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Using Strontium Isotopes to Evaluate the Spatial Variation of Groundwater Recharge

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Abstract

Recharge of alluvial aquifers is a key component in understanding the interaction between floodplain vadose zone biogeochemistry and groundwater quality. The Rifle Site (a former U-mill tailings site) adjacent to the Colorado River is a well-established field laboratory that has been used for over a decade for the study of biogeochemical processes in the vadose zone and aquifer. This site is considered an exemplar of both a riparian floodplain in a semiarid region and a post-remediation U-tailings site. In this paper we present Sr isotopic data for groundwater and vadose zone porewater samples collected in May and July 2013 to build a mixing model for the fractional contribution of vadose zone porewater (i.e. recharge) to the aquifer and its variation across the site. The vadose zone porewater contribution to the aquifer ranged systematically from 0% to 38% and appears to be controlled largely by the microtopography of the site. The area-weighted average contribution across the site was 8% corresponding to a net recharge of 7.5 cm. Given a groundwater transport time across the site of ~1.5 to 3 years, this translates to a recharge rate between 5 and 2.5 cm/yr, and with the average precipitation to the site implies a loss from the vadose zone due to evapotranspiration of 83% to 92%, both ranges are in good agreement with previously published results by independent methods. An uranium isotopic (²³⁴U/²³⁸U activity ratios) mixing model for groundwater and surface water samples indicates that a ditch across the site is hydraulically connected to the aquifer and locally significantly affects groundwater. Groundwater samples with high U concentrations attributed to natural bio-reduced zones have ²³⁴U/²³⁸U activity ratios near 1, suggesting that the U currently being released to the aquifer originated from the former U-mill tailings.

Keywords: ⁸⁷Sr/⁸⁶Sr; Uranium isotopes; semiarid environment; vadose zone; hydrology; microtopography

Introduction

Understanding and modeling the processes governing the biogeochemical behavior of riparian floodplains requires constraining the rates and spatial distribution of infiltration

of precipitation through the vadose zone and of groundwater recharge. This flux of water from the land surface carries dissolved constituents, including nutrients and contaminants, through the vadose zone to groundwater. Hence the vadose zone plays a crucial role in connecting the atmosphere to the lithosphere to drive terrestrial hydrospheric processes that affect both groundwater and surface water quality. In semi-arid environments, where precipitation rates are relatively low and rates of evapotranspiration high, net recharge to aquifers can be difficult to estimate using conventional methods (Dripps and Bradbury 2007). Common methods to estimate recharge include (Scanlon et al. 2002) those based on chloride mass balance (e.g. Manna et al. 2016, Alcalá and Custodio 2014), vadose water/tensiometer profile measurements, radio-tracers (e.g. ^3H , ^{36}Cl , ^{14}C , Cartwright et al. 2017 and references therein), vadose porewater $\delta^{18}\text{O}/\delta\text{D}$ profiles (e.g. Singleton et al. 2004, Gaj et al. 2016, and ref.s in Koeniger et al. 2016)), temperature profiles (e.g. Irvine et al. 2017, Kikuchi and Ferré 2017) geophysical methods (e.g. Rimon et al. 2007, Salve 2011), and numerical modeling (e.g. Keese et al. 2005, Wang et al. 2009, Carrera-Hernández et al. 2012, Tran et al. 2016). Isotopic techniques utilizing strontium (Sr) and uranium (U) have been used to gauge long-term weathering and water infiltration rates within the vadose zone (e.g. Bullen et al. 1996, Maher et al. 2006, Singleton et al. 2006, Maher et al. 2003, Cartwright and Morgenstern 2012) as well as assessing vadose contributions to groundwater (e.g. Hogan et al. 2000, Singleton et al. 2006, Christensen et al. 2007) and groundwater contributions to surface water (e.g. Paces and Wurster 2014, Barbieri et al. 2017). Strontium, a trace element with geochemical behavior similar to Ca, has a naturally radiogenic isotope, ^{87}Sr , produced by the decay of ^{87}Rb (half-life= 4.92×10^{10} yrs). This results in variation in the $^{87}\text{Sr}/^{88}\text{Sr}$ ratio of Sr that depends on the geochemical and geologic histories of the source rock and its minerals. This variation can be used to trace Sr from different sources in the environment (e.g. Barbieri et al 2005, Brinck and Frost 2007), and to investigate water-rock interaction (e.g. DePaolo 2006, Brown et al. 2013). Likewise U has naturally variable isotopic composition, in particular the $^{234}\text{U}/^{238}\text{U}$ ratio that depends on the occurrence of processes that disturb the secular equilibrium in the decay chain between the ^{238}U parent, and the ^{234}U great-granddaughter. In the case of porewater, with time the alpha recoil effect (Kigoshi 1971) results in $^{234}\text{U}/^{238}\text{U}$ activity

ratios greater than one, that can be countered by dissolution of minerals with U with activity ratios of 1 or less (Porcelli and Swarzenski, 2003).

Here we compare the Sr isotopic compositions (specifically $^{87}\text{Sr}/^{86}\text{Sr}$ ratios) of vadose zone porewaters to those of groundwater samples in order to evaluate the spatial variation of the contribution of vadose zone sourced water to the local aquifer. We test this method at the Rifle Site in Colorado, a well-studied field laboratory situated along the Colorado River. It is an exemplar both of a floodplain in a semiarid environment and of a remediated U-mine tailings site. We also use $^{234}\text{U}/^{238}\text{U}$ activity ratios to examine the local connection of surface water to the aquifer and the current sources of U to the aquifer. Our focus is on the relative contribution of vadose zone water to the aquifer, rather than on the absolute rate of infiltration or weathering/chemical exchange processes within the vadose zone.

The Rifle Site

The Rifle Site is situated along the north bank of the Colorado River near the city of Rifle in western Colorado. The following description comes in part from the final site report (DOE, 1999). The site is located within the Colorado River floodplain where a former uranium-vanadium ore mill and its associated tailings were situated (Fig. 1). The tailings pile was a source of U contamination of the local groundwater, and was removed and the site remediated from 1992 to 1996 through the Uranium Mill Tailings Remedial Action (UMTRA) program under the U.S. Department of Energy. As part of the remediation process, along with the removal of tailing piles, contaminated surface soils across the site were excavated to an average depth of ~2 m and replaced with material derived from excavation of the near-by Estes Gulch Disposal Site. The ~2 m of fill is a key feature of the site in that it provides a relatively uniform vadose source with a potentially contrasting Sr isotopic signature compared to the aquifer sediments. The fill material consisting of cobbly loam overlies ~4 m of Quaternary alluvial material consisting of quartz/feldspar sands, with silty and coarser pebble/cobble interbeds. The Quaternary alluvium overlies the Tertiary age Wasatch formation which forms the bottom boundary at 6-7 m depth of the upper unconfined aquifer. The water table depth within the floodplain is seasonally variable, ranging from a low of about 4 m below the soil surface to a maximum of about 1.5 m depth below the soil surface during the late

spring producing a typical swing of ~2.5 m (Williams et al. 2011, Yabusaki et al. 2017). However during 2013, the year of this study, the spring water table rise was greatly muted to about a 1m rise due to a relatively dry year resulting in low peak-flow of the Colorado River. The groundwater flow direction is generally from 220° to 180° from N across the site towards the Colorado River, with groundwater velocities in the range of 0.1m/day to 0.6m/day with slower velocities associated with high river stands (Williams et al. 2011).

The site is bounded to the north first by US Route 6 and then a set of bluffs. A N–S ditch crosses the eastern end of the site, carrying water from Cemetery Creek across the site to the Colorado River. Along the shore of the Colorado River, the site is bounded by built-up railroad tracks that limits direct inundation of the Rifle Floodplain by the river. The main portion of the Rifle Floodplain (west of the N–S ditch) covers an area of ~0.135 km² (13.5 hectare, ~33.4 Acres), while the catchment has an area of ~1.583 km². For purposes of description, the region around the Rifle site and environs can be divided into three areas: the plateau to the north of US Rte 6 (called Plateau below), the area to the east of the NS Ditch, and the region adjacent to the river.

The Rifle Site has been used for a series of experiments utilizing several well galleries to investigate the effect of a range of injected amendments on U concentrations in the aquifer via biostimulation and U desorption (Anderson et al. 2003, Yabusaki et al. 2007, Fox et al. 2012, Long et al. 2015). These series of experiments were designed to explore methods of groundwater U remediation by U desorption from aquifer sediments with subsequent promotion of U(VI) reduction by stimulation of microbial activity. Associated with these experiments were studies demonstrating isotopic fractionation of ²³⁵U/²³⁸U ratios due to the induced reduction processes (Bopp et al. 2010, Shiel et al. 2016), while desorption of U off of the aquifer sediments had indiscernible effects on ²³⁵U/²³⁸U ratios (Shiel et al. 2013). Subsequent work at the Rifle site has involved the study of natural reduction zones within the aquifer (Campbell et al. 2012, Qafoku et al. 2014, Wainwright et al. 2016, Janot et al 2016) the effect of seasonal water table fluctuation on the biogeochemistry of the lower vadose zone and upper aquifer (Arora et al. 2016, Yabusaki et al. 2017), and evaluation of the microbially driven flux of CO₂ from the vadose zone (Tokunaga et al. 2016).

Methods

Sample Collection and Treatment

Samples collected and analyzed for this study include surface water, groundwater seeps, groundwater from monitoring wells, and samples from multilevel pore-water samplers installed (TT1) within the vadose zone near well SY08 (Fig. 1). All samples were filtered to 0.22 μm and subsequently acidified with high-purity concentrated nitric acid to a pH of ~ 2 . Filtering was done to avoid contributions of Sr from suspended particulate matter, while acidification was done to avoid absorption of Sr to the HDPE of the sample bottles. Groundwater monitoring wells were sampled in May and again in July 2013. This period brackets the peak in water table elevation. In situ, direct pore water samples at TT1 were taken in April, May and June 2013. Geochemical data and hydrological data for sampling campaigns of monitoring conducted by other Rifle researchers at around these times are available upon request at wfsfa-data@googlegroups.com. As separate samples of pore water composition, sediment samples collected during the boring of TT1 (Fig. 1) were also analyzed. These were treated with DI H_2O , and the leachates separated by centrifugation to produce representations of the porewater present in the sediment samples at the time of collection.

Sr and U Isotopic Analyses

Separate aliquots of groundwater, porewater and surface water samples were evaporated in Teflon vials for Sr and U isotopic analyses. The dried aliquots were treated with concentrated nitric acid and dried again to breakdown any organics in the samples. The aliquots for Sr isotopic analysis were brought back up into 8 M HNO_3 for loading on Teflon micro-columns filled with Sr specific resin (Eichrom Technologies). Matrix elements were eluted with 8 M HNO_3 , and the Sr collected off the column with DI H_2O . For isotopic analysis, the purified Sr separates were dried down and then taken up in 2% phosphoric acid and dried on Re filaments with a TaCl emitter solution. The Sr samples were then analyzed for $^{87}\text{Sr}/^{86}\text{Sr}$ ratios on a Triton multicollector TIMS (Thermo-Fisher). During the course of the analyses, the average $^{87}\text{Sr}/^{86}\text{Sr}$ of NBS987 was 0.710260 ± 9 ($\pm 2\text{s}$ external; $n=10$). Sr concentrations were measured on separate sample aliquots by quadrupole ICPMS.

Chemical separation of U was accomplished using TRU resin (Eichrom Technologies) in Teflon micro-columns. The U aliquots were dried down and taken up in 1.5 M HNO₃ for loading on the columns. Matrix elements were eluted with 1.5 M HNO₃, and the U stripped off the column and collected using 0.3 N HF. The U separates were then dried down and taken up in 0.3 N HNO₃ for measurement of ²³⁴U/²³⁸U isotopic ratios on an IsoProbe multicollector, magnetic sector ICP source mass spectrometer. Instrumental mass bias was monitored using the measured ²³⁸U/²³⁵U ratio corrected to a nominal value of 137.88, and Daly-Faraday inter-calibration measured by bracketing analyses on an in-house secular-equilibrium U standard. Uncertainty in the ²³⁸U/²³⁵U atomic ratio is ≤0.2% 2s, which corresponds to ≤±0.003 2s in the ²³⁸U/²³⁵U activity ratio. U concentrations were measured with the IsoProbe using a comparison of the sample ²³⁸U beam size to the U isotopic standard of known concentration.

Digital Elevation Mapping

A high-resolution surface elevation map was created using a kite-based aerial system, which lifts a consumer-grade digital camera about 40 m above the ground surface. A digital surface model and a geo-referenced mosaic were obtained using automatic image feature detection and matching, structure-from-motion and multiview-stereo techniques. High-accuracy in positioning (< 5 cm in x, y and z directions) was enabled by using a network of ground control points surveyed with a high-precision centimeter-grade RTK DGPS system. The digital terrain model was inferred from the digital surface model by using a moving average filter and removing sharp positive variations which here corresponded to sparse vegetation. The digital terrain model was used to investigate microtopography, flow accumulation, and surface drainage pathways.

Results

The Sr isotopic compositions and Sr concentration of the groundwater, seep, and surface water samples are provided in Table 1. In Figure 2, contours of average (May & July) groundwater and surface water ⁸⁷Sr/⁸⁶Sr ratios have been overlaid onto the location map. Seeps (samples KHW 1 through KHW 5) along the base of the bluffs, representing upgradient groundwater from beneath the Plateau, have relatively low ⁸⁷Sr/⁸⁶Sr ratios ranging from 0.71075 to 0.71092 (ave. 0.71084±0.00006) for samples taken in May and July 2013. Samples from groundwater monitoring wells SY02, SY03, SY04, SY05 and

309 along the western edge of the site also have relatively low $^{87}\text{Sr}/^{86}\text{Sr}$ (0.71063-
0.71092, ave. = 0.71079 ± 0.00014) and also represent upgradient groundwater. Higher
 $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are found in the central portion of the Rifle Floodplain down towards the
river, ranging up to 0.71114. The highest $^{87}\text{Sr}/^{86}\text{Sr}$ measured (~ 0.71130) are for
groundwater samples from well SY08 adjacent to TT1, and create a steep, local high in
the contour map (Figure 2). Relatively low $^{87}\text{Sr}/^{86}\text{Sr}$ at wells 304 and 742 coincide with
low $^{87}\text{Sr}/^{86}\text{Sr}$ measured in surface water from the North-South Ditch. Surface water from
nearby locations (US6 Culvert East & West, Quarry, Rice Paddy, Quarry, Cemetery Ck.,
and Cemetery Telephone) that potentially contribute water to the NS Ditch range in
 $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from 0.71095–0.71101, falling along a rough mixing line with the NS
Ditch samples. Samples from wells 304 and 742 fall near this mixing line, close to the
N–S Ditch samples. The influence of the NS Ditch on wells 304 and 742 is also seen in
 $^{234}\text{U}/^{238}\text{U}$ activity ratios (see below).

The $^{234}\text{U}/^{238}\text{U}$ activity ratios (here after $(^{234}\text{U}/^{238}\text{U})_a$) and U concentrations of the
analyzed samples are given in Table 2 and presented in Figures 3 and 4. Uranium
concentrations in groundwater at the time of the July sampling campaign range from 18
to 427 $\mu\text{g/L}$, with the highest concentration observed at well 743 near the river. With the
exception of SY-08 with U concentration of 338 $\mu\text{g/L}$, within the central portion of the
site groundwater U concentrations generally increase towards the river. The $(^{234}\text{U}/^{238}\text{U})_a$
of up-gradient groundwater from under the Plateau as represented by samples from bluff
seeps (KHW2, KHW3, KHW4 and KHW5) and peripheral SY wells (SY2, SY3 and
SY4) ranges from 1.39 to 1.46 (average 1.42 ± 0.02 1sd). These samples also have an
average U concentration of 28 ± 5 $\mu\text{g/L}$. Within the central part of the site, groundwater
 $(^{234}\text{U}/^{238}\text{U})_a$ varies spatially north to south from 1.40 down to 1.05 with the lowest values
associated with high (over 150 $\mu\text{g/L}$) U concentrations at wells near the river, and locally
at wells SY08 and 656 (Figure 4).

Strontium and uranium isotopic data for vadose zone samples from TT1, both
porewaters and sediment leachates, are presented in Tables 3 and 4 and Figure 5. Overall
the pattern of $^{87}\text{Sr}/^{86}\text{Sr}$ with depth is similar between the sediment DI H_2O leachates and
the directly sampled porewaters (Fig. 5), with ratios ranging from 0.7111 to 0.7118. The
highest $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are at a depth of ~ 2.5 -3.0 m near or just below the base of the fill,

while the lowest ratios are for the shallowest samples (≤ 1 m depth). The concentration of Sr in TT1 vadose zone porewater samples ranges from $\sim 1,370$ ppb to 10,000 ppb. At the 0.5 m depth, the Sr concentration increases with time (between April to June 2013) from 1376 ppb to 7090 ppb, while the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio remains unchanged within the analytical uncertainties, consistent with greater porewater evaporation at the shallower depths. A limited set of vadose porewater samples from TT1 were analyzed for $(^{234}\text{U}/^{238}\text{U})_a$ (Table 4) have values ranging from 1.21 to 1.27 and U concentrations from 336 ppb to 248 ppb.

To assess potential mixing relationships, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are plotted against the inverse of the Sr concentration for groundwater samples collected in July 2013 and porewater samples (Fig. 6). In such a diagram, samples involved in a mixing relationship will fall along a straight line or array, with mixing endmembers lying at opposite ends of the array. Samples from groundwater wells and seeps form a steep array between about 0.71065 towards 0.7113 with increasing Sr concentration. At the upper end of this array, overlapping and extending the array, are vadose zone samples from TT1, with the highest Sr concentrations (6900-7900 $\mu\text{g/L}$) and $^{87}\text{Sr}/^{86}\text{Sr}$ (0.71162 – 0.71165) corresponding to samples from the 2.5 and 3 m depths near the water table. To the right on the diagram, with lower Sr concentrations, are two Colorado River samples taken upstream and downstream from the Rifle site. The downstream Colorado River sample is pulled to the right from the upstream sample towards the Rifle Floodplain groundwater array, presumably because of the export to the Colorado River of groundwater from the Rifle site. Intermediate between the Colorado samples and the Rifle array are two seeps, KHW7 and KHW8. These seeps are located at the far eastern corner of the site at the base of a bluff at the top of which are two municipal overflow basins that receive Colorado River water. Thus, from the Sr isotopic and concentration data, we infer that KHW7 and KHW8 represent Colorado River water that has infiltrated from the basins and mixed with local groundwater.

A similar diagram for mixing relationships based on $(^{234}\text{U}/^{238}\text{U})_a$ and U concentrations is presented in Fig. 7. In this case, groundwater sourced under the Plateau, has high $(^{234}\text{U}/^{238}\text{U})_a$ ratios and moderate U concentrations, while Rifle groundwater tends to have low $(^{234}\text{U}/^{238}\text{U})_a$ and high U concentration, particularly near the river in the

central portion of the site and at SY08. In contrast, surface water samples from the N-S ditch have low U concentration and high ($^{234}\text{U}/^{238}\text{U}$)_a similar to Plateau groundwater.

Discussion

Isotopic Mixing Models and Gauging Local Recharge to the Rifle Aquifer

The Sr isotopic and concentration data can be used as a basis for a mixing model between Rifle groundwater and vadose zone porewater to quantify the recharge of the aquifer from the vadose zone and its spatial variation. Equations 1 and 2 can be used to model the Sr concentrations and the $^{87}\text{Sr}/^{86}\text{Sr}$ of mixtures of various proportions of the model end-members.

The Sr concentration of the mixture of two waters, $[\text{Sr}]_M$, is:

$$[\text{Sr}]_M = f([\text{Sr}]_A - [\text{Sr}]_B) + [\text{Sr}]_B \quad \text{Eq. 1}$$

where f is the fraction of water A, and $[\text{Sr}]_A$ and $[\text{Sr}]_B$ are the concentrations of Sr in water A and water B respectively (Faure 1986).

The $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of that mixture, $(^{87}\text{Sr}/^{86}\text{Sr})_M$, is given by (Faure 1986):----

$$(^{87}\text{Sr}/^{86}\text{Sr})_M = (a/[\text{Sr}]_M) + b \quad \text{Eq. 2}$$

where $a = [([\text{Sr}]_A \cdot [\text{Sr}]_B) \cdot ((^{87}\text{Sr}/^{86}\text{Sr})_B - (^{87}\text{Sr}/^{86}\text{Sr})_A)] / ([\text{Sr}]_A - [\text{Sr}]_B)$

and $b = ([\text{Sr}]_A \cdot ((^{87}\text{Sr}/^{86}\text{Sr})_A - [\text{Sr}]_B \cdot (^{87}\text{Sr}/^{86}\text{Sr})_B) / ([\text{Sr}]_A - [\text{Sr}]_B)$

Equations 1 and 2 are used to calculate model mixing-lines for mixtures between vadose porewater and upgradient groundwater (called the Plateau Groundwater endmember).

For the U concentration and $(^{234}\text{U}/^{238}\text{U})_a$ of two-component water mixtures a similar set of equations are used, with the U concentration of the mixture given by:

$$[\text{U}]_M = f([\text{U}]_A - [\text{U}]_B) + [\text{U}]_B \quad \text{Eq. 3}$$

where f is the fraction of water A, and $[\text{U}]_A$ and $[\text{U}]_B$ are the concentrations of U in water A and water B respectively. Next (Eq. 4), the individual concentrations of ^{234}U and ^{238}U atoms in the mixtures are calculated, a ratio created, and finally normalized by the secular equilibrium value of $^{234}\text{U}/^{238}\text{U}$ of 5.489×10^{-5} given by Cheng et al. (2000).

$$(^{234}\text{U}/^{238}\text{U})_{aM} = \{ (f \cdot [^{234}\text{U}]_A + (1-f) \cdot [^{234}\text{U}]_B) / (f \cdot [^{238}\text{U}]_A + (1-f) \cdot [^{238}\text{U}]_B) \} / 5.489 \times 10^{-5} \quad \text{Eq. 4}$$

where $[^{234}\text{U}]_A$ and $[^{234}\text{U}]_B$ are the ^{234}U concentrations in water A and water B; and $[^{238}\text{U}]_A$ and $[^{238}\text{U}]_B$ are the ^{238}U concentrations in water A and water B respectively.

In the Sr isotopic mixing models, one two end-member pair represents mixing between Plateau groundwater, and Rifle Floodplain vadose zone porewater as represented by May and June samples from the 2.5m deep and 3m deep lysimeters situated at that time above the water table. A second Sr mixing model involves mixing between Rifle Floodplain groundwater and upstream Colorado River. For the U mixing model, again two pairs of end-members are used: one pair representing mixing between Plateau groundwater and the Rifle U groundwater, and the second pair representing mixing between water from the N-S Ditch and Rifle U groundwater. The values used for the end-members in the Sr and U isotopic mixing models are given in Table 5.

The results of the Plateau GW-Vadose Zone Porewater Sr mixing model are presented in Fig. 6 (blue line) and given for individual wells in Table 6. The modeling suggests that the range in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and Sr concentrations observed in groundwater from Rifle Floodplain monitoring wells can be explained by the addition of up to 28% vadose zone porewater (well 656), and 38% in the particular case of SY08, with the majority of wells in the range 0% to 20%. The model results for each well location are plotted in Fig. 8 and compares the May 2013 to the July 2013 results. In addition, the July 2013 results are plotted as a heat map in Fig. 9. In general the percentage contribution of vadose zone porewater to the aquifer increases towards the river within the central portion of the site, with the notable exception of well SY-08 that represents a local high in the vadose contribution. Comparing the model results for the May 2013 and the July 2013 samples suggests in most cases either a modest increase in the vadose contribution over that time period or no change, while wells SY03, SY05 and 0304 each show a small decrease. Comparison of Fig 9 (the heat map of the percentage vadose contribution) to Fig. 10 (the microtopography and inferred drainage network of the site) provides insight into the spatial pattern of the vadose contribution. Areas of lower elevation, shown in greens, contain wells that show higher vadose contribution than wells in the higher elevation areas shown brick red. This suggests that despite only 2.7 m of total relief, the topography of the site influences the spatial distribution of infiltration. An extreme example of local infiltration controlled by local topography is well SY08 that has a

percent vadose contribution of 38%. SY08 is located next to a road in a shallow ditch (inset to Fig. 9) that is commonly observed to gather standing water after precipitation events.

The Sr isotopic model for mixing between Rifle Floodplain groundwater and Colorado River water is shown in Figure 6 as a green line. The model suggests that the Sr isotopic difference seen between Colorado River samples taken upstream (East) and downstream (West) of the Rifle Site can be explained by 2% Rifle Groundwater in the downstream sample. Since the river samples were taken close to shore, this percentage can not be extrapolated to the entire flow of the Colorado and that with dilution by the entire flow this percentage is likely much lower. However, it does suggest that with sampling profiles across the Colorado situated upstream and downstream of the Rifle Site that it may be possible to constrain the flux of groundwater to the river. For seep samples KHW7 and KHW8, which appear to have been affected by seepage of Colorado River water from an overflow pond as described above, the model suggests the addition of about 10% Colorado River water.

The U mixing models are presented in Fig. 7, and the endmember parameters are given in Table 5. Two different mixing lines are given: one (called “Plateau-Rifle”) between upgradient Plateau groundwater and high U concentration, low $(^{234}\text{U}/^{238}\text{U})_a$ Rifle groundwater represented by wells associated with naturally reduced zones (NRZ’s) that harbor U(IV) and with oxidation can be a source of U to the aquifer (Campbell et al. 2012, Qafoku et al 2014, Wainwright et al. 2016) and a second (called “Ditch-Rifle”) between water from the N-S Ditch and again the high U, low $(^{234}\text{U}/^{238}\text{U})_a$ Rifle groundwater. The U concentration and $(^{234}\text{U}/^{238}\text{U})_a$ of samples from wells 304 and 742 near the N-S Ditch can be explained by a mixture with over 80% water from the N-S Ditch. This indicates a significant hydraulic connection between the N-S Ditch and the aquifer, with this influence apparently extending as far as well 305 which is ~70 m to the west of the ditch. Other wells (FP102, 655, LQ109, 305, B01, FP101) in the central part of the site fall along the “Plateau-Rifle” mixing line and have modeled fractions of the Rifle endmember ranging from 15 to 50%. Wells with $(^{234}\text{U}/^{238}\text{U})_a$ less than 1.1 have high U concentrations and are spatially associated with the NRZ’s arrayed parallel to the river. From the “Plateau-Rifle” mixing line it can be argued that the U source associated

with the NRZ's has $(^{234}\text{U}/^{238}\text{U})_a$ close to if not actually 1. Also, porewater from a NRZ sampled at TT3 has high U concentration (1350 ppb) and $(^{234}\text{U}/^{238}\text{U})_a$ of 1.05. Both these observations suggest an association with the milling of U ore that typically is near or at secular equilibrium ($(^{234}\text{U}/^{238}\text{U})_a = 1$), rather than the reduction of U from background groundwater with $(^{234}\text{U}/^{238}\text{U})_a$ approximately 1.4 over time prior to the mills operation and accumulation of the tailings pile.

The reoxidation and release of reduced U from Rifle sediments has been described as related to on-going redox processes in previously existing natural bio-reduced zones (Danczak et al. 2016, Campbell et al. 2011, Yabusaki et al 2017). The $^{234}\text{U}/^{238}\text{U}$ activity ratios near 1 (lowest 1.05) that we observed in the groundwater samples with the highest U concentration suggests that these natural bio-reduced zones had taken up mill-related U that is now being released by these oxidative biogeochemical processes. A consequence of this is the partial decoupling of the Sr and U systematics at Rifle. The groundwater $^{87}\text{Sr}/^{86}\text{Sr}$ composition is affected largely by additions of high Sr concentration vadose porewater with contrasting $^{87}\text{Sr}/^{86}\text{Sr}$, while the groundwater U isotopic composition is affected both by local NRZ's ($(^{234}\text{U}/^{238}\text{U})_a \sim 1$) as well as vadose zone sources ($(^{234}\text{U}/^{238}\text{U})_a$ in TT1 1.21-1.27). However, the mixing relationships seen for $(^{234}\text{U}/^{238}\text{U})_a$ is still useful for discerning the effect of the NS ditch and for constraining the sources of U contamination.

An alternative to infiltration from the vadose zone for the transfer of radiogenic Sr to the aquifer could be the annual spring rise of the water table up into the vadose in which radiogenic Sr would be picked up from the mixing in of vadose pore water. However, water table rise into the vadose zone is unlikely to be the explanation for the 2013 observed spatial variation in groundwater $^{87}\text{Sr}/^{86}\text{Sr}$ and in the calculated vadose contribution to the aquifer. It would be expected that if watertable rise were the primary driver of groundwater $^{87}\text{Sr}/^{86}\text{Sr}$, a more uniform $^{87}\text{Sr}/^{86}\text{Sr}$ ratio would be seen across the site. Instead, as described above, the pattern of $^{87}\text{Sr}/^{86}\text{Sr}$ (and percent vadose contribution) roughly follows the microtopography of the site. Furthermore, unlike other/subsequent years (e.g. 2014, 2015), the water table rise at the Rifle site in 2013 was relatively modest, only about 1 meter (Fig. 11). This rise was insufficient to reach the depth (2.5–3 m) in TT01 that exhibited the most extreme Sr concentration and most radiogenic

$^{87}\text{Sr}/^{86}\text{Sr}$ ratio. The pattern across the site of groundwater $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (as well as the modeled vadose contributions) changes little, or not at all depending on the well, between May and July, a period that brackets the water table peak period, suggesting little additional effect produced by the water table high stand. Instead, it is most likely the spatial pattern of groundwater $^{87}\text{Sr}/^{86}\text{Sr}$ ratios reflects progressive infiltration during groundwater migration across the site. Since, at an average groundwater velocity of ~ 0.3 m/day (range 0.1 to 0.6 m/day Williams et al. 2011) it would take at least 1.5 years for a parcel of groundwater to traverse the middle portion of the site. Indeed a conservative estimate of ~ 2 -3 years for the timescale of cross-floodplain groundwater replacement (Yabusaki et al. 2017) suggests that the observed pattern in $^{87}\text{Sr}/^{86}\text{Sr}$ reflects a relatively long-term (1.5-3 years) process of aggregated recharge from the vadose zone.

The above results for vadose zone recharge to the aquifer can be compared to independent estimates for net infiltration to groundwater and for evaporationtranspiration (ET) loss from the vadose zone. The area-weighted average vadose contribution to the aquifer across the floodplain is approximately 8% and compares well with a simple estimate based on the ratio of the area of the floodplain to the total area of the catchment that yields a vadose recharge contribution across the site of 8.5%. As mentioned above, this likely represents an average recharge over a 1.5 to 3 year period, suggesting a recharge rate in the range of 5.3% to 2.7% per year. The Rifle Site unconfined aquifer with an average porosity of 25% is, on average, ~ 3.75 m thick with an area of 0.135 km^2 , so that at 5.3% to 2.7% recharge per year (by volume) suggests a recharge rate to the aquifer of 5 cm/yr to 2.5 cm/yr. This agrees well with the long-term estimate for recharge calculated for the Rifle aquifer of 5.3 to 1.5 cm/yr (for an average annual total precipitation at the site of 29.5 cm (Western Regional Climate Center)) by Faybishenko et al. (2016) based on meteorological data. With the average precipitation, recharge of 5 cm/yr to 2.7 cm/yr suggests a percentage of precipitation lost to ET of 83% to 92% that is consistent with the range of 70-90% found by Faybishenko et al. (2016). This consistency at the Rifle Site scale lends credence to the interpretation of the groundwater $^{87}\text{Sr}/^{86}\text{Sr}$ data as reflecting local vadose zone recharge to the aquifer. Both estimates of ET are somewhat higher than the regional estimated average of 70-79% for Garfield County by Sanford and Selnick (2013) using climate and land-cover data. It should be noted that the

average precipitation range for Garfield County of 51-75 cm/yr used by Sanford and Selnick (2013) is much higher than the local average precipitation of ~30 cm/yr for the Rifle Site and so their averaging at the county scale likely accounts for this difference.

Our approach for using Sr isotopes for constraining recharge rates is likely useful at a range of semi-arid sites. Other sites, but with undisturbed vadose zones, likely show systematic variation of porewater $^{87}\text{Sr}/^{86}\text{Sr}$ with depth as exemplified by Maher et al. 2003 where a range of 0.0064 in $^{87}\text{Sr}/^{86}\text{Sr}$ was found in just the first 4.5 m of depth. This is nearly ten times the range we observed in the vadose zone at Rifle. Other undisturbed sites are also likely to have variation with depth in $^{234}\text{U}/^{238}\text{U}$ (Maher et al. 2006) providing a second potential vadose porewater tracer. The next requirement is that there be a contrast between the aquifer sediments and the material in the vadose zone. This is likely commonly satisfied since it is not uncommon for recent alluvium from contrasting geological sources to overlie aquifer rocks. The high precision at which Sr isotopes can be measured, along with their natural variation make them particularly sensitive for measuring recharge. At Rifle, particularly large swings of the water table due to years with large spring high-river stage can complicate the interpretation of groundwater isotopic data so that the history of groundwater level at other riparian floodplain should be considered. The advantage of our strategy is that vadose zone porewater compositions are compared directly to groundwater compositions, so that the vadose zone endmember can be directly identified. However this is also a disadvantage due to the additional expense and labor involved in installing vadose zone porewater sampling compared to groundwater monitoring wells.

Conclusions

A $^{87}\text{Sr}/^{86}\text{Sr}$ mixing model was constructed to provide calculated values for the percentage contribution of vadose zone porewater to the aquifer. The spatial variation in the vadose contribution across the site appears to be controlled by the local topography despite only 2.7 m of total relief (average grade of ~1.4%), with low areas of the site exhibiting greater infiltration than nearby sections of the site. Such spatially non-uniform infiltration indicates that the transfer of solutes (contaminants and nutrients) from the vadose zone to the aquifer at the Rifle has also been non-uniform. This has implications

for understanding and modeling the biogeochemical behavior of the site and the persistence of groundwater U contamination.

Based on the average annual precipitation at Rifle site, the estimated area-averaged recharge to the aquifer of 5 cm/yr to 2.5 cm/yr suggests an average 83% to 92% water loss from the vadose zone due to evaporation and transpiration. The eastern portion of the Rifle site appears to have 0% to 4% recharge from the vadose zone to the aquifer, which suggests nearly 100% loss to evapotranspiration in that area. This is expected to limit the vertical mobility of dissolved constituents within the vadose zone and restrict their transfer between the vadose zone and the aquifer to the vertical limits and times of water table rise.

Modeling ($^{234}\text{U}/^{238}\text{U}$) activity ratios of groundwater samples indicates that the N-S ditch that bisects the site is hydrologically connected to the aquifer despite the lining of the ditch during remediation. This result also affects site wide groundwater modeling, providing a boundary condition for the east end of the site (Yabusaki et al. 2017). The ($^{234}\text{U}/^{238}\text{U}$) activity ratios of the highest concentration groundwater samples suggests that the U being released to the aquifer had its origin from the former U mill tailings that was removed in the late 1990's. In particular for locations near the Colorado River, this suggests the past reduction of tailings related U by pre-existing naturally reduced zones (NRZ's) that are now releasing U due to oxidative processes described by (Danczak et al. 2016, Campbell et al. 2011, Yabusaki et al 2017).

Our results demonstrate a strategy for assessing groundwater recharge, using $^{87}\text{Sr}/^{86}\text{Sr}$ ratio and Sr concentration data for groundwater and vadose zone porewater. It is likely other kinds of isotopic or geochemical data can be used in such a fashion as long as there is a contrast between vadose zone porewater and groundwater that can be sufficiently resolved by measurement techniques and the chosen tracer has effectively conservative behavior. Other former U-mill tailings sites across the Western U.S., many of which are situated along river floodplains, may benefit from similar evaluation of recharge spatial variation given the common practice of multiple-well groundwater monitoring programs. This would allow for more responsible management of those sites in a way that is protective of water quality. In addition with the availability of the appropriate samples, this strategy can

also be applied to other semi-arid aquifers where vadose zone recharge can be an important component of understanding the water balance. In this way, our method could be a valuable tool for water managers in water scarce regions to develop effective water resource management plans.

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Figure 1. Location map for monitoring wells in the Rifle Floodplain, along with locations of sampled surface water features. Arrows indicate the typical range in flow direction (220° to 180° from N) over the course of a year (Williams et al. 2011).

Figure 2. Contour map of $^{87}\text{Sr}/^{86}\text{Sr}$ in groundwater samples from monitoring wells and seeps (Red contours), along with $^{87}\text{Sr}/^{86}\text{Sr}$ in surface water samples (Blue contours). Data from Table 1.

Figure 4. Contour map of ($^{234}\text{U}/^{238}\text{U}$) activity ratios in groundwater and surface waters from the NS Ditch based on values given in Table 2.

Figure 5. $^{87}\text{Sr}/^{86}\text{Sr}$ vs. depth for depth-discrete vadose zone samples at well TT1 along with DI extracts from sediment samples produced from the boring of TT1 in March 2013. Data from Tables 3 and 4. The 2013 maximum water table elevation is represented by the grey dashed line. Black arrows indicate the direction in time of changes in $^{87}\text{Sr}/^{86}\text{Sr}$.

Figure 6. $^{87}\text{Sr}/^{86}\text{Sr}$ vs $1/[\text{Sr}]$ showing mixing relationships between vadose samples at TT1 and Rifle Floodplain groundwater. Blue line shows the mixing model of vadose zone water with upgradient (Plateau) groundwater with bold numbers showing the percentage of vadose zone water in Rifle groundwater. Green line shows the mixing model between Rifle Floodplain groundwater and near-shore Colorado River samples with numbers showing the percentage of Rifle Floodplain groundwater. Narrow black arrows point from early to late samples from the same depth in TT1. Samples of the Colorado taken upstream and downstream of the Rifle site show the net effect of exported Floodplain groundwater on the local Colorado $^{87}\text{Sr}/^{86}\text{Sr}$, suggesting ~2% Rifle Groundwater in the near-shore downstream sample. However, the percentage contribution to the whole river flow would be orders of magnitude less.

Figure 7. $(^{234}\text{U}/^{238}\text{U})$ activity ratios vs. the inverse of U concentration illustrating mixing relationships amongst groundwater, surface water and Rifle sources of U held in the aquifer. Based on $(^{234}\text{U}/^{238}\text{U})$ and U concentrations, water in the N-S ditch along the eastern side of the site is in hydraulic connectivity with the aquifer and strongly effects wells 742, 304 and 305, with up to 95% and 85% ditch water in samples from well 742 and 304 respectively. Most other groundwater samples represent variable mixing of upgradient groundwater (Plateau) with Rifle U sources.

Figure 8. The modeled percentage contribution of vadose zone water to the floodplain aquifer using as endmembers the $^{87}\text{Sr}/^{86}\text{Sr}$ of deep (2.5-3m) vadose zone samples at TT1 and the $^{87}\text{Sr}/^{86}\text{Sr}$ of upgradient seep and groundwater samples. Results are shown for groundwater monitoring well samples taken in May and July 2013. Wells in the central and near-river locations show increases with time in the vadose zone contribution to groundwater.

Figure 9. “Heat” map of the percentage contribution of vadose water to the Rifle floodplain aquifer based on the data given for July in the previous figure. Inset shows the micro-topography (elevation in meters) in the local area around an centered on well SY08, illustrating a topographic low surrounding that well that gathers water from both summer rains and melting snow. White circles represent locations of sampled monitoring wells used in the model.

Figure 10. A high-resolution topographic map (with color scale capped at 1621.2 m) of the Rifle Floodplain, with inferred drainage pattern (highest flow accumulations shown in black). Blue circles represent well locations used in the model, with the relative size of the circles representing the size of the contribution of vadose water to the Rifle aquifer. Low topographic areas are coincident with areas of the aquifer with higher percentages of vadose water, suggesting areas of higher infiltration are mapped by the $^{87}\text{Sr}/^{86}\text{Sr}$ of the groundwater samples through the mixing model.

Figure 11. Water table elevation over 2013 for well FP101 near the center of the Rifle Site (Fig. 1). Vertical grey bars indicate the time periods of the two sampling campaigns for this study. The dashed line near the top represents the elevation of the 3m sampling lysimeter within the vadose zone at TT01.

732 **Table 1.** Sr isotopic compositions of groundwater and surface water samples taken in July,
733 2013 and May 2013. Included are Sr concentrations for the July samples

	7/29-7/31/13			5/28-5/30/13	
Location/Name	⁸⁷ Sr/ ⁸⁶ Sr	±2s	[Sr], ppb	⁸⁷ Sr/ ⁸⁶ Sr	±2s
Monitoring Wells					
305	0.710951	6x10 ⁻⁶	4439	0.710922	6x10 ⁻⁶
743	0.711098	6x10 ⁻⁶	6005	0.711082	7x10 ⁻⁶
FP-101	0.711102	6x10 ⁻⁶	7536	0.711083	6x10 ⁻⁶
LQ-105	0.711124	6x10 ⁻⁶	4527	0.711125	7x10 ⁻⁶
LQ-107	0.711136	7x10 ⁻⁶	4412	0.711119	6x10 ⁻⁶
309	0.710631	6x10 ⁻⁶	4563	0.710629	7x10 ⁻⁶
655	0.711055	5x10 ⁻⁶	4749	0.711000	6x10 ⁻⁶
744	0.710990	6x10 ⁻⁶	3728	0.710968	6x10 ⁻⁶
FP-103	0.710893	5x10 ⁻⁶	3381	0.710879	8x10 ⁻⁶
LQ-109	0.710861	6x10 ⁻⁶	4893	0.710853	5x10 ⁻⁶
LR-01	0.710898	5x10 ⁻⁶	4033	0.710881	5x10 ⁻⁶
304	0.710843	7x10 ⁻⁶	3191	0.710873	6x10 ⁻⁶
656	0.711204	6x10 ⁻⁶	4562	0.711190	6x10 ⁻⁶
742	0.710838	5x10 ⁻⁶	3452	0.710816	6x10 ⁻⁶
B01	0.711053	6x10 ⁻⁶	5680	0.711036	7x10 ⁻⁶
FP-102	0.710975	5x10 ⁻⁶	5381	0.710944	7x10 ⁻⁶
SY-01	0.711025	6x10 ⁻⁶	4354	0.711041	7x10 ⁻⁶
SY-02	0.710919	7x10 ⁻⁶	4633	0.710891	7x10 ⁻⁶
SY-03	0.710881	6x10 ⁻⁶	3573	0.710981	5x10 ⁻⁶
SY-04	0.710883	6x10 ⁻⁶	3525	0.710881	8x10 ⁻⁶
SY-05	0.710649	5x10 ⁻⁶	5620	0.710678	6x10 ⁻⁶
SY-06	0.710862	5x10 ⁻⁶	5011	0.710872	8x10 ⁻⁶
SY-08	0.711298	7x10 ⁻⁶	8539	0.711300	7x10 ⁻⁶
310	0.711048	5x10 ⁻⁶	3878	0.711027	8x10 ⁻⁶
JB01	0.711057	6x10 ⁻⁶	5203		
SY-07	0.711566	5x10 ⁻⁶	3749		
U01	0.711084	6x10 ⁻⁶	5650	0.711081	9x10 ⁻⁶
Clough Well #1	0.711239	6x10 ⁻⁶	5334		
Seeps					
KHW-1	0.710801	6x10 ⁻⁶	4272	0.710803	8x10 ⁻⁶
KHW-2	0.710769	6x10 ⁻⁶	2725	0.710745	6x10 ⁻⁶
KHW-3	0.710858	6x10 ⁻⁶	4034	0.710835	6x10 ⁻⁶
KHW-4	0.710895	6x10 ⁻⁶	4386	0.710879	6x10 ⁻⁶
KHW-5	0.710916	7x10 ⁻⁶	4901	0.710899	6x10 ⁻⁶
KHW-7	0.711153	5x10 ⁻⁶	1159		
KHW-8	0.711221	6x10 ⁻⁶	1141		
KHW-9	0.711308	6x10 ⁻⁶	2130		
Surface Water					
Cemetery Ck	0.710987	9.E-06	4550		
Cemetery Telephone	0.710953	5.E-06	4376		
Ditch North	0.710874	7.E-06	3420	0.710860	6x10 ⁻⁶
Quarry	0.710983	5.E-06	5185		
Rice Paddy	0.710895	5.E-06	3416		
U6 East	0.711009	6.E-06	2411		
Cem Ditch			1301		
Ditch South	0.710856	6.E-06	2697	0.710861	7x10 ⁻⁶
Upper Cem Ck	0.710452	6.E-06	3361		
US6 West	0.710961	5.E-06	4872		
Colorado River					
Co. R. East 7/30/13	0.711318	5.E-06	658		
Co. R. West 7/29/13	0.711287	5.E-06	740		

734 **Table 2.** $^{234}\text{U}/^{238}\text{U}$ activity ratios and U concentrations of groundwater and surface water
735 samples taken in July, 2013. Uncertainty in $(^{234}\text{U}/^{238}\text{U})_a < 0.003 \pm 2s$.

	7/29-7/31/13	
Location/Name	$(^{234}\text{U}/^{238}\text{U})_a$	[U], ppb
Monitoring Wells		
305	1.14	50
743	1.08	427
FP-101	1.13	183
LQ-105	1.09	137
LQ-107	1.07	171
309		45
655	1.22	86
744	1.05	230
FP-103	1.08	112
LQ-109	1.17	73
LR-01	1.40	25
304	1.16	28
656	1.07	203
742	1.24	18
B01	1.14	113
FP-102	1.23	75
SY-01	1.19	133
SY-02	1.42	32
SY-03	1.43	29
SY-04	1.46	33
SY-05	1.17	175
SY-06	1.37	24
SY-08	1.09	338
310	1.08	188
JB01		187
SY-07		98
U01	1.08	174
Clough Well #1		98
Seeps		
KHW-1		51
KHW-2	1.41	27
KHW-3	1.41	18
KHW-4	1.40	30
KHW-5	1.39	25
KHW-7		16
KHW-8		15
KHW-9		41
Surface Water		
Ditch North	1.37	8.6
Ditch South	1.38	10.3
Quarry		57
Rice Paddy		31
Cem Ditch		13
Upper Cem Ck		6
US6 West		26

Table 3. Sr isotopic compositions of pore water DI rinses from sediment samples from the boring of TT1.

Depth, m	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2s$
0.15	0.711207	0.000005
0.46	0.711110	0.000007
0.76	0.711285	0.000005
1.07	0.711141	0.000006
1.37	0.711356	0.000005
1.68	0.711406	0.000006
1.98	0.711447	0.000007
2.29	0.711586	0.000005
2.59	0.711821	0.000006
2.90	0.711529	0.000007
3.20	0.711386	0.000006

Table 4. Sr isotopic compositions and concentrations, along with ($^{234}\text{U}/^{238}\text{U}$) activity ratios and U concentrations of depth-discrete vadose zone porewater samples from TT1.

	4/26/2013			5/15/13					6/3/2013		
Depth , m	⁸⁷ Sr/ ⁸⁶ Sr	±2s	[Sr], ppb	⁸⁷ Sr/ ⁸⁶ Sr	±2s	[Sr], ppb	(²³⁴ U/ ²³⁸ U) _a	[U], ppb	⁸⁷ Sr/ ⁸⁶ Sr	±2s	[Sr], ppb
0.50	0.711151	5x10 ⁻⁶	1376	0.711151	6x10 ⁻⁶	6138			0.711152	4x10 ⁻⁶	7090
0.95	0.711215	5x10 ⁻⁶	4036	0.711153	6x10 ⁻⁶	6609			0.711151	6x10 ⁻⁶	7215
1.50	0.711485	6x10 ⁻⁶	5953	0.711485	6x10 ⁻⁶	10041	1.27	248	0.711478	6x10 ⁻⁶	10455
1.94									0.711528	5x10 ⁻⁶	7838
2.43			3723	0.711622	5x10 ⁻⁶	6936	1.27	313	0.711647	6x10 ⁻⁶	7947
2.94				0.711648	5x10 ⁻⁶	6912	1.21	336			9332
3.36	0.711448	6x10 ⁻⁶	4693								

Table 5. Parameters used in the Sr and U isotopic mixing models.

End-member	$^{87}\text{Sr}/^{86}\text{Sr}$	[Sr], ppb	($^{234}\text{U}/^{238}\text{U}$) _a	[U], ppb
Vadose Zone PW	0.71165	9000		
Plateau GW	0.71083	4150	1.41	27
Rifle GW	0.71106	5200	1.07	200
Colorado R. East	0.71132	658		
N-S Ditch			1.38	9

Table 6. Interpolated percentages of Vadose Zone porewater in Rifle groundwater samples based on the Sr isotopic mixing model.

Well name	% Vadose (May 2013)	% Vadose (July 2013)
304	0.5	2.5
305	5.5	7.5
309	0	0
310	12.5	14.5
655	10	14.5
656	26	28
742	0	0.5
743	17	19
744	8.5	10
B01	13.5	14.5
FP101	17	18
FP102	7	9
FP103	3	4.5
LQ105	20	20
LQ107	20	22
LQ109	1	2
LR01	3	4
SY01	14	13
SY02	4	5.5
SY03	10	2
SY04	3	3
SY05	0	0
SY06	3	2
SY08	38	38
U01	17	17