssa sylvatica | black gum | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Wullschleger, 2001 | Nyssa sylvatica | black gum | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Wyman, 2007 | Populus | cottonwood | Gila River | NM | Semiarid |
| Wyman, 2007 | Populus | cottonwood | San Pedro River | AZ | Desert |
| Wyman, 2007 | Populus | cottonwood | Rio Grande River | NM | Desert-Semiarid |
| Dahm, 2002 | Populus deltoides | cottonwood | Rio Grande River-Belen | NM | Semiarid |
| Dahm, 2002 | Populus deltoides | cottonwood | Rio Grande River-South Valley | NM | Semiarid |
| Nagler, 2003 | Populus fremontii | cottonwood | Tucson | AZ | Desert |
| Wyman, 2007 | Prosopis | mesquite | San Pedro River | AZ | Desert |
| Wyman, 2007 | Prosopis | mesquite | San Pedro River | AZ | Desert |
| Owens, 2007 | Quercus alba | white oak | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Wullschleger, 2001 | Quercus alba | white oak | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Owens, 2007 | Quercus prinus | chestnut oak | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Wullschleger, 2001 | Quercus prinus | chestnut oak | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Owens, 2007 | Quercus rubra | red oak | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Wullschleger, 2001 | Quercus rubra | red oak | Oak Ridge Reservation-Anderson County | TN | Humid Subtropical |
| Young, 1985 | Salix amygdaloides | willow | Little Laramie River | WY | Mountainous-Semiarid |
| Young, 1985 | Salix exigua | willow | Little Laramie River | WY | Mountainous-Semiarid |

| Reference (last, date) | Physiographic division | Latitude | Transpiration quantity | Transpiration units | Converted to m/Yr |
|---|---|---|---|---|---|
| Owens, 2007 | Valley & Ridge-Tennessee Section | 36'N | 153 [T] | L/day | |
| Wullschleger, 2001 | Valley & Ridge-Tennessee Section | 36'N | 0.24 [T] | mm/day | |
| Young, 1985 | Southern Rocky Mts. | 41'N | 130-190 [T] | mg/m2/sec | |
| Owens, 2007 | Valley & Ridge-Tennessee Section | 36'N | 63 [T] | L/day | |
| Wullschleger, 2001 | Valley & Ridge-Tennessee Section | 36'N | 0.05 [T] | mm/day | |
| Nagler, 2008 | Basin & Range-Sonoran Desert | 33'N | 8.02 (1.82) [ET] | mm/day (m/year) | |
| Owens, 2007 | Valley & Ridge-Tennessee Section | 36'N | 82 | L/day | |
| Wullschleger, 2001 | Valley & Ridge-Tennessee Section | 36'N | 0.2 [T] | mm/day | |
| Wyman, 2007 | Basin & Range-Mexican Highland | 33'N | 1.4-3.3 [ET] | m/year | |
| Wyman, 2007 | Basin & Range-Mexican Highland | 32'-33'N | 3.1-5.7 [ET] | mm/day | |
| Wyman, 2007 | Basin & Range-Mexican Highland | 32'-37'N | 1.0-1.2 (1-9) [ET] | m/year (mm/day) | |
| Dahm, 2002 | Basin & Range-Mexican Highland | 34'N | 5.9-6.7 (98) | mm/day (cm/year) | |
| Dahm, 2002 | Basin & Range-Mexican Highland | 35'N | 7.2-8.4 (123) | mm/day (cm/year) | |
| Nagler, 2003 | Basin & Range-Sonoran Desert | 32'N | 0.819 [T] (19.5 [ET]) | kg/m2/day (mm/day) | |
| Wyman, 2007 | Basin & Range-Mexican Highland | 32'-33'N | 0.4 (1.6-2.4) [ET] | m/year (mm/day) | |
| Wyman, 2007 | Basin & Range-Mexican Highland | 32'-33'N | 0.6-0.7 [ET] | m/year | |
| Owens, 2007 | Valley & Ridge-Tennessee Section | 36'N | 71 [T] | L/day | |
| Wullschleger, 2001 | Valley & Ridge-Tennessee Section | 36'N | 0.09 [T] | mm/day | |
| Owens, 2007 | Valley & Ridge-Tennessee Section | 36'N | 143.8 [T] | L/day | |
| Wullschleger, 2001 | Valley & Ridge-Tennessee Section | 36'N | 0.14 [T] | mm/day | |
| Owens, 2007 | Valley & Ridge-Tennessee Section | 36'N | 153 [T] | L/day | |
| Wullschleger, 2001 | Valley & Ridge-Tennessee Section | 36'N | 0.01 [T] | mm/day | |
| Young, 1985 | Southern Rocky Mts. | 41'N | 80-150 [T] | mg/m2/sec | |
| Young, 1985 | Southern Rocky Mts. | 41'N | 140-200 [T] | mg/m2/sec | |

| Reference (last, date) | Measurement methods | Comments/qualifiers (plant maturity, location along watershed, water table depth, etc) |
|---|---|---|
| Owens, 2007 | Converted from previous data-Wullschleger, 2001 | See Wullschleger, 2001 for origional data |
| Wullschleger, 2001 | Xylem sap flux | air temp, relative humidity, and radiation monitored, age of trees ranging from 40-75 years, mean annual rainfall (30-years) 134 cm |
| Young, 1985 | water relations-stomatal conductance | air temp, relative humidity, and Xylem pressure monitored, high elevation site-2865m, test site had no slope & poor drainage, shrub cover 49% |
| Owens, 2007 | Converted from previous data-Wullschleger, 2001 | See Wullschleger, 2001 for origional data |
| Wullschleger, 2001 | Xylem sap flux | air temp, relative humidity, and radiation monitored, age of trees ranging from 40-75 years, mean annual rainfall (30-years) 134 cm |
| Nagler, 2008 | ground surveys and remote sensing | distance from river (5,100m), depth to water table (2.2-2.8m), ground surveys-soil moisture & electrical conductivity of groundwater, remote sensing-Moderate Resolution Imaging Spectrometer (MODIS) |
| Owens, 2007 | Converted from previous data-Wullschleger, 2001 | See Wullschleger, 2001 for origional data |
| Wullschleger, 2001 | Xylem sap flux | air temp, relative humidity, and radiation monitored, age of trees ranging from 40-75 years, mean annual rainfall (30-years) 134 cm |
| Wyman, 2007 | Lysimeters | |
| Wyman, 2007 | Sap Flux | |
| Wyman, 2007 | EC | EC-Eddy Covairance |
| Dahm, 2002 | EC, Water Budget | EC-Eddy Covairance, ET at flooded site, data collected over 1 year, temp, humidity, & atm pressure monitored, contained few understory trees |
| Dahm, 2002 | EC, Water Budget | EC-Eddy Covairance, ET at nonflooded site, data collected over 1 year, temp, humidity, & atm pressure monitored, understory of russian olive and saltcedar |
| Nagler, 2003 | Sap Flux, canopy temp methods | sap flow measured by stem heat-balance method, canopy temp, air temp, wind speed, and relative humidity monitored |
| Wyman, 2007 | BREB | BREB-Bowen Ratio Energy Balance |
| Wyman, 2007 | EC | EC-Eddy Covariance |
| Owens, 2007 | Converted from previous data-Wullschleger, 2001 | See Wullschleger, 2001 for origional data |
| Wullschleger, 2001 | Xylem sap flux | air temp, relative humidity, and radiation monitored, age of trees ranging from 40-75 years, mean annual rainfall (30-years) 134 cm |
| Owens, 2007 | Converted from previous data-Wullschleger, 2001 | See Wullschleger, 2001 for origional data |
| Wullschleger, 2001 | Xylem sap flux | air temp, relative humidity, and radiation monitored, age of trees ranging from 40-75 years, mean annual rainfall (30-years) 134 cm |
| Owens, 2007 | Converted from previous data-Wullschleger, 2001 | See Wullschleger, 2001 for origional data |
| Wullschleger, 2001 | Xylem sap flux | air temp, relative humidity, and radiation monitored, age of trees ranging from 40-75 years, mean annual rainfall (30-years) 134 cm |
| Young, 1985 | water relations-stomatal conductance | air temp, relative humidity, and Xylem pressure monitored, low elevation site-2255m, site had good drainage & surrounded by arid short-grass prairie, shrub cover 20% |
| Young, 1985 | water relations-stomatal conductance | air temp, relative humidity, and Xylem pressure monitored, low elevation site-2255m, site had good drainage & surrounded by arid short-grass prairie, shrub cover 20% |

| Reference (last, date) | Plant species (Scientific) | Plant name (Common) | Location City/Area | State | Climatic Region |
|---|---|---|---|---|---|
| Young, 1985 | Salix planifolia | willow | Sally Creek, Medician Bow Mts. | WY | Mountainous-Semiarid |
| Young, 1985 | Salix wolfii | willow | Sally Creek, Medician Bow Mts. | WY | Mountainous-Semiarid |
| Nagler, 2003 | Salix gooddingii | willow | Tucson | AZ | Desert |
| Wyman, 2007 | Sporobolus | sacaton grass | San Pedro River | AZ | Desert |
| Wyman, 2007 | Tamarix | saltcedar | Gila River | AZ | Desert |
| Wyman, 2007 | Tamarix | saltcedar | Gila River | AZ | Desert |
| Wyman, 2007 | Tamarix | saltcedar | Gila River | AZ | Desert |
| Wyman, 2007 | Tamarix | saltcedar | Gila River | AZ | Desert |
| Robinson, 1965 | Tamarix | saltcedar | Safford Valley-Gila River | AZ | Desert |
| Robinson, 1965 | Tamarix | saltcedar | Safford Valley-Gila River | AZ | Desert |
| Robinson, 1965 | Tamarix | saltcedar | Safford Valley-Gila River | AZ | Desert |
| Wyman, 2007 | Tamarix | saltcedar | Colorado River | AZ-CA | Desert |
| Nagler, 2008 | Tamarix | saltcedar | Lower Colorado River-Cibola National Wildlife Refuge | AZ | Desert |
| Nagler, 2008 | Tamarix | saltcedar | Lower Colorado River-Cibola National Wildlife Refuge | AZ | Desert |
| Nagler, 2008 | Tamarix | saltcedar | Lower Colorado River-Cibola National Wildlife Refuge | AZ | Desert |
| Wyman, 2007 | Tamarix | saltcedar | Rio Grande River | NM | Desert-Semiarid |
| Wyman, 2007 | Tamarix | saltcedar | Pecos River | NM | Desert-Semiarid |
| Robinson, 1965 | Tamarix | saltcedar | Pecos River Valley | NM | Desert-Semiarid |
| Robinson, 1965 | Tamarix | saltcedar | Carlsbad | NM | Desert |
| Robinson, 1965 | Tamarix | saltcedar | Carlsbad | NM | Desert |
| Wyman, 2007 | Tamarix | saltcedar | Virgin River | NV | Desert |
| Cleverly, 2002 | Tamarix ramosissima | saltcedar | Rio Grande River-Bosque del Apache | NM | Desert-Semiarid |
| Dahm, 2002 | Tamarix ramosissima | saltcedar | Rio Grande River-Bosque del Apache-South | NM | Desert-Semiarid |
| Dahm, 2002 | Tamarix ramosissima | saltcedar | Rio Grande River-Sivilleta | NM | Desert-Semiarid |
| Cleverly, 2002 | Tamarix ramosissima | saltcedar | Rio Grande River-Sevilleta National Wildlife Refuge | NM | Desert-Semiarid |

| Reference (last, date) | Physiographic division | Latitude | Transpiration quantity | Transpiration units | Converted to m/Yr |
|---|---|---|---|---|---|
| Young, 1985 | Southern Rocky Mts. | 41'N | 220 [T] | mg/m2/sec | |
| Young, 1985 | Southern Rocky Mts. | 41'N | 230 [T] | mg/m2/sec | |
| Nagler, 2003 | Basin & Range-Sonoran Desert | 32'N | 0.772 [T] (24.8 [ET]) | kg/m2/day (mm/day) | |
| Wyman, 2007 | Basin & Range-Mexican Highland | 32'-33'N | 0.3-1.6 [ET] | mm/day | |
| | | | | | |
| Wyman, 2007 | Basin & Range-Sonoran Desert | 32'-33'N | 1.2-3 [ET] | m/year | 1.2-3 [ET] |
| Wyman, 2007 | Basin & Range-Sonoran Desert | 32'-33'N | 1.0-3.4 [ET] | m/year | 1.0-3.4 [ET] |
| Wyman, 2007 | Basin & Range-Sonoran Desert | 32'-33'N | 0.7 [ET] | m/year | 0.7 [ET] |
| Wyman, 2007 | Basin & Range-Sonoran Desert | 32'-33'N | 1.3 [ET] | m/year | 1.3 [ET] |
| Robinson, 1965 | Basin & Range-Sonoran Desert | 32'-33'N | 9.2 [water use] | acre-feet/acre | 2.8 [ET] |
| Robinson, 1965 | Basin & Range Sonoran Desert | 32'-33'N | 7.0 [water use] | acre-feet/acre | 2.13 [ET] |
| Robinson, 1965 | Basin & Range Sonoran Desert | 32'-33'N | 4.0 [water use] | acre-feet/acre | 1.22 [ET] |
| Wyman, 2007 | Basin & Range-Sonoran Desert | 31'-35'N | 1.7 [ET] | m/year | 1.7 [ET] |
| Nagler, 2008 | Basin & Range-Sonoran Desert | 33'N | 4.91 [ET] | mm/day | 1.79 [ET] |
| Nagler, 2008 | Basin & Range-Sonoran Desert | 33'N | 5.04 [ET] | mm/day | 1.84 [ET] |
| Nagler, 2008 | Basin & Range-Sonoran Desert | 33'N | 4.16 [ET] | mm/day | 1.52 [ET] |
| Wyman, 2007 | Basin & Range-Mexican Highland | 32'-37'N | 1.1-1.2 [ET] | m/year | 1.1-1.2 [ET] |
| Wyman, 2007 | Great Plains-Pecos Valley | 32'-36'N | >0.6-1.1 [ET] | m/year | >0.6-1.1 [ET] |
| Robinson, 1965 | Great Plains-Pecos Valley | 32'-36'N | 5.0 [water use] | acre-feet/acre | 1.52 [ET] |
| Robinson, 1965 | Basin & Range-Sacramento section | 32'N | 5.5 [water use] | acre-feet/acre | 1.68 [ET] |
| Robinson, 1965 | Basin & Range-Sacramento section | 32'N | 4.7 [water use] | acre-feet/acre | 1.43 [ET] |
| Wyman, 2007 | Basin & Range-Great Basin | 36'-38'N | .07-1.4 (0-12.5) [ET] | m/year (mm/day) | .07-1.4 [ET] |
| Cleverly, 2002 | Basin & Range-Mexican Highland | 33'N | 122 [ET] | cm/year | 1.22 [ET] |
| Dahm, 2002 | Basin & Range-Mexican Highland | 33'N | 6.9-7.8 (111-122) [ET] | mm/day (cm/year) | 1.11-1.22 [ET] |
| Dahm, 2002 | Basin & Range-Mexican Highland | 34'N | 5.1-5.5 (74-76) [ET] | mm/day (cm/year) | .74-.76 [ET] |
| Cleverly, 2002 | Basin & Range-Mexican Highland | 34'N | 74 [ET] | cm/year | .74 [ET] |

| Reference (last, date) | Measurement methods | Comments/qualifiers (plant maturity, location along watershed, water table depth, etc) |
|---|---|---|
| Young, 1985 | water relations-stomatal conductance | air temp, relative humidity, and Xylem pressure monitored, high elevation site-2865m, test site had no slope & poor drainage, shrub cover 49% |
| Young, 1985 | water relations-stomatal conductance | air temp, relative humidity, and Xylem pressure monitored, high elevation site-2865m, test site had no slope & poor drainage, shrub cover 49% |
| Nagler, 2003 | Sap Flux, canopy temp methods | sap flow measured by stem heat-balance method, canopy temp, air temp, wind speed, and relative humidity monitored |
| Wyman, 2007 | BREB | BREB-Bowen Ratio Energy Balance |
| | | |
| Wyman, 2007 | Lysimeters | |
| Wyman, 2007 | Lysimeters | |
| Wyman, 2007 | Water Budget | |
| Wyman, 2007 | Water Budget | |
| Robinson, 1965 | Unspecified | water level depth at 4.0 ft, plants grown in tanks |
| Robinson, 1965 | Unspecified | water level depth at 8.0 ft, plants grown in tanks |
| Robinson, 1965 | Unspecified | average annual use, plants under natural conditions, ave 61% cover density |
| Wyman, 2007 | BREB | BREB-Bowen Ratio Energy Balance |
| Nagler, 2008 | ground surveys and remote sensing | distance from river (750m), depth to water table (3.7-4.0m), ground surveys-soil moisture & electrical conductivity of groundwater, remote sensing-Moderate Resolution Imaging Spectrometer (MODIS) |
| Nagler, 2008 | ground surveys and remote sensing | distance from river (1,500m), depth to water table (3.4-3.7m), ground surveys-soil moisture & electrical conductivity of groundwater, remote sensing-Moderate Resolution Imaging Spectrometer (MODIS) |
| Nagler, 2008 | ground surveys and remote sensing | distance from river (200m), depth to water table (2.7-3.4m), ground surveys-soil moisture & electrical conductivity of groundwater, remote sensing-Moderate Resolution Imaging Spectrometer (MODIS) |
| Wyman, 2007 | EC | EC-Eddy Covariance |
| Wyman, 2007 | EC | EC-Eddy Covariance |
| Robinson, 1965 | Unspecified | plants grown in tanks |
| Robinson, 1965 | Unspecified | water level depth at 2.0 ft, plants grown in tanks |
| Robinson, 1965 | Unspecified | water level depth at 4.0 ft, plants grown in tanks |
| Wyman, 2007 | BREB | BREB-Bowen Ratio Energy Balance |
| Cleverly, 2002 | EC | EC-Eddy Covariance, max ET at flooded site, elevation at site-1375m, temp & relative humidity monitored |
| Dahm, 2002 | EC, Water Budget | EC-Eddy Covariance, ET at flooded site, data collected over 2 years, temp, humidity, & atm pressure monitored |
| Dahm, 2002 | EC, Water Budget | EC-Eddy Covairance, ET at nonflooded site, data collected over 2 years, temp, humidity, & atm pressure monitored |
| Cleverly, 2002 | EC | EC-Eddy Covariance, max ET at unflooded site, elevation at site-1430m, temp & relative humidity monitored |

| Reference (last, date) | Plant species (Scientific) | Plant name (Common) | Location City/Area | State | Climatic Region |
|---|---|---|---|---|---|
| Nagler, 2003 | Tamarix ramosissima | saltcedar | Tucson | AZ | Desert |
| Sala, 2006 | Tamarix ramosissima | saltcedar | Virgin River-Duck Club site | NV | |
| Sala, 2006 | Tamarix ramosissima | saltcedar | Virgin River-Half Way Wash site | NV | |
| Devitt, 1998 | Tamarix ramosissima | saltcedar | Virgin River-Lake Mead National Recreational Area | NV | |
| Si, 2005 | Tamarix ramosissima | saltcedar | | | |
| Si, 2005 | Tamarix ramosissima | saltcedar | | | |
| Si, 2005 | Tamarix ramosissima | saltcedar | | | |
| Si, 2005 | Tamarix ramosissima | saltcedar | | | |
| Si, 2005 | Tamarix ramosissima | saltcedar | | | |
| Si, 2005 | Tamarix ramosissima | saltcedar | | | |
| Si, 2005 | Tamarix ramosissima | saltcedar | | | |
| | | | | | |
| Wyman, 2007 | Various | annual weeds, grasses, & bare soil | Pecos River | NM | Desert-Semiarid |
| Wyman, 2007 | Various | bare soil & sparse annual weeds | Gila River | AZ | Desert |
| Wyman, 2007 | Various | salt grass/saltcedar | Rio Grande River | NM | Desert-Semiarid |
| Wyman, 2007 | Various | salt grass | Sonora | Mexico | Desert |
| Wyman, 2007 | Various | salt grass | Various Sites | | |

| Reference (last, date) | Physiographic division | Latitude | Transpiration quantity | Transpiration units | Converted to m/Yr |
|---|---|---|---|---|---|
| Nagler, 2003 | Basin & Range-Sonoran Desert | 32'N | 0.674 [T] | kg/m2/day | |
| Sala, 2006 | | 36'N | 5.9-16.3 [T] (3.1-8.2) [ET] | mm/day (mm/day) | 2.15-5.95 [T] 1.13-3 [ET] |
| Sala, 2006 | | 36'N | 5.5-8.3 [ET] | mm/day | 2-3.03 [ET] |
| Devitt, 1998 | | 36'N | 0-12.5 (75-145) [ET] | mm/day (cm/year) | |
| Si, 2005 | | | 1.3-3.1 [ET] | mm/day | .47-1.13 [ET] |
| Si, 2005 | | | 7.2-9.5 [ET] | mm/day | 2.63-3.47 [ET] |
| Si, 2005 | | | 6.2-9.4 [ET] | mm/day | 2.26-3.43 [ET] |
| Si, 2005 | | | 2.2-15.8 [ET] | mm/day | .8-5.77 [ET] |
| Si, 2005 | | | 3.1-8.2 [ET] | mm/day | 1.13-3 [ET] |
| Si, 2005 | | | 2.0-2.7 [ET] | mm/day | .73-.99 [ET] |
| Si, 2005 | | | 0-6.9 [ET] | mm/day | 0-2.51 [ET] |
| | | | | | |
| Wyman, 2007 | Great Plains-Pecos Valley | 32'-36'N | 0.6-0.7 [ET] | m/year | |
| Wyman, 2007 | Basin & Range-Sonoran Desert | 32'-33'N | 0.6 [ET] | mm/day | |
| Wyman, 2007 | Basin & Range-Mexican Highland | 32'-37'N | 0.7-0.8 (1-6) [ET] | m/year (mm/day) | |
| Wyman, 2007 | Basin & Range-Sonoran Desert | 28'-32'N | 1.1-4.5 [ET] | mm/day | |
| Wyman, 2007 | | | 0.3-1.2 [ET] | m/year | |

| Reference (last, date) | Measurement methods | Comments/qualifiers (plant maturity, location along watershed, water table depth, etc) |
|---|---|---|
| Nagler, 2003 | sap flow, canopy temperature methods | sap flow measured by stem heat-balance method, canopy temp, air temp, wind speed, and relative humidity monitored |
| Sala, 2006 | Sap flux [T], Penman-Monteith [ET] | Average water-table depth 2.0-3.0 m, Annual avg.rainfall-135 mm/yr, Global shortwave radiation, air temp, relative humidity, wind velocity, and rainfall monitored |
| Sala, 2006 | Sap flux, Penman-Monteith [ET] | Average water-table depth 0.5-1.0 m, Annual avg.rainfall-135 mm/yr, Global shortwave radiation, air temp, relative humidity, wind velocity, and rainfall monitored |
| Devitt, 1998 | BREB | BREB-Bowen Ratio Energy Balance, Depth to water table varied-2 to >3m, Vapor pressure, air temp, wind speed and wind direction monitored |
| Si, 2005 | Near-IR | Data cited in paper |
| Si, 2005 | Bowen ratio | Data cited in paper |
| Si, 2005 | Lysimeters | Data cited in paper |
| Si, 2005 | Lysimeters | Data cited in paper |
| Si, 2005 | Penman-Monteith | Data cited in paper |
| Si, 2005 | Blaney-Criddle | Data cited in paper |
| Si, 2005 | Three-dimensional EC | Data cited in paper |
| | | |
| Wyman, 2007 | EC | EC-Eddy Covariance |
| Wyman, 2007 | Water Budget | |
| Wyman, 2007 | EC | EC-Eddy Covariance |
| Wyman, 2007 | Lysimeters | |
| Wyman, 2007 | Lysimeters | |

# APPENDIX 3
## Lithologic Logs and Photos

**MONTANA WELL LOG REPORT**

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is complied electronically from the contents of the Ground-Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

**Other Options**

Plot this site on a topographic map
View hydrograph for this site

**Site Name: H-1**
**GWIC Id: 246794**

**Section 1: Well Owner**

**Owner Name**
N/A

**Section 2: Location**

| Township | Range | Section | Quarter Sections |
|---|---|---|---|
| 06N | 37E | 1 | SE¼ NW¼ SW¼ SE¼ |

| County | Geocode |
|---|---|
| TREASURE | |

| Latitude | Longitude | Geomethod | Datum |
|---|---|---|---|
| 46.29556 | 107.03721 | NAV-GPS | NAD27 |

| Altitude | Method | Datum | Date |
|---|---|---|---|
| 2589.23 | MAP | NAD27 | 9/16/2008 |

| Addition | Block | Lot |
|---|---|---|
| | | |

**Section 3: Proposed Use of Water**
MONITORING (1)

**Section 4: Type of Work**
Drilling Method: WATER ROTARY AND JET

**Section 5: Well Completion Date**
Date well completed: Friday, September 12, 2008

**Section 6: Well Construction Details**

**Borehole dimensions**

| From | To | Diameter |
|---|---|---|
| 0 | 14 | 3 |

**Casing**

| From | To | Diameter | Wall Thickness | Pressure Rating | Joint | Type |
|---|---|---|---|---|---|---|
| 0 | 12.5 | 1.25 | 0.25 | | GLUED | PVC-SCHED 40 |

**Completion (Perf/Screen)**

| From | To | Diameter | # of Openings | Size of Openings | Description |
|---|---|---|---|---|---|
| 12.5 | 13.5 | 1.25 | | | SAW SLOTS |

**Annular Space (Seal/Grout/Packer)**

| From | To | Description | Cont. Fed? |
|---|---|---|---|
| 0 | 10 | BENTONITE | |

**Section 7: Well Test Data**

Total Depth: 13.8
Static Water Level: 2.51
Water Temperature:

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

**Section 8: Remarks**

**Section 9: Well Log**
**Geologic Source**
110ALVM - ALLUVIUM (QUATERNARY)

| From | To | Description |
|---|---|---|
| 0 | 2 | TOPSOIL CLAY CLAY LOAM |
| 2 | 12 | SAND FINE GRAINED WELL SORTED UNCONSOLIDATED |
| 12 | 14 | GRAVEL COBBLES UP TO 2 CM WELL ROUNDED WELL SORTED SHARP CONTACT |

**Driller Certification**

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

**Name:** JOHN WHEATON
**Company:**
**License No:** MWC-46
**Date Completed:** 9/12/2008

Montana's Ground-Water Information Center (GWIC) | Site Report | V.11.2010 http://mbmggwic.mtech.edu/sqlserver/v11/reports/SiteSummary.asp?gwic...

**MONTANA WELL LOG REPORT**

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**Other Options**

Plot this site on a topographic map
View hydrograph for this site

**Site Name: H-2**
**GWIC Id: 246795**

### Section 1: Well Owner

**Owner Name**

N/A

### Section 2: Location

| Township | Range | Section | Quarter Sections |
|---|---|---|---|
| 06N | 37E | 1 | SE¼ NW¼ SW¼ SE¼ |

| County | Geocode |
|---|---|
| TREASURE | |

| Latitude | Longitude | Geomethod | Datum |
|---|---|---|---|
| 46.2957 | 107.03777 | NAV-GPS | NAD27 |

| Altitude | Method | Datum | Date |
|---|---|---|---|
| 2589.3 | MAP | NAD27 | 9/16/2008 |

| Addition | Block | Lot |
|---|---|---|
| | | |

### Section 3: Proposed Use of Water

MONITORING (1)

### Section 4: Type of Work

Drilling Method: WATER ROTARY AND JET

### Section 5: Well Completion Date

Date well completed: Friday, September 12, 2008

### Section 6: Well Construction Details

**Borehole dimensions**

| From | To | Diameter |
|---|---|---|
| 0 | 12.5 | 3 |

**Casing**

| From | To | Diameter | Wall Thickness | Pressure Rating | Joint | Type |
|---|---|---|---|---|---|---|
| 0 | 11.5 | 1.25 | 0.25 | | GLUED | PVC-SCHED 40 |

**Completion (Perf/Screen)**

| From | To | Diameter | # of Openings | Size of Openings | Description |
|---|---|---|---|---|---|
| 11.5 | 12.5 | 1.25 | | | SAW SLOTS |

**Annular Space (Seal/Grout/Packer)**

| From | To | Description | Cont. Fed? |
|---|---|---|---|
| 0 | 9.5 | BENTONITE | |

### Section 7: Well Test Data

Total Depth: 12.5
Static Water Level: 2.66
Water Temperature:

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

### Section 8: Remarks

### Section 9: Well Log

**Geologic Source**

110ALVM - ALLUVIUM (QUATERNARY)

| From | To | Description |
|---|---|---|
| 0 | 2 | TOPSOIL CLAY LOAM |
| 2 | 10.5 | SAND FINE GRAINED WELL SORTED UNCONSOLIDATED |
| 10.5 | 13 | GRAVEL COBBLES UP TO 2 CM WELL ROUNDED WELL SORTED SHARP CONTACT |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

**Driller Certification**

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

**Name:** JOHN WHEATON
**Company:**
**License No:** MWC-46
**Date Completed:** 9/12/2008

**MONTANA WELL LOG REPORT**

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is complied electronically from the contents of the Ground-Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

**Other Options**

Plot this site on a topographic map
View hydrograph for this site

**Site Name: H-3**
**GWIC Id: 246796**

### Section 1: Well Owner

**Owner Name**
N/A

### Section 2: Location

| Township | Range | Section | Quarter Sections |
|---|---|---|---|
| 06N | 37E | 1 | SW¼ NW¼ SW¼ SE¼ |

| County | Geocode |
|---|---|
| TREASURE | |

| Latitude | Longitude | Geomethod | Datum |
|---|---|---|---|
| 46.29552 | 107.03889 | NAV-GPS | NAD27 |

| Altitude | Method | Datum | Date |
|---|---|---|---|
| 2590 | MAP | NAD27 | 9/16/2008 |

| Addition | Block | Lot |
|---|---|---|
| | | |

### Section 3: Proposed Use of Water

MONITORING (1)

### Section 4: Type of Work

Drilling Method: WATER ROTARY AND JET

### Section 5: Well Completion Date

Date well completed: Friday, September 12, 2008

### Section 6: Well Construction Details

**Borehole dimensions**

| From | To | Diameter |
|---|---|---|
| 0 | 10 | 3 |

**Casing**

| From | To | Diameter | Wall Thickness | Pressure Rating | Joint | Type |
|---|---|---|---|---|---|---|
| 8.2 | 9.2 | 1.25 | 0.25 | | GLUED | PVC-SCHED 40 |

**Completion (Perf/Screen)**

| From | To | Diameter | # of Openings | Size of Openings | Description |
|---|---|---|---|---|---|
| 8.2 | 9.2 | 1.25 | | | SAW SLOTS |

**Annular Space (Seal/Grout/Packer)**

| From | To | Description | Cont. Fed? |
|---|---|---|---|
| 0 | 5 | BENTONITE | |

### Section 7: Well Test Data

Total Depth: 9.2
Static Water Level: 3.39
Water Temperature:

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

### Section 8: Remarks

### Section 9: Well Log

**Geologic Source**

110ALVM - ALLUVIUM (QUATERNARY)

| From | To | Description |
|---|---|---|
| 0 | 2 | TOPSOIL CLAY CLAY LOAM |
| 2 | 9 | SAND FINE GRAINED WELL SORTED UNCONSOLIDATED |
| 9 | 10 | GRAVEL COBBLES UP TO 2 CM WELL ROUNDED WELL SORTED SHARP CONTACT |

**Driller Certification**

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

**Name:** JOHN WHEATON
**Company:**
**License No:** MWC-46
**Date Completed:** 9/12/2008

Figure A3-1a. Meteorological station.

Figure A3-1b. Detail of meteorological station.

Figure A3-2. Well 3 recorded baseline conditions.

October 8, 2008: After wells were installed.

Figure A3-3a. Well 1.

Figure A3-3b. Well 2.

October 8, 2008: After wells were installed.

Figure A3-3c. Well 1 detail.

Figure A3-3d. Well 2 detail.

May 10, 2009: Early spring, before leaf-out.

Figure A3-4a. Well 1.

Figure A3-4b. Well 2.

July 30, 2009: After Russian Olive trees were cut.

Figure A3-5a. Well 1.

Figure A3-5b. Well 2.

July 30, 2009: Cutting Russian Olive.

Figure A3-6a.

Figure A3-6b.

Figure A3-6c.

Figure A3-6d.

September 3, 2009: After Saltcedar were cut.

Figure A3-7a. Well 1.

Figure A3-7b. Well 2.

September 3, 2009: After all trees were removed.

Figure A3-8a. Field site after all trees were removed.

Figure A3-8b. Surveying relative well altitudes.

Figure A3-8c. Russian Olive stump one month after being treated with Remedy.

October 23, 2009: End of field work.

Figure A3-9a. Well 1.

Figure A3-9b. Well 2.

# APPENDIX 4
Saturated Paste Extraction Analyses

ENERGY LABORATORIES, INC. • P.O. Box 30916 • 1120 South 27th Street • Billings, MT 59107-0916
800-735-4489 • 406-252-6325 • 406-252-6069 fax • eli@energylab.com

# ANALYTICAL SUMMARY REPORT

September 15, 2009

Elizabeth Meredith
MT Bureau of Mines and Geology
1300 N 27th
Billings, MT 59101

Workorder No.: B09090611

Project Name: Hysham Salt Cedar

Energy Laboratories Inc received the following 4 samples for MT Bureau of Mines and Geology on 9/4/2009 for analysis.

| Sample ID | Client Sample ID | Collect Date | Receive Date | Matrix | Test |
|---|---|---|---|---|---|
| B09090611-001 | N Transect 6 Ft | 09/03/09 13:00 | 09/04/09 | Soil | Cations, Saturated Paste<br>Alkalinity, Water Extractable<br>Chloride, Water Extractable<br>Conductivity<br>pH, Saturated Paste<br>Saturated Paste Extraction<br>Sulfate, Water Extractable |
| B09090611-002 | N Transect 20 Ft | 09/03/09 13:00 | 09/04/09 | Soil | Same As Above |
| B09090611-003 | E Transect 8 Ft | 09/03/09 13:00 | 09/04/09 | Soil | Same As Above |
| B09090611-004 | E Transect 35 Ft | 09/03/09 13:00 | 09/04/09 | Soil | Same As Above |

Any exceptions or problems with the analyses are noted in the Laboratory Analytical Report, the QA/QC Summary Report, or the Case Narrative.

The results as reported relate only to the item(s) submitted for testing.

If you have any questions regarding these tests results, please call.

**Report Approved By:** Tonya Mallett

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800-735-4489 • 406-252-6325 • 406-252-6069 fax • eli@energylab.com

## LABORATORY ANALYTICAL REPORT

| | | | |
|---|---|---|---|
| Client: | MT Bureau of Mines and Geology | Report Date: | 09/15/09 |
| Project: | Hysham Salt Cedar | Collection Date: | 09/03/09 13:00 |
| Lab ID: | B09090611-001 | DateReceived: | 09/04/09 |
| Client Sample ID: | N Transect 6 Ft | Matrix: | Soil |

| Analyses | Result | Units | Qualifiers | RL | MCL/ QCL | Method | Analysis Date / By |
|---|---|---|---|---|---|---|---|
| SATURATED PASTE | | | | | | | |
| pH, sat. paste | 7.70 | s.u. | | 0.10 | | ASAM10-3.2 | 09/11/09 13:36 / srm |
| Conductivity, sat. paste | 9.50 | mmhos/cm | | 0.01 | | ASA10-3 | 09/11/09 13:36 / srm |
| Calcium, sat. paste | 22.1 | meq/L | D | 0.09 | | SW6010B | 09/12/09 03:37 / tao |
| Magnesium, sat. paste | 37.2 | meq/L | | 0.08 | | SW6010B | 09/12/09 03:37 / tao |
| Sodium, sat. paste | 98.8 | meq/L | D | 0.1 | | SW6010B | 09/12/09 03:37 / tao |
| Alkalinity, sat. paste | 532 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:11 / ehb |
| Bicarbonate, sat. paste | 538 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:11 / ehb |
| Carbonate, sat. paste | 55 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:11 / ehb |
| Bicarbonate | 9 | meq/L | | | | ASA10-3 | 09/14/09 16:11 / ehb |
| Sulfate, sat. paste | 7430 | mg/L | D | 20 | | ASA10-3 | 09/11/09 13:25 / kh |
| Chloride, sat. paste | 264 | mg/L | D | 20 | | ASA10-3 | 09/11/09 13:25 / kh |

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix interference.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

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## LABORATORY ANALYTICAL REPORT

| | | | |
|---|---|---|---|
| **Client:** | MT Bureau of Mines and Geology | **Report Date:** | 09/15/09 |
| **Project:** | Hysham Salt Cedar | **Collection Date:** | 09/03/09 13:00 |
| **Lab ID:** | B09090611-002 | **DateReceived:** | 09/04/09 |
| **Client Sample ID:** | N Transect 20 Ft | **Matrix:** | Soil |

| Analyses | Result | Units | Qualifiers | RL | MCL/ QCL | Method | Analysis Date / By |
|---|---|---|---|---|---|---|---|
| SATURATED PASTE | | | | | | | |
| pH, sat. paste | 7.30 | s.u. | | 0.10 | | ASAM10-3.2 | 09/11/09 13:36 / srm |
| Conductivity, sat. paste | 2.45 | mmhos/cm | | 0.01 | | ASA10-3 | 09/11/09 13:36 / srm |
| Calcium, sat. paste | 12.4 | meq/L | | 0.05 | | SW6010B | 09/12/09 03:45 / tao |
| Magnesium, sat. paste | 8.93 | meq/L | | 0.08 | | SW6010B | 09/12/09 03:45 / tao |
| Sodium, sat. paste | 8.01 | meq/L | D | 0.07 | | SW6010B | 09/12/09 03:45 / tao |
| Alkalinity, sat. paste | 390 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:25 / ehb |
| Bicarbonate, sat. paste | 406 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:25 / ehb |
| Carbonate, sat. paste | 34 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:25 / ehb |
| Bicarbonate | 7 | meq/L | | | | ASA10-3 | 09/14/09 16:25 / ehb |
| Sulfate, sat. paste | 1080 | mg/L | | 1 | | ASA10-3 | 09/14/09 20:36 / kh |
| Chloride, sat. paste | 54 | mg/L | | 1 | | ASA10-3 | 09/11/09 13:36 / kh |

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix interference.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

ENERGY LABORATORIES, INC. • P.O. Box 30916 • 1120 South 27th Street • Billings, MT 59107-0916
800-735-4489 • 406-252-6325 • 406-252-6069 fax • eli@energylab.com

## LABORATORY ANALYTICAL REPORT

| | | | |
|---|---|---|---|
| Client: | MT Bureau of Mines and Geology | Report Date: | 09/15/09 |
| Project: | Hysham Salt Cedar | Collection Date: | 09/03/09 13:00 |
| Lab ID: | B09090611-003 | DateReceived: | 09/04/09 |
| Client Sample ID: | E Transect 8 Ft | Matrix: | Soil |

| Analyses | Result | Units | Qualifiers | RL | MCL/ QCL | Method | Analysis Date / By |
|---|---|---|---|---|---|---|---|
| SATURATED PASTE | | | | | | | |
| pH, sat. paste | 7.70 | s.u. | | 0.10 | | ASAM10-3.2 | 09/11/09 13:36 / srm |
| Conductivity, sat. paste | 9.15 | mmhos/cm | | 0.01 | | ASA10-3 | 09/11/09 13:36 / srm |
| Calcium, sat. paste | 25.0 | meq/L | D | 0.09 | | SW6010B | 09/12/09 03:49 / tao |
| Magnesium, sat. paste | 39.6 | meq/L | | 0.08 | | SW6010B | 09/12/09 03:49 / tao |
| Sodium, sat. paste | 87.3 | meq/L | D | 0.1 | | SW6010B | 09/12/09 03:49 / tao |
| Alkalinity, sat. paste | 586 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:30 / ehb |
| Bicarbonate, sat. paste | 638 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:30 / ehb |
| Carbonate, sat. paste | 38 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:30 / ehb |
| Bicarbonate | 10 | meq/L | | | | ASA10-3 | 09/14/09 16:30 / ehb |
| Sulfate, sat. paste | 7110 | mg/L | D | 20 | | ASA10-3 | 09/11/09 13:48 / kh |
| Chloride, sat. paste | 514 | mg/L | D | 20 | | ASA10-3 | 09/11/09 13:48 / kh |

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix interference.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

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## LABORATORY ANALYTICAL REPORT

| | | | |
|---|---|---|---|
| **Client:** | MT Bureau of Mines and Geology | **Report Date:** | 09/15/09 |
| **Project:** | Hysham Salt Cedar | **Collection Date:** | 09/03/09 13:00 |
| **Lab ID:** | B09090611-004 | **DateReceived:** | 09/04/09 |
| **Client Sample ID:** | E Transect 35 Ft | **Matrix:** | Soil |

| Analyses | Result | Units | Qualifiers | RL | MCL/ QCL | Method | Analysis Date / By |
|---|---|---|---|---|---|---|---|
| **SATURATED PASTE** | | | | | | | |
| pH, sat. paste | 7.70 | s.u. | | 0.10 | | ASAM10-3.2 | 09/11/09 13:36 / srm |
| Conductivity, sat. paste | 5.09 | mmhos/cm | | 0.01 | | ASA10-3 | 09/11/09 13:36 / srm |
| Calcium, sat. paste | 26.9 | meq/L | | 0.05 | | SW6010B | 09/12/09 03:57 / tao |
| Magnesium, sat. paste | 18.5 | meq/L | | 0.08 | | SW6010B | 09/12/09 03:57 / tao |
| Sodium, sat. paste | 26.5 | meq/L | D | 0.07 | | SW6010B | 09/12/09 03:57 / tao |
| Alkalinity, sat. paste | 295 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:36 / ehb |
| Bicarbonate, sat. paste | 306 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:36 / ehb |
| Carbonate, sat. paste | 27 | mg/L | | 2 | | ASA10-3 | 09/14/09 16:36 / ehb |
| Bicarbonate | 5 | meq/L | | | | ASA10-3 | 09/14/09 16:36 / ehb |
| Sulfate, sat. paste | 3260 | mg/L | D | 10 | | ASA10-3 | 09/11/09 14:11 / kh |
| Chloride, sat. paste | 146 | mg/L | D | 10 | | ASA10-3 | 09/11/09 14:11 / kh |

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
D - RL increased due to sample matrix interference.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

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# QA/QC Summary Report

**Client:** MT Bureau of Mines and Geology **Report Date:** 09/15/09
**Project:** Hysham Salt Cedar **Work Order:** B09090611

| Analyte | Result | Units | RL | %REC | Low Limit | High Limit | RPD | RPDLimit | Qual |
|---|---|---|---|---|---|---|---|---|---|
| **Method: ASA10-3** | | | | | | | | Batch: 41370 | |
| **Sample ID: LCS-41370** | Laboratory Control Sample | | | | Run: IC202-B_090911A | | | 09/11/09 12:38 | |
| Chloride, sat. paste | 3350 | mg/L | 25 | 107 | 50 | 150 | | | |
| **Sample ID: B09090033-001AMS** | Sample Matrix Spike | | | | Run: IC202-B_090911A | | | 09/11/09 13:02 | |
| Chloride, sat. paste | 115 | mg/L | 1.0 | 100 | 70 | 130 | | | |
| **Sample ID: B09090033-001AMSD** | Sample Matrix Spike Duplicate | | | | Run: IC202-B_090911A | | | 09/11/09 13:13 | |
| Chloride, sat. paste | 116 | mg/L | 1.0 | 104 | 70 | 130 | 0.7 | 20 | |
| **Sample ID: B09090611-001ADUP** | Sample Duplicate | | | | Run: IC202-B_090911A | | | 09/11/09 14:00 | |
| Chloride, sat. paste | 276 | mg/L | 25 | | | | 4.4 | 30 | |
| **Sample ID: LCS-41370** | Laboratory Control Sample | | | | Run: IC202-B_090911A | | | 09/11/09 12:38 | |
| Sulfate, sat. paste | 1800 | mg/L | 25 | 84 | 50 | 150 | | | |
| **Sample ID: B09090033-001AMS** | Sample Matrix Spike | | | | Run: IC202-B_090911A | | | 09/11/09 13:02 | |
| Sulfate, sat. paste | 376 | mg/L | 1.0 | 103 | 70 | 130 | | | |
| **Sample ID: B09090033-001AMSD** | Sample Matrix Spike Duplicate | | | | Run: IC202-B_090911A | | | 09/11/09 13:13 | |
| Sulfate, sat. paste | 379 | mg/L | 1.0 | 106 | 70 | 130 | 0.8 | 20 | |
| **Sample ID: B09090611-001ADUP** | Sample Duplicate | | | | Run: IC202-B_090911A | | | 09/11/09 14:00 | |
| Sulfate, sat. paste | 7880 | mg/L | 25 | | | | 5.9 | 50 | |
| **Method: ASA10-3** | | | | | | | | Batch: R135840 | |
| **Sample ID: B09090244-001A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| Conductivity, sat. paste | 0.480 | mmhos/cm | 0.010 | | | | 2.1 | 30 | |
| **Sample ID: B09090294-010A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| Conductivity, sat. paste | 0.580 | mmhos/cm | 0.010 | | | | 1.7 | 30 | |
| **Sample ID: B09090294-020A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| Conductivity, sat. paste | 1.00 | mmhos/cm | 0.010 | | | | 8.3 | 30 | |
| **Sample ID: B09090294-030A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| Conductivity, sat. paste | 0.180 | mmhos/cm | 0.010 | | | | 5.4 | 30 | |
| **Sample ID: B09090611-001A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| Conductivity, sat. paste | 9.47 | mmhos/cm | 0.010 | | | | 0.3 | 30 | |
| **Sample ID: LCS-0909111336** | Laboratory Control Sample | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| Conductivity, sat. paste | 8.15 | mmhos/cm | 0.010 | 93 | 50 | 150 | | | |

**Qualifiers:**

RL - Analyte reporting limit.

ND - Not detected at the reporting limit.

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# QA/QC Summary Report

**Client:** MT Bureau of Mines and Geology
**Project:** Hysham Salt Cedar

**Report Date:** 09/15/09
**Work Order:** B09090611

| Analyte | Result | Units | RL | %REC | Low Limit | High Limit | RPD | RPDLimit | Qual |
|---|---|---|---|---|---|---|---|---|---|
| **Method: ASA10-3** | | | | | | | | Batch: R135953 | |
| **Sample ID: LCS-41370** | Laboratory Control Sample | | | | Run: MISC-WC_090914G | | | 09/14/09 16:05 | |
| Alkalinity, sat. paste | 220 | mg/L | 2.0 | 69 | 50 | 150 | | | |
| Bicarbonate, sat. paste | 269 | mg/L | 2.0 | 69 | 50 | 150 | | | |
| **Sample ID: B09090611-001ADUP** | Sample Duplicate | | | | Run: MISC-WC_090914G | | | 09/14/09 16:18 | |
| Alkalinity, sat. paste | 544 | mg/L | 2.0 | | | | 2.3 | 50 | |
| Bicarbonate, sat. paste | 559 | mg/L | 2.0 | | | | 3.9 | 50 | |
| Carbonate, sat. paste | 51.6 | mg/L | 2.0 | | | | 5.8 | 50 | |
| Bicarbonate | 9.17 | meq/L | 0.033 | | | | | | |
| **Method: ASAM10-3.2** | | | | | | | | Batch: R135840 | |
| **Sample ID: B09090244-001A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| pH, sat. paste | 7.10 | s.u. | 0.10 | | | | 1.4 | 10 | |
| **Sample ID: B09090294-010A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| pH, sat. paste | 6.50 | s.u. | 0.10 | | | | 0 | 10 | |
| **Sample ID: B09090294-020A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| pH, sat. paste | 6.20 | s.u. | 0.10 | | | | 1.6 | 10 | |
| **Sample ID: B09090294-030A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| pH, sat. paste | 6.90 | s.u. | 0.10 | | | | 1.5 | 10 | |
| **Sample ID: B09090611-001A DUP** | Sample Duplicate | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| pH, sat. paste | 7.70 | s.u. | 0.10 | | | | 0 | 10 | |
| **Sample ID: LCS-0909111336** | Laboratory Control Sample | | | | Run: MISC-SOIL_090911C | | | 09/11/09 13:36 | |
| pH, sat. paste | 6.90 | s.u. | 0.10 | 97 | 90 | 110 | | | |
| **Method: SW6010B** | | | | | | | | Batch: 41370 | |
| **Sample ID: LCS-41370** | Laboratory Control Sample | | | | Run: ICP201-B_090911A | | | 09/12/09 03:34 | |
| Calcium, sat. paste | 52.9 | meq/L | 0.092 | 100 | 50 | 150 | | | |
| Magnesium, sat. paste | 32.5 | meq/L | 0.082 | 96 | 50 | 150 | | | |
| Sodium, sat. paste | 40.6 | meq/L | 0.15 | 95 | 50 | 150 | | | |
| **Sample ID: B09090611-001A DUP** | Sample Duplicate | | | | Run: ICP201-B_090911A | | | 09/12/09 03:41 | |
| Calcium, sat. paste | 22.4 | meq/L | 0.092 | | | | 1.4 | 30 | |
| Magnesium, sat. paste | 37.7 | meq/L | 0.082 | | | | 1.6 | 30 | |
| Sodium, sat. paste | 101 | meq/L | 0.15 | | | | 2.6 | 30 | |
| **Sample ID: B09090611-003AMS2** | Sample Matrix Spike | | | | Run: ICP201-B_090911A | | | 09/12/09 03:53 | |
| Calcium, sat. paste | 49.6 | meq/L | 0.095 | 99 | 50 | 150 | | | |
| Magnesium, sat. paste | 78.7 | meq/L | 0.082 | 95 | 50 | 150 | | | |
| Sodium, sat. paste | 112 | meq/L | 0.15 | | 50 | 150 | | | A |

**Qualifiers:**

RL - Analyte reporting limit.

ND - Not detected at the reporting limit.

A - The analyte level was greater than four times the spike level. In accordance with the method % recovery is not calculated.

# Energy Laboratories Inc
# Workorder Receipt Checklist

## MT Bureau of Mines and Geology

B09090611

Login completed by: Darwin C. Miller | Date and Time Received: 9/4/2009 2:10 PM

Reviewed by: BL2000\kmcdonald | Received by: klb

Reviewed Date: 9/8/2009 9:06:21 AM | Carrier name: Hand Del

| | | | |
|---|---|---|---|
| Shipping container/cooler in good condition? | Yes ☑ | No ☐ | Not Present ☐ |
| Custody seals intact on shipping container/cooler? | Yes ☐ | No ☐ | Not Present ☑ |
| Custody seals intact on sample bottles? | Yes ☐ | No ☐ | Not Present ☑ |
| Chain of custody present? | Yes ☑ | No ☐ | |
| Chain of custody signed when relinquished and received? | Yes ☑ | No ☐ | |
| Chain of custody agrees with sample labels? | Yes ☑ | No ☐ | |
| Samples in proper container/bottle? | Yes ☑ | No ☐ | |
| Sample containers intact? | Yes ☑ | No ☐ | |
| Sufficient sample volume for indicated test? | Yes ☑ | No ☐ | |
| All samples received within holding time? | Yes ☑ | No ☐ | |
| Container/Temp Blank temperature: | 21°C | | |
| Water - VOA vials have zero headspace? | Yes ☐ | No ☐ | No VOA vials submitted ☑ |
| Water - pH acceptable upon receipt? | Yes ☐ | No ☐ | Not Applicable ☑ |

Contact and Corrective Action Comments:

None

ENERGY LABORATORIES

# Chain of Custody and Analytical Request Record

Page _____ of _____

**PLEASE PRINT- Provide as much information as possible.**

| | | | |
|---|---|---|---|
| Company Name: Montana Bureau of Mines & Geology | Project Name, PWS, Permit, Etc.: Hysham Salt Cedar | Sample Origin State: MT | EPA/State Compliance: Yes ☐ No ☐ |
| Report Mail Address: 1300 N 27th St. Billings MT 59101 | Contact Name: Elizabeth Meredith; Phone/Fax: 406-657-2929 | Email: emeredith@mtech.edu | Sampler: (Please Print) |
| Invoice Address: | Invoice Contact & Phone: email only per Client-KB | Purchase Order: | Quote/Bottle Order: |

Special Report/Formats – ELI must be notified prior to sample submittal for the following:

☐ DW ☐ GSA ☐ POTW/WWTP ☐ State: ________ ☐ Other: ________

☐ A2LA ☐ EDD/EDT (Electronic Data) **Format:** ________ ☐ LEVEL IV ☐ NELAC

**Number of Containers** Sample Type: A W S V B O — Air Water Soils/Solids Vegetation Bioassay Other

ANALYSIS REQUESTED: EC, PH, CA, MG, NA; ALK, CL, SO4 — SEE ATTACHED — Normal Turnaround (TAT)

**R U S H** — Contact ELI prior to **RUSH** sample submittal for charges and scheduling – See Instruction Page

Comments: Quote $80/sample per Wynn-KB. Ask Wynn if questions

Shipped by: hand. Cooler ID(s): . Receipt Temp: 21 °C. On Ice: Yes (No). Custody Seal: Y (N). Bottles/Coolers: B C. Intact: Y (N). Signature Match: Y (N)

| | SAMPLE IDENTIFICATION (Name, Location, Interval, etc.) | Collection Date | Collection Time | MATRIX | EC, PH, CA, MG, NA / ALK, CL, SO4 | LABORATORY USE ONLY |
|---|---|---|---|---|---|---|
| 1 | N transect Cft | 9/3/09 | 13:00 | | X | B09090611-001 |
| 2 | N transect 20 ft | 9/3/09 | \| | | X | -002 |
| 3 | E transect 8 ft | 9/3/09 | \| | | X | -003 |
| 4 | E transect 35 ft | 9/3/09 | 13:00 | | X | -004 |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |

**Custody Record MUST be Signed**

| | | | | | |
|---|---|---|---|---|---|
| Relinquished by (print): Elizabeth Meredith | Date/Time: 9/4/09 | Signature: Elizabeth Meredith | Received by (print): | Date/Time: | Signature: |
| Relinquished by (print): | Date/Time: | Signature: | Received by (print): | Date/Time: | Signature: |
| Sample Disposal: Return to Client: ______ | Lab Disposal: ______ | | Received by Laboratory: Kris Buehler | Date/Time: 9/4/09 14:10 | Signature: |

In certain circumstances, samples submitted to Energy Laboratories, Inc. may be subcontracted to other certified laboratories in order to complete the analysis requested. This serves as notice of this possibility. All sub-contract data will be clearly notated on your analytical report. Visit our web site at www.energylab.com for additional information, downloadable fee schedule, forms, and links.

Minteqa2 Species Table for North Transect at 6 feet.

| Component | % of total mComponent concentration | Species name |
|---|---|---|
| Cl-1 | 98.302 | Cl-1 |
| | 0.361 | CaCl+ |
| | 1.095 | MgCl+ |
| | 0.241 | NaCl (aq) |
| Ca+2 | 40.462 | Ca+2 |
| | 0.243 | CaCl+ |
| | 57.609 | CaSO4 (aq) |
| | 1.378 | CaHCO3+ |
| | 0.308 | CaCO3 (aq) |
| Mg+2 | 46.038 | Mg+2 |
| | 0.015 | Mg2CO3+2 |
| | 0.439 | MgCl+ |
| | 52.067 | MgSO4 (aq) |
| | 0.175 | MgCO3 (aq) |
| | 1.263 | MgHCO3+ |
| Na+1 | 89.852 | Na+1 |
| | 0.203 | NaHCO3 (aq) |
| | 0.182 | NaCl (aq) |
| | 9.739 | NaSO4- |
| | 0.024 | NaCO3- |
| CO3-2 | 0.496 | CO3-2 |
| | 0.224 | NaHCO3 (aq) |
| | 0.015 | Mg2CO3+2 |
| | 91.198 | HCO3- |
| | 2.983 | H2CO3* (aq) |
| | 0.364 | MgCO3 (aq) |
| | 2.618 | MgHCO3+ |
| | 1.698 | CaHCO3+ |
| | 0.379 | CaCO3 (aq) |
| | 0.027 | NaCO3- |
| SO4-2 | 78.005 | SO4-2 |
| | 12.518 | MgSO4 (aq) |
| | 8.231 | CaSO4 (aq) |
| | 1.245 | NaSO4- |

Minteqa2 Saturation Index for North Transect at 6 feet.

| Mineral | log IAP | Sat. Index | Stoichiometry | | | |
|---|---|---|---|---|---|---|
| Anhydrite | -4.54 | -0.18 | 1 Ca+2 | 1 SO4-2 | | |
| Aragonite | -7.673 | 0.663 | 1 Ca+2 | 1 CO3-2 | | |
| Artinite | 5.456 | -4.144 | -2 H+1 | 2 Mg+2 | 1 CO3-2 | 5 H2O |
| Brucite | 12.847 | -4.253 | 1 Mg+2 | 2 H2O | -2 H+1 | |
| CaCO3xH2O | -7.673 | -0.528 | 1 Ca+2 | 1 CO3-2 | 1 H2O | |
| Calcite | -7.673 | 0.807 | 1 Ca+2 | 1 CO3-2 | | |
| Dolomite (disordered) | -15.063 | 1.477 | 1 Ca+2 | 1 Mg+2 | 2 CO3-2 | |
| Dolomite (ordered) | -15.063 | 2.027 | 1 Ca+2 | 1 Mg+2 | 2 CO3-2 | |
| Epsomite | -4.258 | -2.132 | 1 Mg+2 | 1 SO4-2 | 7 H2O | |
| Gypsum | -4.54 | 0.07 | 1 Ca+2 | 1 SO4-2 | 2 H2O | |
| Halite | -4.429 | -5.979 | 1 Na+1 | 1 Cl-1 | | |
| Huntite | -29.845 | 0.123 | 3 Mg+2 | 1 Ca+2 | 4 CO3-2 | |
| Hydromagnesite | -16.716 | -7.95 | 5 Mg+2 | 4 CO3-2 | -2 H+1 | 6 H2O |
| Lime | 12.565 | -20.134 | -2 H+1 | 1 Ca+2 | 1 H2O | |
| Magnesite | -7.391 | 0.069 | 1 Mg+2 | 1 CO3-2 | | |
| Mg(OH)2 (active) | 12.847 | -5.947 | 1 Mg+2 | 2 H2O | -2 H+1 | |
| Mg2(OH)3Cl:4H2O | 15.737 | -10.263 | 2 Mg+2 | 1 Cl-1 | -3 H+1 | 7 H2O |
| MgCO3:5H2O | -7.391 | -2.851 | 1 Mg+2 | 1 CO3-2 | 5 H2O | |
| Mirabilite | -6.05 | -4.936 | 2 Na+1 | 1 SO4-2 | 10 H2O | |
| Natron | -9.183 | -7.872 | 2 Na+1 | 1 CO3-2 | 10 H2O | |
| Nesquehonite | -7.391 | -2.721 | 1 Mg+2 | 1 CO3-2 | 3 H2O | |
| Periclase | 12.847 | -8.737 | -2 H+1 | 1 Mg+2 | 1 H2O | |
| Portlandite | 12.565 | -10.139 | 1 Ca+2 | 2 H2O | -2 H+1 | |
| Thenardite | -6.05 | -6.372 | 2 Na+1 | 1 SO4-2 | | |
| Thermonatrite | -9.183 | -9.82 | 2 Na+1 | 1 CO3-2 | 1 H2O | |
| Vaterite | -7.673 | 0.241 | 1 Ca+2 | 1 CO3-2 | | |

Minteqa2 Species Table for North Transect at 20 feet.

| Component | % of total mComponent concentration | Species name |
|---|---|---|
| Cl-1 | 98.614 | Cl-1 |
| | 0.504 | CaCl+ |
| | 0.616 | MgCl+ |
| | 0.267 | NaCl (aq) |
| Ca+2 | 67.549 | Ca+2 |
| | 0.124 | CaCl+ |
| | 29.427 | CaSO4 (aq) |
| | 2.635 | CaHCO3+ |
| | 0.266 | CaCO3 (aq) |
| Mg+2 | 72.336 | Mg+2 |
| | 0.21 | MgCl+ |
| | 25.031 | MgSO4 (aq) |
| | 0.143 | MgCO3 (aq) |
| | 2.272 | MgHCO3+ |
| Na+1 | 97.609 | Na+1 |
| | 0.213 | NaHCO3 (aq) |
| | 0.051 | NaCl (aq) |
| | 2.119 | NaSO4- |
| CO3-2 | 0.141 | CO3-2 |
| | 0.237 | NaHCO3 (aq) |
| | 87.465 | HCO3- |
| | 8.157 | H2CO3* (aq) |
| | 0.088 | MgCO3 (aq) |
| | 1.407 | MgHCO3+ |
| | 2.266 | CaHCO3+ |
| | 0.229 | CaCO3 (aq) |
| SO4-2 | 72.326 | SO4-2 |
| | 9.936 | MgSO4 (aq) |
| | 16.228 | CaSO4 (aq) |
| | 1.509 | NaSO4- |

Minteqa2 Saturation Index for North Transect at 20 feet.

| Mineral | log IAP | Sat. Index | Stoichiometry | | | |
|---|---|---|---|---|---|---|
| Anhydrite | -5.095 | -0.735 | 1 Ca+2 | 1 SO4-2 | | |
| Aragonite | -7.999 | 0.337 | 1 Ca+2 | 1 CO3-2 | | |
| Artinite | 3.683 | -5.917 | -2 H+1 | 2 Mg+2 | 1 CO3-2 | 5 H2O |
| Brucite | 11.795 | -5.305 | 1 Mg+2 | 2 H2O | -2 H+1 | |
| CaCO3xH2O | -7.999 | -0.855 | 1 Ca+2 | 1 CO3-2 | 1 H2O | |
| Calcite | -7.999 | 0.481 | 1 Ca+2 | 1 CO3-2 | | |
| Dolomite (disordered) | -16.112 | 0.428 | 1 Ca+2 | 1 Mg+2 | 2 CO3-2 | |
| Dolomite (ordered) | -16.112 | 0.978 | 1 Ca+2 | 1 Mg+2 | 2 CO3-2 | |
| Epsomite | -5.208 | -3.082 | 1 Mg+2 | 1 SO4-2 | 7 H2O | |
| Gypsum | -5.095 | -0.485 | 1 Ca+2 | 1 SO4-2 | 2 H2O | |
| Halite | -5.087 | -6.637 | 1 Na+1 | 1 Cl-1 | | |
| Huntite | -32.336 | -2.368 | 3 Mg+2 | 1 Ca+2 | 4 CO3-2 | |
| Hydromagnesite | -20.654 | -11.888 | 5 Mg+2 | 4 CO3-2 | -2 H+1 | 6 H2O |
| Lime | 11.908 | -20.791 | -2 H+1 | 1 Ca+2 | 1 H2O | |
| Magnesite | -8.112 | -0.652 | 1 Mg+2 | 1 CO3-2 | | |
| Mg(OH)2 (active) | 11.795 | -6.999 | 1 Mg+2 | 2 H2O | -2 H+1 | |
| Mg2(OH)3Cl:4H2O | 13.389 | -12.611 | 2 Mg+2 | 1 Cl-1 | -3 H+1 | 7 H2O |
| MgCO3:5H2O | -8.112 | -3.572 | 1 Mg+2 | 1 CO3-2 | 5 H2O | |
| Mirabilite | -6.774 | -5.66 | 2 Na+1 | 1 SO4-2 | 10 H2O | |
| Natron | -9.679 | -8.368 | 2 Na+1 | 1 CO3-2 | 10 H2O | |
| Nesquehonite | -8.112 | -3.442 | 1 Mg+2 | 1 CO3-2 | 3 H2O | |
| Periclase | 11.795 | -9.789 | -2 H+1 | 1 Mg+2 | 1 H2O | |
| Portlandite | 11.908 | -10.796 | 1 Ca+2 | 2 H2O | -2 H+1 | |
| Thenardite | -6.774 | -7.096 | 2 Na+1 | 1 SO4-2 | | |
| Thermonatrite | -9.679 | -10.316 | 2 Na+1 | 1 CO3-2 | 1 H2O | |
| Vaterite | -7.999 | -0.086 | 1 Ca+2 | 1 CO3-2 | | |

Minteqa2 Species Table for East Transect at 8 feet.

| Component | % of total mComponent concentration | Species name |
|---|---|---|
| Cl-1 | 96.273 | Cl-1 |
| | 0.437 | CaCl+ |
| | 1.229 | MgCl+ |
| | 2.06 | NaCl (aq) |
| Ca+2 | 46.192 | Ca+2 |
| | 0.507 | CaCl+ |
| | 51.191 | CaSO4 (aq) |
| | 1.73 | CaHCO3+ |
| | 0.379 | CaCO3 (aq) |
| Mg+2 | 51.747 | Mg+2 |
| | 0.021 | Mg2CO3+2 |
| | 0.901 | MgCl+ |
| | 45.553 | MgSO4 (aq) |
| | 0.213 | MgCO3 (aq) |
| | 1.561 | MgHCO3+ |
| Na+1 | 91.302 | Na+1 |
| | 0.23 | NaHCO3 (aq) |
| | 0.342 | NaCl (aq) |
| | 8.098 | NaSO4- |
| | 0.028 | NaCO3- |
| CO3-2 | 0.498 | CO3-2 |
| | 1.898 | NaHCO3 (aq) |
| | 0.02 | Mg2CO3+2 |
| | 88.697 | HCO3- |
| | 2.85 | H2CO3* (aq) |
| | 0.398 | MgCO3 (aq) |
| | 2.918 | MgHCO3+ |
| | 2.043 | CaHCO3+ |
| | 0.448 | CaCO3 (aq) |
| | 0.231 | NaCO3- |
| SO4-2 | 69.622 | SO4-2 |
| | 12.182 | MgSO4 (aq) |
| | 8.646 | CaSO4 (aq) |
| | 9.551 | NaSO4- |

Minteqa2 Saturation Index for East Transect at 8 feet.

| Mineral | log IAP | Sat. Index | Stoichiometry | | | |
|---|---|---|---|---|---|---|
| Anhydrite | -4.535 | -0.175 | 1 Ca+2 | 1 SO4-2 | | |
| Aragonite | -7.525 | 0.811 | 1 Ca+2 | 1 CO3-2 | | |
| Artinite | 5.63 | -3.97 | -2 H+1 | 2 Mg+2 | 1 CO3-2 | 5 H2O |
| Brucite | 12.906 | -4.194 | 1 Mg+2 | 2 H2O | -2 H+1 | |
| CaCO3xH2O | -7.525 | -0.381 | 1 Ca+2 | 1 CO3-2 | 1 H2O | |
| Calcite | -7.525 | 0.955 | 1 Ca+2 | 1 CO3-2 | | |
| Dolomite (disordered) | -14.801 | 1.739 | 1 Ca+2 | 1 Mg+2 | 2 CO3-2 | |
| Dolomite (ordered) | -14.801 | 2.289 | 1 Ca+2 | 1 Mg+2 | 2 CO3-2 | |
| Epsomite | -4.286 | -2.159 | 1 Mg+2 | 1 SO4-2 | 7 H2O | |
| Gypsum | -4.535 | 0.075 | 1 Ca+2 | 1 SO4-2 | 2 H2O | |
| Halite | -3.206 | -4.756 | 1 Na+1 | 1 Cl-1 | | |
| Huntite | -29.353 | 0.615 | 3 Mg+2 | 1 Ca+2 | 4 CO3-2 | |
| Hydromagnesite | -16.198 | -7.432 | 5 Mg+2 | 4 CO3-2 | -2 H+1 | 6 H2O |
| Lime | 12.657 | -20.042 | -2 H+1 | 1 Ca+2 | 1 H2O | |
| Magnesite | -7.276 | 0.184 | 1 Mg+2 | 1 CO3-2 | | |
| Mg(OH)2 (active) | 12.906 | -5.888 | 1 Mg+2 | 2 H2O | -2 H+1 | |
| Mg2(OH)3Cl:4H2O | 16.131 | -9.869 | 2 Mg+2 | 1 Cl-1 | -3 H+1 | 7 H2O |
| MgCO3:5H2O | -7.276 | -2.736 | 1 Mg+2 | 1 CO3-2 | 5 H2O | |
| Mirabilite | -4.241 | -3.127 | 2 Na+1 | 1 SO4-2 | 10 H2O | |
| Natron | -7.231 | -5.92 | 2 Na+1 | 1 CO3-2 | 10 H2O | |
| Nesquehonite | -7.276 | -2.606 | 1 Mg+2 | 1 CO3-2 | 3 H2O | |
| Periclase | 12.906 | -8.678 | -2 H+1 | 1 Mg+2 | 1 H2O | |
| Portlandite | 12.657 | -10.047 | 1 Ca+2 | 2 H2O | -2 H+1 | |
| Thenardite | -4.241 | -4.563 | 2 Na+1 | 1 SO4-2 | | |
| Thermonatrite | -7.231 | -7.868 | 2 Na+1 | 1 CO3-2 | 1 H2O | |
| Vaterite | -7.525 | 0.388 | 1 Ca+2 | 1 CO3-2 | | |

Minteqa2 Species Table for East Transect at 35 feet.

| Component | % of total mComponent concentration | Species name |
|---|---|---|
| Cl-1 | 97.714 | Cl-1 |
| | 0.701 | CaCl+ |
| | 0.839 | MgCl+ |
| | 0.747 | NaCl (aq) |
| Ca+2 | 55.518 | Ca+2 |
| | 0.214 | CaCl+ |
| | 42.747 | CaSO4 (aq) |
| | 1.23 | CaHCO3+ |
| | 0.29 | CaCO3 (aq) |
| Mg+2 | 61.034 | Mg+2 |
| | 0.374 | MgCl+ |
| | 37.329 | MgSO4 (aq) |
| | 0.16 | MgCO3 (aq) |
| | 1.089 | MgHCO3+ |
| Na+1 | 95.048 | Na+1 |
| | 0.131 | NaHCO3 (aq) |
| | 0.116 | NaCl (aq) |
| | 4.69 | NaSO4- |
| | 0.015 | NaCO3- |
| CO3-2 | 0.432 | CO3-2 |
| | 0.683 | NaHCO3 (aq) |
| | 89.424 | HCO3- |
| | 3.09 | H2CO3* (aq) |
| | 0.29 | MgCO3 (aq) |
| | 1.978 | MgHCO3+ |
| | 3.25 | CaHCO3+ |
| | 0.766 | CaCO3 (aq) |
| | 0.077 | NaCO3- |
| SO4-2 | 69.224 | SO4-2 |
| | 10.171 | MgSO4 (aq) |
| | 16.943 | CaSO4 (aq) |
| | 3.662 | NaSO4- |

Minteqa2 Saturation Index for East Transect at 35 feet.

| Mineral | log IAP | Sat. Index | Stoichiometry | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Anhydrite | -4.591 | -0.231 | 1 | Ca+2 | 1 | SO4-2 | | | | |
| Aragonite | -7.62 | 0.716 | 1 | Ca+2 | 1 | CO3-2 | | | | |
| Artinite | 4.993 | -4.607 | -2 | H+1 | 2 | Mg+2 | 1 | CO3-2 | 5 | H2O |
| Brucite | 12.734 | -4.366 | 1 | Mg+2 | 2 | H2O | -2 | H+1 | | |
| CaCO3xH2O | -7.62 | -0.475 | 1 | Ca+2 | 1 | CO3-2 | 1 | H2O | | |
| Calcite | -7.62 | 0.86 | 1 | Ca+2 | 1 | CO3-2 | | | | |
| Dolomite (disordered) | -15.361 | 1.179 | 1 | Ca+2 | 1 | Mg+2 | 2 | CO3-2 | | |
| Dolomite (ordered) | -15.361 | 1.729 | 1 | Ca+2 | 1 | Mg+2 | 2 | CO3-2 | | |
| Epsomite | -4.713 | -2.586 | 1 | Mg+2 | 1 | SO4-2 | 7 | H2O | | |
| Gypsum | -4.591 | 0.019 | 1 | Ca+2 | 1 | SO4-2 | 2 | H2O | | |
| Halite | -4.203 | -5.753 | 1 | Na+1 | 1 | Cl-1 | | | | |
| Huntite | -30.843 | -0.875 | 3 | Mg+2 | 1 | Ca+2 | 4 | CO3-2 | | |
| Hydromagnesite | -18.231 | -9.465 | 5 | Mg+2 | 4 | CO3-2 | -2 | H+1 | 6 | H2O |
| Lime | 12.855 | -19.844 | -2 | H+1 | 1 | Ca+2 | 1 | H2O | | |
| Magnesite | -7.741 | -0.281 | 1 | Mg+2 | 1 | CO3-2 | | | | |
| Mg(OH)2 (active) | 12.734 | -6.06 | 1 | Mg+2 | 2 | H2O | -2 | H+1 | | |
| Mg2(OH)3Cl:4H2O | 15.268 | -10.732 | 2 | Mg+2 | 1 | Cl-1 | -3 | H+1 | 7 | H2O |
| MgCO3:5H2O | -7.741 | -3.201 | 1 | Mg+2 | 1 | CO3-2 | 5 | H2O | | |
| Mirabilite | -5.453 | -4.339 | 2 | Na+1 | 1 | SO4-2 | 10 | H2O | | |
| Natron | -8.482 | -7.171 | 2 | Na+1 | 1 | CO3-2 | 10 | H2O | | |
| Nesquehonite | -7.741 | -3.071 | 1 | Mg+2 | 1 | CO3-2 | 3 | H2O | | |
| Periclase | 12.734 | -8.85 | -2 | H+1 | 1 | Mg+2 | 1 | H2O | | |
| Portlandite | 12.855 | -9.849 | 1 | Ca+2 | 2 | H2O | -2 | H+1 | | |
| Thenardite | -5.453 | -5.775 | 2 | Na+1 | 1 | SO4-2 | | | | |
| Thermonatrite | -8.482 | -9.119 | 2 | Na+1 | 1 | CO3-2 | 1 | H2O | | |
| Vaterite | -7.62 | 0.294 | 1 | Ca+2 | 1 | CO3-2 | | | | |