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Quantifying stream flow loss to groundwater on alluvial valley streams in Sonoma County

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Abstract

Surface flow is a crucial factor for the ecology of a stream. River-groundwater interactions, in turn, are crucial for these flows, as they determine whether streams are gaining or loosing surface flow. Gill Creek, in California's wine county, is a prime case study of these river- aquifer interactions, and their ecological and social implications. We took flow measurements at various places along the longitudinal profile of Gill Creek, with the purpose of finding if discharge decreases as the creek passes through an alluvial fan formation in Alexander Valley, Sonoma County, and if so at what rates. Results suggest Gill Creek is a "losing stream," and conclusions are that further studies of the stream and its relation to the aquifer are needed to more adequately address the prevention of stranding of anadromous fish species.

Introduction

In the Russian River, river-ground-water interactions influence the timing and magnitude of surface stream flows and therefore are key processes that determine the habitat suitability for endangered and threatened salmonids found there (URRSA, 2009). For example, juvenile steelhead rear in Russian River tributary streams before outmigrating to the ocean as smolts (URRSA, 2009). In the Russian River watershed anadromous fish species, including juvenile steelhead, use spawning and rearing habitats usually found in its tributaries upstream of and within alluvial fans, and adequate flow is important to creating quality rearing habitat for juvenile steelhead. (URRSA, 2009). Numerous tributary streams drain to the Russian River from steep canyons across the alluvial fans that occur at the creeks' canyon outlets (URRSA, 2009). Alluvial fans are gently sloping fan-shaped landforms that are created over long periods of time by the deposition of eroded sediment from an upland source usually by fluvial processes (AFTF, 2010). These fluvial sediments are typically higher in hydraulic conductivity than the adjacent uplands (Fleckenstein et al. 2003) and are recognized by river ecologists to be ecologically important because they control river-groundwater interactions, providing connectivity with groundwater resources (Woessner, 2000). The term "river- groundwater interaction" refers mainly to the exchange of water between surface and sub-surface features. Within these interactions, surface flow can infiltrate becoming groundwater or groundwater can resurface becoming surface flow (AGWT, 2003). Commonly, river-groundwater interactions control low river flows (Fleckenstein et al. 2003). When the head of the groundwater aquifer is lower than the stage of the stream, the surface water may begin to infiltrate into the aquifer effectively causing the stream to lose discharge as it flows downstream. This is referred to as an influent stream, or more commonly a "losing stream" (AGWT, 2003).

In alluvial fans, the porosity and depth of the soils can cause the accentuation of this infiltration process and increase the probability of having a "losing stream" (Fleckenstein et al. 2003). Additionally, because the flat topography and rich groundwater aquifers that form in alluvial fans make these ideal for agricultural practices, there tends to be extensive use of the groundwater reservoirs. Further lowering of groundwater levels, potentially from over-pumping of these reservoirs, can further contribute to a stream losing its flow (Kondolf et. al. 1987) and can cause problems for the ecology of the stream (Fleckenstein et al. 2003). For instance, lowered water tables have resulted in the elimination of base flows along lower stream reaches in various rivers in California used for spawning habitat by endangered or threatened anadromous fish species (Fleckenstein et al. 2003). In the case the Russian River, exacerbated low flow conditions in its tributaries specifically have been seen to strand juvenile steelhead trout, causing a "take" of this threatened species (URRAS, 2009). Hence it is important to understand the causes and rates of infiltration for these streams so that land and water use can be managed to limit the impact of surface flow diversions and shallow groundwater on stream flow. In the Upper Russian River, river-groundwater interactions are key processes defining the timing and magnitude of surface stream flows and therefore influence the habitat suitability for anadromous fish species (URRAS, 2009).

The purpose of this study is to examine the river-groundwater interactions in Gill Creek, a tributary to the Russian River in Sonoma County, CA, and to determine if it is a losing stream and if so at what rates it is losing. To do this we conducted a series of flow measurements along the longitudinal profile for the alluvial fan reach of Gill Creek. This study is intended to directly benefit landowners who have concern about the stranding of these species.

Study Site - Gill Creek, Sonoma County

Gill Creek is a tributary to the Russian River, located in Sonoma County, California. Its location is 38°43'44" N. latitude and 122°52'35" W. longitude. Gill Creek and its tributaries drain a basin of approximately 7.43 square miles. Gill Creek is a second order stream and has approximately 3.75 miles of blue line stream, according to the USGS Geyserville 7.5 minute quadrangle. It drains out of the wooded hills onto an alluvial fan that is planted extensively with vineyards before it reaches its confluence with the Russian River. Gill Creek provides rearing habitat for steelhead and there have been observed fish strandings within its alluvial fan reach in the late spring early summer months as the creek becomes disconnected from the Russian River (D. Fanucchi, personal communication, April 2011).

Methods

We obtained general information about the site from Matt Deitch who has done many hydrologic studies in the region (M. Deitch, CEMAR, Berkeley, California, personal communication, April 2011). The information he provided included the general geologic features of the site, the hydrologic character of Gill Creek, and the land and water use within the catchment. We then confirmed this information by reviewing the aerial photographs (Figure 1) and the National Elevation Dataset for the site from the USGS Seamless Server. Using the Surface Analysis tool in Geographic Information Systems (GIS) we created a contour surface and converted this to a Triangular Irregular Networks (TIN) of elevations using the 3D analyst tool (Figure 2) and slopes (Figure 3). From these layers and the aerial photos we were able to get a general idea of the larger geologic context of the site by its plan form and slope as well as the adjacent land use and other site constraints. Using this information we delineated the upstream extent of our study at the River Road crossing and the downstream extent of our study at the confluence of Gill Creek and the Russian River. We then measured the total stream length in this reach using the GIS measuring tool and demarcated three sub-reaches, referred to as the upstream, middle, and downstream sub-reaches, for which we would measure flow in the field (Figure 1). Lastly, we interviewed Dave Fanucchi, a local farmer and landowner in the watershed, who gave us information regarding his observations of Gill Creek including changes in flow this month and over the spring months in general as well as his observations regarding steelhead fish strandings (D. Fanucchi, personal communication, April 2011).

Depth to Groundwater Measurement

In the downstream sub-reach there is a groundwater monitoring well approximately sixty horizontal feet perpendicular to the channel from where we measured flow (Figure 10). In order to determine depth to groundwater in the creek bed we surveyed the channel bed and the base of the well using an auto level. We then measured the depth to groundwater in the well using a tape measure. We were able to estimate the depth to groundwater relative to the creek channel bed by adjusting the measured depth to groundwater from the well elevation, and comparing it to the creek elevation.

Topographic Surveys

Using an auto level, we completed a 150 ft. long longitudinal profile at each sub-reach. This we used to graph how the water elevation changed as the stream moved downstream (Figure 11).

Flow Measurement

Flow measurements were collected within each of the three sub-reaches in Gill Creek on three days in 2011: April 8, 2011, April 17, 2011, and April 29, 2011. Within each reach a cross section of stream in which the flow was unimpeded by obstructions was chosen and flow was measured in 0.5 foot increments at 0.6 times the depth from the water surface at each increment using a Price mini-current meter. The average velocity was determined by counting the revolutions of the meter that occurred within at least 30 seconds at each increment. The area of each increment was calculated by multiplying the respective depth by the 0.5 feet width and its discharge was calculated by multiplying the average velocity by the increment area. The total discharge for each sub-reach was then calculated as the sum of all its increments' discharges.

Data Analysis

By comparing the calculated discharges of each sub-reach we determined the estimated amount of discharge lost due to infiltration between sub-reaches on each sampling date. We also determined the total discharge lost and the percent discharge lost over the entire reach as well as the rate of loss over the total length of stream by dividing the total loss for each sampling day by the stream length. Finally, we compared data from the different sample days by determining the total flow reduction and the percent reduction for each sub-reach. In this way we also compared the two days' observed total loss between the up and downstream sub-reaches and determined the changes in rate of loss over the 16 days between site visits.

Results

GIS Analysis

Based on gently sloping fan-shaped landform shown in the TIN and elevation maps, we determined that the study site is located on an alluvial fan. We also determine that this reach of the creek is constricted on both sides by vineyards. There is approximately 4,144 linear feet of creek between River Road and the confluence with the Russian River. We located the upstream sub-reach directly below where River Road crosses the creek at the apex of the alluvial fan (Figure 4-5). The middle sub-reach is located directly below the large S shaped meander approximately halfway between the road crossing and the confluence with the Russian River (Figure 6-7). The downstream sub-reach was located next to the well used for groundwater monitoring approximately 650ft from Gill Creek's confluence with the Russian River (Figure 8-9).

Depth to Groundwater Results

Based on field survey measurements, the elevation of the top of the groundwater well in the downstream sub-reach (Figure 10) was 8.26 ft higher than the elevation of the stream bed. The length from the top of the well vertical to the groundwater table was 10.72 ft. From these measurements, we calculated the groundwater was approximately 2.46 feet below the creek bed on April 17.

Flow Results

Between April 8th and April 29th the average discharge of the three sub-reaches decreased by 3 ft^3/sec (Table 1). As of April 8th, the discharge in Gill Creek reduced by a total of 4.9 ft^3/sec between the up and downstream sub-reaches at a rate of 0.0012 ft^3/sec per linear foot of stream. By April 17th it had reduced by a total of 3.8 ft^3/sec between the up and downstream reach at a rate of 0.0009 ft^3/sec per linear foot of stream. Finally, by April 29th the creek discharge reduced by 1.1

ft^3/sec at a rate of 0.0003 ft^3/sec per linear foot of stream (Figure 12). This corresponds to a 90% loss between the 8th and the 17th and a 100% loss by April 17th between the up and downstream sub-reaches. By April 29th, Gill Creek ceased surface flow, meaning that Gill Creek lost 100% of its flow between the up and downstream sub-reaches to ground water by April 17th. All reaches experienced reduced discharge on April 17TH compared with April 8th and on April 29th compared with April 17th. The reduction in discharge increased from upstream to downstream with a 30% reduction in the upstream sub-reach, a 69% reduction in the middle sub-reach and a 100% reduction in the downstream sub-reach between the 8th and the 17th. Similarly, there was a 71% reduction in the upstream sub-reach, and 100% reduction in the middle sub-reach between the 8th and the 17th. However, on April 17th the rate of loss reduced by 0.0003 ft^3/sec per linear foot of stream compared to the rate of loss on April 8th. On April 29th the rate of loss reduced by an additional 0.0006 ft^3/sec per linear foot of stream.

Our results are summarized in Table 1 below.

Table 1. Gill Creek Flow Measurement

Approximate length of total stream reach (feet)		4144	
Sample Date	4/8/2011	4/17/2011	4/29/2011
sub-reach			
Upstream	5.5	3.8	1.1
Middle	4.2	1.3	0
Downstream	0.5	0	0
Average Discharge	3.4	1.7	0.4
Total loss between up and downstream site (ft3/sec)	4.9	3.8	1.1
% loss between up and downstream site	91%	100%	100%
Rate of loss((ft3/sec)ft-1	0.0012	0.0009	0.0003

Change in average discharge between visits (ft3/sec)	% Change in total discharge between visits
-3.0	-22%
Change in rate of loss	-0.0009

	Change in discharge between visits (ft3/sec)			% Change in discharge between visits		
sub-reach						
Upstream		-1.6	**-2.7**		-69%	**-29%**
Middle		-2.9	**-1.3**		**-30%**	-100%
Downstream		-0.5	**0**		-100%	-100%

Discussion

Based on our interview with Mr. Fanucchi, it was observed that the stream became disconnected from the Russian River within the past month and our data supports this observation. Based on observations and measurements taken by Matt Deitch on the 8^{th} of April, the stream became disconnected earlier than that date. Our data also indicates that Gill Creek is a losing stream. The stream discharge was measured to be decreasing as it moved downstream. Over sixteen days (between site visits) the total discharge at all sub-reaches decreased. Additionally, the ground water was measured to be below the stream bed surface by over two feet which supports a supposition that Gill Creek is losing due most likely to infiltration.

However, due to limited time, only three flow measurements were taken at each sub-reach so it is difficult to develop relationships describing flow recession throughout the study period. Additionally, the total loss and the rate the stream is losing to the groundwater per linear foot of stream were seen to decrease between the two days that flow was measured. This suggests that the stream is not infiltrating at a steady rate. Due to the limited amount of data collected we are not able to extrapolate exactly how the rate of lose changed before our first sampling date or how it will change into the future. Other factors that were not measured such as potentially varying degrees of hydraulic conductivity along the reach, evapo-transpiration rates and those factors contributing to it (surface area of water exposed to the air, air temperature, vegetation cover, etc.), and water extraction by adjacent or upstream landowners etc. may also be significantly affecting the rate and amount of discharge being lost from the stream.

Further studies of the alluvial groundwater and stream flow are necessary for better determining river-groundwater interactions. Additional stream flow measurements will improve the prediction of when and how quickly the stream will dry up. The completion of detailed topographic, vegetation, infiltration, and groundwater surveys may also illuminate other factors contributing to Gill Creek's drying rate. This information will be useful for future land and water use planning particularly for the purpose of supporting quality anadromous fish habitat. By being able to better predict factors impacting the drying rate of Gill Creek, land owners and water managers can better plan water extraction to support anadroumous fish needs.

Figures

Figure 1. Aerial Photograph of Gill Creek showing water courses, sub-reach Locations and the Groundwater Monitoring Well Location.

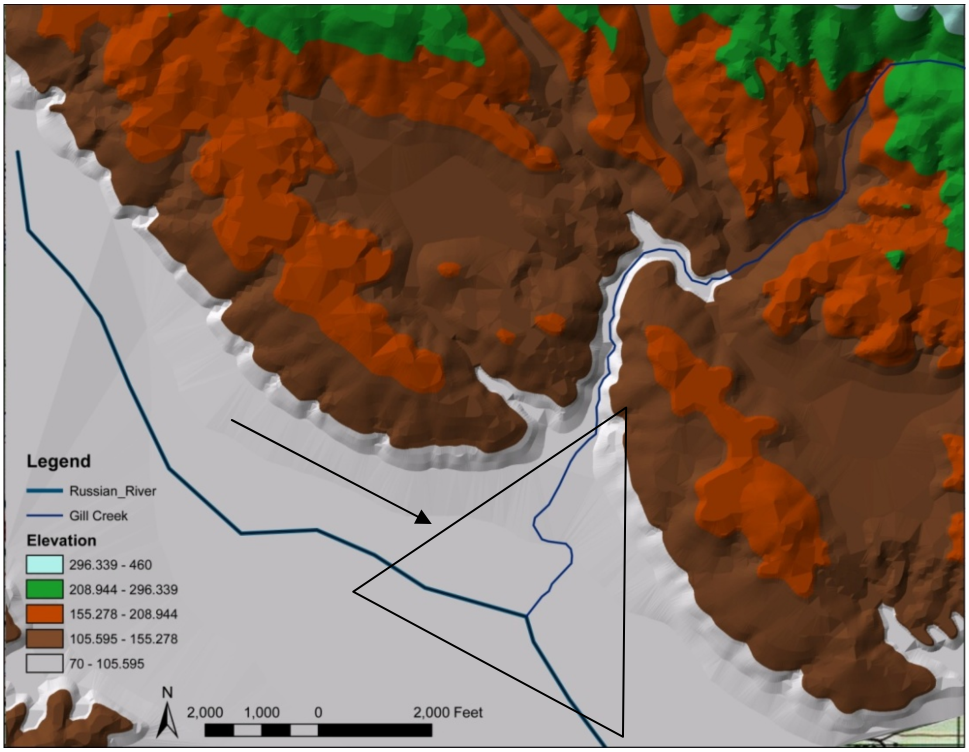

Figure 2. Gill Creek Watershed Elevation Map

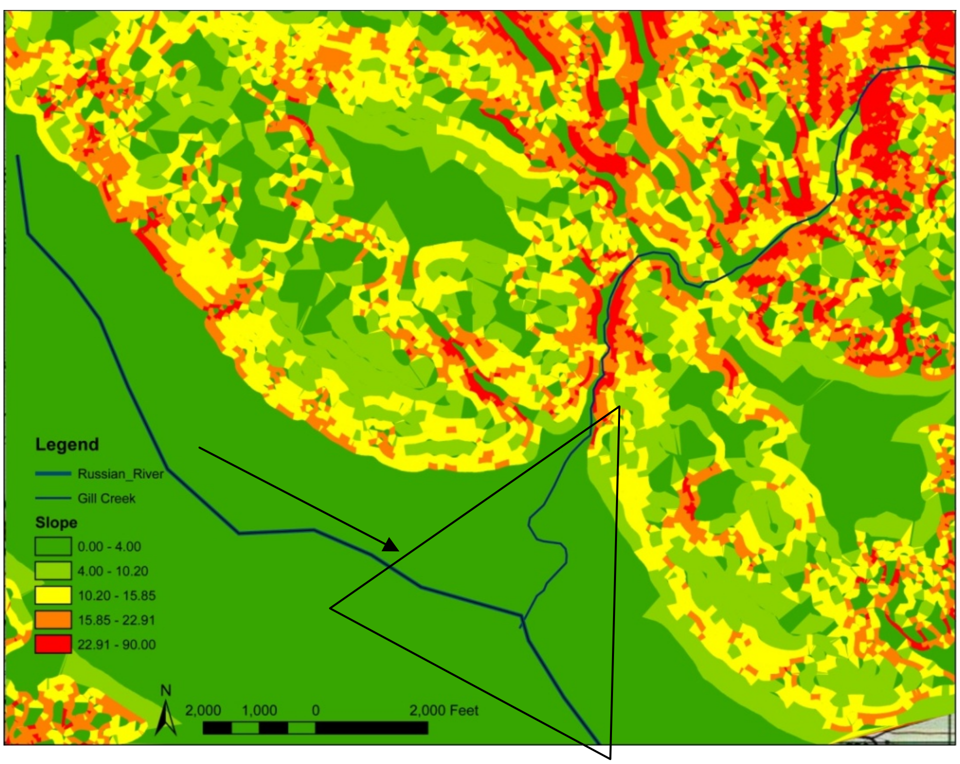

Figure 3. Gill Creek Watershed Slope Map

Figure 4. Upstream sub-reach looking upstream

Figure 5. Upstream sub-reach looking downstream

Figure 6. Middle sub-reach looking upstream

Figure 7. Middle sub-reach looking downstream

Figure 8. Downstream sub-reach looking upstream

Figure 9. Downstream sub-reach looking downstream

Figure 10. Groundwater Monitoring Well Site

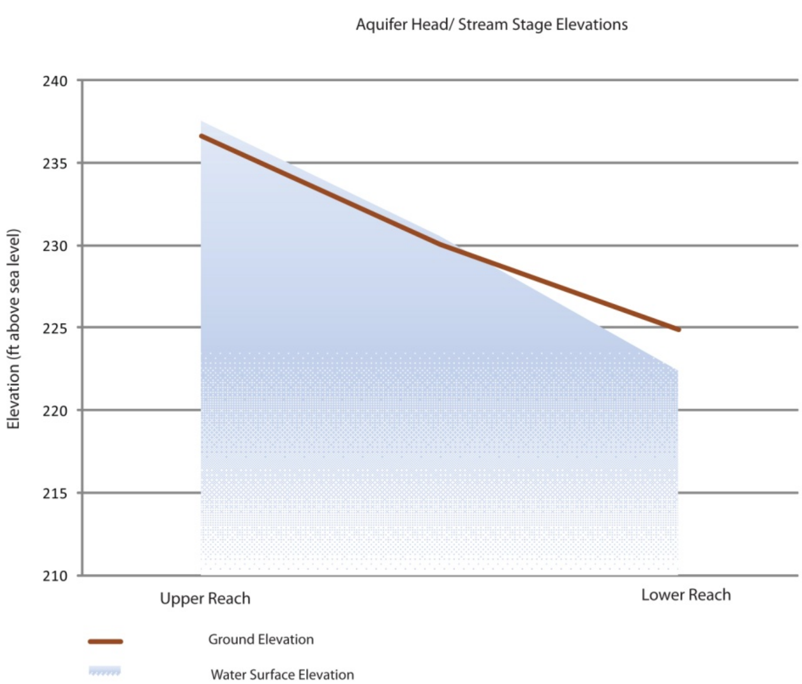

Figure 11. Water surface elevation change in the study reach

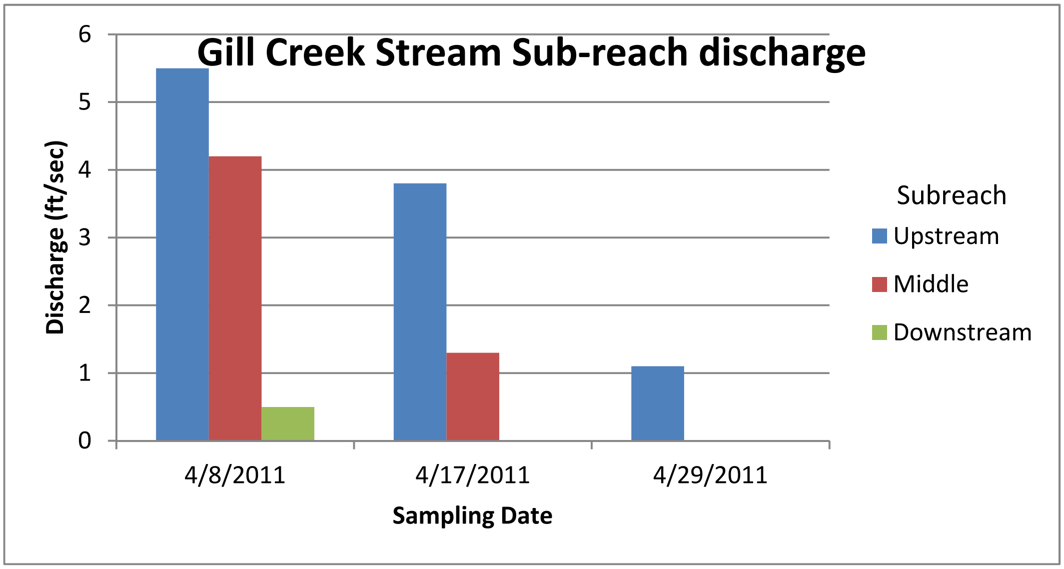

Figure 12. Change in flow as seen between sub-reaches and between sampling dates.

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