Ground and Surface Water Interaction in Ephemeral Wetlands, San Luis Valley, Colorado

Brian Kappen[*] and William Sanford
Department of Geosciences, Colorado State University

John Sanderson
Graduate Degree Program in Ecology, Colorado State University

Abstract: Groundwater- surface water interactions were studied at Mishak Lakes and Blanca Wetlands, ephemeral wetlands located in the arid San Luis Valley of Colorado. Hydraulic conductivities and hydraulic gradients along with major ion chemistry and stable isotope composition of ground and surface water were determined. At Mishak Lakes, groundwater mounding occurs beneath the basins despite the presence of a laterally consistent low permeability layer, suggesting that recharge occurs through macropores. Isotope enrichment between sampling rounds was used to estimate recharge at approximately 51% of total surface water volume loss. The recharge rate has been estimated to be 4.3 mm/day. The estimated evaporation rate over the same time was estimated at 4.1 mm/day.

At Blanca Wetlands, higher elevation basins receive a nearly constant supply of water, and recharge creates a locally high water table equal to the elevation to surface water near the basin margins. Isotope data indicates that recharge primarily occurs below the higher basins. As surface water flows into lower elevation basins more distant from the source, chloride replaces bicarbonate as the dominant anion, resulting in salt precipitation as the basins evaporate to completion.

1. Introduction

The San Luis Valley (SLV) is an arid region, receiving less than 20 cm of precipitation annually (Leonard and Watts, 1988). The lack of surface water makes groundwater the primary resource for all water users. A reasonable understanding groundwater recharge is necessary to forecast long-term groundwater supply. Recharge in the northern part of the SLV has been studied on a large scale by Huntley (1979) and others, however, detailed study of recharge from surface water is lacking because it is a small component of the overall water budget. Surface water features have been considered of negligible importance to regional recharge (Huntley, 1976; 1979).

Several perennial and ephemeral wetlands that support migratory bird populations exist throughout the valley. This study was implemented to determine the groundwater – surface water interaction at SLV wetlands, which will improve wetland management decisions and groundwater supply prediction. Two wetlands were selected for study: Mishak Lakes and Blanca Wetlands. Both wetlands are located in the northern part of the valley, approximately 50 km apart and on opposite sides of a groundwater divide (Leonard and Watts, 1988). The water supply for both wetlands may be impacted by the Closed Basin Project (CBP), which augments flow in the Rio

Grande River with water pumped from the unconfined aquifer. A hydrogeologic model by Leonard and Watts (1988) predicts up to 0.6 meters of drawdown under Mishak Lakes and up to 3 meters of drawdown under Blanca Wetlands due to CBP withdrawals. These two wetlands are both supplied primarily by artesian groundwater. Topography, shallow stratigraphy, and water chemistry, however, differ significantly between them. Therefore, these two wetlands should suggest a range of possible groundwater-surface water interaction scenarios.

The objectives of this study were to 1) evaluate the hydraulic connection between groundwater and surface water with respect to shallow stratigraphy, 2) estimate recharge rates from the basins to shallow groundwater, 3) improve the water budget at Mishak Lakes with an independent recharge estimation, and 4) determine the cause of salt precipitation at Blanca Wetlands. To address these questions, hydrologic data including major ion chemistry and stable isotope composition were analyzed and compared.

2. Setting

The San Luis Valley (SLV) is an arid region of south-central Colorado, bounded by the San Juan and Sangre de Christo mountain ranges on the west and east, respectively. The upper stratigraphic unit in the SLV consists of undifferentiated Pleistocene and Holocene sediments ranging from clay to gravel (Leonard and Watts, 1988). A shallow, unconfined aquifer and a confined aquifer exist within these deposits. The confining unit is the first significant and continuous clay layer encountered from the surface, which
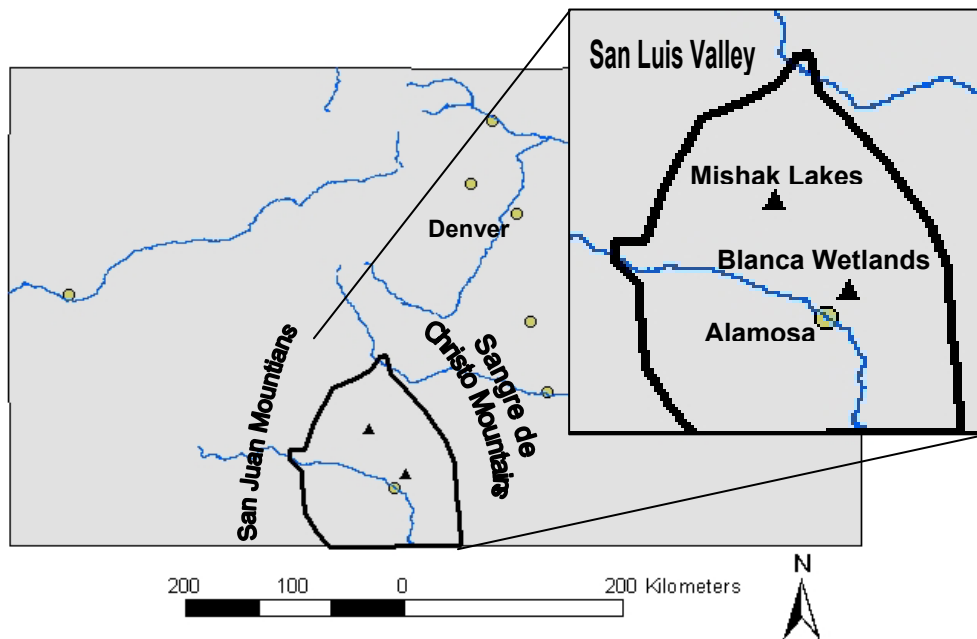
Figure 1. Approximate boundaries of the San Luis Valley in Colorado with wetland locations indicated by the triangles.

occurs between 60 and 120 feet below ground surface (bgs). This study is concerned with interaction between surface water and the unconfined aquifer.

2.1 Mishak Lakes

The Mishak Lakes wetlands are located in the north-central part of the San Luis Valley (SLV), approximately 50 km north of Alamosa, Colorado. The wetlands consist of a series of shallow, flat-bottomed basins connected by poorly defined channels ((Figure 2) Sanderson and Kotliar, 1999). Historically, the primary source of water for the wetlands was Russell Creek. The creek originates at Russell Springs approximately 14.5 km west of Mishak Lakes. The creek also collects water from snowmelt in the San Juan Mountains, which form the western border of the SLV. During the middle of the twentieth century, several artesian wells were completed in the vicinity of Russell Springs, substantially increasing flow in Russell Creek. Currently, a
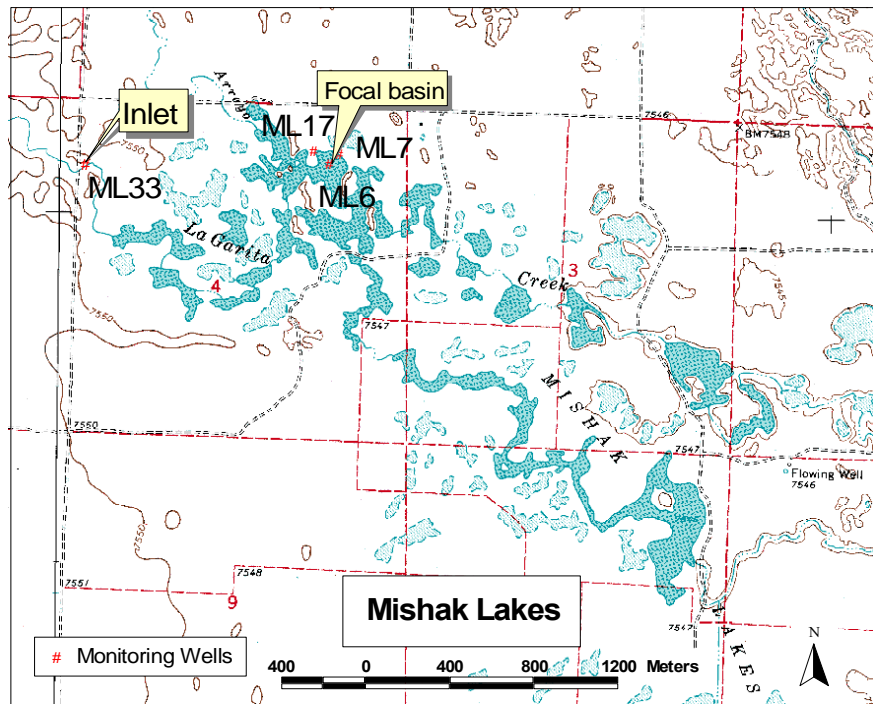

Figure 2. Mishak Lakes study area, northern San Luis Valley, Colorado.

large amount of that water is diverted between May and November for irrigation. These diversions mimic natural stream flow conditions; the system receives water in the spring as it would from snowmelt, then the water supply terminates and the basins become completely dry by the end of summer. Because the creek has upstream users, there is currently no way to ensure a predictable water supply. The basins at Mishak Lakes are shallow (generally less than 1 meter), and the surrounding uplands are relatively flat. A laterally consistent low permeability (clay) layer that exists near ground surface appears to limit infiltration. This study was focused on the inlet to the
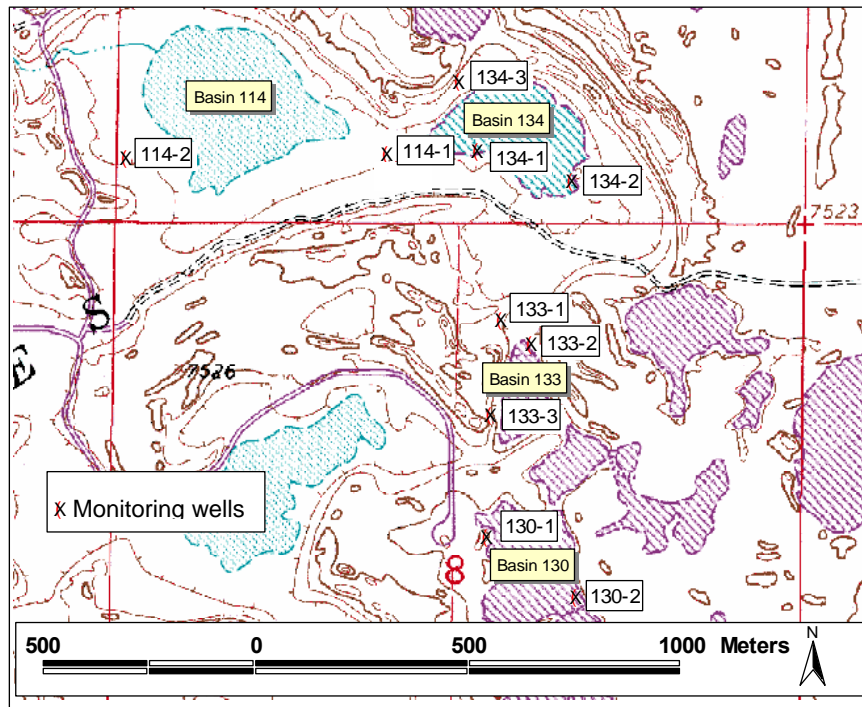
Figure 3. Blanca Wetlands study area, central San Luis Valley, Colorado.

wetlands and the focal basin, which is the last basin to become dry in the summer.

2.2 Blanca Wetlands

The Blanca Wetlands are located approximately 12 km northeast of Alamosa, Colorado, 50 km southeast of Mishak Lakes. Some basins contain water continuously, while others become dry toward the end of summer. The water supply wells are onsite and used exclusively for wetland maintenance. The basins are deeper than those at Mishak Lakes (generally 1 to 2 meters), and the uplands surrounding the basin have more relief and are dominated by vegetated sand dunes.

The soils at Blanca Wetlands are composed of fine-grained sand, with significant silt content in low-lying areas. Salt precipitation occurs in low-lying basins, which may be affecting water quality. Total dissolved solids concentrations in the unconfined aquifer beneath Blanca Wetlands are up to 50 times greater than that in the majority of the SLV (Repplier et al., 1981). This is most likely a result of the topographic position the wetlands occupy. This is the lowest area in the entire SLV - no outlet for surface water exists. Fossils discovered at Blanca Wetlands indicate that, prior to modern irrigation, wetlands naturally occurred in this area (Lucero, 2003). In the recent past, however, it has become very rare for surface water to naturally flow into this area.

Many basins at Blanca Wetlands are controlled in a series such that an artesian well feeds a higher elevation basin, and water then flows by gravity through pipes under earthen dams into lower elevation basins. The final

(lowest) basin in the series has no outlet so water must either evaporate or infiltrate. One of these series, basin numbers 130 through 114 (in order of decreasing elevation), was studied and assumed to be representative of any series in the wetlands (see Figure 3). An artesian well and spring feed basin 130 and from there water flows north and west into basin 114, which has no surface outlet. When the basins are filled to maximum level, the surface water in basin 130 is slightly less than three meters higher than water in basin 114.

3. Methods

The ground and surface water interaction at the wetlands was investigated using three main characteristics: physical properties of near-surface stratigraphy, major ion chemistry, and stable isotope composition. The chemical and isotopic composition of groundwater and surface water were compared within individual wetland basins to evaluate the degree of hydraulic connection and estimate recharge rates.

3.1 Physical Characterization

To estimate hydraulic conductivity of the soils, falling-head permeameter tests were performed on samples of near-surface sediment according to the method outlined by Lee et al. (2003). Sediment for these tests was collected in plastic cores using a hand auger with a hammer attachment. To minimize sample disturbance, the cores were capped with rubber stoppers and placed directly into the permeameter apparatus.

Groundwater flow direction and hydraulic gradient were determined from water elevations in monitoring wells. At Mishak Lakes, wells were installed for previous studies. At Blanca Wetlands, a total of ten monitoring wells were installed near the edges of the basins. The wells are constructed with 5 cm diameter PVC casing with 30 cm screened intervals, completed with sand and a bentonite seal. The wells were set as deep as possible using a hand auger - typically about 2 meters below ground surface (bgs).

3.2 Major Ion Chemistry

At Mishak Lakes, well completion information was reviewed to determine appropriate sampling locations. Wells that are near or within a basin and have screened intervals below the clay layer provided valid spatial comparison to surface water, while at the same time accounting for stratigraphic influence. Ground and surface water samples were collected on April 24 and May 20, 2003 from the focal basin and wetland inlet. Samples from four wells in these areas were collected in April and samples from two wells in the focal basin were collected in May. Additionally, samples of artesian source water were collected to understand the initial chemical composition of source water. At Blanca wetlands, ground and surface water samples were collected at the ten monitoring wells on July 31, 2003.

All water samples were analyzed for pH, conductivity, total dissolved solids, and several major ions: Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, B, and NO_3. The chemical differences between groundwater and surface water were used as an indication of hydraulic connection. These parameters were also compared according to basin elevation and distance from the water source.

3.3 Stable Isotope Composition

Stable isotope compositions are ratios of heavy to light isotopes that are compared to a reference standard and reported as deviation in parts per thousand. For this study hydrogen and oxygen isotopes were used (ratios ^{2}H to ^{1}H and ^{18}O to ^{16}O, respectively). Evaporation causes isotopic enrichment, or higher ratios. The trend of evaporative enrichment can be traced back to the intersection with the global meteoric water line (GMWL) for an indication of the isotopic composition of source water. The GMWL represents mean isotopic compositions of precipitation around the world (Clark and Fritz, 1997). In this case, the source water is primarily artesian groundwater plus a limited amount of runoff and direct precipitation. Similar to chemical differences, isotopic differences between ground and surface water were used as an indication of hydraulic connection.

Higher evaporation rates cause isotope fractionation to be a non-equilibrium process that is affected, among other factors, by surface temperature and humidity (Clark and Fritz, 1997). The percent evaporative loss from the focal basin can be calculated using the change in isotopic enrichment between the two sampling rounds if average temperature and humidity can be reasonably estimated. Temperature data for a nearby weather station were obtained from the National Climatic Data Center (NCDC), and an average humidity of 52% was estimated from the slope of the evaporative enrichment using equations developed by Gonfiantini (Clark and Fritz, 1997). The total enrichment is the sum of enrichment that occurs between 1) liquid and vapor and 2) the boundary layer and the vapor (the boundary layer is immediately above the water surface where the humidity is 100%). The boundary layer – vapor reaction is the non - equilibrium part of the fractionation (Clark and Fritz, 1997). The evaporative loss can be modeled by a Rayleigh Distillation as:

$$\varepsilon^{18}O_{total} \times \ln f = \delta^{18}O_o - \delta^{18}O_f \qquad (1)$$

where $\varepsilon^{18}O_{total}$ is the total enrichment, f is the fraction of the reservoir remaining, and $\delta^{18}O_o$ and $\delta^{18}O_f$ are the original and final isotope values respectively. The equation takes the same form using ^{2}H. Evaporative loss using this equation can only be calculated for the basins that do not receive a constant supply of source water. Otherwise, the amount of enrichment will reflect a mix of water with varying residence times. At Mishak Lakes, surface water input had ceased previous to the first sampling round.

By solving the Rayleigh distillation for 'f ', the fraction of water in a basin lost to evaporation over time can be calculated. A first-order approximation of recharge volume (V_R) is then estimated by:

$$V_R = (1-f)V_I - V_F \qquad (2)$$

where V_I is the initial volume and V_F if the final volume. A model has been developed for the Mishak Lakes focal basin by Sanderson (2004) that relates volume to depth. The model is essentially an elevation grid that approximates the shape of the basin floor. Dividing the depth of water recharged by the time between sampling rounds yields a groundwater recharge rate.

4. Results and Discussion

4.1 Mishak Lakes

Hydraulic conductivities measured on sediments from Mishak Lakes range from 3.6×10^{-10} to 1.3×10^{-6} (Table 1), with a 4-order-of-magnitude increase from the clay layer to the underlying silty sand. The minimum clay thickness observed in the focal basin was approximately 12 cm. Water level measurements from the wells at the focal basin depicted in Figure 4 reveal that water table mounding is obvious approximately 6 weeks after the basin begins to fill. The shape of the mound suggests that recharge is more or less vertical, ruling out flow around the edges of the basin. Given the hydraulic conductivity and thickness of the clay, this amount of recharge cannot be explained by interstitial flow. Thus, preferential flow paths (e.g. cracks, root holes, animal disturbances) must exist in the clay layer.
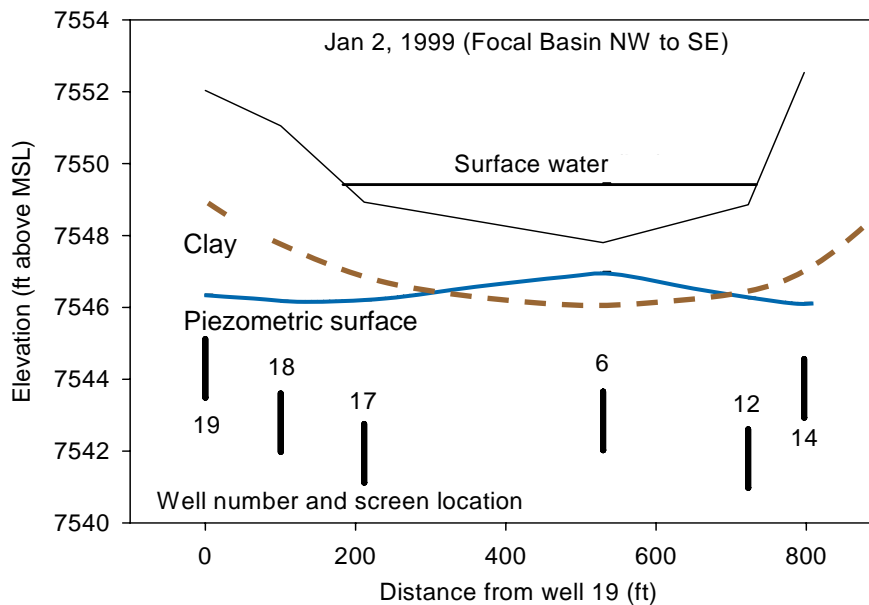

Figure 4. Groundwater mound formation beneath the Mishak Lakes focal basin approximately 6 weeks after the basin begins filling.

The results of chemical analyses on water samples reveal that surface and shallow groundwater at Mishak Lakes are sodium bicarbonate type. The results are depicted as Stiff diagrams in Figure 5. In general, groundwater contains higher overall concentrations of dissolved constituents. The exception to this relationship occurs at the inlet to the system (ML33), where the concentrations are similar. It would be reasonable to conclude from this data that the low permeability material is discontinuous or nonexistent at the inlet, allowing unimpeded infiltration and mixing between surface and groundwater. However, the stable isotope results from the same samples contradict this conclusion. Instead it is theorized that the observed water table mounding (Figure 4) causes a decrease (possibly reversal) of horizontal hydraulic gradient beneath the basins. Consequently, the velocity of groundwater near the water table decreases, which increases water-sediment interaction time. As a result, groundwater contains higher dissolved ion concentrations than surface water.

Table 1. Falling head permeameter test results of soil collected at Mishak Lakes focal basin.

| Description	Depth (cm)	Test #	K (m s^{-1})
Clay	24 - 40	1	**3.6 x 10^{-10}**
Silty sand	40 - 56	1	1.1 x 10^{-6}
Silty sand	40 - 56	2	7.0 x 10^{-7}
Silty sand	40 - 56	3	2.1 x 10^{-6}
	40 - 56	**Avg**	**1.3 x 10^{-6}**
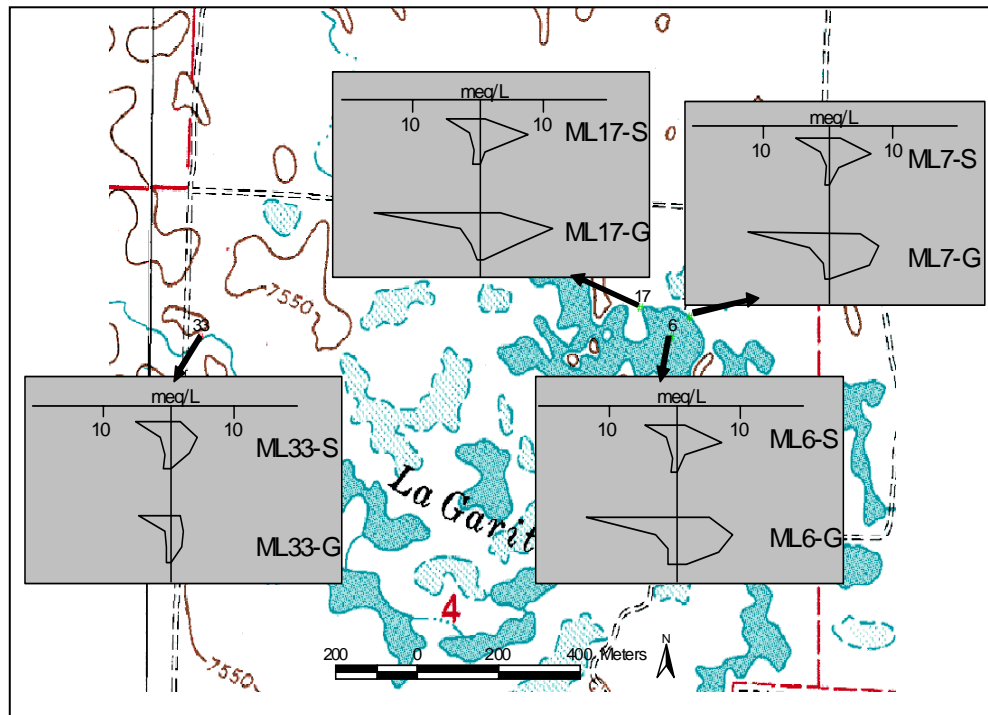
Figure 5. Stiff diagrams of sample results at four locations (one from the inlet and three from the focal basin) at Mishak Lakes – April 24, 2003. Surface water results are denoted be 'S' and groundwater by 'G'. Cations represent vertices on the left side and are (in order vertically) Na, Ca, Mg, K. Anions represent vertices on the right side and are (in order vertically) Cl, HCO$_3$, SO$_4$, NO$_3$.

The isotope results of the April 24, 2003 sampling round are depicted in Figure 6. Surface water samples occur in a tight group of similar enrichment (and therefore residence time in the basin) as expected. Enrichment is also evident in each groundwater sample, and the distribution of composition along the trend of evaporative enrichment reflects differing degrees of mixing with infiltrating water from the basin. For example, more mixing has occurred at location ML7 than at ML33 because the isotopic composition of sample ML7 is closer to that of surface water. In fact, the largest difference in isotopic composition occurs at ML33 which is the reason the chemical similarity at this location discussed earlier is not interpreted as recharge.

The Rayleigh distillation equation (1) was used to estimate percent evaporative loss from the focal basin between the two sampling rounds. The results were 42% using ^{18}O and 36% using ^{2}H, with an average of 39%. This means that approximately 39% of the water in the focal basin on April 24 had been lost to evaporation by May 20. The depth at the center of the focal basin was measured on both sampling dates. The change in depth was related to total volume evaporated based on the basin model created by Sanderson (2004).

Taking into account model and measurement uncertainty, the best estimates of initial volume (V_I) on April 24 and final volume (V_F) on May 20 were 4990 m^3 and 1010 m^3, respectively. The evaporated volume (V_I*f) was then 1946 m^3. Using equation 2, the recharge volume (V_R) was 2034 m^3,
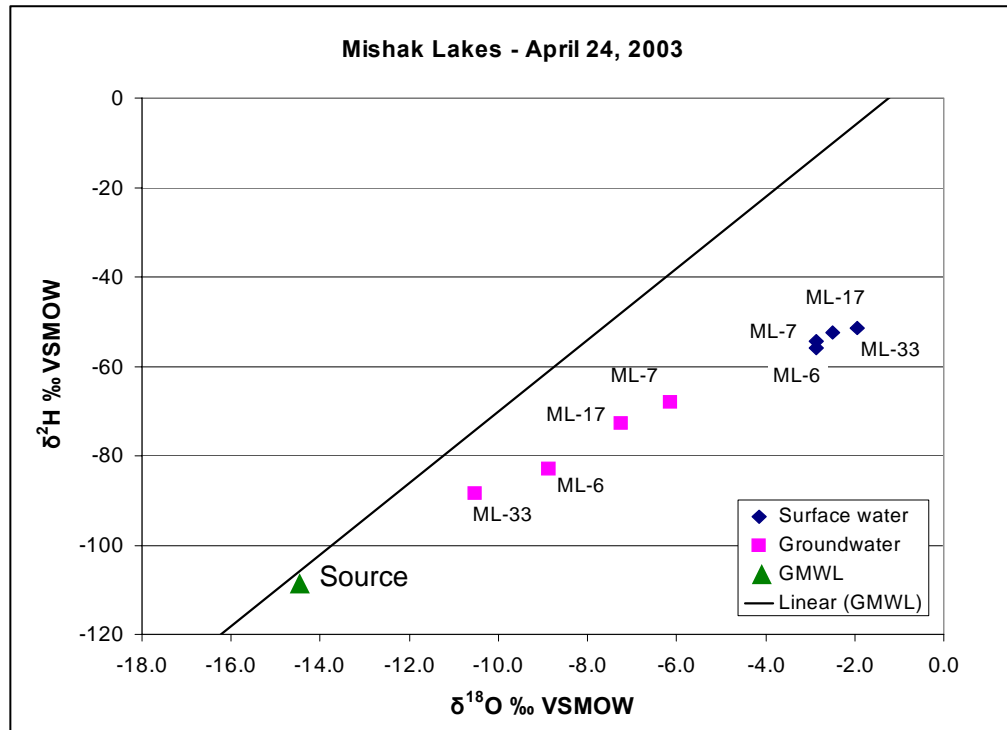
Figure 6. The distribution of shallow groundwater isotope compositions indicates mixing of source water (precipitation and artesian groundwater) and surface water. The difference in slope between the GMWL and the trend of evaporative enrichment reflects the low humidity in the SLV.

which was converted to depth by dividing by surface water area. These calculations represent a first-order approximation. Because evaporation and recharge occur simultaneously, the volume of water subject to evaporation is not technically V_I. Therefore, V_I *f is a slight overestimation of the evaporated volume, and that error is passed on to the recharge volume. Using this method, the evaporation rate is 4.1 mm/day, and the recharge rate is 4.3 mm/day. The theoretical evapotranspiration (ET) rate over this time is 5.7 mm/day based on weather data from a nearby station. The stable isotope approach does not consider transpiration by grasses on the basin floor, however, transpiration alone cannot account for the 1.6 mm/day difference. ET of water flowing through the basin edges would significantly affect the recharge rate. This possibility cannot be excluded. The NCDC reports an average of 0.97 cm of precipitation in May, 2003 for the two stations nearest Mishak Lakes. This input does not affect the estimated recharge rate range. The recharge rate reported above is consistent with basin floor recharge rate estimates calculated by Wood et al. (1997) in a macropore recharge study in the semi-arid southern high plains (Texas and New Mexico).
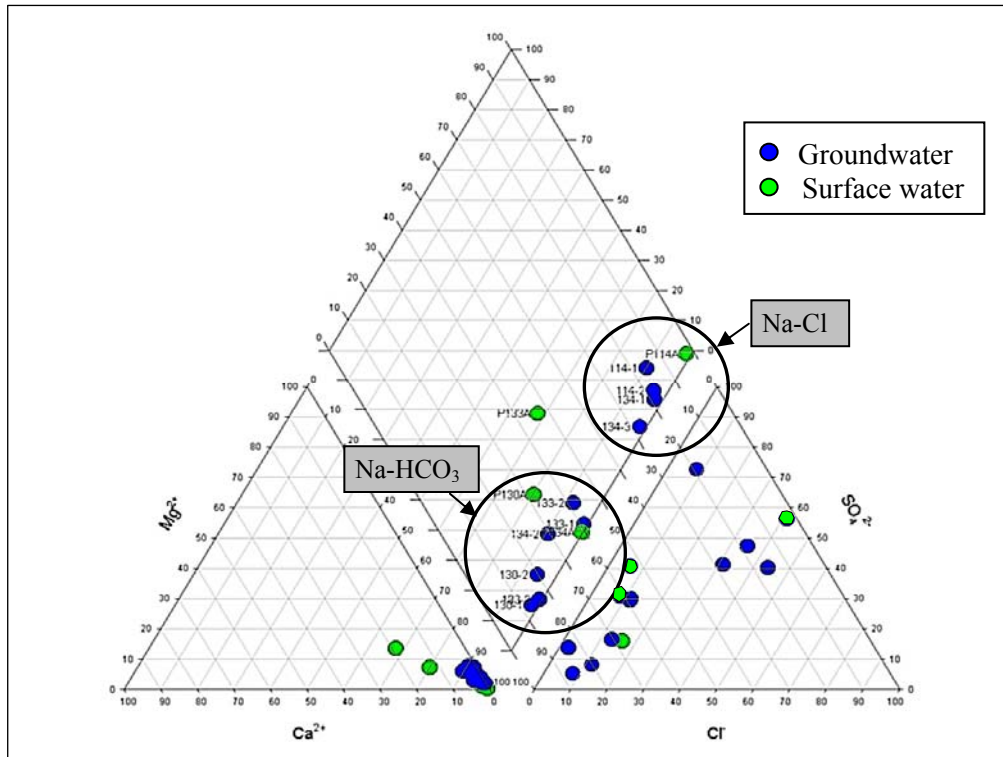
4.2 Blanca Wetlands

Groundwater along the series of basins studied flows toward basin 114. The gradient from basin 130 to 114 is approximately 0.003. There is a distinct change in major ion chemistry from basins 130 and 133 to basins 134 and 114. Both groundwater and surface water change from sodium-bicarbonate type in the upper basins to sodium-chloride type in the lower basins. The change occurs within Basin 134, as well 134-2 has the characteristics of the former group and wells 134-1 and 134-3 have characteristics of the latter. The surface water sample from basin 134, which is Na-HCO$_3$ type, was collected next to well 134-2. The results of chemical analyses are presented in Figure 7. These results suggest that salt is precipitated in low elevation basins during evaporation because of the change in water chemistry.

As expected, total dissolved solids (TDS) concentrations in groundwater increase with decreasing elevation (Table 2). TDS range from 1,030 mg/L beneath the highest basin (130) to 24,059 mg/L beneath the lowest basin (114). These concentrations are consistent with the 2,200 to 10,200 mg/L range reported by Repplier et al. (1981) in the vicinity of Blanca Wetlands. Note the difference in TDS between wells 114-1 and 114-2, which

Table 2. Total dissolved solids concentrations arranged in order of decreasing basin elevation. P114A was collected from an area with solids visibly precipitating.

| Sample	TDS (mg/L)	Sample	TDS (mg/L)	Sample	TDS (mg/L)	Sample	TDS (mg/L)
P130A	305	P133A	434	P134A	9,573	P114A	67,453
130-1	1,030	133-1	6,633	134-1	9,327	114-1	3,750
130-2	2,649	133-2	4,975	134-2	378	114-2	24,059
		133-3	1,814	134-3	14,773		

Figure 7. Piper Diagram of Blanca Wetlands samples collected on July 31, 2003. Two distinct water types occur: a sodium-bicarbonate type associated with the upper basins and a sodium-chloride type associated with the lower basins. These types apply to both surface and ground water. The change occurs within basin 134; that is the groundwater from well 134-2 is of the Na-HCO₃ type while that from wells 134-1 and 134-3 are Na-Cl type (see Figure 3 for locations).

are located on opposite ends of basin 114, approximately 600 meters apart. There appears to be a much greater surface water connection at 114-2 (the west end of the basin). This relationship is also seen in the isotope data presented in Table 3.

The distribution of surface water isotope results presented in Figure 8 varies much more than at Mishak Lakes. Samples P130A and P133A and B are considerably depleted in comparison to P114A and P134A and B (upper right of the graph) which were collected from basins further down the flow path. This difference results from continuous mixing with groundwater that discharges from a spring and an artesian well that feed basin 130. The

Table 3. July 31, 2003 stable isotope results listed in order of decreasing elevation and increasing distance from the water source. 'Avg' signifies that average results from wells around a single basin are listed.

Surface water			Groundwater		
Sample	$\delta^{18}O$ ‰	δ^2H ‰	Sample	$\delta^{18}O$ ‰	δ^2H‰
P130A	-5.2	-51	130-Avg	-6.8	-60.8
P133B	0.4	-26	133-Avg	-9.9	-74.6
P134B	10.1	26	134-Avg	-11.5	-85.7
P114A	8.0	19	114-1	-12.2	-89.1
			114-2	-1.7	-41

130
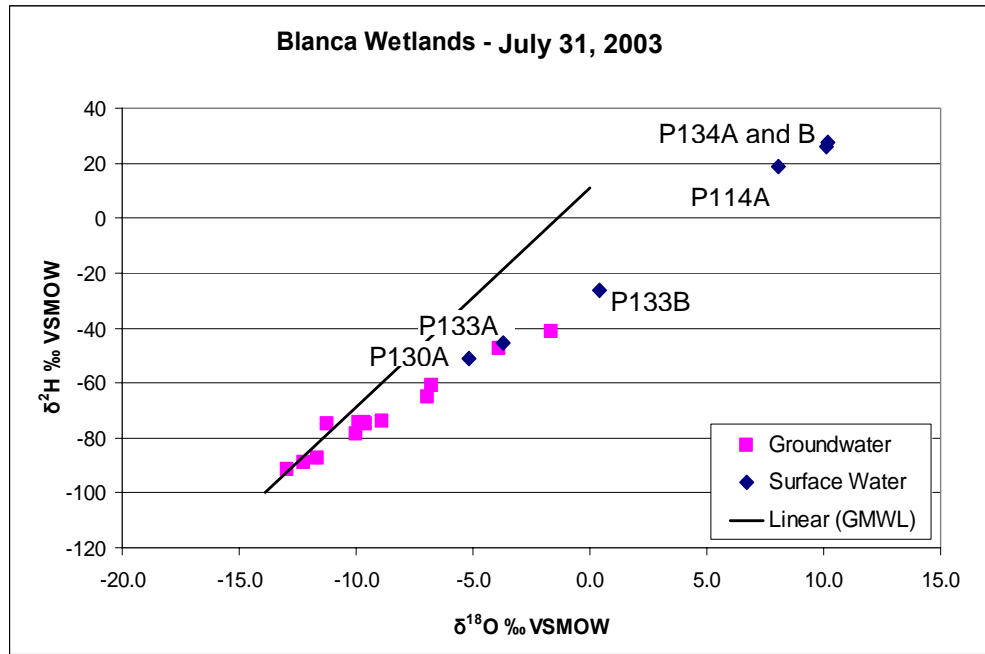
Figure 8. Isotopic composition of surface water occurs in two groups, one more enriched than the other. The more enriched group (the three samples at the upper right of the graph) had no surface connection to upper basins on the sampling date and thus were not continuously mixing with discharging groundwater from a well and spring adjacent to basin 130.

evaporative enrichment in basins 130 and 133 is decreased through mixing with the fresh groundwater. At the time of collection, there was no surface water connection to basins 134 and 114, so their waters were more enriched.

Table 3 lists the isotope results from the July 31, 2003 sampling round in order of decreasing basin elevation and distance from the water source. The similarity in groundwater and surface water composition at basin 130 suggests that a locally high water table is maintained around the basin by recharging surface water. The difference in composition increases in downstream basins. The large difference between ground and surface water isotope composition in the final two basins indicates that recharge is very limited. An exception occurs at well 114-2 (the west end of basin 114) which is enriched as a result of mixing with surface water. Recharge at 114-2 is also indicated by the TDS results (Table 2).

5. Summary and Conclusions

Although the two wetlands studied have similar water sources and climate, their location within the SLV and corresponding topography appears to dictate their importance as points of recharge. At Mishak Lakes, a recharge rate of 4.3 mm/day causes a 30 cm high groundwater mound to form beneath the focal basin. The discrepancy between relatively rapid groundwater mound formation after the focal basin fills and the low permeability of the clay layer is logically explained by preferential flow. The variation in groundwater –

surface water mixing indicated by groundwater isotopic compositions supports the idea of preferential flow, as flow paths will likely not be equally distributed across the basin.

At Blanca Wetlands, the elevation of individual basins appears to dictate hydrologic processes. Higher elevation basins that receive a steady water supply maintain a locally high water table with direct recharge. This is supported by similar isotopic and chemical composition of surface water and groundwater near the basin margins. It is unknown, however, what amount of recharge is conveyed to the regional water table. Monitoring wells at the upper basin margins only penetrate the locally elevated water table. In the lower basins, the increased difference in isotopic composition between groundwater and surface water indicates recharge is very limited with the exception of the west side of basin 114. Preliminary hydraulic conductivity values from sediments at basins 134 and 114 are on the order of 10^{-7} to 10^{-9} m s^{-1}, which supports the limited recharge conclusion.

The chemical composition of water at Blanca Wetlands changes from sodium-bicarbonate type to sodium-chloride type as water flows into lower basins. Soil analysis is needed to determine whether additional chloride is dissolved from soil or if existing chloride is simply concentrated by evaporative enrichment. This analysis will also indicate if salt is accumulating in low-lying areas or if an annual cycle of dissolution and precipitation relates to the basin flooding cycle.

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