Report for 2004MT31B: Defining river recharge and three-dimensional areas of contribution to production wells adjacent to a losing river, Western Montana

- Conference Proceedings:
  - Cook, R.C.. A.A. Tallman and W.W. Woessner. 2004. Preliminary results for defining river recharge and the fate of arsenic in the shallow groundwater system adjacent to a losing river, western Montana. Center for Riverine Science and Stream Renaturalization Conference Proceedings. Univeristy of Montana, Missoula.
  - Tallman, A.A., R.C. Cook and W.W. Woessner. 2004. Preliminary results of a capture zone study on bank-side production wells and their interaction with a perched river in an alluvial aquifer, western Montana. Center for Riverine Studies and Stream Renaturalization Conference Proceedings. University of Montana, Missoula.
  - Tallman, A.A., R.C. Cook and W.W. Woessner. 2005. Identifying the factors controlling the sources and quantity of water captured by municipal supply wells in the highly conductive Missoula aquifer, western Montana. National Ground Water Association Ground Water Summit.

Report Follows

ABSTRACT:

The Clark Fork River in Missoula MT has been reported to provide 50 to 80 % of the recharge to the Sole Source Missoula Aquifer that serves over 60,000 Missoula area residents. If this principle recharge source to the unconfined aquifer becomes contaminated, water from high yield municipal wells may be at risk. This work is addressing the zones of contribution and source water quality. This includes characterization of stream stage, streambed temperature gradients, streambed vertical gradients, and streambed hydraulic conductivity as well as water level trends, the distribution of aquifer hydraulic conductivity, and both vertical and horizontal gradients. These parameters along with sets of geochemical data are being used to produce and calibrate a three-dimensional transient ground water flow model that examines the timing, quantities and sources of water to riverside production wells. The preliminary conceptual model suggests the river is perched 5 to 16 ft above the aquifer and is losing water to the aquifer. The wells derive about 90.5% of their water from river recharge and approximately 7% from underflow originating from an up gradient canyon. These values are supported by vertical leakage rates computed from head and in-stream temperature profiles and discharge estimates computed using general aquifer properties. The results are also supported by general chemistry and stable isotope data. Numerical modeling will be used to evaluate the current conceptual model and test additional representations as new data are generated.

OBJECTIVES:

The purpose of this study is two-fold; 1) to determine the capture zone for municipal wells near the Clark Fork River based on transient modeling of the aquifer system and 2) to investigate the fate and transport of arsenic in the Clark Fork River – Missoula Aquifer system.

METHODS:

Thirty five groundwater and surface water sites are monitored. Water chemistry is monitored at 22 sites including 4 production wells 15 monitoring wells, 3 surface water locations, and one streambed peizometer. Water levels are monitored at 35 sites, 3 production wells, 28 monitoring wells and 4 surface water sites (Figure 1.).

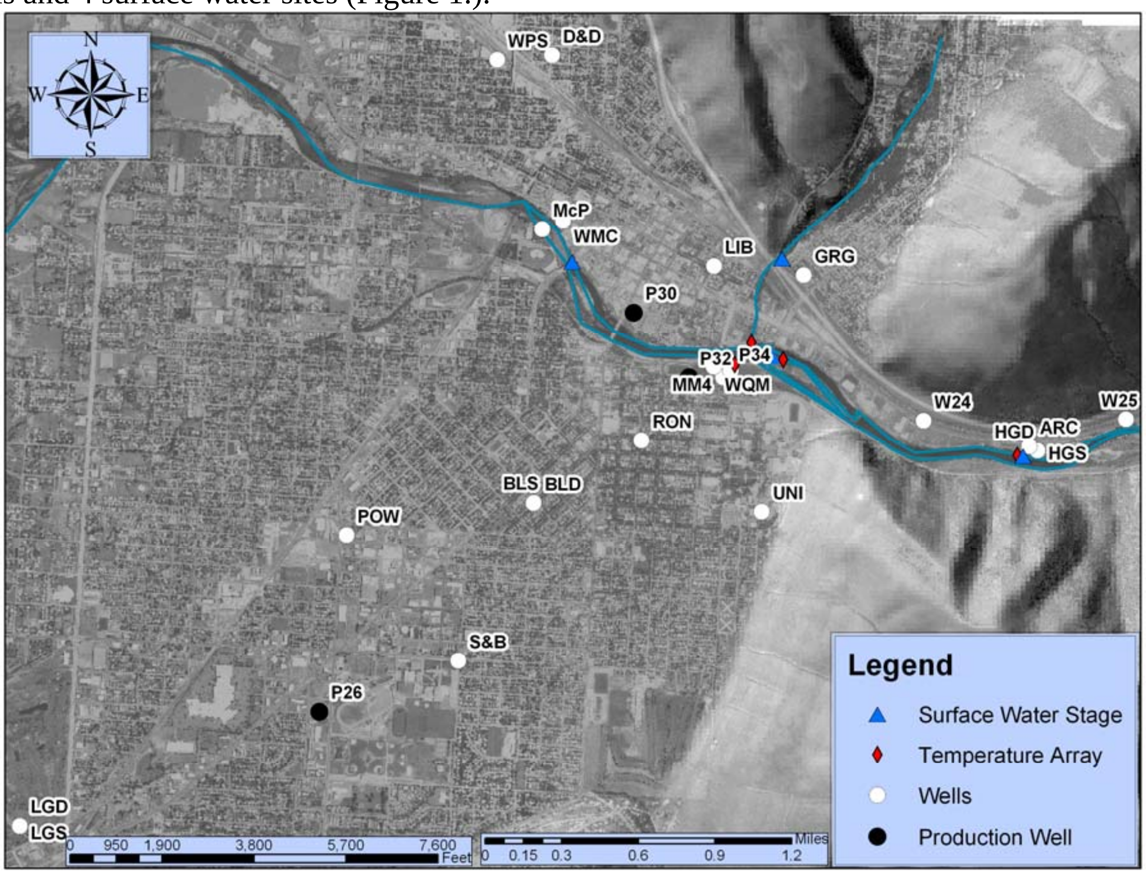

Figure 1. Site Locations

CHEMISTRY METHODS

Sample Sites: Nineteen wells (four deep production wells and 15 monitoring wells), and three surface water sites (Clark Fork River in two sites, Rattlesnake Creek), were sampled weekly from May the sites will be sampled three times a month.   to August, biweekly until October, then monthly through February. From March through June

Field Methods: Field geochemical parameters (pH, temperature and electric conductivity) were measured at each sampling site. Monitoring wells were pumped (using a Grundflos pump) until three bore-hole volumes had been removed. A new disposable polyethylene bailer was then used to collect enough water to rinse the bottle and obtain a sample. Production wells were sampled from a spigot before any treatment. The Clark Fork River and Rattlesnake Creek were sampled by wading out into moving water and sampling at a range of depths to obtain a representative sample. During each round of sampling field duplicates and blanks were taken for quality assurance and quality control.

All samples were collected using ultra clean techniques to reduce the possibility of contamination (after Mickey, 1998 and MBEL Sampling Method #2). This process involved using ultra cleaned 120 mL nalgene bottles that were doubled-bagged and handled by one set of “clean hands” and one set of “dirty hands.” “Dirty hands” only touched the external bag, while “clean hands” only touched the internal bag and sample bottles. Each bottle was rinsed with sample water three times. Surface water samples were collected underwater, and samples from wells were filled to overflowing and capped so that there was minimal head space. “Clean hands” placed the sample in an individual zip-lock bag which was then placed in an open external bag. “Dirty hands” sealed the external bag. Additional samples for anions were collected in non-acid washed bottles. These samples were collected after the ultra clean samples since detection levels for anions are much higher and the same precautions do not need to be taken. All samples were stored on ice.

Lab Methods: Samples were filtered in lab as soon as possible (and no longer then 48 hours after sampling) using ultra clean syringes and <0.45 μm syringe filters (MBEL SOP 2004_06_21 Tallman) All filtering took place in a hood (MBEL McKinnon and Nagorski, 2000). New ultra clean 30 mL bottles were rinsed and filled, then acidified with 2% HNO_3 for preservation. Anion samples were filtered after the respective ultra clean samples, using the same filter but first rinsing the syringe with the anion sample. Isotope samples were not filtered; instead a 30 mL bottle was filled to an inverted meniscus and capped to incorporate as little air as possible. Isotopes were analyzed at The University of Alaska Fairbanks by the Water and Environmental Research Center’s Stable Isotopes Facility. All other analyses were performed at The University of Montana. The ultra clean samples were analyzed for As, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Pb, and Zn using MEBL EPA6020mod method ICP-MS analysis for metals. Alkalinity was determined in mg/L of $CaCO_3$ using titration, and F, Cl, NO_3, NO_2 and SO_4 were determined using Ion Chromatography.

Quality control/quality assurance: Field duplicates and blanks, along with lab splits are used with internal and external standards to ensure precision and accuracy. From the field duplicates and lab splits a 95% confidence level was calculated for each result from MS, IC and Isotope analyses.

Modeling Methods

Field and Analytical Methods:

The geologic and hydrogeologic setting was characterized with a detailed review of the literature, interpretation of well logs, core data, geologic studies, drillers' data, consultant reports, and the drilling of four additional monitoring wells. Well logs were utilized to create lithologic cross sections of the Missoula Aquifer.

The water table was monitored through a network of 29 wells established along the river near production wells and extending down groundwater gradient. Two production wells and five monitoring wells were instrumented with Solinst Leveloggers, recording water level and temperature data on an hourly basis. Twenty-nine wells located along the CFR and down gradient were measured for water level every two weeks through the peak of the hydro period and then on a monthly basis, using electric tape measurements to the top of casing.

Surface water stage measurements were collected at three sites along the CFR and at one site on Rattlesnake Creek. Stage monitoring sites along the CFR included a staff gauge in Hellgate Canyon, a mini-stilling well fitted with a Solinst Levelogger below the walking bridge and a bridge-to-water measurement site at Orange St. Bridge. The Rattlesnake Creek stage was monitored via a bridge-to-water measurement site on Railroad St. Bridge. Supplementary river flow measurements were collected from the upper and lower USGS gauging sites.

Fluxes through the streambed were obtained using temperature trends and from stream discharge measurements. The river, Rattlesnake Creek, and the irrigation ditch were instrumented with multilevel temperature recording sandpoints. Temperatures were recorded on an hourly basis by a series of temperature i-buttons at one foot intervals to a depth of three feet below the river surface (Johnson et. al., 2005). Hydraulic conductivities and fluxes were estimated for the streambed by calibrating a one-dimensional heat transport model using VS2DHI, to observed temperature trends (Bartilino and Niswonger, 1999, Constantz 1996 &1998, Constantz et al., 2003, Hsieh et. al., 2000, Ronan et al., 1998). Streambed fluxes were also calculated from Stream discharge measurements performed at four transects along the CFR. The gaging was done in March utilizing a SonTek Acoustic Doppler Profiler RiverCAT (Sloat, 2003). Two additional stream discharge measurements were taken along Rattlesnake Creek utilizing a SonTek Acoustic Doppler Flowmeter.

Further, aquifer characterization to derive hydrogeologic properties and hydrogeologic boundaries included pumping and slug tests. Three pump tests were executed, pumping the Arthur St. well *(P32)* and monitoring both the Madison Street well *(P34)* and well MM4. Each test was run for 6 hours, pumping at a rate of 3500 gpm, water levels were recorded at 10 second intervals. The pump tests were analyzed with the Neuman method (Fetter, 1994). Hydraulic conductivity of the aquifer was estimated at four additional sites based on pneumatic slug tests utilizing a Geoprobe Pneumatic Slug Test Kit, with adaptations to fit various well casing sizes (Geoprobe Systems, 2002). The pneumatic slug tests were analyzed with a high K Bouwer and Rice model (Butler and Garnett, 2000). The hydraulic conductivity of the streambed was also estimated at four sites via falling head tests. A minimum of three falling head tests were performed at each site. A steel peizometer was installed in the stream bed and fitted with a 2.5 ft falling head cell, marked at 4 inch intervals. Time was recorded as the water level dropped to each successive interval. The streambed falling head tests were analyzed with the Bouwer and Rice equation (Bouwer, 1989 & Fetter, 1994).

The water budget, geology, and hydrogeology of the system were compiled into a conceptual model of the aquifer. A three-dimensional transient numerical model was designed with Ground Water Vistas modeling program. The model encompasses approximately five square miles, discretized in 150 X 150 ft grid spacing. It is unconfined with an approximate thickness of 250 ft. The model is three dimensional, with seven layers, the depth and thickness of these layers are based on well screen locations and on the silty sand layer lying at approximately 100 ft below the surface (Figure 2). Hydraulic conductivities have been set based on my conductivity tests and the tests of other local studies. The model was calibrated to observed head data and river flux determined from stream gaging and temperature trends.

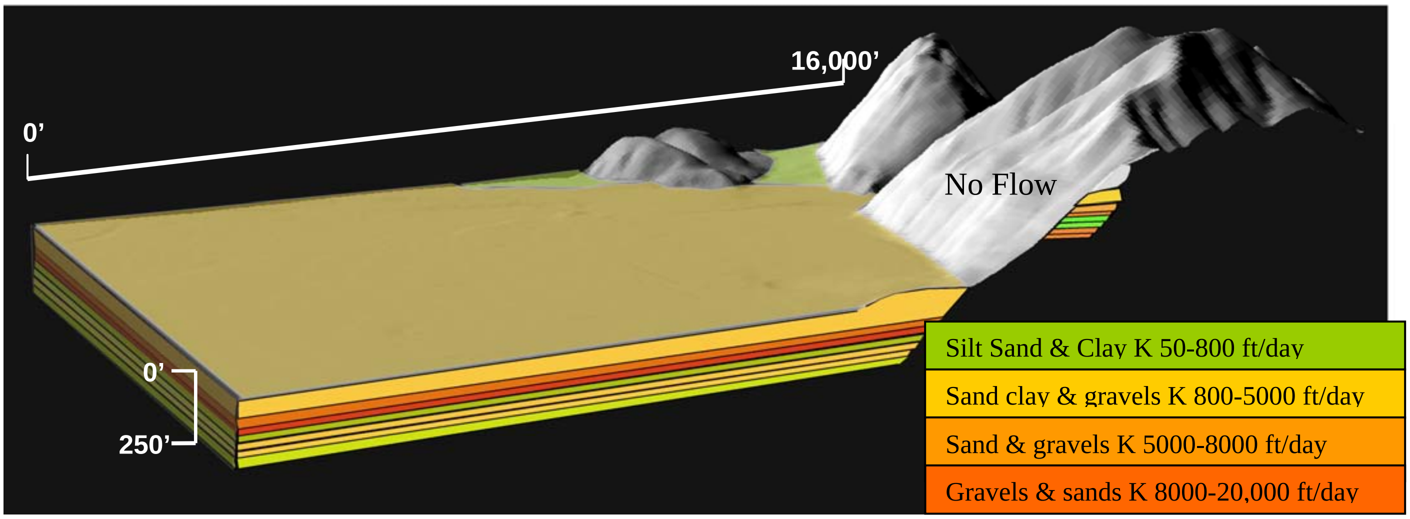

Figure 2. Generalized 3-D model setup

<u>PRELIMINARY RESULTS</u>:

CHEMISTRY RESULTS

Isotopes: The isotope data to date shows that there is a strong connection between the Clark Fork River and groundwater (Figure 3). The slight differences between the groundwater and the river water suggest that some other sources (regional precipitation, springs, and/or regional groundwater) are also contributing water to the Missoula aquifer. However, the isotopic signal of the groundwater appears to be driven primarily by the chemistry of the Clark Fork. Sampling will continue through June in order to catch a runoff event with a distinct isotopic signal.

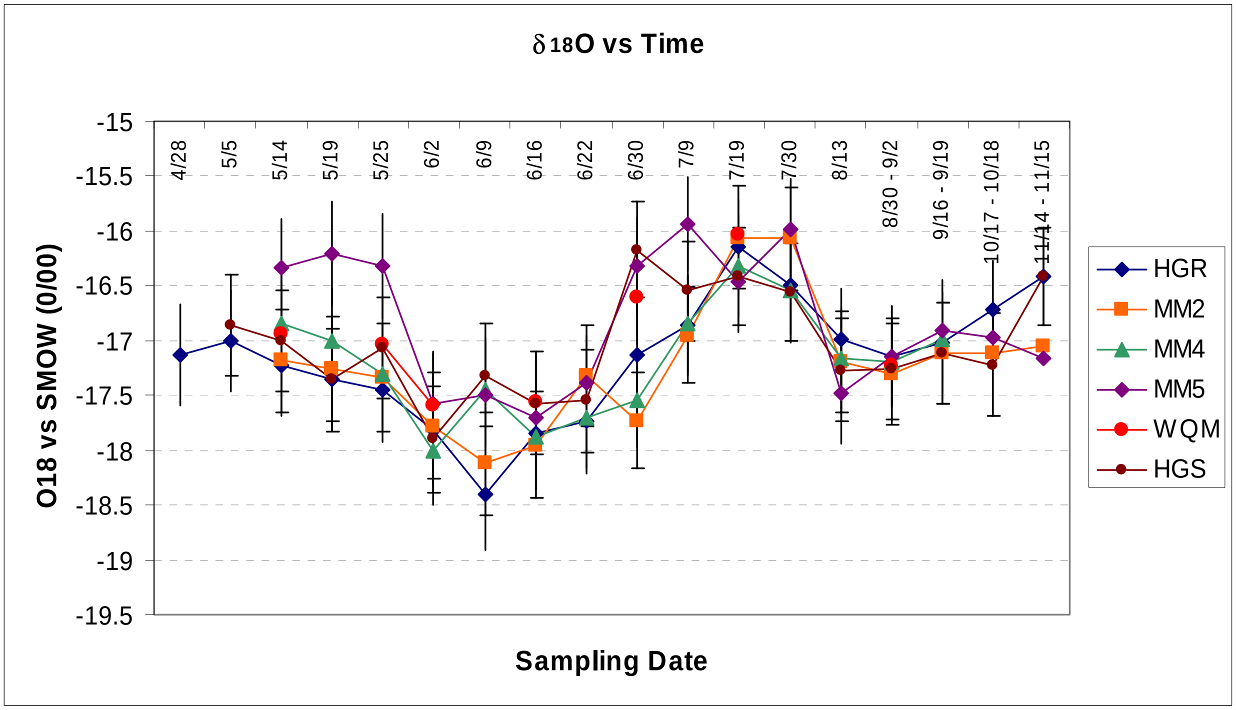

Figure 3. The Clark Fork River (HGR) controls the isotopic signal of groundwater. MM2, MM4, MM5, WQM and HGS are all monitoring wells near the river. Similar trends are found for distal wells.

General Chemistry: Most elements (with the exception of Cu) behave conservatively in the river, and concentrations are controlled by discharge. River discharge does not appear to control the concentrations found in groundwater samples. This is most likely due to chemical and physical reactions taking place in the vadose zone and/or in the aquifer. Plotting all of the sample sites on a piper diagram (Figure 4) illustrates the similarity among water types.

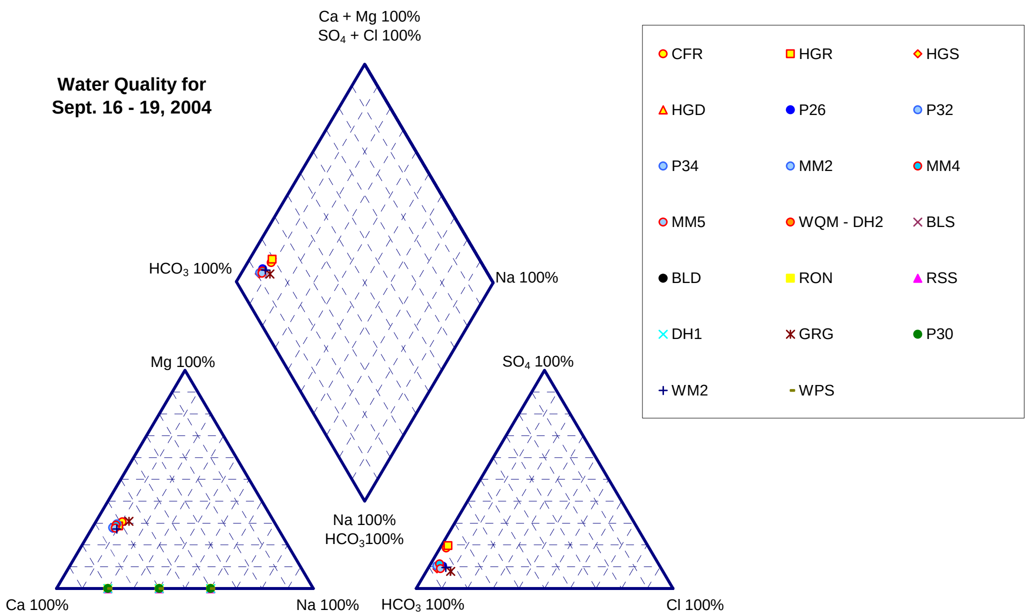

Figure 4. All water types plot in the same general area, making distinction between the river and groundwater difficult.

Arsenic: The fate of arsenic in the system is very interesting. Most of the year, it appears as though As is lost to the aquifer or vadose zone. This happens when there is a higher concentration of As in the river than in the groundwater (Figure 5). There are other times, when As values are higher in the groundwater than the river, when excess As is released from the aquifer system to the groundwater (Figure 5).

Milltown Reservoir was lowered approximately 8 feet during July, and was held at a low stand until the middle of August. Samples taken every three days during that period at both a shallow monitoring well and a production well show an immediate response to the increased concentration of arsenic in the river (Figure 6). While the level of arsenic in the river has remained high, concentrations in the wells declined to levels similar to pre-drawdown conditions (Figure 7).

In general, the wells farther from the river have lower As concentrations, and the lowest concentrations are in wells on the north side of the river (Figure8). Rattlesnake creek has very low concentrations of arsenic and is therefore probably diluting the groundwater on the north side of the river.

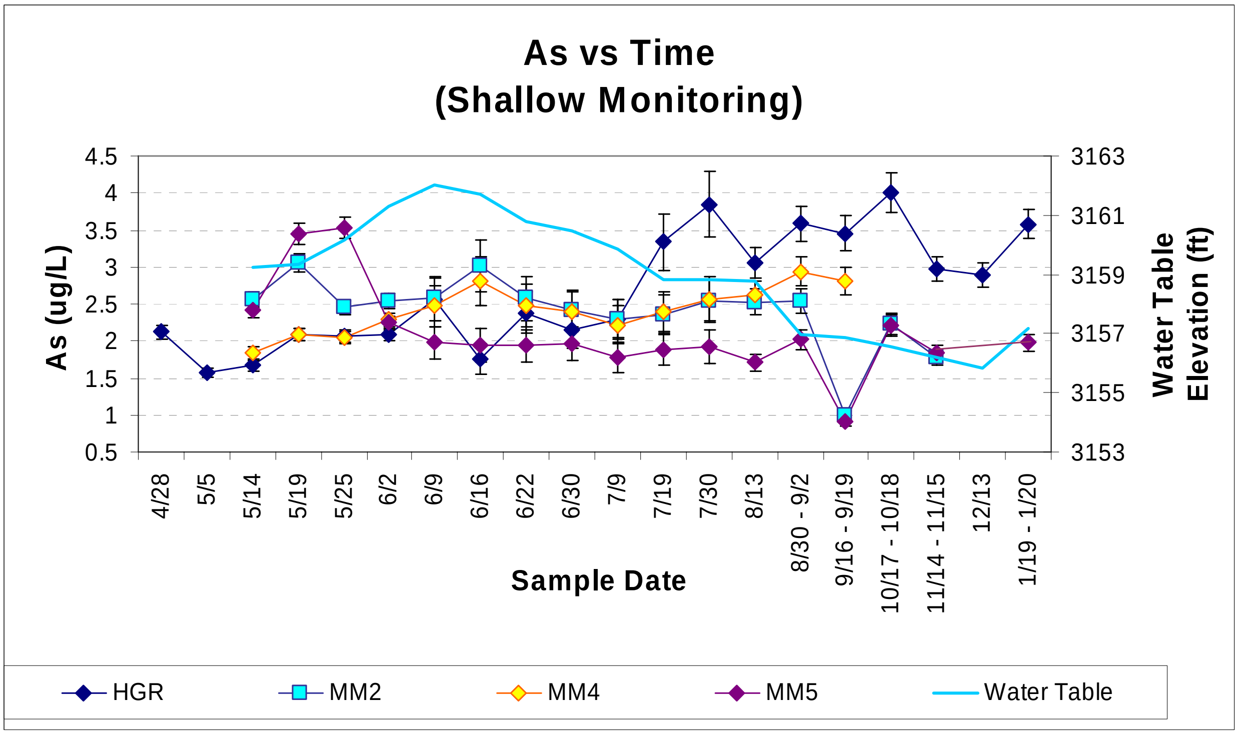

Figure 5. Note that when the water table is high (May through July), As in the monitoring wells (MM2 and MM4) is higher than in the river (HGR). After the Milltown drawdown (7/19) the river had higher arsenic values than any of the monitoring wells.

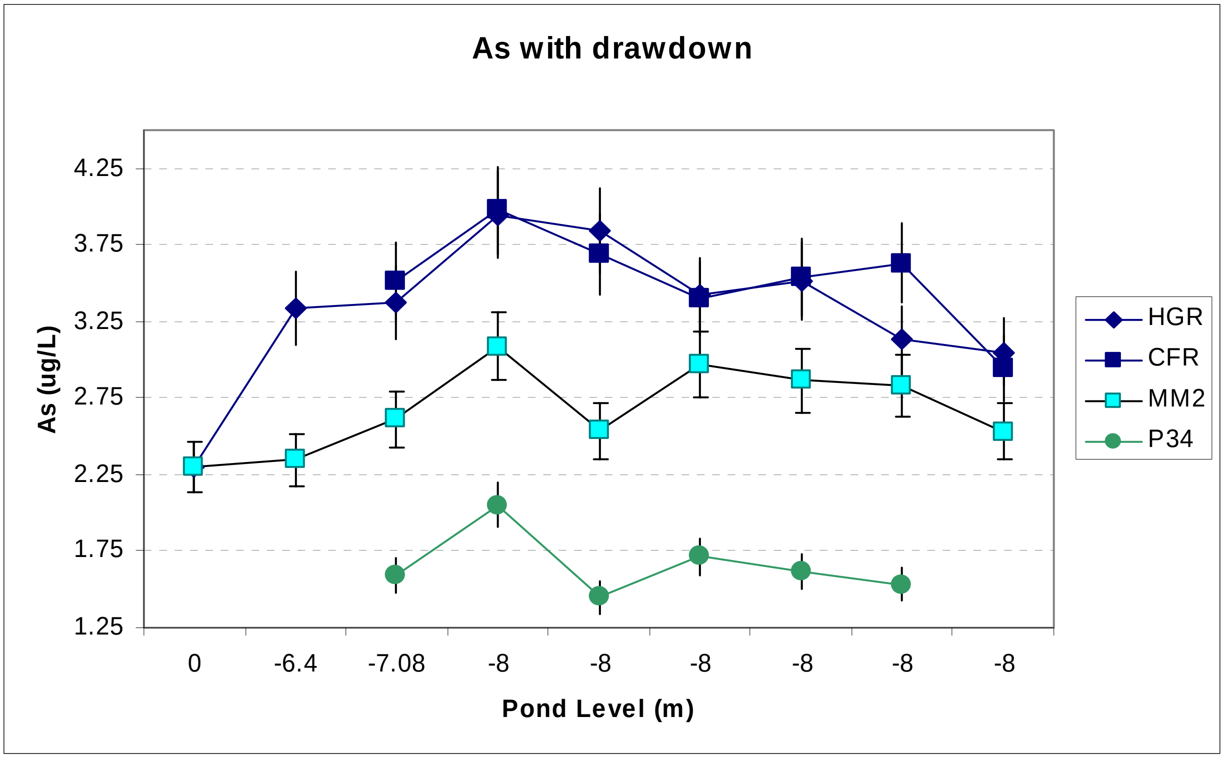

Figure 6. Arsenic concentrations in the river (HGR and CFR), a shallow monitoring well (MM2) and a production well (P34) during the drawdown of Milltown reservoir.

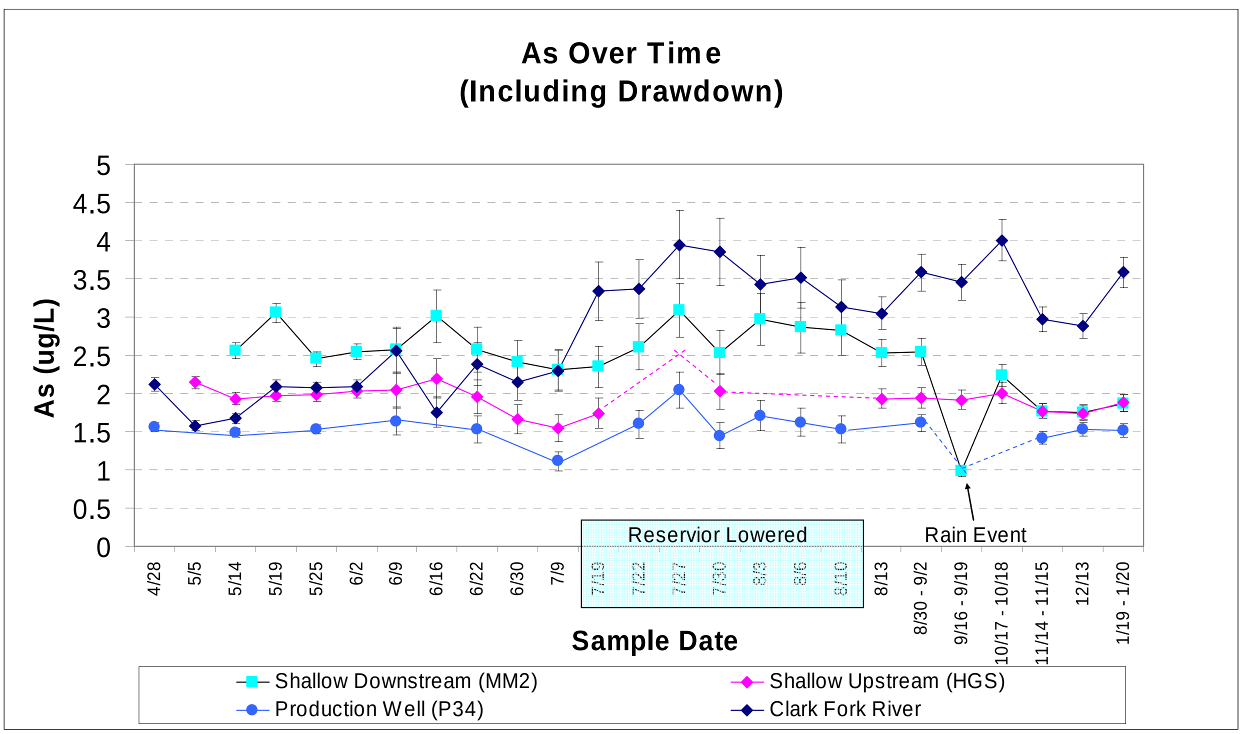

Figure 7. Arsenic data for the study period, including the drawdown event at Milltown (shaded box). The low values at MM2 and P34 are most likely due to a rain event and a pulse of clean water from Rattlesnake creek, since the well upstream from the confluence was not affected.

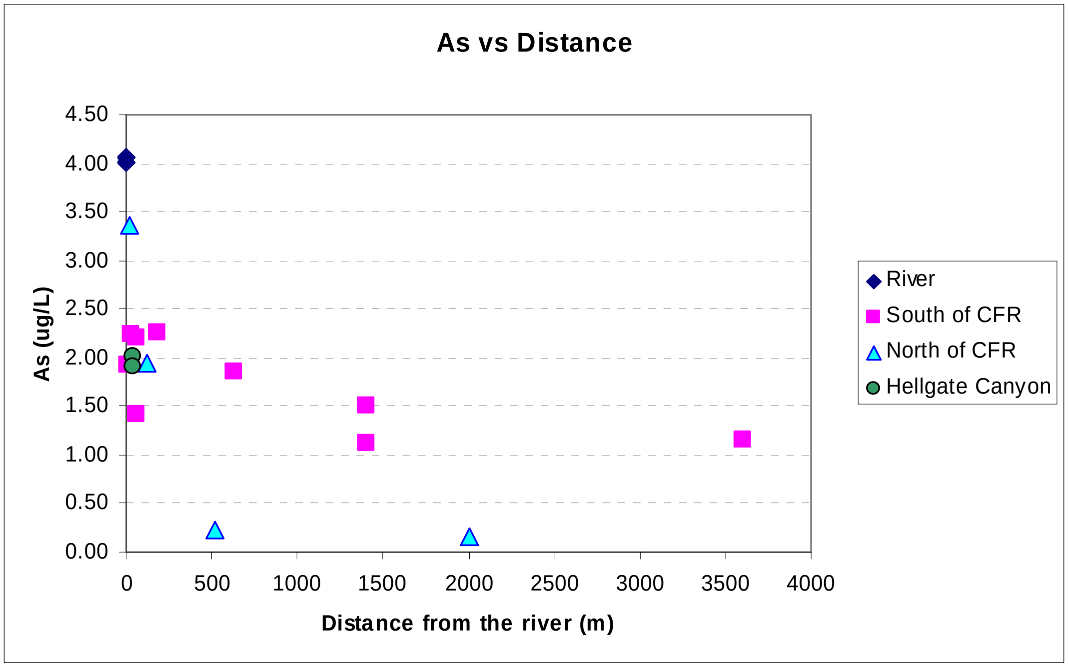

Figure 8. Concentrations of arsenic decrease with distance from the river. Distal wells on the north side have the lowest concentrations.

MODELING RESULTS

Groundwater and surface water monitoring reveal the river is perched above the aquifer. In Hellgate Canyon the river is perched 9 to 10 feet above the water table, and in the Missoula valley the river is perched 16 to 20 feet above the water table. The CFR acts as a hydraulic divide between the northern and southern portions of the valley. However, in the vicinity of Rattlesnake creek this trend is less apparent (Figure 9).

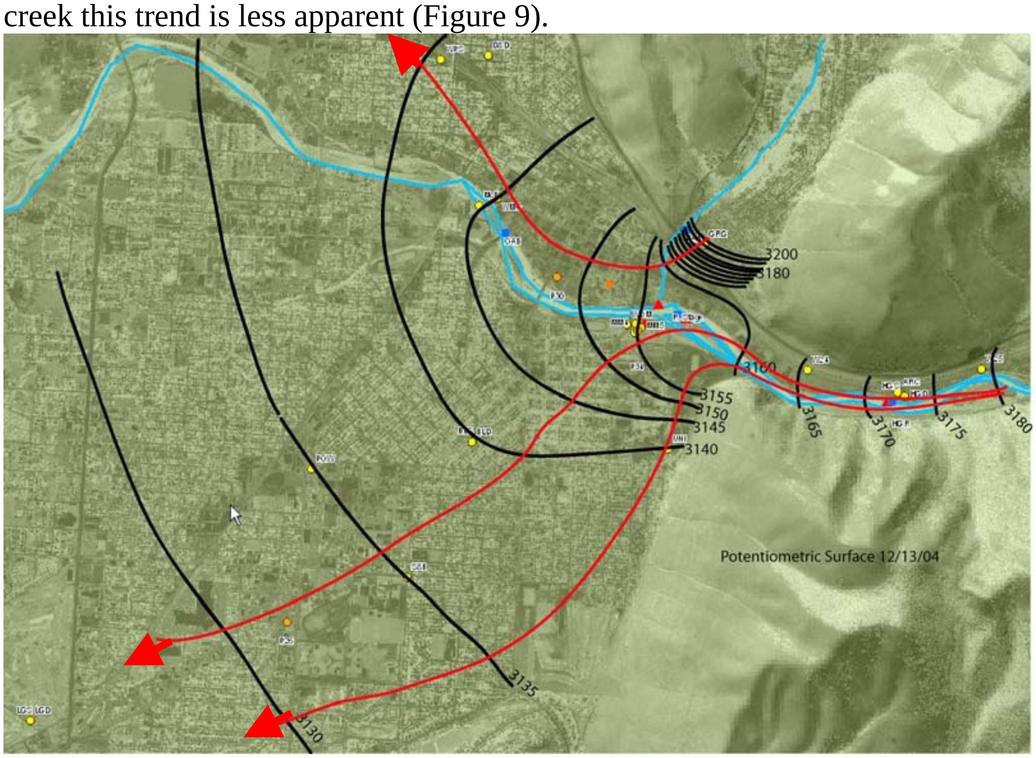

Figure 9. Potentiometric Surface 12/13/2004

Temperature monitoring and modeling indicate the CFR is losing water. Preliminary modeling results suggest the riverbed at the mouth of Hellgate Canyon has a vertical hydraulic conductivity of 5.5 ft/day, a flux of 6.75 ft^3/day per square foot of riverbed. Stream discharge measurements through this area indicate the river is loosing approximately10ft^3/day ranging from 6 to13.4 ft^3/day.

The hydraulic conductivity distribution based on our testing correlates with past conductivity values. Miller, (1991) determined a hydraulic conductivity of 6150 ft/day with his aquifer test at the Maurice St. Well located 500 ft east from the Arthur St. well. Our tests indicate a conductivity of 7030 ft/day at the Arthur St. well (Figure 10).

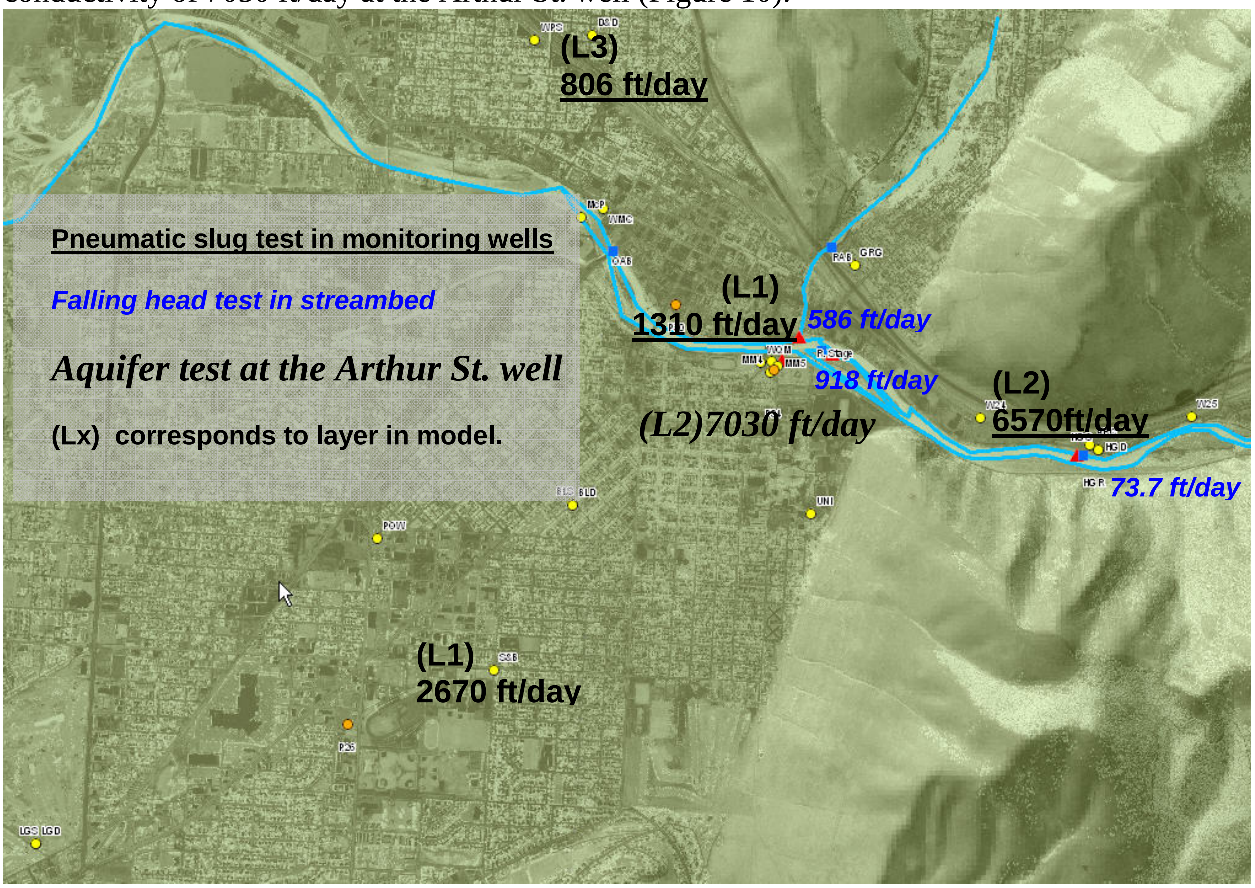

Figure 10. Hydraulic Conductivity Distribution

Preliminary modeling results for steady state conditions of March 2005, indicate the aquifer is primarily recharged by the CFR (Table 1).

Preliminary Modeling Results	
Source	Contribution to Missoula Aquifer
Clark Fork River Leakage	90.5%
Underflow From Up Gradient	7.0%
Rattlesnake Creak Leakage	2.5%

Table 1. Aquifer recharge sources.

PUBLICATIONS ASSOCIATED WITH THIS PROJECT:

Cook, R.C., Tallman A.A. and Woessner W.W., 2004. Preliminary Results for Defining River Recharge and the Fate of Arsenic in the Shallow Groundwater System Adjacent to a Losing River, Western Montana. Center for Riverine Science and Stream Re-naturalization Conference Proceedings.

Tallman, A.A., Cook, R.C., and Woessner, W.W., 2004 Preliminary Results of a Capture Zone Study on Bank-side Production Wells and Their Interaction With a Perched River in an Alluvial Aquifer, Western Montana. Center for Riverine Science and Stream Re-naturalization Conference Proceedings.

Tallman, A.A., Cook, R.C., and Woessner, W.W. 2005. Identifying the Factors Controlling the Sources and Quantity of Water Captured by Municipal Supply Wells in the Highly Conductive Missoula Aquifer, Western Montana. National Ground Water Association Groundwater Summit, Conference Proceedings.

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