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Baseflow Monitoring in the Last Chance Watershed:
Big Flat Meadow and Rowland-Charles Reach of Last Chance Creek

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Technical Summary Report

prepared for

Plumas County Flood Control and Water Conservation District

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Executive summary

Project description

1. The objective is to examine how to quantify baseflow augmentation after stream restoration, by comparing pre- and post-restoration baseflow environmental isotope signatures.
2. Data were collected from two sites in the Last Chance watershed: Big Flat on Cottonwood Creek and the Rowland-Charles Reach of Last Chance Creek. Samples were collected from streams, wells and springs for analysis of the isotopes deuterium and oxygen-18, major ion chemistry, together with field EC, temperature, stream stage and well water level data.
3. Environmental tracer data proved useful in clarifying stream-to-ground water interactions and suggest a way to quantifying baseflow augmentation.

Summary of findings:

Big Flat on Cottonwood Creek

1. The tracer data confirm that the Big Flat floodplain aquifer is recharged by infiltration in the upper meadow channel, which then discharges back into the lower meadow channel.
2. Isotope and streamflow data indicate that in a period of four weeks in February 2005 the floodplain aquifer was recharged with 55 ac-ft, raising the ground water table by about 3 ft. This water is slowly discharged back into the channel in the following three months.
3. Flow and water chemistry data also indicate that after mid-March the floodplain aquifer and downstream channel received inflow from the underlying bedrock aquifer from upland ground water recharge, further augmenting Cottonwood Creek flow.
4. In this hydrologic setting ephemeral channel flow depends mostly on upstream channel inflow, leading to floodplain aquifer recharge, which is returned into the channel by mid-summer.

Rowland-Charles Reach of Last Chance Creek

1. These data show the significance of upland ground water recharge for maintaining flow in a small intermittent stream channel.
    a. The floodplain aquifer receives year round ground water inflow from the eastern and western upland bedrock regions, sufficient to raise the ground water table by 4 to 7 ft in winter and spring, leading to ephemeral stream flow.
    b. After April ground water discharge from the western uplands diminishes, making floodplain ground water levels subside and depriving the channel of its water source. The channel is dry by mid June.
2. In this hydrologic setting ephemeral channel flow depends almost entirely on upland ground water recharge.

Implications for stream restoration projects

Although this project did not have the benefit of pre- and post-restoration project data, it provided valuable insights into the utility of isotope data to examine baseflow augmentation in two different ephemeral floodplain settings:

1. Increased floodplain aquifer storage due to meadow restoration can be measured by comparing pre- and post-restoration baseflow isotope characteristics, under one or both of the following conditions:
    a. Stream water isotope signatures change from winter into spring and summer.
    b. Ambient floodplain aquifer water isotope signatures uniquely differ from stream water.
2. Increased floodplain ground water storage can be measured in at least two ways:
    a. Comparison of up- and downstream tracer compositions, for pre- and post-project data.
    b. Comparing pre- and post-restoration aquifer composition as a function of ground water level changes.

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Introduction

This report is an analysis of the isotope and other environmental tracer data collected between fall 2004 and fall 2005 from ground and stream waters in the Last Chance Creek subwatershed of the Feather River basin. This work is the subject of the Last Chance Baseflow Monitoring Project. The main objective was to explore alternative methods to assess the impacts of stream channel restoration on baseflow. This report is an attempt to provide a comprehensive analysis of the findings made in this project, aimed at providing a more complete picture of the hydrologic situation in two limited reaches in the Last Chance watershed.

Background

Baseflow augmentation is one long range benefit believed to be derived from watershed restoration. From a conceptual hydrological standpoint this argument has a great deal of validity. However, baseflow augmentation is difficult to measure, particularly in small, ungaged watersheds. Hydrograph separation based on physical stream flow is of limited use in small watersheds since physical stream flow measurements are of limited resolution. This leads to significant uncertainty whether flow increases are due to restoration or natural annual variability of ground water influx (for example in an unusually wet year or period of years). The issue is further complicated by the probabilistic nature of stream flow data.

It is quite possible that late year stream flow is less affected by spring flood flow temporarily stored in the floodplain, but maybe more so by ground water discharged from the upgradient reaches. In other words, conceptually, late year channel flows in an upper watershed meadow can be made up of several components, listed in decreasing order of importance:

1. Channel flow from the reaches upstream of the meadow. i.e. baseflow released from upstream alluvial areas and/or adjacent uplands.
2. Baseflow originating from the upland areas directly adjacent to the meadow, entering the floodplain deposits from the bedrock underlying and adjacent to the meadow.
3. Baseflow released from the floodplain aquifer of the meadow.

Among these three components the third makes up the smallest portion and is therefore the most difficult one to identify. However, it is the portion most affected by channel degradation and is thus of greatest interest in stream channel and meadow restoration projects.

In the opinion of this author the benefit of baseflow augmentation due to meadow restoration is very difficult (if not impossible) to quantify by means of physical streamflow measurements (the problem is explained in more detail in Attachment B, using the example of Big Flat meadow).

Project purpose and scope

To date very little, if any information is available about how ground water and stream water interact in the hydrologic settings of the Last Chance watershed. While the effect of baseflow augmentation is readily visible in many restoration projects, it is typically quantified in terms of water table rise and ecological parameters. Measuring benefits in terms of water yield for sustaining ecosystems in the late season have so far been limited by our limited understanding of stream-ground water interactions. Under these conditions it is difficult to design effective monitoring programs to measure yield due to baseflow augmentation.

The goal of this project is to explore alternative methods to quantify baseflow augmentation due to stream and meadow restoration projects. The intent is to identify hydrograph components (i.e. surface flows, shallow meadow aquifer, upland subsurface flows) by their environmental isotope signatures. Then compare pre-restoration with post-restoration baseflow signature characteristics to discern the baseflow augmentation due to restoration.

This project utilizes naturally-occurring isotopes of hydrogen and oxygen (deuterium and oxygen-18) together with selected major dissolved ions in stream and ground water to help overcome limitations inherent in physical flow measurements.

The Big Flat project had no pre-restoration isotopic data to be compared with post-project data since restoration has already been implemented. The initial concept for the Rowland-Charles Reach of LCC was for pre-project data to be collected for later comparison. However, this research project did not commence until after restoration was completed in the fall of 2004. Therefore at neither site was it possible to compare pre- and post-restoration conditions.

This required a change in sampling strategy where isotope data collected above and below each project were characterized, allowing analysis of the effects of channel and meadow restoration in-between.

Although this was the second choice strategy, the data has significantly improved our understanding of environmental tracer patterns under conditions of stream-ground water interactions in these landscape settings, which is a prerequisite for efficiently assessing the success of restoration enhancing ground water storage.

It is anticipated that the greatest benefit of this project will be in being able to devise better monitoring programs for upcoming restoration projects. One particular project that may benefit from what was learned from this project will be the Red Clover Restoration project near McReynolds Creek, completed in summer 2006.

Acknowledgments

This project was funded by the Plumas Watershed Forum and administered by the Plumas County Flood Control District. Thanks go to Tom Hunter and the Forum members for taking an interest in this problem and approving the proposal that is the basis of this project. Most importantly, both Jim Wilcox and Leslie Mink deserve most credit for taking upon themselves the formidable challenges of winter data collection, having to travel long hours to remote sites by snowmobile. Thanks also go to Terry Benoit and Jim Wilcox for many helpful discussions and review of the initial draft.

Project locations

Two separate hydrologic sites were monitored in the Last Chance Creek (LCC) watershed:

1. Big Flat Meadow, on Cottonwood Creek, a tributary to LCC. This is located on Plumas National Forest (USFS) land, Beckwourth Ranger District (Section 36 of T.27N.,R.13E. and Section 1 of T. 26N., R 13E.).
2. The Upper Last Chance Creek Project: this area includes two sub-reaches (Rowland-Charles Reach and the Charles Bird Reach), about 3500 ft apart. Channels in Rowland-Charles Reach were restored in the Fall of 2004 (Section 7 of T25N-R16E). The Charles-Bird Reach (Sections 1 and 6 of T25N-R15E) is slated for future restoration and is currently being used as a control reach. The project is located on Nature Conservancy Land:

These project areas are shown on the two location maps in Figures 1 and 2.

The two sites markedly differ in their hydrologic features. Both sites are located within areas subject to ongoing restoration efforts.

Data collection

Samples were collected from streams, wells, springs and precipitation for analysis of the isotopes deuterium and oxygen-18, major ion chemistry. EC, temperature, stream stage and well water level data were collected in the field. Adequate sample representation was assured by sampling only well mixed channel reaches. Ground water samples were collected by bailer from monitoring wells installed with _ inch galvanized steel pipe (‘drive probes’), stainless steel well points, _ inch PVC casing, or 4 inch PVC sewer pipe. These improvised monitoring wells were originally intended only for measuring depth to ground water.

For the small diameter wells a bailer was made from 3/8 inch copper pipe. Isotope samples were collected in 40 ml glass vials with screw caps and Teflon liners. Chemistry samples were collected in 250 ml plastic bottles. Well water levels were measured with an electric well sounder.

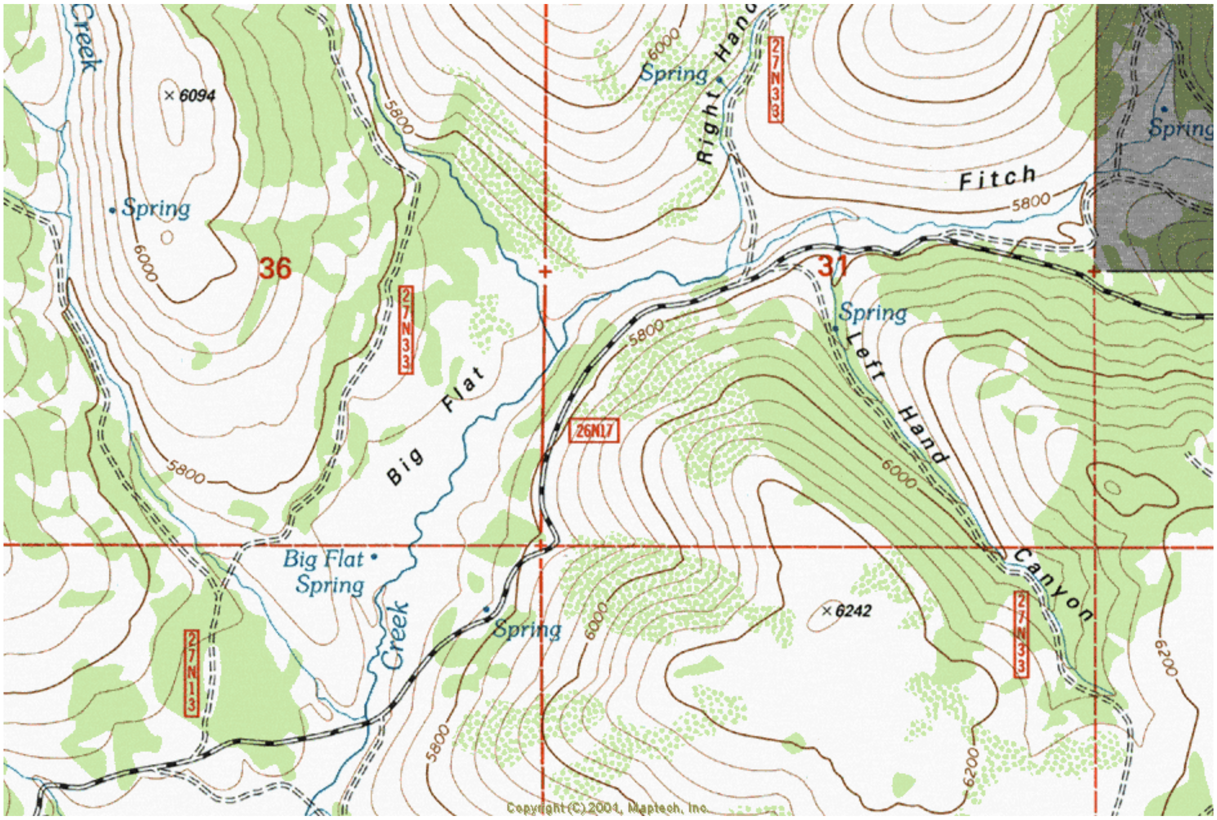

Figure 1: Location map, Big Flat Meadow on Cottonwood Creek

Sample schedules

Both project sites have been subject to intense data collection before the advent of this project, and will continue in the future - by Plumas Corporation, UC Davis and Stanford University. Fall, summer and spring field data collection was conducted mostly by the author of this report. Winter data collection was "piggybacked" onto the ongoing monitoring, via snowmobile, of the Last Chance Creek Watershed Project conducted by Plumas Corporation.

Data were collected in about 30 day intervals beginning in November 2004, continuing through winter and into early summer 2005:

1. At the Last Chance Creek site 54 isotope samples were collected in 10 sample runs between December 16, 2004 and June 16, 2005, after which streamflow ceased.
2. At the Big Flat site a total of 72 isotope samples were collected in 12 sample runs, beginning in November 2004 and ending on November 27, 2005.

Isotope analysis was conducted by UC Davis Isotope Labs. A select number of samples were also analyzed for major ion chemistry by Sierra Environmental Monitoring Lab in Reno, Nevada.

Graphic presentation of isotope concentrations

The non-technical reader may notice that isotope concentrations are displayed as negative values. These are units of “per mil deviation from the SMOW standard”, where ‘SMOW’ stands for ‘standard mean ocean water’. In other words isotope concentrations of oxygen-18 and deuterium in water are expressed in comparison with ocean water (SMOW). The values are negative since on land meteoric waters are typically depleted with these isotopes, when compared to ocean water. It should be kept in mind that the more isotope concentration a sample contains, the less negative its isotope value is, and vice versa.

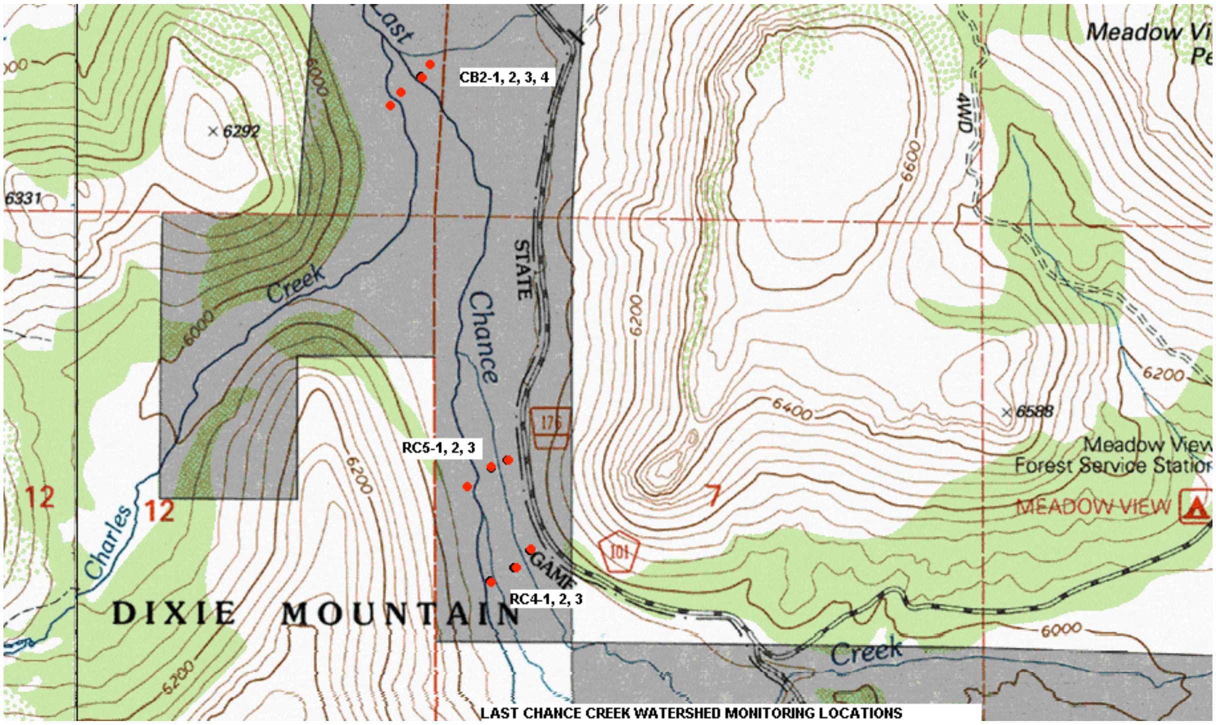

Figure 2: Location map, Rowland-Charles Reach of Last Chance Creek

Big Flat Meadow on Cottonwood Creek

The 47 acre Big Flat Meadow is located on a SSW flowing reach of Cottonwood Creek. The general slope of the meadow increases in the lower 1/3 of the meadow, where a small spring emerges. Cottonwood Creek flows into LCC about two miles further south. The NNE extent of the meadow is about 3500 ft, and meadow width is up to about 700 ft. A topographic map is shown in Figure 1.

The hydrologic features were summarized by Sagraves (1996, p. 13). Flow conditions in Cottonwood Creek follow a well defined seasonal pattern. Snowmelt runoff makes up the bulk portion of runoff, between late January and May or June. Peak runoff levels are in March and April. Typically flows end by midsummer (June-July).

This area encompasses the Big Flat Restoration Project, completed in 1995. Originally equipped with at least 20 monitoring wells and two stream gauging stations Big Flat has been subject to ongoing data collection since the mid 1990's (Sagraves, 1996; 1998, 2006). Stream flow monitoring began in 1994, the summer before the stream channel was restored. With at least nine monitoring wells and two recording gauging stations data collection will continue into the foreseeable future (Jim Wilcox, pers. com.).

Several types of low cost monitoring wells were originally installed to test their efficacy, resulting in numerous installations of limited utility due to improvised and poor construction methods (dictated by budget limitations). Many of these monitoring wells were affected by sedimentation or damaged by animals. Difficult winter site access and logistics posed a further constraint on data collection and most of these monitoring wells were monitored in irregular intervals. Only in three monitoring wells was it possible to collect a more continuous data record, covering up to 12 months. A six-inch well, is located in the upper meadow. Since no drillers log is available, nothing is known about its construction details, though a sounding indicates that this well is more than 100 ft deep.

The layout of the pertinent monitoring wells sampled are shown on a schematic sketch map in Figure 3, conveniently simplified for the Summary reader’s overview.

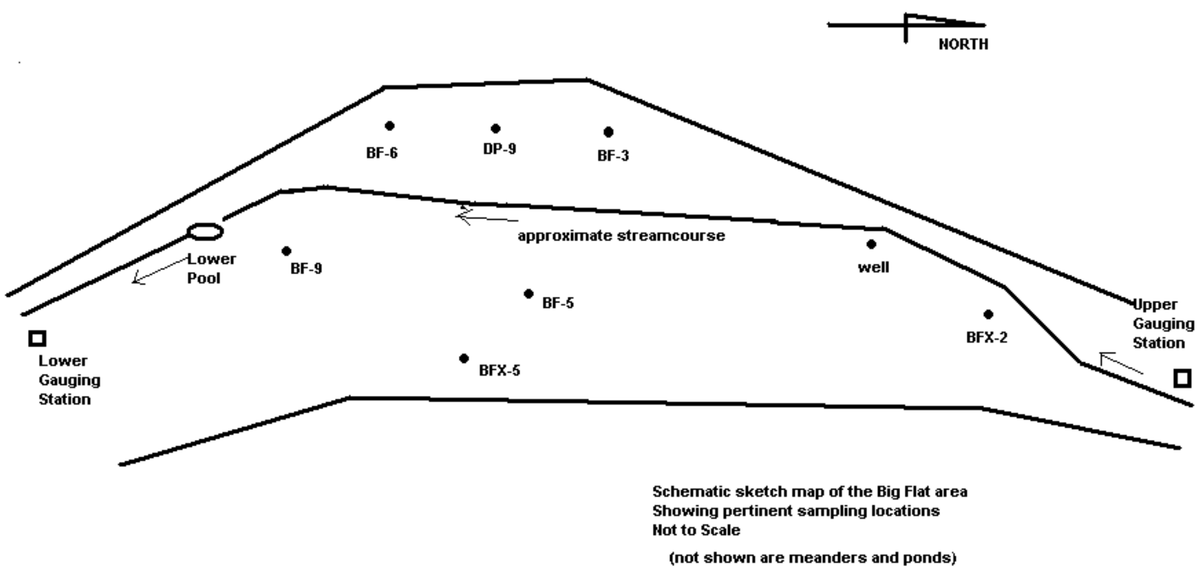

Figure 3: Big Flat Meadow, schematic sketch map of pertinent monitoring well locations at Big Flat.

Floodplain aquifer responses to stream flow

The isotope data in stream water show wide variations between summer and winter. Ground waters follow these changes but with smaller ranges, suggesting displacement by channel infiltration.

Figure 4 and Figure 5 are Deuterium and O-18. Shown here are:

a. Stream water Deuterium and O-18 changes at the upstream (green), and downstream (red) gauges.

b. Upper and lower floodplain aquifer Deuterium and O-18 changes (light and dark blue).

c. Bedrock aquifer composition in East Spring (black), located about 1000 ft east of the lower stream gauge, next to Fitch Canyon Road (Figure 1). (It was not possible to obtain a bedrock aquifer sample from the six-inch well in the upper meadow).

d. The local meteoric water line (LMWL) serves as a reference line. It is a regression of snow isotope data collected nearby. Stream waters plot away from the LMWL due to changes in snow melt composition before and during infiltration.

Figure 4: Isotope changes in Big Flat stream flow

1. Cottonwood Creek is an intermittent stream. It began flowing upstream in late January 2005, about four weeks before it started flowing downstream in late February. Streamflow ended in mid-June 2005 (though samples were obtained in mid-December from a pool in the lower meadow).
2. Stream water compositions changed significantly at both gauges. On Figure 4 the data plots resemble loops, with the lower end in late February (close to bedrock aquifer composition) and the upper end in June.
3. After June 2005 stream water data were affected by evaporation when flow diminished to stagnant puddles.

In summary, beginning in early winter stream water changed from a composition somewhere in the upper right diagram toward a composition resembling that of ground water in bedrock aquifer (lower left plot). Then throughout the remaining winter and into the summer it shifted back to the upper right, attaining its final "summer" composition.

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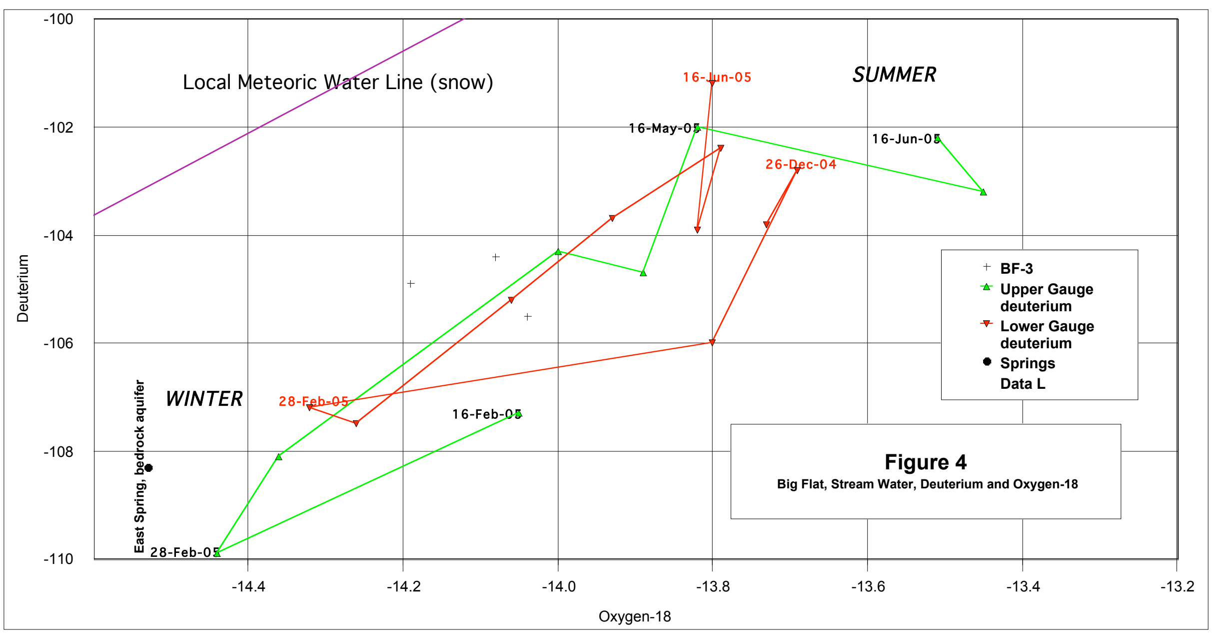


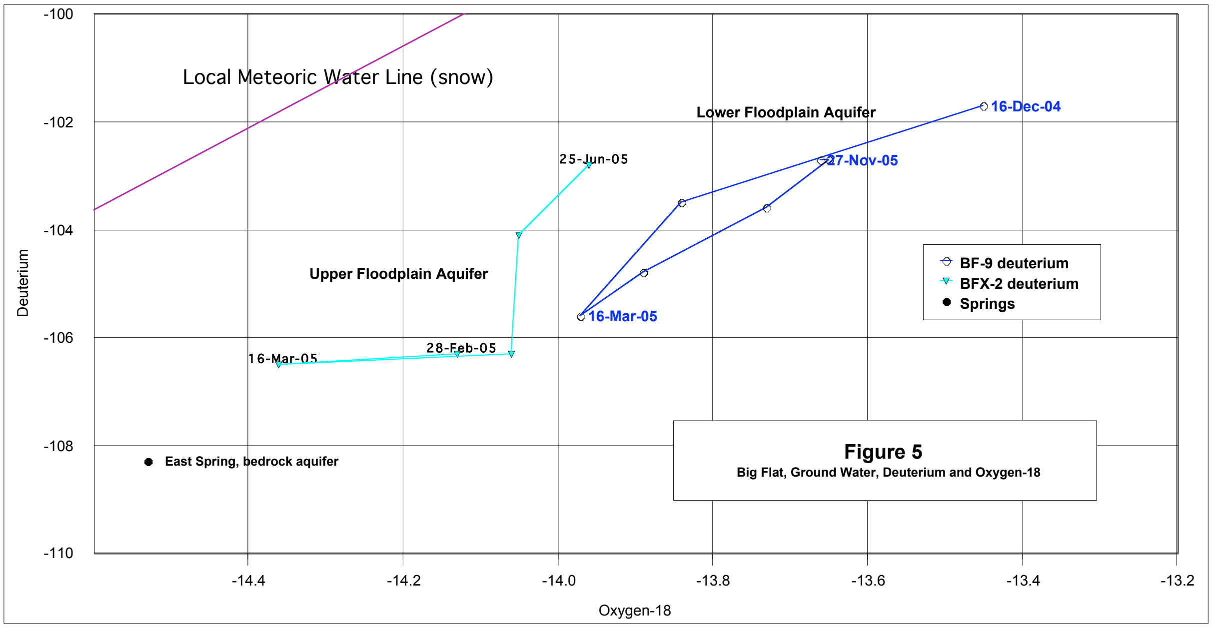
Figure 5: Changes in floodplain aquifer composition

1. Upper and lower floodplain aquifer compositions are represented by data from two monitoring wells, BFX-2 and BF-9, which are about 1800 ft apart. BFX-2, in the upper floodplain, is about 750 feet down gradient from the upper stream gauging station. BF-9, in the lower floodplain, is about 900 ft upgradient from the lower gauge (see Figure 3).
2. The floodplain ground water isotope data trend between summer stream water (upper right) and bedrock aquifer composition (lower left). The patterns resemble those observed in the stream waters, however the range (variability) is much narrower.
3. The changes in floodplain aquifer are significant, indicating mixing between two source waters.

a. Since ground water patterns mimic stream water changes. Since it range is exceeded by that of channel water it is concluded that stream water infiltrated into the floodplain aquifer - not vice versa. This supports what has been hypothesized before.

b. Inundation by a water resembling winter stream water composition is more complete in the upper than the lower floodplain aquifer. This suggests that most infiltration occurred in the upper channel, while some ground water was discharged back into the downstream channel.

The data indicate that inundation by stream water is a gradual process that continued as long as Cottonwood Creek was flowing.



Ground water levels and channel flow responses

The following discussion ill show that the isotope data support the conclusions derived from monitoring well water levels and stream flow data. For brevity only deuterium will be used, since a similar analysis using oxygen-18 yields the same results.

Our understanding of the interaction between floodplain aquifer and streamflow is enhanced by comparing isotope composition changes with ground water levels and stream hydrographs. These data are combined in Figure 6 and Figure 7:

1. Time is plotted on the horizontal axis - spanning almost 12 months. The reader should be aware that the straight lines connecting points are only connecting momentary sampling events. They are only approximations of a continuum.
2. The upper portions of the diagrams show ground water levels measured in monitoring wells BFX-2 and BF-9 (light and dark blue).
3. The lower portion shows the deuterium isotope changes in stream water and floodplain aquifer (BFX-2 and BF-9, shown in light and dark blue). Also shown is ground water deuterium measured in East Spring.
4. Also shown is the difference in channel flow between upstream and downstream gauges (thick blue line - downstream minus upstream flow as measured by the continuous flow recorders). Whenever this thick blue line is greater than zero more water flowed out of the meadow than what flowed in, and vice versa:
    a. Before the first week of March outflow was less than inflow (below zero line), i.e. when the floodplain aquifer was recharged by upstream channel infiltration. An exception occurred in the second week of January when the lower gauge recorded flow, while no flow occurred upstream.
    b. Beginning in the third week of March outflow increased and eventually became larger than inflow, i.e. the meadow discharged water.
    c. The significance of the two peaks in the second segment will be discussed later.

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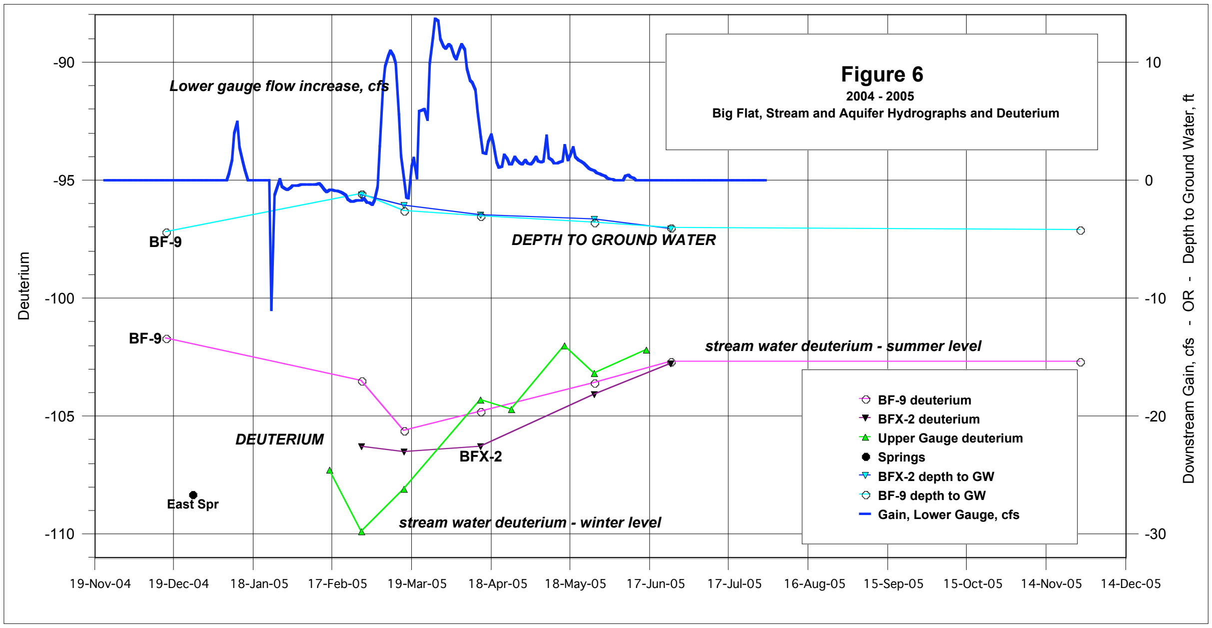

Figure 6: streamflow and ground water levels

1. Ground water levels in the floodplain aquifer rose from about 3 ft below grade in December to near-ground-level in late February. Thereafter ground water levels declined until about mid-June, and then remained about 3 ft below ground level. This is observed in both BF-9 and BFX-2.
2. Rising monitoring well water levels correlate with the period when inflow was larger than outflow. On the other hand, declining monitoring well water levels correspond to the time when more water flowed out of the meadow channel.
3. These changes are expected during streambed infiltration into the floodplain aquifer. Once the aquifer was fully recharged ground water began to be discharged. When monitoring well water levels declined more water flowed out of the meadow than what flowed in.

Evidently meadow recharge began in the second half of January, continuing until about mid-March, when outflow became larger than inflow. This situation continued until the fourth week in May, when upstream flow had diminished to a mere trickle of less than 0.05 cfs, while downstream flow continued at about .2 cfs. By mid-June streamflow had ceased at both stations, though ponding water could still be found throughout the entire channel.

Clearly, beginning in late January the floodplain (meadow) aquifer was recharged by channel infiltration, which was completed in four weeks, i.e. by late February. After that the infiltrated water was discharging into the lower channel while being continuously recharged upstream. Concurrently, ground water levels rose to a maximum in late February and then declined to a minimum in mid-June, and remained at that level until the end of the year. In other words after mid-June the meadow generated no more baseflow.

Figure 6; Streamflow and floodplain aquifer isotope changes

1. Shown in the lower half are the deuterium changes for the 12 month period:
   a. Monitoring wells BF-9 and BFX-2 (purple and black).
   b. Stream water at the upper gauging station (green).
2. Changes are significant. For this discussion two sources are postulated, based on deuterium levels;
   a. “stream water” with deuterium at about -102.

b. “ground water” with deuterium at about -110.

3. When the stream began flowing at the upper gauge in mid-February stream water composition resembled “ground water” (green line). Thereafter it changed until it gradually resembled “stream water” in late May, until it ceased to flow in mid-June. - These changes turned out to be useful to identify the effect of channel infiltration.

4. Isotope composition of the floodplain aquifer (monitoring wells BF-9 and BFX-2) mimicked the changes in stream water composition. These changes are seen as evidence of channel infiltration into the floodplain aquifer:
   a. During the preceding fall (and summer), i.e. before the advent of channel flow, the floodplain aquifer was filled with ground water resembling “stream water” (see BF-9 data), presumably derived from the previous summer’s stream flow.
   b. Sometime before mid-February the upper channel started flowing and stream water resembling ground water began infiltrating into the floodplain aquifer, changing floodplain aquifer composition between ground water (East Spring) and stream water (summer).
   c. Assuming simple mixing, the deuterium composition suggests that by late February stream water component in the floodplain aquifer constituted about 20%. This had increased to about 60% in mid-March. By mid-April upper and lower floodplain aquifer composition were practically the same as in the channel. In other words previous year’s water near these monitoring wells had been completely replaced by renewed channel infiltration.

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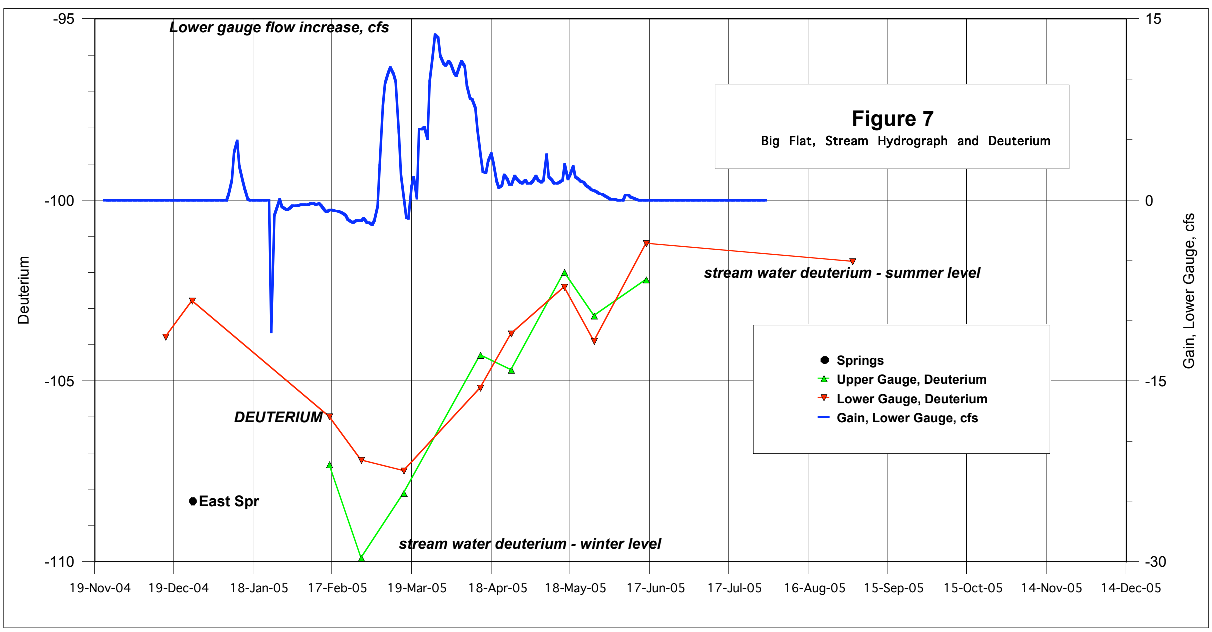


Figure 7: Changes in up- and downstream channel water composition

In Figure 7 up- and downstream composition changes over time are plotted in green and red. Since the late 2004 downstream data record is spotty it was augmented with data from an in-stream pool (’lower pool’) near BF-9. Also included are the downstream net flow gains (thick blue line).

Observations:

1. Although the lower gauge deuterium mimics upper gauge deuterium, there are also some significant differences:
   a. In January and February, downstream deuterium is still much higher than upstream.
   b. In late March the two trends eventually ‘merged’. Thereafter both trends increase at similar rates until about mid-June. After that flow diminishes to mere stagnant puddles.
2. The difference between the green and red lines in February and March are an indication that by

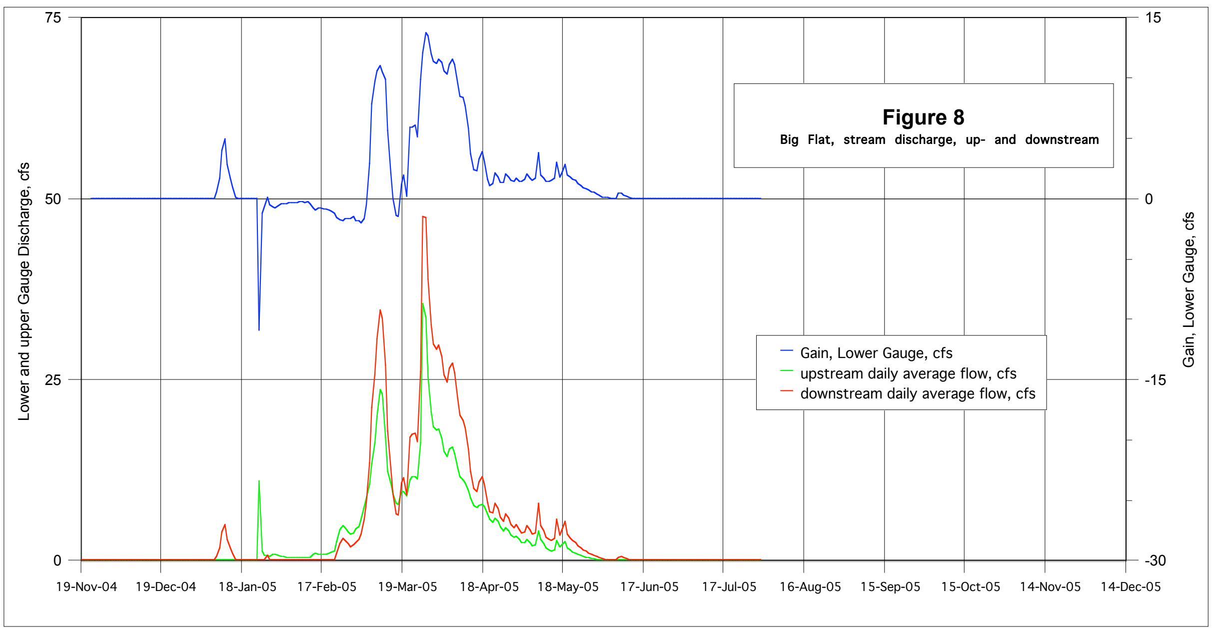
that time channel infiltration was not yet complete in the lower meadow aquifer. - *This feature provides a potential means to assess the efficiency of meadow aquifer recharge due to channel restoration (to be discussed later).*

In summary, these data suggest that floodplain aquifer composition changes largely follow stream channel water composition, which suggests that exchange of water between stream and aquifer is fairly efficient. Probably this is facilitated by floodplain aquifer water flowing downstream in the permeable floodplain sediments, after being recharged in the upper channel and discharged in the lower channel, making room for further upstream channel infiltration.

Stream discharge data

The following comparison of up- and downstream flow data shows that after the Big Flat floodplain aquifer had been recharged by channel infiltration, ground water discharge from upland bedrock aquifer recharge also plays an important role in determining Cottonwood Creek streamflow patterns.

Big Flat stream flow records were summarized by Tim Sagraves in several March 2006 e-mail memos to Plumas Corporation (Leslie Mink, pers. communication, May 2006). The implications from these data could not be ignored and were thus integrated into this report. The 2005 streamflow data are plotted in Figure 8, showing upstream and downstream flows (green and red). Also shown are the differences between downstream and upstream flows, shown in blue (plotted at larger scale).



According to the 2005 flow records, Cottonwood Creek began flowing by January 25. Significant flow was first recorded at the lower gauge by February 21. In that period inflow into Big Flat was about 55 acre-ft, before the lower channel started flowing. It is hereby implied that water flowing into Big Flat while no water flowed out of Big Flat, was water that infiltrated from the channel into the floodplain aquifer. Assuming a floodplain aquifer area of 47 acres, and specific yields between 22% and 40% (Heath, 1986, page 8), the resulting rise in floodplain aquifer ground water table would have been 3 and 5.5 ft. This water table rise compares well with rises observed in monitoring wells BF-9 and BFX-2. In other words the floodplain aquifer was recharged in that four-week period.

The records also show that after March 6 outflow from Big Flat was greater than inflow. The creek continued flowing until mid summer. By mid June flow in the upper reach had dried up, while in the lower reach flow had diminished to a trickle. When comparing the entire up- and downstream flow records, the total over 12 months flowing into and out of the meadow was 1617 and 2306 ac-ft. Clearly the areas above the x-axis (zero) are larger than those below, because more water flowed out than flowed into the meadow. It can be argued that this is water discharged from the meadow aquifer. Assuming an area of 47 acres for the Big Flat meadow, and a specific yield between 22 and 40% for the floodplain aquifer, the required corresponding ground water table declines of 35 to 66 ft would be unrealistically high, suggesting that most of the increased downstream discharge can not be attributed to water released from storage in the floodplain aquifer.

Instead the difference of 634 ac-ft (2306-1617-55 = 634 ac-ft) came from elsewhere. It can be argued that in this case most of the additional water discharged into Cottonwood Creek below Big Flat originated from the surrounding and underlying bedrock aquifer. Under this scenario the upland contribution to total annual stream discharge of the Big Flat reach of Cottonwood Creek was almost 40%.

Snowmelt beginning in February leads to upland ground water recharge and rising ground water tables. Onset of rising ground water tables in bedrock aquifers at this time of the year is a common observation. It is only to be expected that this will lead to increased discharge into the floodplain aquifer from the surrounding and underlying bedrock aquifers. The few Big Flat monitoring wells flowing artesian may be an indication that this is happening.

Evidence of deep ground water entering the meadow aquifer in select zones is found n the major cation and anion data. While stream waters' EC values are on average 70 to 100 uMhos/cm, EC in most monitoring wells is in the same range. However, in a few monitoring EC is much higher, and their wide ranges are indicative of subsurface mixing (between 290 and 560 uMhos/cm, depending on season). With calcium and alkalinity about four times as high as in stream water these monitoring wells are most likely affected by influx of deep ground water.

But why is this inflow not visible in the isotope data? Most likely winter stream channel isotope signature is determined by the same kind of ground water discharge in reaches above Big Flat, since similar gains in channel flow are to be expected upstream. In other words ground water discharge from bedrock into the floodplain aquifer and subsequently into the stream channel has the same isotope composition as the stream water entering Big Flat at the upstream gauge.

In summary a comparison of the 2004-2005 upstream and downstream Cottonwood Creek data at Big Flat Meadow indicate that downstream channel flow was not only augmented by aquifer floodplain storage but also by inflow from the underlying bedrock aquifer. This is supported by ground water chemistry patterns. For certain, this feature deserves further examination, since it implies the significance of upland ground water recharge affecting streamflow.

Synopsis of the Big Flat data record

The preceding discussion demonstrated that the stream water composition entering Big Flat undergoes significant seasonal changes. It thereby affects not only the lower gauging station, but also the floodplain aquifer. To understand the cause of these changes it is important to realize that Big Flat is only one short reach of about 0.65 miles on a stream which is about 20 miles long. In other words streamflow at the upper gauge in Big Flat is the result of ground water discharge in the stream reaches above (‘upstream baseflow’).

The data indicate that streamflow composition entering the meadow is a continuum between 2 mixing end members, the relative significance of which changes with time. Another possibility are changing contributions from at least two upstream ‘sub watersheds’.

It is, however, conspicuous that the early stage stream water is apparently like typical bedrock ground water. This gradually changes in the subsequent three months until it resembles a second source. Similar observation have been made in the hydrologic literature, where the initial pulse of streamflow is deep ground water, and the later stream water is derived from shallow ground water (‘hyporheic zone’ - defined as a subsurface volume of sediment and porous space adjacent to a stream through which stream water readily exchanges). Hereby it should be noted that the term ‘surface water’ compared to ‘ground water’ has little meaning in this context, since in this hydrologic setting essentially all stream water is derived from ground water (see for example Winter et al., 1998).

These stream flow source patterns should be further investigated since they may tell a great deal about how these headwaters watersheds function. Hopefully it may also provide a means of understanding how a watershed responds to changing land use patterns. Clearly, these data support what has been hypothesized before, i.e. a floodplain aquifer does get recharged not only during flood events inundating the floodplain, but also from channel infiltration.

The observations made herein also show that the benefits of channel restoration on floodplain aquifer storage using pre- and post-project environmental tracer data maybe a feasible option. By comparing pre-project with post-project data it is possible that the upstream to downstream difference in isotope composition can be used as a measure of increased floodplain aquifer storage due to channel restoration. In a setting similar as in Big Flat the difference between upstream and downstream isotope trends in the winter would be increased from pre- to post-project data, if ground water storage was increased due to restoration.

An unexpected feature so far evident only in the Cottonwood Creek discharge data, is that beginning in mid-March the downstream channel and the floodplain aquifer receive ground water from the underlying bedrock aquifer, as a result of upland ground water recharge.

Rowland-Charles Reach of Last Chance Creek

This portion of the project encompasses Rowland-Charles and Charles-Bird Reaches of Last Chance Creek (LCC). For the purpose of this project this is referred to as the 'Rowland-Charles Reach of LCC'. This ephemeral reach of Last Chance Creek is north-south oriented, as shown on the topographic map in Figure 2. The valley width here is less than _ mile in the south, and about _ mile in the north.

A systematic sketch map of monitoring wells and stream gauging stations is included in Figure 9.

Based on the monitoring well installation data depth to bedrock is no more than 9 ft and 13 ft in the southern and northern central valley sediments. In the Rowland-Charles Reach, LCC had developed two parallel degraded (down cut) channels, less than 1000 ft apart, at about 5800 ft elevation. The valley here is probably defined by a NS trending fault, with a 6600 ft high ridge in the east. Springs discharging at the contact between granite and volcanics at about 6200 ft elevation suggest that this is probably an important ground water recharge area, supplying baseflow to LCC from the east, evident in the valley with low elevation springs and what appears to be phreatophyte vegetation on the eastern floodplain fans.

Ground water data were collected in three of four monitoring well transects, installed in the summer 2001. Each transect in the Rowland-Charles Reach (RC4 and RC5) consists of 3 monitoring wells (1/2 inch perforated steel pipe) placed in lines perpendicular to the stream channels with one monitoring well located west and two east of the restored LCC stream channel.

The Charles-Bird Reach has two transects (CB2 and CB3) consisting of 4 monitoring wells each. These transects are located approximately 0.4 miles downstream (north) of the Rowland-Charles Reach, one above and one below the confluence of Charles Creek with LCC. Only the monitoring wells in transect CB2 were monitored. The valley here begins to trend NW, and the active floodplain maintains its width due to a prominent alluvial fan entering from the northeast. This reach likely receives baseflow from the 6200 ft ridge to the east and the small drainage to the northeast.

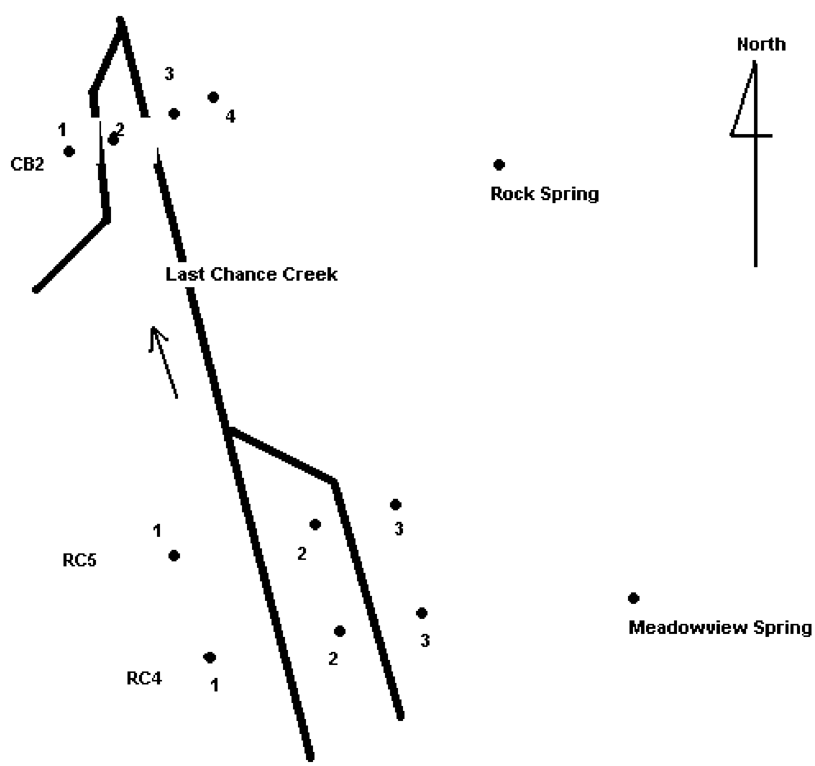


Figure 9: Schematic site map, Rowland-Charles reach, Last Chance Creek. Staff gauges were installed at profiles RC4 (upper) and CB2 (lower).

Stream stage data were collected at RC4 in the south (upstream) and at CB2 in the north (downstream) about 1.5 miles apart. Two springs, Meadowview and Rock Spring, located on the lower eastern valley slope were also sampled.

Channel restoration conducted in summer 2004 encompassed only the RC4 and RC5 monitoring well transects.

Rowland-Charles Reach is a stream-floodplain-aquifer system that differs from that seen in Big Flat, although both Cottonwood Creek and the Rowland-Charles Reach of last Chance creek are ephemeral:

1. Rowland-Charles Reach floodplain aquifer is wider than that of Big Flat Meadow (2000 ft versus 500 ft).
2. Rowland-Charles Reach floodplain aquifer depth is one-third that of Big Flat Meadow (9 and 35 ft).

General comments

Due to the significant logistic challenges and poor monitoring well construction features the data record from this reach sometimes contains frustrating gaps. Nevertheless, these data permit a number of interesting observations that lead to some very useful conclusions.

The following analysis examines correlations between deuterium, stream stages, and ground water levels. For brevity the discussion is limited to deuterium only, since comparison with oxygen-18 data yields similar results.

> *The discussion will show that in the summer and fall the floodplain aquifer received ground water flow from the east. This had changed by April when the western floodplain aquifer became inundated by recharge from the west raising the ground water table. As expected, the stream water composition followed ground water composition until mid-May, after which ground water levels declined and channel flow ceased altogether.*

Deuterium, stream stage and ground water levels

Figure 10: Deuterium changes correlating with ground water levels.

Deuterium is plotted on the horizontal axis and depth to ground water on the vertical axis. Also shown are stream stages at the upper and lower gauges (green and red).

Observations:

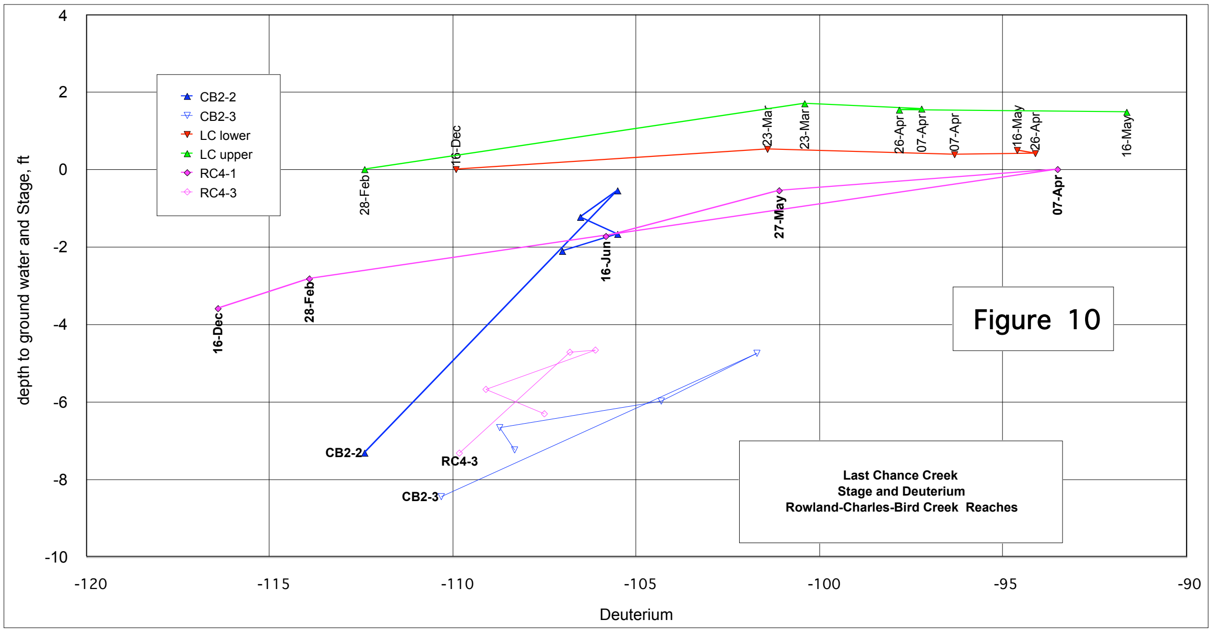
1. Deuterium changes in the stream channel, depending on stage and season (red and green), follow an increasing trend from late February (left) until flow ceased in late May (right).
2. Ground water deuterium levels are lowest when the ground water table is low, and vice versa. Plotted here are the data from four selected monitoring wells (blue and purple).
3. Deuterium in the monitoring wells increased until early April, together with ground water levels. Both declined thereafter, back to levels similar as in the preceding December.

> *Evidently the floodplain aquifer experienced influx of water, from a source with different isotope composition, leading to rising ground water levels. The following discussion will demonstrate that the source of recharge was ground water influx from he underlying and surrounding bedrock aquifer, eventually discharging into the channel.*

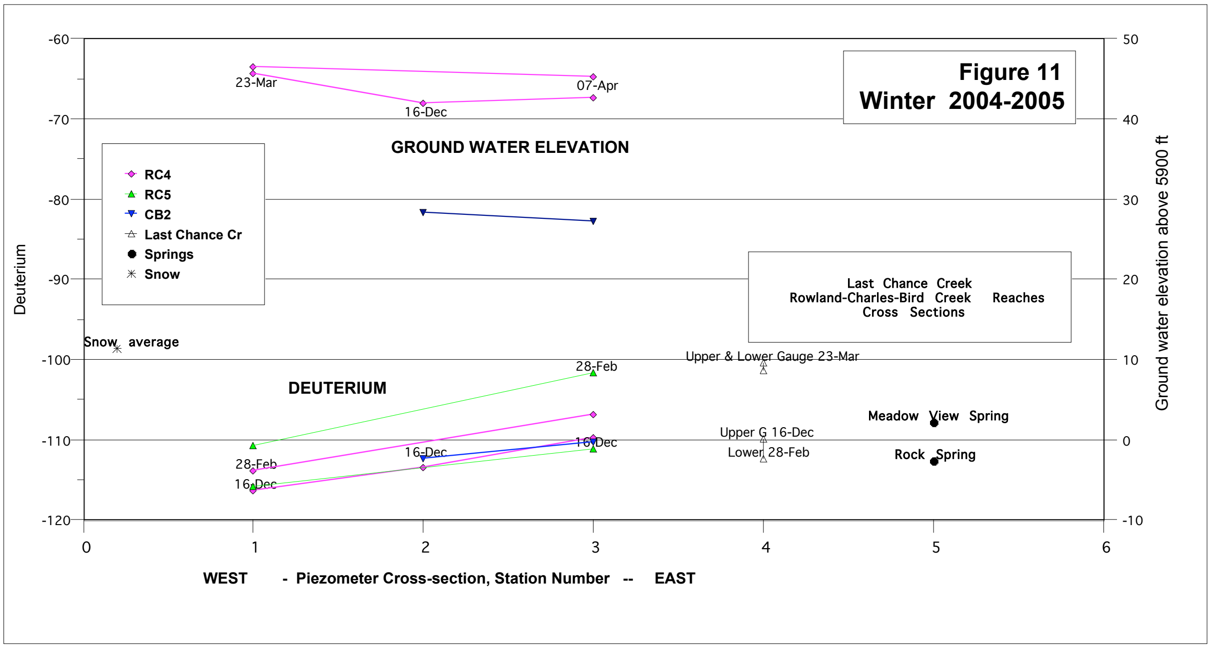
Winter and spring interactions between channel and floodplain aquifer.

In Figure 11 deuterium levels are shown for selected monitoring wells for the winter of 2004-2005. The same are shown in Figure 12 for the Spring and Summer of 2005.

The diagrams are approximations of cross sections across the floodplain, as if looking north, with the monitoring well locations from left to right (west to east). Locations 1, 2 and 3 pertain to each monitoring well number, while their location on the diagram is only a schematic plot, not to scale, on the horizontal axis. Deuterium concentrations and ground water table elevations are plotted on the left and right vertical axes, respectively.



Shown on the far right are the spring water concentrations, the springs being located on the eastern valley slope. Also shown are the concentrations measured at the stream gauge locations, for selected sampling dates. To avoid an unnecessarily cluttered plotting pattern the gauging station data were plotted at location 4, i.e. to the right of the monitoring well location points. In actuality the channel monitoring sites are located somewhere between monitoring well locations 1 and 2.



Data included in these two diagrams were selected to be able to demonstrate the nature of surface-to-ground water interactions in this floodplain. Here, again, as in the Big Flat data analysis, deuterium levels are compared to discern similarities and thereby determine water sources. Though not included here, the oxygen-18 data yield similar results.

The reader should be cautioned to not confuse deuterium levels in the lower diagrams with water levels. While the same colors are used, the ground water elevations are shown in the upper diagram. A survey was conducted by Jim Wilcox to obtain absolute (relative) top-of-casing elevations before the monitoring wells were destroyed.

Figure 11: Deuterium and ground water levels, winter of 2004-2005.

1. Winter floodplain aquifer water levels and ‘deuterium profiles’ are ‘tilted’ to the west. Deuterium in all monitoring wells increased from December until February due to ground water influx.
2. Ground water deuterium levels are higher in the east than in the west. Eastern monitoring wells resemble the spring waters to the east, as expected. In the west (locations 1 and 2) deuterium is still much lower (no ground water data is available from the bedrock slope in the west).
3. Streamflow was first observed in December though it did not become significant until mid-March. Early channel flow deuterium resembles the eastern springs, indicating early ground water discharge from the east initiating channel flow.
4. By March channel flow deuterium was significantly higher than in the springs, probably due to early channel flow arriving from upstream reaches in the south.
5. Channel deuterium levels increased over time, with upper and lower gauging station deuterium levels practically the same every time they were sampled. The streamflow composition increased from December until late March due t a combination of ground water discharge from the east and channel inflow from the south.

Figure 12: Deuterium and ground water levels, spring and summer 2005.

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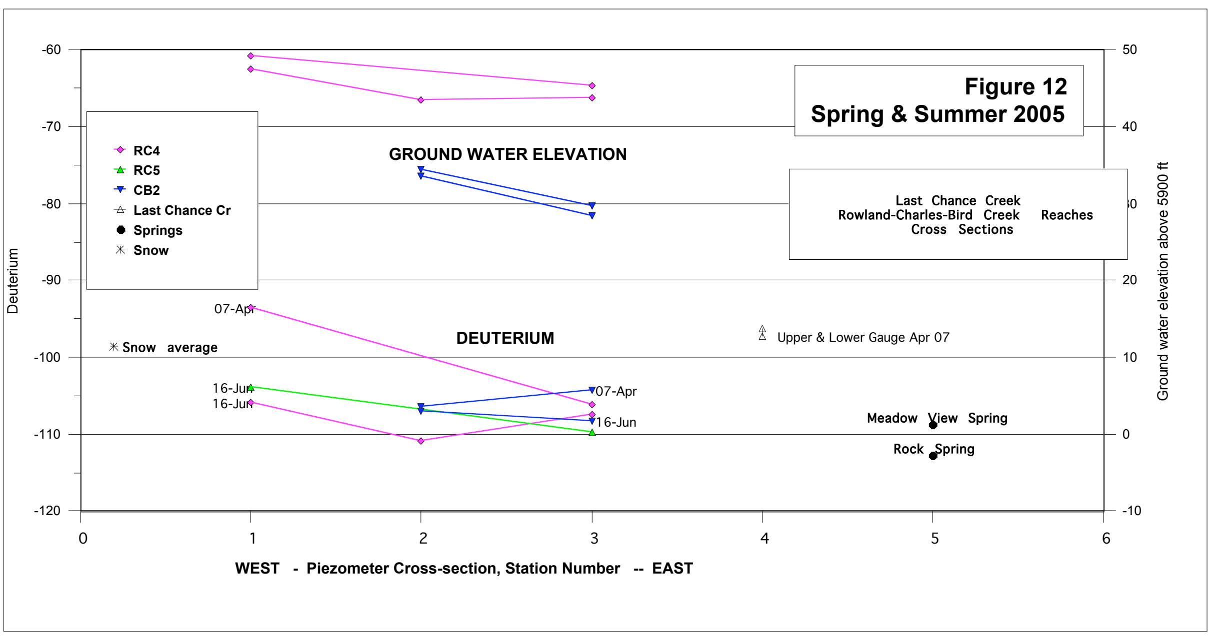

1. In April floodplain aquifer deuterium began to increase in the west, eventually to levels far above those observed in the east.
2. From this point on stream water composition followed the upward trend in the west, indicating channel flow was maintained by ground water discharge from the west.
3. Increased ground water discharge from the west is supported by increasing easterly ground water flow gradients in this period.

Synopsis of the Rowland-Charles Reach data record

Based on these data channel flow in this ephemeral reach of Last Chance Creek is maintained by ground water discharge from the underlying floodplain aquifer, and to a lesser degree by upstream channel inflow. Since the valley floor at less than 6000 ft is surrounded by mountains in the east and west, ranging to more than 8000 ft elevation significant ground water flow into the valley and the floodplain aquifer is to be expected. The springs flowing year-round are evidence for that.

The deuterium data from ground and stream water support this. Ground water flow entering the valley from the east and emerging in the eastern springs dominates the floodplain aquifer in the summer and fall. This ground water flow from the east increases in early winter (December) which leads to the first flows in the previously dry stream channel.

In the spring recharge from the western bedrock aquifer had increased, leading to an accelerated rise in the floodplain ground water table, thereby increasingly dominating stream water composition. Channel flow ceased soon after ground water levels started to decline, depriving the ephemeral stream of its water source.

The most important conclusion: in this channel ephemeral stream flow patterns are determined by upland recharge discharging into the channel via a limited volume floodplain aquifer.

Assessing baseflow augmentation with environmental tracers

How can environmental tracers be applied to assess baseflow augmentation? The objective of this project are:

a. To collect environmental tracer data to further our understanding of the stream-to-ground water interaction in two stream reaches in the Last Chance Watershed.
b. To use that information to identify how tracers can be used to evaluate the effect of meadow restoration projects on baseflow.

Data collected indeed enhanced our understanding of how stream water isotope data change both during channel infiltration and ground water discharge into the channel.

Isotope time series

In Big Flat Meadow pre- and post-project ground water table data suggest that the meadow restoration project has resulted in elevating the ground water table. Less clear is to what extent the project has enhanced the differential between maximum and minimum seasonal ground water level changes. An increase of these changes is desirable since the magnitude of this change determines how much water is stored in and drained from the floodplain aquifer.

In the preceding discussion it was postulated that the difference between up- and downstream isotope composition is an indication of stream water infiltrating and discharging back into the stream (see vertical distance between red and green curves in Figure 6 and Figure 7). Unfortunately no pre-project isotope data are available for comparison. However, it is conceivable that a stream flowing in a degraded channel at a level 7 to 10 ft below the restored channel depth has little potential to infiltrate into the surrounding floodplain aquifer. In other words floodplain aquifer storage would be almost nil, and the downstream water composition would be almost identical to upstream water composition.

To demonstrate this effect, aquifer mixing composition changes were simulated using a spreadsheet. It was hereby assumed that the average daily channel infiltration volume is about 3% of the original floodplain aquifer storage volume (based on actual stream flow data collected in Big Flat). The results of this simulation are plotted in Figure 13.

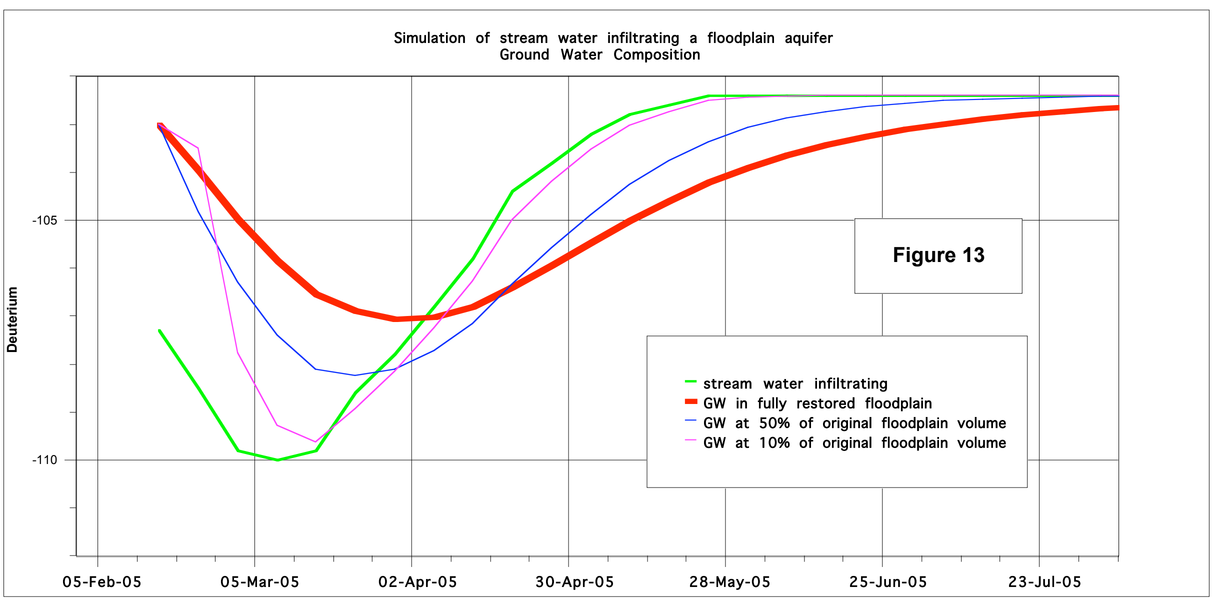

Figure 13

The stream water composition, sampled at the upstream gauge is plotted in green. Ground water composition in a fully restored aquifer is plotted in red. Correspondingly, ground water composition under increasingly degraded floodplain condition are plotted in blue and purple.

The initial stream and ground water composition were those from Big Flat. Surprisingly, the data for the restored floodplian simulation mimic the original data patterns reasonably well (compare Figure 6 and Figure 13).

As expected under most degraded conditions the ground water composition would be almost identical to the inflowing stream water composition. This thinking can be taken one step further by modeling up- and downstream channel composition to estimate the impact of restoration. To go even further, the actual baseflow enhancement volume can be estimated with a digital model, whereby the tracer data can serve as a verification tool.

It is hereby postulated that the differences between upstream and downstream composition can be seen as a measure of how efficient the system is at accommodating channel infiltration, and how efficient it is at releasing it. Presumably the vertical distance of these two trends is dependent on how long it takes to completely replace the floodplain aquifer water with channel water. In other words, the farther apart the two curves the more storage occurs, and vice versa.

Aquifer composition and ground water levels

When an unconfined aquifer receives influx of water of a different composition, a correlation between depth to ground water and mixing composition is to be expected. Given the limited thickness of most mountain meadow floodplain aquifers complete mixing is likely. This is demonstrated in Figure 10 where tracer composition plots as a function of depth (linear correlation). Since restoration is expected to result in increased floodplain storage capacity, restoration should result not only in higher ground water levels, but also in changing tracer concentrations. In Figure 10 this would result in a shift to the right and reduced slopes in post restoration data .

Summary

Baseflow augmentation due to meadow restoration can be measured by comparing pre- and post-restoration baseflow isotope characteristics. However, the hydrologic setting has to meet at least one or both of two conditions:

a. Stream water isotope signatures changes from winter into spring and summer.
b. Ambient floodplain aquifer water isotope signatures differ uniquely from that of stream water.

Under ideal conditions the tracer patterns observed in this project may very well lend themselves as a tool to estimate the degree of baseflow augmentation. More so they may serve as verification tools for hydrologic models.

By comparing such data from the pre- and post-restoration phases one may be able to determine ground water storage efficiency. Determining the vertical separation between the curves and the time it takes to close the ‘gap’ between the two curves may be a measure of restoration efficiency.

Recommendations

Apart from the logistic challenges posed by this project, obtaining good isotope tracer data can be a comparatively low cost effort. From that standpoint this project has yielded a lot of information. Several recommendations are made:

1. Based on what was learned in this project other restoration projects should be sought out for similar data collection, maybe in more ideal hydrologic settings. A more continuous data record would be beneficial, ideally in weekly intervals. For that purpose projects closer by would be beneficial to better handle site access and inclement weather conditions.

2. To obtain a more continuous sampling and data record one may want to seek out (if not develop) automated sampling equipment. Crest gauges installed not only on streams but also in wells may provide a useful way of obtaining a more complete range of ground water fluctuations.

3. One my even seek out funding for modeling projects in ideal setting to further our understanding of isotope tracer patterns in these settings.

4. The significance of upland ground water recharge on streamflow patterns was one unexpected realization growing out of this data analysis. This feature should be further examined.

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Attachment A: Big Flat hydrology synopsis

The difficult task of physically measuring baseflow augmentation can be demonstrated in Big Flat. Before restoration Big Flat meadow had a deeply incised, degraded channel which was restored in the mid 1990's with a "plug-and-pond" system. With an area about 47 acres in size during a flood event that covers the floodplain for example with 12 inches of water, the meadow would store 47 acre-feet of surface water. Usually most of this is released back into the stream channel within a few hours, while some of this water infiltrates into the floodplain aquifer.

Data from Big Flat indicate that ground water table fluctuations can be between 3 and 5 ft within a given year (Sagraves, 1998). Assuming a specific yield of 12% (e.g. Fetter, 1988, p. 74) for the meadow floodplain deposits, Big Flat Meadow can store and release between 17 and 28 acre-ft of ground water per year. This water is slowly released back into the stream channel in the following 6 to 9 months.

Recent data from Big Flat Meadow also suggest the beneficial impact of recent stream channel restoration. When compared to the pre-project water table, this impact has reportedly resulted in an average of 1.5 ft post-restoration increased ground water table rise (Sagraves, 1998). Again, using a specific yield of 0.12, increased bank storage due to channel restoration has increased by 8.5 ac-ft per year, or 30%.

It is difficult to convincingly measure baseflow augmentation since base flow released from the meadow is only a small fraction of flow measured in the stream channel below Big Flat Meadow. Assuming 8.5 acre-feet of baseflow is released from the meadow due to baseflow augmentation over a period of 6 to 9 months, this results in an average flow of about 0.02 cfs. When compared to between 0.1 to 1 cfs of channel flow late in the year (Sagraves 1998) it is doubtful that this small amount can be convincingly distinguished from channel flow entering the meadow by using only physical streamflow measurements, given the probabilistic nature of these data.

This problem is further complicated by not knowing how much ground water enters the meadow aquifers from the surrounding bedrock, and which is also discharged into the channel. Using only physical stream flow measurements this is next to impossible to separate from the hydrograph data.

The foregoing discussion demonstrates that it is quite possible that late year stream flow is less affected by spring flood flow temporarily stored in the floodplain, but maybe more so by ground water discharged from the reaches upgradient of the Big Flat meadow.

Attachment B: Calculations

Estimating mixing fractions of stream water in the alluvial aquifer

Using a simple mixing equation the fraction of stream channel infiltration (leakage) into the alluvial aquifer can be approximated. The mixing equation is:

$$ECa = ECU \times Vu - ECc \times (1 - Vu)$$

EC stands for environmental tracer concentration, V for volume fraction (smaller than 1.0) and the subscripts a, u and c stand for floodplain aquifer mixture, upstream channel water and late summer floodplain aquifer composition. The fraction of upstream channel water in the floodplain aquifer during the winter can be estimated by rearranging the above equation:

$$Vg = (ECa - ECc)/(ECg - Ec)$$

The fraction of upstream channel water in the floodplain aquifer can then be estimated by $Vc = (1 - Vg)$.