Report for 2003MT9B: Mountain front groundwater recharge: groundwater-surface water exchange across an alpine-valley bottom transition

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  - Covino, T, B.L. McGlynn, R. Sojda and B. Edwards. 2004. Groundwater-surface water exchange across an alpine-valley transition. Montana Chapter of the American Water Resources Association Annual Meeting, Helena, Montana.

Report Follows

Mountain Front Groundwater Recharge: Groundwater-Surface Water Exchange Across an Alpine-Valley Bottom Transition

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<u>*Abstract*</u>

Mountain front recharge (MFR) contributes significantly to valley aquifer recharge in mountainous regions, yet adequate understanding of this process is lacking. GW recharge at the mountain front and subsequent GW discharge in the valley bottom are important hydrological processes in mountain watersheds. Interactions between GW and SW are gaining increasing recognition as an outstanding research need. In many valleys, streams change in both space and time from *losing* water to GW to *gaining* water from GW as they flow toward the valley-bottom. Alpine to valley bottom transition zones play a key role in regulating the amount, timing, and chemistry of stream water exiting the mountains and reaching the valley floor. We hypothesize that alpine-valley transitions function as hydrologic and biogeochemical buffers and both GW recharge and discharge zones. More specifically, we hypothesize that streams often recharge GW near the mountain front and receive older stored GW further downstream. To investigate these hypotheses we applied physical hydrology techniques, tracer injections, and geochemical hydrograph separations in the Humphrey Creek watershed in southwestern Montana. A network of four stream gauging stations, 19 wells, and 18 piezometers were installed for monitoring physical hydrology. Our intensive instrumentation network allowed us to assess the spatial and temporal variability of mountain front GW recharge and GW-SW interactions across an alpine-valley transition. Geochemical signatures were used to partition stream flow into alpine and GW sources, and tracer injections were used to quantify GW recharge/discharge over various reaches. When investigating complex GW-SW interactions it is necessary to use multiple lines of evidence to understand these processes. Our results demonstrate that much of the alpine streamwater recharges GW at the mountain front and that older GW of a different chemical composition sustains down-valley stream discharge. Down-valley stream discharge was dominated by GW inputs and responded to GW stage. A critical GW stage height was necessary to sustain down-valley channel flow, as this is the only major input to channel flow during early and late season base flow. Conversely, GW contributed little to stream flow in the upper reaches (MFR zone) of the study area. Much of the water exiting the mountains recharged GW in MFR zone throughout the summer. Water exiting the mountains as channel flow and water reaching the lake as channel flow were not the same water and had different sources and geochemistry (alpine water versus older stored groundwater). This was due to GW-SW exchange occurring in the MFR zone and across the valley floor, which controlled stream water geochemistry and buffered hydrograph response in the valley bottom. This exchange resulted in significant changes in SW chemistry moving from alpine, to MFR zone, to the valley bottom, and muted fluctuations in channel flow, both at high and low flow. Implications are that mountain front GW recharge magnitudes over long timescales control valley aquifer storage state which combined with alpine runoff magnitude control stream water quantity and geochemical composition downstream.

Research Objectives

Many valley bottoms receive significant inputs of water from mountain front groundwater (GW) recharge, yet this process is not well understood. The precise definition of the mountain front has been ambiguous in the literature (Wilson and Guan, 2004). For the purposes of this project the mountain front recharge (MFR) zone will be defined as the zone between the mountain block-piedmont break in slope and the piedmont-valley bottom break in slope. GW-surface water (SW) exchange that occurs in the MFR zone, and across the valley bottom, is important in controlling SW chemistry, and stream discharge magnitude. Although GW-SW exchange has received increasing attention as a research need, adequate understanding of these processes has not been attained. Stream discharge and valley aquifer storage in mountainous regions are largely dependent on MFR and GW-SW exchange, and understanding these hydrological processes is important. The goals of this project were to use physical hydrology, injected stream tracers, and geochemical hydrograph separations to understand mountain front GW recharge and GW-SW exchange in the Humphrey Creek watershed in south-western Montana (Figure 1). Specifically, we sought to:

(1) elucidate areas of GW recharge and discharge,
(2) quantify GW recharge/discharge over specific reaches,
(3) determine source water contributions to stream flow and how they impact SW chemistry and discharge magnitude,
(4) determine how physical relationships between GW and SW impact all of these processes.

Furthermore, we sought to know how all of the above listed objectives varied both spatially and temporally.

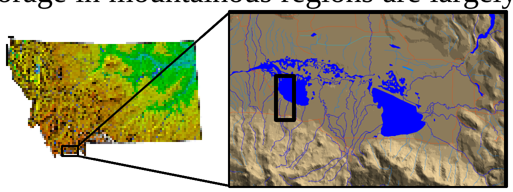

Figure 1. Location of the Humphrey Creek watershed in south-western Montana.

Methodology

Physical hydrology, injected stream tracers, and geochemical hydrograph separations were used to investigate the questions and objectives proposed above. A network of 19 wells, 18 piezometers, and four gauging stations were installed in the Humphrey Creek watershed to investigate the physical hydrology (Figure 2). Injected stream tracers were used to quantify GW recharge/discharge over specific reaches of Humphrey Creek. Geochemical hydrograph separations were used to determine source water contributions to stream flow. These methods were combined and used together to help answer the questions posed in this project. Studying complex GW-SW exchange processes requires a combined approach in order to correctly identify dominant mechanisms controlling these processes.

Study Site

The Humphrey Creek watershed is located in the Red Rock Lakes National Wildlife Refuge in southwestern Montana (Figure 1). Humphrey Creek flows from south to north, originating in the Centennial Mountains and flows into Lower Red Rock Lake draining a 351 ha watershed. The headwaters of the creek begin above tree line in the alpine region of the watershed. Humphrey Creek then flows through sub-alpine mixed coniferous forest, exits the forest and flows through upland grasses, willows, and shrubs and enters the valley bottom where the vegetation consists of sedges, rushes, grasses and willows. The area of instrumentation begins where Humphrey Creek exits the coniferous forest and continues to the lake edge (Figure 2). The soils in the study site range from cobbly silts in the upland, and peat, to clay, to sand, to gravel in the lowland. The geology of the Humphrey Creek watershed consists of tertiary volcanics, underlain by upper cretaceous, Mesozoic, Paleozoic, and pre-cambrian rocks in the alpine zone and landslide debris, lake sediments, and alluvial deposits in the valley bottom.

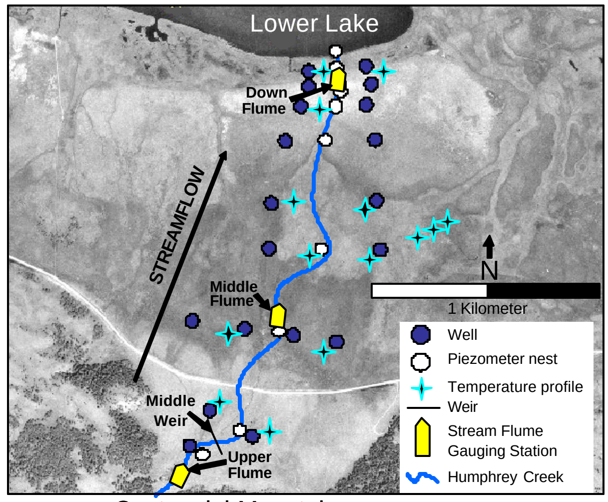

Figure 2. Study site instrument layout for the Humphrey Creek watershed. Humphrey Creek flows to the north, draining the Centennial Mountains into Lower Red Rock Lake.

<u>Stream Gauging</u>

Three inch Parshall flumes were installed in Humphrey Creek during the spring of 2004 (Figure 3) for stream gauging purposes. Flumes were anchored in the bed and banks of the stream to force stream water through the flume. This was done by excavating an appropriate area necessary to insert the flume wingwalls and subsequently backfilling the area. In total three flumes were installed; one in the upper reach of the study area (referred to as upper flume), a second in the middle reach of the study area (referred to as middle flume), and a third in the lower reach of the study area (referred to as down flume). Each flume was instrumented with data loggers (either Druck pressure transducers connected to Campbell CR10 data loggers, or Tru-Track capacitance rods) installed in the stilling well to collect stage measurements on ten minute intervals. Discharge was calculated based on stage-discharge rating curves we

Figure 3. Example of three inch Parshall flume installed in Humphrey Creek.

developed. Measurements began in the end of April or early May and continued until the end of August or September, 2004 (dependent on cessation of channel flow).

A rectangular weir was installed in Humphrey Creek prior to the project, and was also utilized for stream gauging. This weir is located between the upper and middle flumes and is referred to as middle weir. A section of stream behind the weir was widened and deepened to create a stilling pool. A stilling well was built on the upstream side of the weir and was instrumented with a Tru-Track capacitance rod. Stage measurements were recorded on a ten minute interval, and were taken from the end of April to the end of September, 2004. Again, a stage-discharge rating curve was developed.

Velocity-area gauging was used at each flume and the weir to help calibrate the rating curves for the flumes and the weir. This method was also used to gauge the stream in locations where a flume or a weir did not exist, in order to get an estimate of discharge at that location. A Marsh-McBirney Flo-Mate 2000 portable flow meter was used in the velocity-area gauging of the stream. Velocity-area gauging occurred on a regular basis (nearly daily) from the beginning of May to the end of August, 2004.

Dilution gauging with sodium chloride (NaCl) was used to help calibrate flume and weir rating curves. Breakthrough curves were obtained with Campbell CS547A conductivity and temperature probes connected to Campbell CR10 data loggers. Measurements were taken every 5 seconds during dilution gauging experiments. Integration of the area under the breakthrough curve yields discharge.

<u>Wells and Piezometers</u>

Wells were installed in transects perpendicular to the stream from the mountain front to the valley bottom lake edge (see Figure 2) to capture the shape of the local GW table surrounding Humphrey Creek. Most wells were instrumented with Tru-Track data loggers which recorded GW height measurements every ten minutes. Hand measurements of the wells occurred regularly. Hand measurements included GW height, conductivity (specific conductance in mS cm^{-1}), and temperature. Nested piezometers were installed in the channel bed of Humphrey Creek to determine the vertical gradients in the GW table at each transect (see Figure 2). Again, most piezometers were equipped with Tru-Track capacitance rods recording measurements on ten minute intervals. Hand measurements were the same as for wells. These measurements began in March, 2004 and continued through September, 2004.

<u>Water Sampling</u>

GW samples were taken from wells, piezometers and springs for later chemical analysis. GW samples were obtained with a hand held peristaltic pump, and lines were always pumped and purged before sample was taken. Clean plastic bottles were rinsed with sample three times before filling. Samples were filtered through 0.45 µm polypropylene filters and stored in the dark at 4°C until analysis. SW samples were taken from stream gauging locations either by hand or by ISCO auto samplers. ISCO auto samplers pump sample via a peristaltic pump and pump and purge lines before filling clean plastic sample bottles. Hand SW samples were taken in clean plastic bottles, and bottles were rinsed with sample three times before filling. All SW samples were filtered through 0.45 µm polypropylene filters and stored in the dark at 4°C until analysis.

Data Loggers

We installed Campbell CR10X data loggers at upper, middle, and down flumes. Data collected was stream stage, SW conductivity (SC in mS cm^{-1}), SW temperature, soil moisture, and air temperature. Stream stage was measured with a Druck PDCR 1230 pressure transducer, stream water conductivity and temperature was measured with a Campbell CS547A conductivity and temperature probe, soil moisture was measured with a Campbell CS616 water content reflectometer, and air temperature was recorded with Thermocron I-buttons. A Campbell TE525 tipping bucket rain gauge was installed at middle flume to collect rain data. Campbell data loggers collected measurements from each sensor every ten minutes, except for rain data which was registered each time the bucket tipped. Tru-Track capacitance rod data loggers were also installed in flume and weir stilling wells, GW wells, and piezometers. Tru-Track data loggers measured water height, water temperature, and logger temperature on ten minute intervals.

Figure 4. Example of Campbell data logger set-up with solar panel. Logging stream stage, conductivity, temperature, and soil moisture.

Chemical Analysis

Water samples were analyzed for major ions with a Metrohm-Peak compact ion chromatograph. Sodium (Na), ammonium (NH_4), potassium (K), calcium (Ca), and magnesium (Mg) were measured on a Metrosep C-2-250 cation column. Nitrate (NO_3), nitrite (NO_2), chloride (Cl), bromide (Br), phosphate (PO_4), and sulphate (SO_4) were measured on a Metrosep C-2-250 anion column. And silica (Si) was measured as silicate (SiO_4) on a Hamilton PRP-X100 anion column.

Hydrograph Separation and Uncertainty

Hydrograph separations were used to determine contributions to stream flow from the alpine zone (AL) and the valley bottom GW. Real time separations were made using conductivity. GW conductivity was known and AL and SW conductivity were measured real time on ten minute intervals. Chemical analysis of samples and regression of ion concentration versus conductivity was used to validate this separation. A two-component separation can be solved by simultaneously solving equations one and two.

$$Q_{AL} = \left[\frac{C_{ST} - C_{GW}}{C_{AL} - C_{GW}}\right] Q_{ST} \ \textbf{(1)}; \quad Q_{GW} = \left[\frac{C_{ST} - C_{AL}}{C_{GW} - C_{AL}}\right] Q_{ST} \ \textbf{(2)}; \quad Q_{ST} = Q_{GW} + Q_{AL} \ \textbf{(3)}$$

Where Q_{AL} is the contributions to discharge from alpine waters, Q_{GW} is the contributions to discharge from valley bottom GW, Q_{ST} is the stream discharge, and C_{AL}, C_{GW}, and C_{ST} are alpine conductivity, GW conductivity, and stream conductivity, respectively. Uncertainty analysis was applied to the hydrograph separations following the methods of Genereux (1998) using equations four and five.

$$W_{f_{AL}} = \left\{ \left[\frac{C_{GW} - C_{ST}}{(C_{GW} - C_{AL})^2} W_{C_{AL}} \right]^2 + \left[\frac{C_{ST} - C_{AL}}{(C_{GW} - C_{AL})^2} W_{C_{GW}} \right]^2 + \left[\frac{-1}{C_{GW} - C_{AL}} W_{C_{ST}} \right]^2 \right\}^{1/2} \quad \textbf{(4)}$$

$$W_{f_{GW}} = \left\{ \left[\frac{C_{AL} - C_{ST}}{(C_{AL} - C_{GW})^2} W_{C_{GW}} \right]^2 + \left[\frac{C_{ST} - C_{AL}}{(C_{AL} - C_{GW})^2} W_{C_{AL}} \right]^2 + \left[\frac{-1}{C_{AL} - C_{GW}} W_{C_{ST}} \right]^2 \right\}^{1/2} \quad \textbf{(5)}$$

Where $W_{f_{AL}}$ is the uncertainty in the AL component, $W_{f_{GW}}$ is the uncertainty in the GW component, W_{AL}, W_{GW}, and W_{ST} are the analytical errors in AL, GW, and stream conductivity measurements, and C_{AL}, C_{GW}, and C_{ST} are AL, GW, and stream conductivities.

Salt Tracer Experiments

Salt tracer experiments occurred in May, June, July, and August, 2004. Sodium chloride (NaCl) was used for salt tracer experiments. Salt was injected as a slug above upper flume at the edge of the coniferous forest. Breakthrough curves were gathered at five downstream locations: upper flume, middle weir, a transect between the road and middle weir (referred to as south transect 1), a transect between the road and the middle flume (referred to as north transect 0), and middle flume. Data at the three most upstream locations (upper flume, middle weir, and south transect 1) were collected with Campbell data loggers and Campbell CS547A conductivity and temperature probes on five second intervals. At the two most downstream locations (north transect 0, and middle flume) measurements were made with a YSI conductivity, temperature, and pH probe on ten second intervals. Salt tracer injections allow us to accurately assess the stream discharge at each measurement location by knowing the mass injected and the accumulated change in concentration. Accurate discharge measurements at five measurement locations allows us to apply a water balance technique to estimate the amount of water being lost from the stream as GW recharge.

Principal Findings

Results indicate that significant GW recharge occurs at the mountain front, GW-SW exchange is dynamic (spatially and temporally), and GW recharge and GW-SW exchange control valley bottom aquifer storage, SW chemistry, and stream discharge magnitude.

Stream Discharge and Conductivity

Stream discharge was highest in the upper reaches of the study site, in the mountain front GW recharge zone (Figure, 5). Much of the water exiting the mountains as channel flow in this zone was lost from the stream as GW recharge. Stream discharge subsequently decreased at downstream locations (Figure, 5). Stream discharge responded to rain events with pulsed increases in channel flow. However the bulk of the discharge seems to be driven by snowmelt. Peak discharge occurred on June, 9th at upper and middle flumes, and on June, 10th at down flume. Down flume, located near the lake edge in the valley bottom, had a flashy hydrograph and was very responsive to rain events. This is presumably due to the limited storage available in this part of the landscape. GW

GW was close to the ground surface in the area around down flume and soils were moist, which may account for the responsiveness of stream discharge to rain events at down flume. Conversely, at middle and upper flumes the stream hydrograph was not as responsive to rain events. This is presumably due to greater available storage in these zones. The water table was far deeper in these reaches and soils were dry. As such, moisture inputs from rain events contributed to recharging GW and soil moisture, and less input was directed to the stream. Stream water conductivity at upper and middle flumes were similar. The conductivity at these locations was near 0.2 mS cm^{-1} during the rising limb and peak of the hydrograph. Conductivity rose slightly during late season base flow. Rain events caused spiked decreases in conductivity, as low conductivity water contributions to stream flow were increased. At down flume the early season conductivity was much higher, compared to middle and upper flumes. Conductivity was near 0.6 ms cm^{-1} when channel flow began in May at down flume and had a convex shape. It was high during the early season, fell during peak flow, and began climbing again during late season flow. This shows high GW contributions during early season flow, increased AL contributions during peak flow, and high GW contributions to

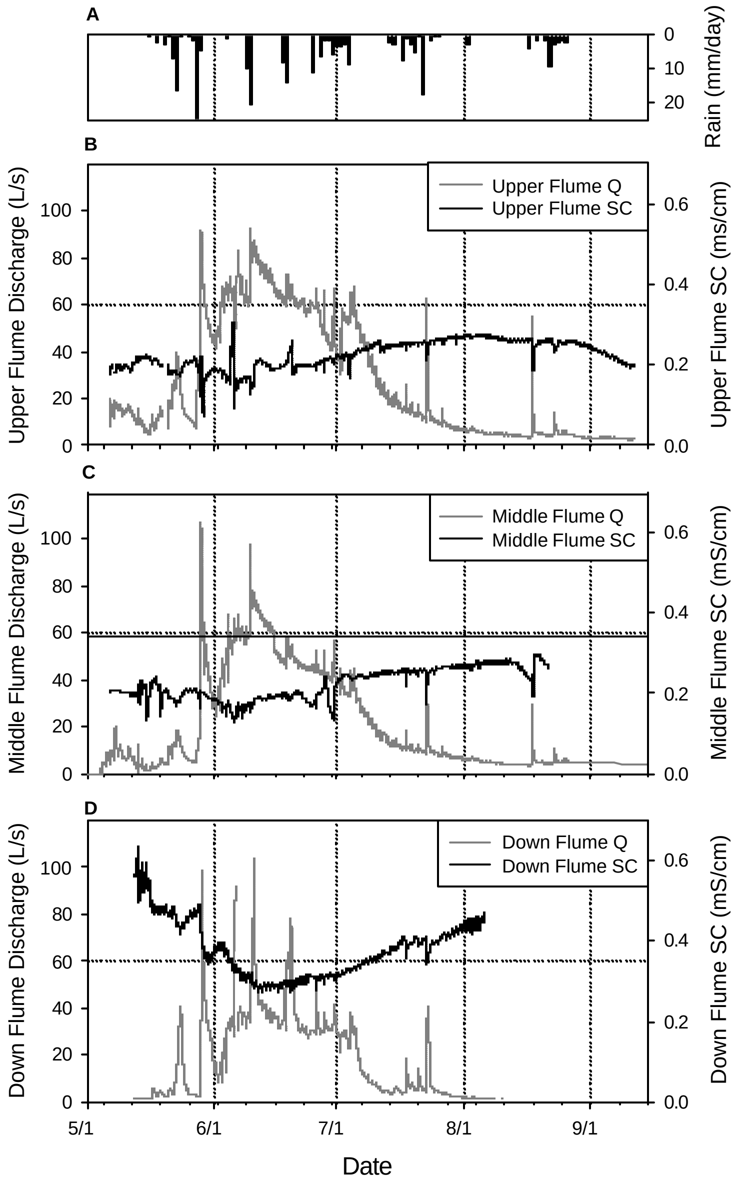

Figure 5. (A) Daily rain totals (mm/day). Stream hydrograph and conductivity (SC) for upper flume (B), middle flume (C), and down flume (D) from 5/1-9/15/2004.

stream flow during late season flow. Interestingly, peak daily flow due to diurnal fluctuations occurred between 10:00 and 12:00, and low flow occurred near 20:00. This suggests alpine controls on water exiting the mountains and a lag time in response moving downstream. If local evapotranspiration (ET) were controlling diurnal fluctuations, expectations would be that peak flow would occurr late at night or early in the morning. This data suggests that alpine ET, occurring late at night or early in the morning, is controlling transition zone and valley bottom discharge, and there is a lag time associated with water moving out of the mountains to the transition zone. Fluctuations in conductivity lag behind discharge fluctuations which suggests a particle transport mechanism (conductivity transport) versus a pressure wave propagation transport (discharge transport). Hydrologic lag times associated with ET have been observed by other studies (Bond et al., 2002), as have differences between water (pressure wave propagation) and tracer (particle transport) movement through watersheds (USGS, 1997). Stream discharge peaked before lake stage peaked (Figure 6). This shows that stream discharge is controlling lake response. Stream and GW gradients were into the lake and drove lake response.

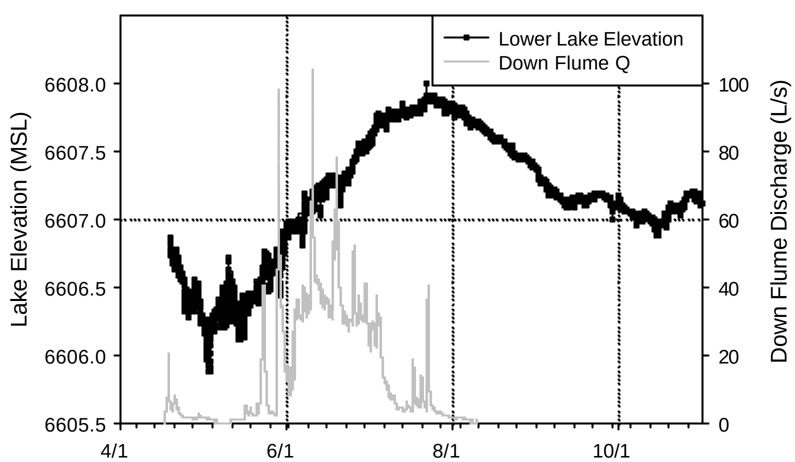

Figure 6. Time series of Lower Red Rock Lake elevation and stream discharge at down flume. Stream peak occurred much earlier in the summer than did lake peak.

<u>Wells and Piezometers</u>

GW levels were deep relative to ground surface in the MFR zone (first two lateral well transects) of the study area (Figure 7). Wells in this zone were completed to depths between 1.7 and 2.8 meters, and were dry for most of the season (April to September, 2004). Well completion depths were determined by the depth to which hand augering was possible. GW levels in this area rose during peak discharge and GW was able to be seen in wells. GW hydrographs in this zone largely followed the shape of the stream hydrograph. GW was often disconnected from stream water in this zone, showing that depths to GW were greater than the depth of the stream bed. This makes GW inputs to channel flow not possible and gradients were consequently out of the stream. Thus, the stream was losing in the MFR zone and contributed to GW and soil moisture recharge. Depths to GW relative to ground surface in the valley bottom were shallow, and GW was often at or near the ground surface in this zone (Figure 8). In north well 71 (NW 71) and north well 72 (NW 72) a sharp rise in GW levels can be seen around March, 20. Prior to this sharp increase in GW levels there was significant water ponding on top of frozen soils in the valley bottom. It seems that thawing soils allowed significant amounts of water to infiltrate to the GW table at this time. Water inputs were due to spring snowmelt in the valley bottom which occurs prior to melt of snow higher in the watershed. This event contributed significantly to local GW recharge, and also initiated channel flow in the valley bottom. A similar increase in GW levels could have occurred in the upper reaches

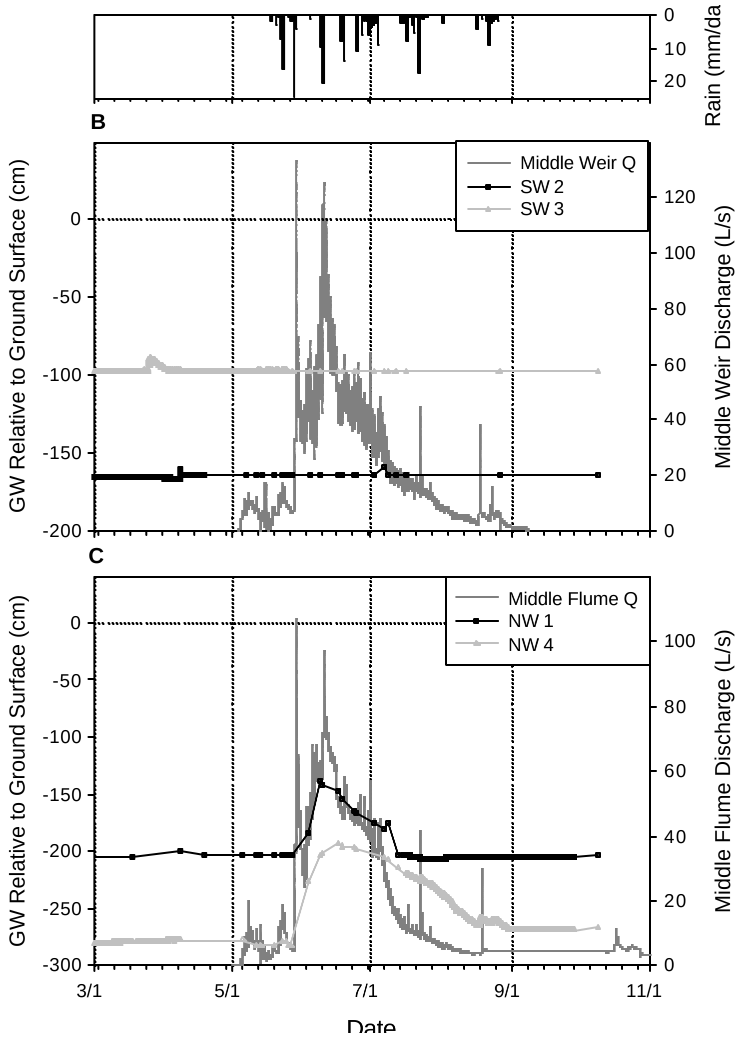

Figure 7. (A) Daily rain totals (mm/day). (B) GW levels for SW 2 & 3, with stream discharge from middle weir; and, (C) GW levels for NW 1 & 4, with discharge from middle flume for 3/1-11/1/2004. Flat lines in wells signify well completion depths. These wells are from the two upper-most transects of wells in the study site.

of the study area (MFR zone), however, due to great depths to GW, wells in this zone were dry during this period and there is no data to assess this possibility.

Nested piezometers were installed in the stream channel. Vertical GW gradients were upward at north piezometers 60 (NP 60) and 61 (NP 61), which are approximately half way between the MFR zone and Lower Red Rock Lake (Figure 9). Further downstream towards the lake, GW gradients were mostly lateral (Figure 9). This results in substantial GW contributions to stream flow near NP60 and 61. Lateral GW gradients make subtle gradients in and out of the stream possible and some GW-SW mixing may occur in this situation. GW inputs to channel flow near NP 60 and 61 and subsequent exchange between GW and SW substantially altered the chemistry of valley bottom SW compared to SW in the MFR zone. South piezometers 1 (SP 1) and 2 (SP2) and north piezometers 1 (NP 1) and 2 (NP 2) which are located in the MFR zone generally did not have water in them (Figure 10). This shows that GW depths in the MFR zone were deeper than the channel bed and gradients were out of the stream. Changes in GW gradients and GW-SW exchange across the study area impacted SW chemistry and attenuated hydrograph response. In some reaches (MFR zone) GW was being recharged by stream water, while in other reaches GW was discharging to the stream. These interactions seem to control much of the SW chemistry and stream hydrograph response in the watershed.

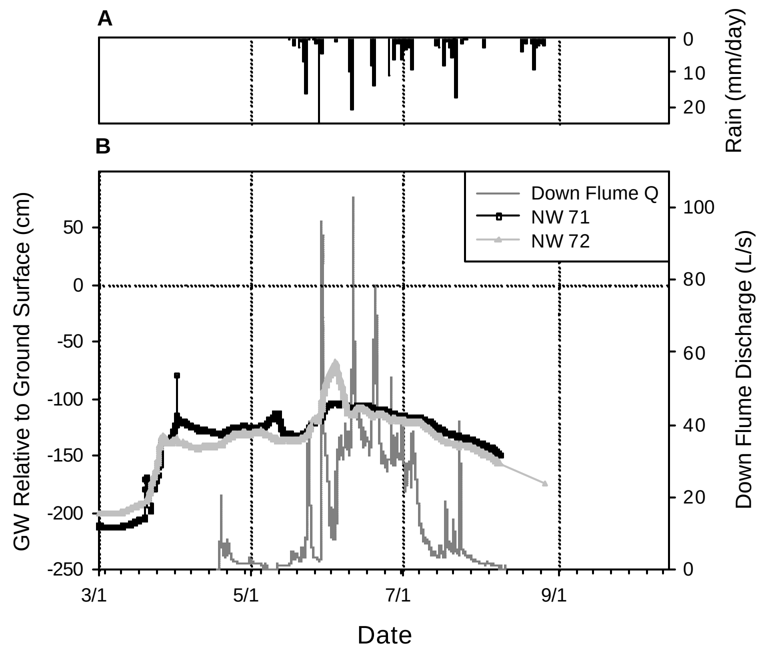

Figure 8. (A) Daily rain totals (mm/day). (B) GW levels for NW 71 & 72 with stream discharge for down flume from 3/1-10/15/2004. NW 71 & 72 are located in the valley bottom near down flume.

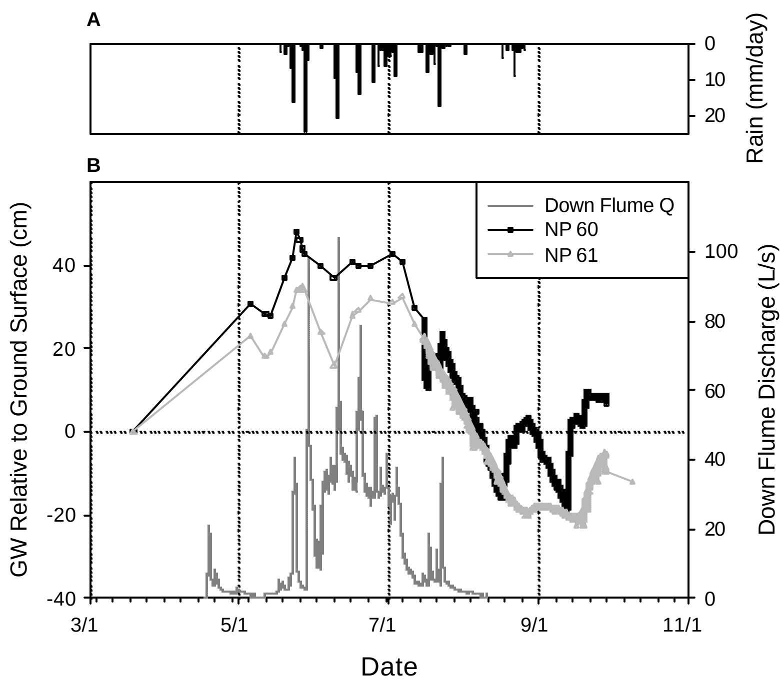

Figure 9. (A) Daily rain totals (mm/day). (B) GW levels for piezometers NP 60 & 61 and stream discharge for down flume from 3/1-11/1/2004. NP 60 is the deeper of the two nested piezometers indicating upward gradients.

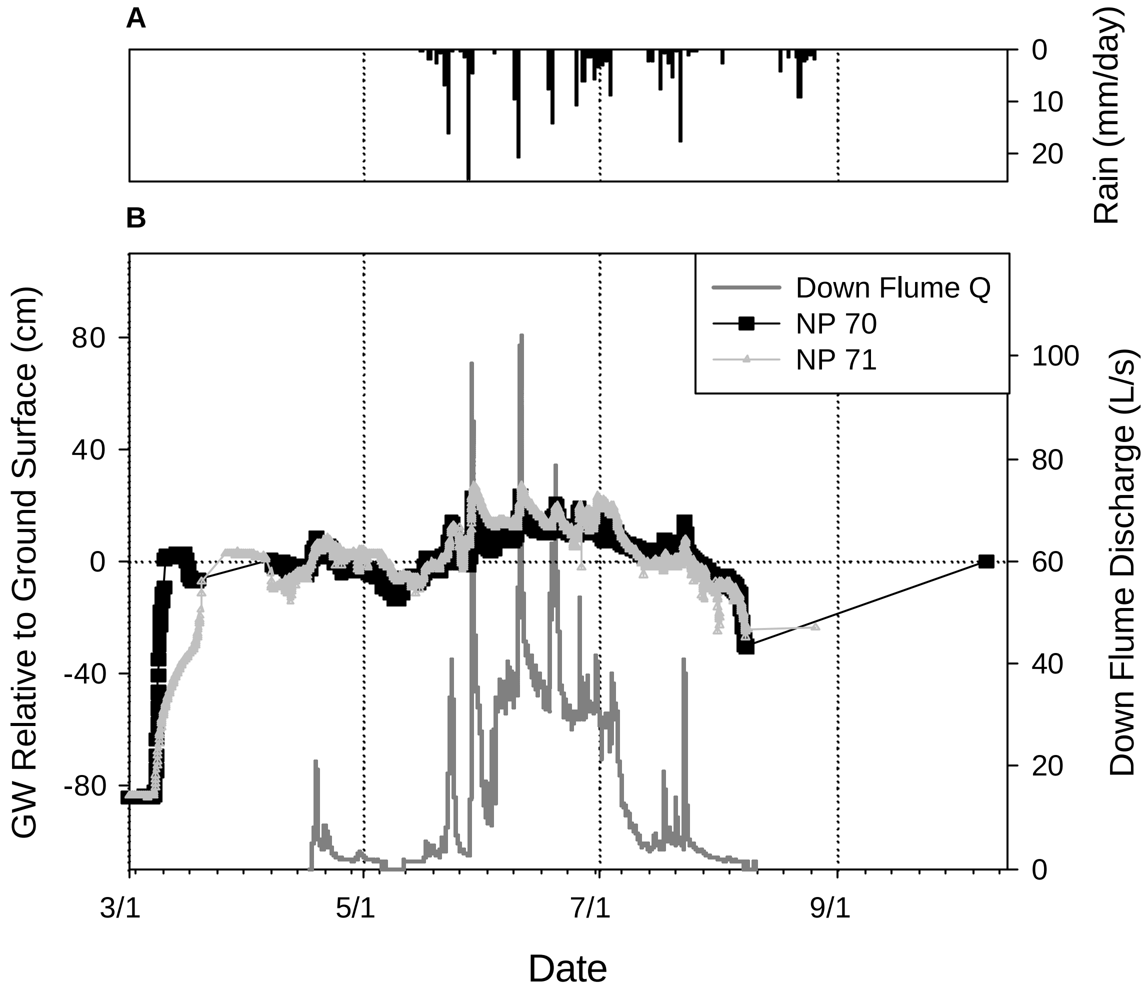

Figure 10. (A) Daily rain totals (mm/day). (B) GW levels for piezometers NP 70 & 71 with down flume stream discharge from 3/1-10/15/2004. NP 70 & 71 are located in the valley bottom near down flume. NP 70 is the deeper piezometer, gradients are lateral.

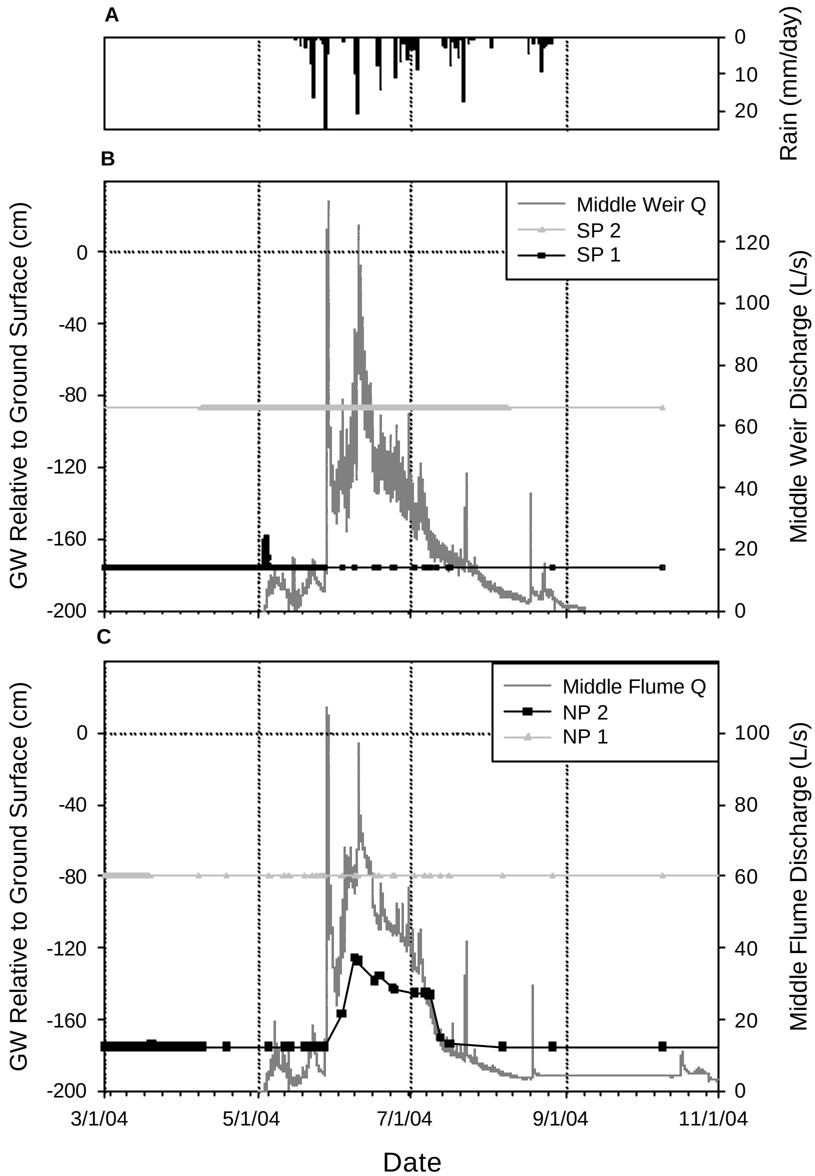

Figure 11. (A) Daily rain totals. (B) GW levels for piezometers SP 1 & 2, and stream discharge for middle weir, and (C) GW levels for piezometers NP 1 & 2 and stream discharge for middle flume. Black symbols are the deeper piezometers (SP 1 and NP 2). SP 1, SP 2, and NP 1 were dry for nearly all of the year. These piezometers are located in the upper reaches of the study area in the MFR sone.

Hydrograph Separations

Hydrograph separations showed marked changes in contributions from AL and GW to stream flow between middle and down flumes (Figure 11). Water in the channel at middle flume was composed mostly of AL water, conversely, water in the channel at down flume had substantial GW contributions to total discharge. From hydrograph separations we can determine how much water would be expected in the channel if there were not GW contributions to channel flow at down flume. There would be significantly less discharge at down flume and the period of time that channel flow occurred would be shorter. GW sustains early and late season base flow in this reach. As such GW-SW exchange serves to change the chemistry of water found in the channel between middle and down flumes, increases the amount of stream discharge at down flume, and lengthens the amount of time that channel flow occurs at down flume. Since stream discharge was less at down versus middle flume we might had assumed that Humphrey Creek was

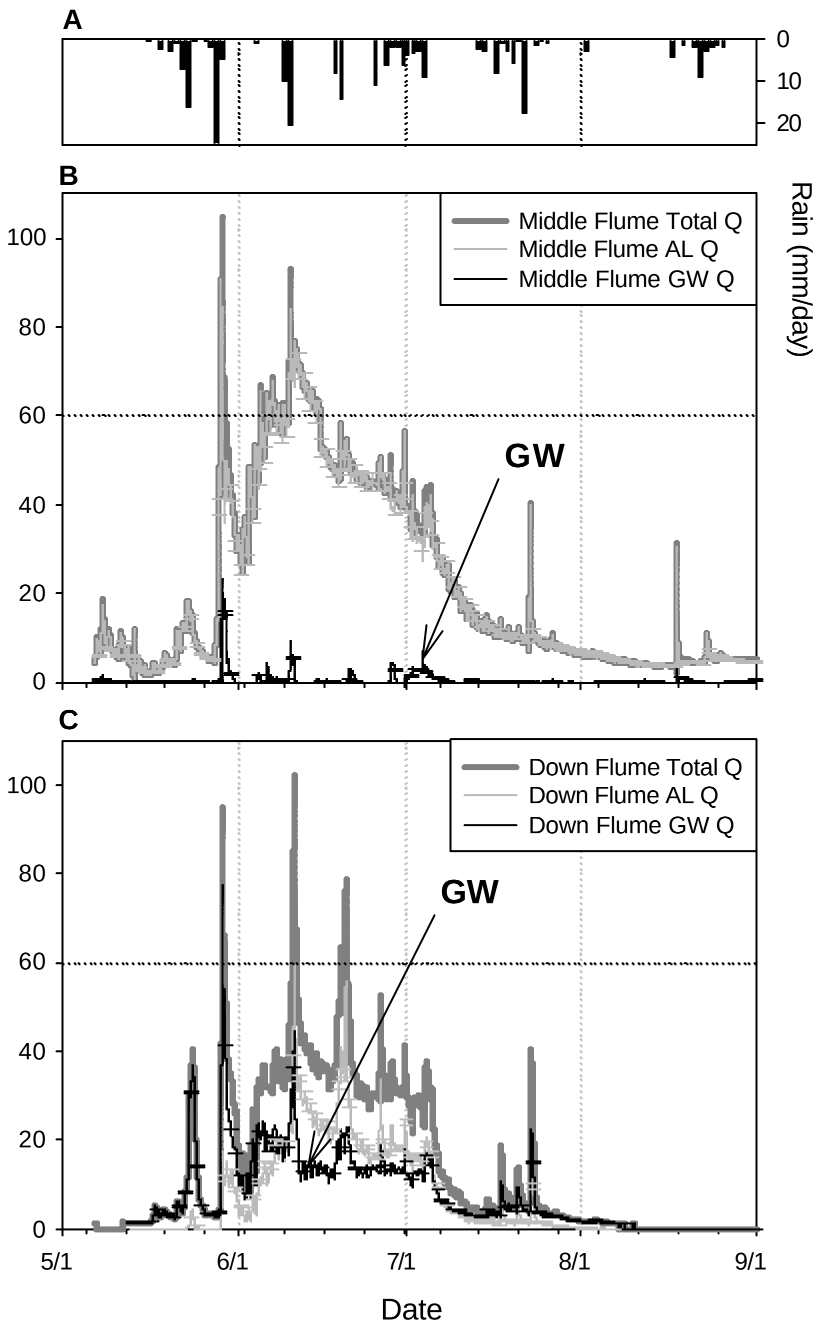

Figure 12. (A) Daily rain totals (mm/day). (B) Hydrograph separation for middle flume (GW and AL components of total discharge), and (C) hydrograph separation for down flume. Error bars on separation indicate the uncertainty in the separation.

simply a losing stream between these two reaches if we had not applied hydrograph separations. Hydrograph separations show us that although there is less water in the channel at down flume versus middle flume, Humphrey Creek actually gains significant GW in the down flume reach. The dynamic interaction between GW and SW, where GW recharge is occurring in ceratin reaches and GW discharge in others, seems to have significant impact on hydrological processes in the Humphrey Creek watershed. It is possible that similar interactions are important in other mountain watersheds, and mountain front GW recharge and GW-SW exchange might be a significant driver of hydrological processes in these settings. Combining physical hydrology with geochemical hydrograph separations allows researches to more thoroughly investigate the hydrology of these watersheds.

Salt Tracer Injections

Analysis of salt tracer experiment data is still occurring and will be completed shortly. This data will allow us to assess the amount of GW recharge and GW discharge occurring over specific reaches, and to estimate the volume of water exiting and entering the channel over these reaches. This data will be used in concert with physical hydrology data, and hydrograph separations to further analyze and investigate mountain GW recharge and GW-SW exchange in the Humphrey Creek watershed and the impact these mechanisms have on hydrological processes.

Publications & Citations

Covino, T., McGlynn, B.L., Sojda, R., and B. Edwards. *Mountain Front Groundwater Recharge: Groundwater-Surface Water Exchange Across an Alpine–Valley Transition*. American Geophysical Union Fall Meeting. Fall, 2004.

Covino, T., McGlynn, B.L., Sojda, R., and B. Edwards. *Groundwater-Surface Water Exchange Across an Alpine–Valley Transition*. Montana Chapter of the American Water Resources Association Annual Meeting. Fall, 2004. **FIRST PLACE IN STUDENT PAPER COMPETITION.**

This work is currently be finalized in a Masters thesis titled *Mountain Front Groundwater Recharge: Groundwater-Surface Water Exchange Across an Alpine-Valley Bottom Transition*, and will be submitted for publication in peer reviewed journals such as *Water Resources Research* or *Journal of Hydrology*. This work has also led to ideas that will be pursued in future proposals to further this research.

Notable Achievements & Awards

TIM COVINO, FIRST PLACE IN STUDENT PAPER COMPETITION: Montana Chapter of the American Water Resources Association Annual Meeting. Fall, 2004.

Covino, T., McGlynn, B.L., Sojda, R., and B. Edwards. *Groundwater-Surface Water Exchange Across an Alpine–Valley Transition*. Montana Chapter of the American Water Resources Association Annual Meeting. Fall, 2004. **FIRST PLACE IN STUDENT PAPER COMPETITION**

TIM COVINO, 2005-2006 Montana USGS 104b Research Fellow

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