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Using strontium isotopes to evaluate the spatial variation of groundwater recharge

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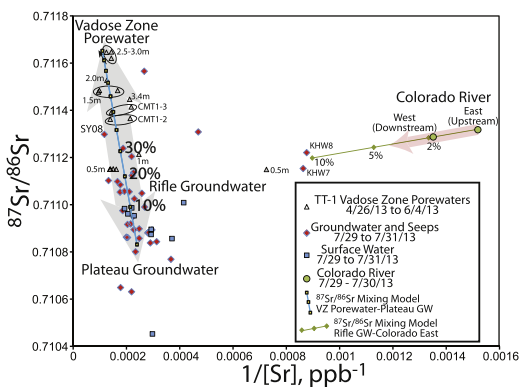
HIGHLIGHTS

- Recharge to the Rifle aquifer measured using 87Sr/86Sr
- Recharge rate averaged across the site estimated to be 5 to 2.5 cm/yr
- Average evapotranspiration loss from vadose zone estimated to 83% to 92%
- Spatial variation of recharge affected by topography despite its small range
- $^{234}U/^{238}U$ suggests U being released from NRZ's originated from removed U-tailings.

GRAPHICAL ABSTRACT



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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. A uranium isotopic ($^{234}U/^{238}U$ 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

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high U concentrations attributed to natural bio-reduced zones have $^{234}U/^{238}U$ activity ratios near 1, suggesting that the U currently being released to the aquifer originated from the former U-mill tailings.

1. 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. ^{3}H, ^{36}Cl, ^{14}C, Cartwright et al., 2017 and references therein), vadose porewater $\delta^{18}O/\delta D$ profiles (e.g. Singleton et al., 2004, Gaj et al., 2016, and refs. 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 $= 4.92 \times 10^{10}$ yrs). This results in variation in the

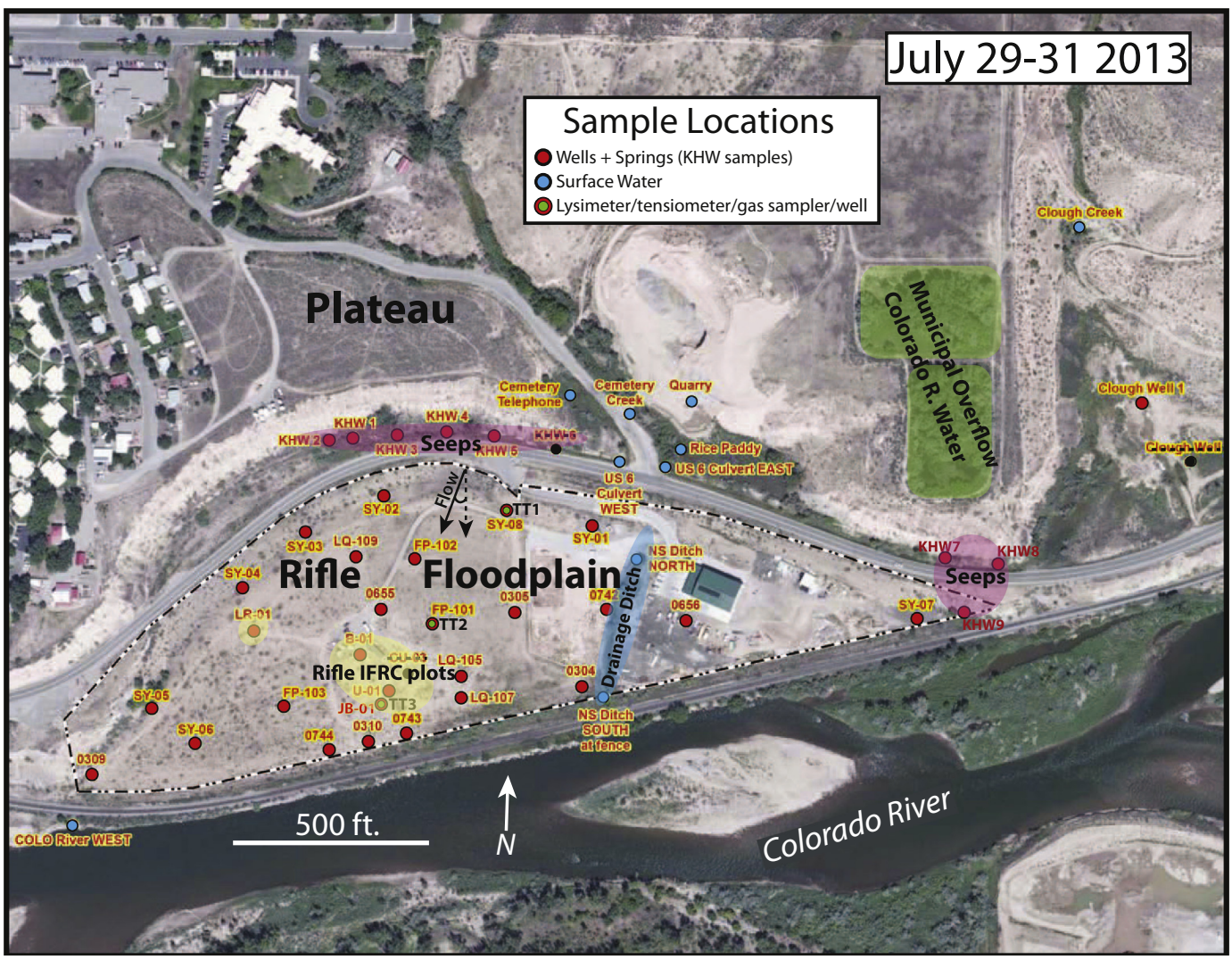

Fig. 1. Location map for monitoring wells in the Rifle Floodplain, along with locations of sampled surface water features. Black arrows indicate the typical range in flow direction (220° to 180° from N) over the course of a year (Williams et al., 2011).