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LOCAL SHALLOW GROUNDWATER DRAWDOWN AND BASEFLOW CESSATION DUE TO REGIONAL GROUNDWATER PUMPING

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ABSTRACT: The existing concept of buffers presupposes that local-scale easements can protect ecosystem structure and function. However, regional-scale processes control many elements of ecosystem structure and function in riparian systems. In this study, we show how local-scale easements fail to protect dry-season shallow groundwater and associated baseflow from the effects of regional groundwater pumping on Little Stony Creek above East Park Reservoir on the east front of the Coast Range, California. Isotopic and geochemical procedures indicate that shallow groundwater and associated baseflow are recharged primarily by regional groundwater discharge, while hydrometric procedures suggest that groundwater pumping in the regional groundwater flow system results in shallow groundwater drawdown and associated baseflow cessation. We believe that the existing concept of buffers must be changed to reflect current understanding of ecosystem structure and function in riparian systems if resource conservation efforts are to be successful. Therefore, we propose that the existing concept of buffers be extended to include regional-scale management of areas critical to the structure and function of the larger hydrologic systems in which riparian systems exist such as groundwater recharge zones and hydrological flowpaths.
KEY TERMS: groundwater; baseflow; water source; groundwater pumping; buffers

INTRODUCTION

The existing concept of buffers presupposes that local-scale easements can protect ecosystem structure and function. However, regional-scale processes control many elements of ecosystem structure and function in riparian systems. For example, shallow groundwater supporting riparian systems may be recharged by stream water, regional groundwater, or mixed stream water and regional groundwater (Rains 2003). In each case, regional-scale water use can impact local-scale ecosystem structure and function. Therefore, local-scale easements cannot buffer the effects of all regional-scale activities. In this paper, we show how local-scale easements fail to protect dry-season shallow groundwater and associated baseflow from the effects of regional groundwater pumping on Little Stony Creek above East Park Reservoir on the east front of the Coast Range, California.

SITE DESCRIPTION

Location and Character

This study was conducted where Little Stony Creek flows into East Park Reservoir on the east front of the Coast Range, northern California (Figure 1). Little Stony Creek flows down the east front of the Coast Range through a high-gradient bedrock canyon. At the canyon mouth, Little Stony Creek flows north through a low-gradient alluvial valley for approximately 3 km before discharging to East Park Reservoir. The alluvial valley supports a regionally-unique mosaic of oak savannah, tule marsh, sedge meadow, and riparian forest. The juxtaposition of these diverse habitats supports high diversity resident and migratory bird populations including a large population of tricolored blackbird (*Agelaius tricolor*), a California State Species of Special Concern (Hamilton, 1998). The site is managed by the U.S. Bureau of Reclamation. The site is lightly grazed in the wet season but is otherwise undeveloped on the valley bottom and adjacent hillslopes. The lack of development on the valley bottom and adjacent hillslopes provides a physical buffer that protects the site from potential impacts associated with intensive and continuous grazing, roads, and low-density rural housing in the surrounding areas.

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Geology and Hydrogeology

The Little Stony Creek alluvial valley is bound on the west by the Franciscan Complex and underlain and bound on the east by the Great Valley Group (Figure 2). The Franciscan Complex is composed of Mesozoic and Cenozoic metasedimentary, metavolcanic, and serpentinitic rocks formed in an accretionary prism during subduction of oceanic plates under the western margin of the North American craton (Blake and Jones, 1981). The Great Valley Group is composed of Upper Jurassic to Upper Cretaceous mudstones, siltstones, and sandstones deposited in a forearc basin (Dickinson and Rich, 1972; Ingersoll and Dickinson, 1990). The Stony Creek Thrust Fault trends north-by-northwest at the contact between the Franciscan Complex and the Great Valley Group (Jennings and Strand, 1960; Brown, 1964).

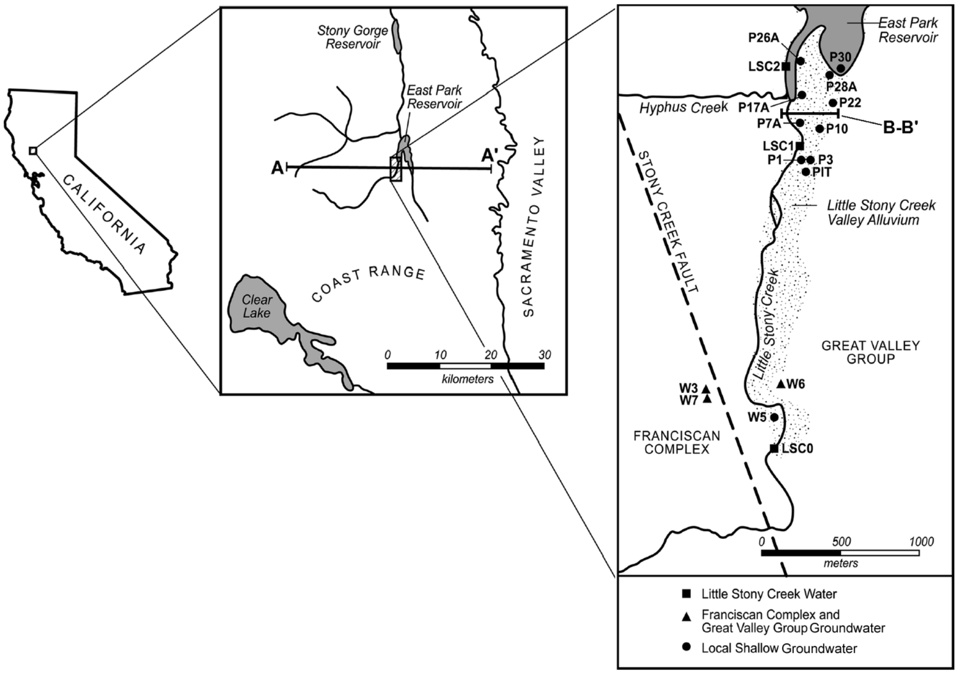


Figure 1. Regional and local settings showing the locations of the geological cross-sections and the water sample locations.

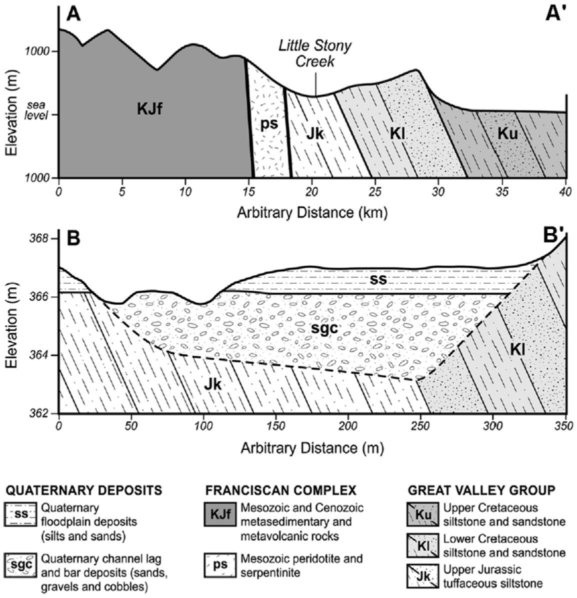


Figure 2. Geological cross-sections at A-A' and B-B'. Vertical exaggerations are 5x and 25x, respectively.

Regional groundwater flow systems are located in the Franciscan Complex and Great Valley Group (Figure 2). Both regional groundwater flow systems are developed for local municipal water supply purposes. A local surface water and groundwater flow system is located in Little Stony Creek and the Little Stony Creek alluvial deposits (Figure 2). The local flow system is not developed for any water supply purposes.

METHODS

A combined geochemical and hydrometric approach was employed in this study. Stable isotope ratios and dissolved constituent concentrations were used to determine the sources of the local shallow groundwater and associated baseflow, while stream stage and groundwater head were used to infer the potential effects of regional groundwater pumping.

Sample Collection and Analytical Procedures

Water samples were collected at 17 locations in September 2000 (Figure 1). Little Stony Creek waters (LSC0, LSC1, and LSC2), Franciscan Complex groundwaters, Great Valley Group groundwater, and local shallow groundwaters were collected and analyzed for oxygen-18 and deuterium ratios and for major cation and anion concentrations.

Oxygen-18 (^{18}O) and deuterium (D) analyses were conducted on a Finnigan 251 isotope ratio mass spectrometer utilizing a constant temperature water bath for equilibration in aqueous samples. Oxygen-18 and deuterium are reported in the conventional delta notation (δ) where

$$\delta = (R_{sample}/R_{standard} - 1) * 1000$$

and R is the ratio $^{18}O/^{16}O$ or D/H for oxygen-18 and deuterium, respectively (Craig, 1961). The resulting sample values of $\delta^{18}O$ and δD are reported in per mil (‰) deviation relative to Vienna Standard Mean Ocean Water (VSMOW) and, by convention, the $\delta^{18}O$ and δD of VSMOW are set at 0 ‰ VSMOW (Gonfiantini, 1978). Analytical precisions were ±0.05 and ±1.0 ‰ for oxygen-18 and deuterium analyses, respectively.

Major cation (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anion (Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}) analyses were conducted at the UC Davis Division of Agriculture and Natural Resources Analytical Laboratory. Analytical precisions typically exceeded 1% for all cations and anions.

Two-End, Mass-Balance Mixing Model

The relative contributions of possible source waters to local shallow groundwater and associated baseflow were estimated using a two-end, mass-balance mixing model with $\delta^{18}O$ as a conservative natural tracer. The two-end, mass-balance mixing model was

$$\delta^{18}O_L = \delta^{18}O_A * (x) + \delta^{18}O_B * (1 - x)$$

where $\delta^{18}O_L$, $\delta^{18}O_A$, and $\delta^{18}O_B$ are the $\delta^{18}O$ of the local shallow groundwater and associated baseflow, end member A, and end member B, respectively. $\delta^{18}O$ can be a conservative tracer since fractionation occurs primarily as a function of conservative mixing, evaporation, or high-temperature water-rock interaction and does not occur as a function of uptake by vegetation (Gat, 1996). Thus, $\delta^{18}O$ can yield accurate estimates of groundwater recharge in large and small basins in arid and semi-arid environments (Wood and Sanford, 1995). Furthermore, natural tracers are easy to use, integrate over long periods of time, and yield results that are consistent with injected tracer experiments (Hill and Lymburner, 1998).

Hydrometric Characterization

Groundwater head and stream stage were measured in the local flow system on the lower alluvial reach immediately up gradient from the backwater effect of East Park Reservoir. Groundwater head was measured in piezometers located 50 and 200 m from the channel. Piezometers were screened over 0.3 m intervals below the water table. Stream stage was measured in a stilling well directly adjacent to the channel. Groundwater head and stream stage were measured hourly with pressure transducers and dataloggers (Global Water WL15).

RESULTS

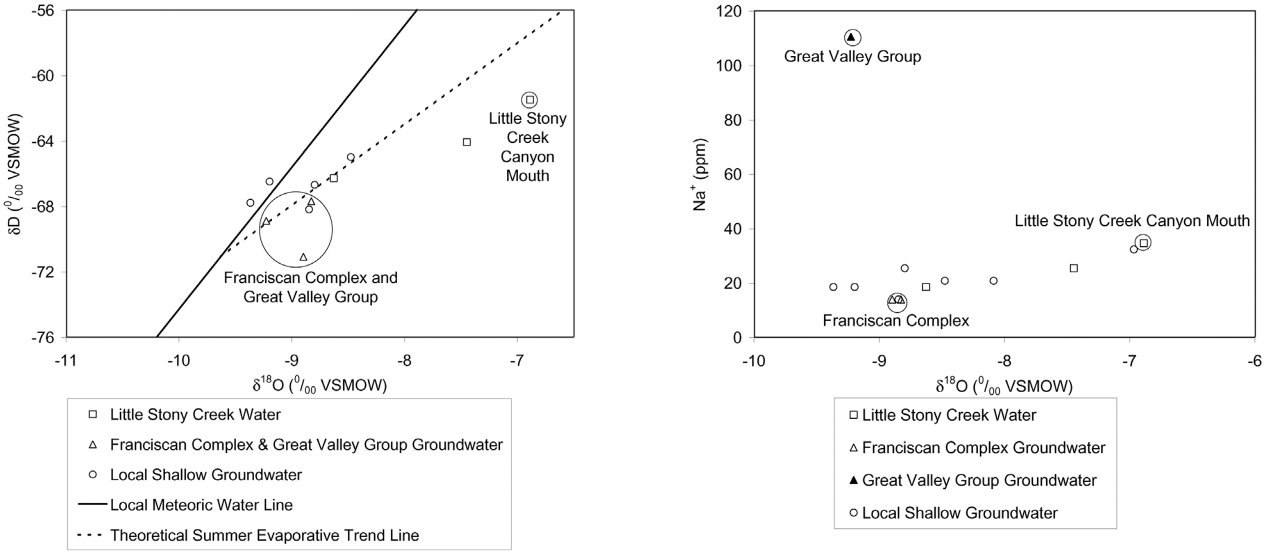
Possible Sources of Local Shallow Groundwater and Associated Baseflow

There are three possible sources of recharge to the local flow system: Little Stony Creek water at the canyon mouth, Franciscan Complex groundwater, and Great Valley Group groundwater. Field observations indicate that Little Stony Creek water flows into the subsurface at the canyon mouth and thereafter flows intermittently through the middle and lower alluvial reaches. The Franciscan Complex and Great Valley Group flow systems also may recharge the local flow system along the upper, middle, and lower alluvial reaches. However, insufficient data exist to determine whether and to what extent this occurs. Limited hydrometric measurements indicate that the hydraulic gradients from the Franciscan Complex and Great Valley Group flow systems to the local flow system are 0.06 and 0.04, respectively. However, these hydrometric data alone are insufficient to determine whether Franciscan Complex and/or Great Valley Group groundwaters discharge to or pass beneath the local flow system. East Park Reservoir and direct precipitation are not prominent sources of recharge to the local flow system because hydraulic gradients are always from the local flow system to East Park Reservoir (Rains et al., 2004) and dry season precipitation is extremely rare (Rains and Mount, 2002)

Isotopic and Geochemical Evidence

Little Stony Creek water at the canyon mouth had $\delta^{18}O$ and δD of -6.89 and -61.5 ‰ VSMOW, respectively, while Franciscan Complex and Great Valley Group groundwaters had mean $\delta^{18}O$ and δD of -8.99 and -69.2 ‰ VSMOW, respectively. Local shallow groundwater and associated baseflow on the middle and lower alluvial reaches had mean $\delta^{18}O$ and δD of -8.68 and -66.4 ‰ VSMOW, respectively. Therefore, local shallow groundwater and associated baseflow on the middle and lower alluvial reaches plot between Little Stony Creek water at the canyon mouth and Franciscan Complex/Great Valley Group groundwaters on a $\delta^{18}O$ v. δD scatterplot (Figure 3). Franciscan Complex and Great Valley Group groundwaters were indistinguishable from one another using solely deuterium and oxygen-18.

All Little Stony Creek waters, Franciscan Complex groundwaters, and local shallow groundwaters were Mg-Ca-HCO_3 water types, while the Great Valley Group groundwater was a Na-HCO_3 water type. The two groups of waters were largely distinguishable by their Na^+ concentrations. All Little Stony Creek waters, Franciscan Complex groundwaters, and local shallow groundwaters had mean Na^+ concentrations of 20.3 mg/L, while the Great Valley Group groundwater had a Na^+ concentration of 110.4 mg/L. Local shallow groundwaters and associated baseflow on the middle and lower alluvial reaches plot on a mixing line between Little Stony Creek water at the canyon mouth and Franciscan Complex groundwaters on a $\delta^{18}O$ v. Na^+ scatterplot (Figure 3). Therefore, local shallow groundwater and associated baseflow on the middle to lower alluvial reaches likely were recharged by Little Stony Creek water at the canyon mouth and Franciscan Complex groundwater.

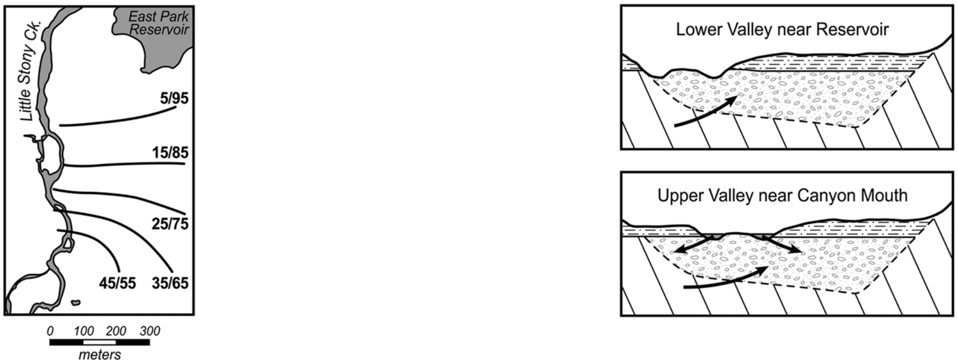


(a) (b)

Figure 3. (a) Deuterium and oxygen-18 with solid line representing the local meteoric water line (LMWL) and dashed line representing the theoretical summer evaporative trend line (TSETL) (Rains and Mount, 2002). (b) End members and mixing line.

Two-End, Mass-Balance Mixing Model

The assumption of the two-end, mass-balance mixing model was that local shallow groundwater and associated baseflow on the middle and lower alluvial reaches were instantaneous mixes of Little Stony Creek water at the canyon mouth and Franciscan Complex groundwater. Little Stony Creek water at the canyon mouth accounted for approximately 90 percent of local shallow groundwater and associated baseflow on the upper alluvial reach, while Franciscan Complex groundwater accounted for approximately 90 percent of the of local shallow groundwater and associated baseflow on the lower alluvial reach (Figure 4). Simple, linear, least-squares regression indicates that the relative contribution of Little Stony Creek water at the canyon mouth decreased and the relative contribution of Franciscan Complex groundwater increased down the valley ($R^2 = 0.81$, $P < 0.01$). Therefore, local shallow groundwater and associated baseflow on the middle and lower alluvial reaches are recharged by Little Stony Creek water at the canyon mouth and Franciscan Complex groundwater, with Little Stony Creek water at the canyon mouth the more prominent source of recharge on the upper alluvial reach and Franciscan Complex groundwater the more prominent source of recharge on the lower alluvial reach.



(a) (b)

Figure 4. (a) Percentage of Little Stony Creek water at the canyon mouth (numerator) and Franciscan Complex groundwater (denominator) in local shallow groundwater and associated baseflow on the lower alluvial reach near the reservoir and (b) schematic cross-sections showing a conceptual model of recharge to the local flow system on the lower alluvial valley near the reservoir and the upper alluvial valley near the canyon mouth.

Possible Effects of Regional Groundwater Pumping

The two municipal water supply wells screened in the Franciscan Complex flow system and located approximately 2 km southwest and up gradient of the lower alluvial reach near the reservoir were pumped in late July and early August with pumping beginning on or around July 24 (William Dunn, personal communication, 28 September 2000). Groundwater head and stream stage on the lower alluvial reach near the reservoir showed accelerated declines beginning on July 24 (Figure 5). Prior to July 24, groundwater head and stream stage declined at approximately 0.5 and 0.2 mm/d, respectively. Beginning on July 24, groundwater head and stream stage declined at approximately 1.2 and 0.7 mm/d, respectively. On July 28, stream flow ceased. Immediately thereafter, stream stage was simply a surface expression of groundwater in a remnant pool and stream stage declined at approximately 4.1 mm/d until stream stage and groundwater head equalized. A rare summer storm on August 7 resulted in groundwater recharge and stream flow. Recovery, however, was short-lived and the accelerated declines soon continued.

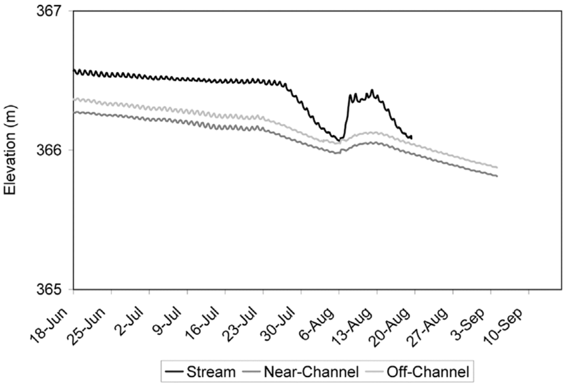


Figure 5. Dry-season time series of stream stage and groundwater head in the local flow system on the lower alluvial reach.

DISCUSSION

Local shallow groundwater and associated baseflow are recharged by Little Stony Creek water at the canyon mouth and Franciscan Complex groundwater. Little Stony Creek water flows into the subsurface at the canyon mouth and thereafter flows intermittently through the middle and lower alluvial reaches. Thus, Little Stony Creek water at the canyon mouth is a point source to the local flow system on the upper alluvial reach. Hydraulic gradients from the Franciscan Complex flow system to the local flow system are relatively steep. The Franciscan Complex groundwater discharges to the shallow, weathered siltstones and sandstones which directly underlay the local flow system, and these shallow, weathered deposits provide a shallow, permeable contact between the Franciscan Complex flow system and the local flow system through which Franciscan Complex groundwater can pass. The local flow path lies perpendicular to the Franciscan Complex flow path so the Franciscan Complex flow system is a line source of water to the local flow system on the upper, middle, and lower alluvial reaches. This allows Franciscan Complex groundwater to accumulate in the local flow system and become increasingly prominent in the down-valley direction.

There are no dams or diversions and no water supply wells in the local flow system up gradient of the site. Thus, groundwater drawdown and associated baseflow cessation likely were caused by pumping of the two municipal water supply wells screened in the Franciscan Complex flow system and located approximately 2 km southwest of the site. These municipal water supply wells are pumped periodically to fill a storage tank. Groundwater pumping in these municipal water supply wells results in a large drawdown in the Franciscan Complex flow system (William Dunn, personal communication, September 28, 2000; William Gustavson, personal communication, October 10, 2000). The large drawdown reduces the hydraulic gradient and associated groundwater discharge from the Franciscan Complex flow system to the local flow system which likely causes the observed groundwater drawdown and associated baseflow cessation in the local flow system.

Extensive dry-season withdrawals from the Franciscan Complex flow system could substantially reduce the amount of water available to the local flow system. If this occurs, then local-scale easements could fail to protect ecosystem structure and function because critical dry-season shallow groundwater and associated baseflow could be reduced or eliminated. We believe that the existing concept of buffers must be changed to reflect current understanding of ecosystem structure and function in riparian systems if resource conservation efforts are to be successful. Therefore, we propose that the existing concept of buffers be extended to include regional-scale management of areas critical to the structure and function of the larger hydrologic systems in which riparian systems exist such as groundwater recharge zones and hydrological flowpaths.

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