Effects of Meadow Restoration on Stream Flow in the Feather River Watershed

A Review Based on Monitoring Data and Pertinent Research

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"Over the past quarter century, there has been a gathering recognition that streams and groundwater are a single linked resource and need to be considered together when assessing water availability in terms of management issues such as irrigation, recreation, wildlife, and overall ecology of watersheds."

American Geophysical Union (2012)

Executive Summary

The impetus for meadow restoration projects, such as “pond-and-plug” treatments, in North Fork Feather River watersheds came from a desire to reduce sediment delivery. The primary identified sources of erosion are stream channels that are deeply downcut below meadow elevation and roads with poor location or design. Erosion from meadow channels is substantially reduced by effectively restoring flows at meadow elevation. In addition to increased erosion, channel down-cutting results in faster and more extensive draining of meadows. As a result, restoration projects result in changes to the timing and volume of water delivered.

The purpose of this paper is to briefly describe the nature of the expected changes to flow due to restoration and to summarize results of flow monitoring conducted to date, particularly in the Red Clover Creek and Last Chance Creek drainages. In addition to monitoring data, this briefing draws extensively from studies that are particularly pertinent to meadow improvement treatments in the upper Feather River watershed.

The Feather River Coordinated Resource Management (CRM) Steering Committee expects that this 6-page Executive Summary provides sufficient detail for most readers. However, readers are encouraged to review the entire briefing, as the full paper provides detailed discussion and information that supports the statements made in this Executive Summary.

In general, when compared with a down-cut meadow stream channel system, flow regimes that result after restoration of the floodplain and water table are much closer to the historic, pre-European settlement (pre-1850) condition. That being said, changes to flow following restoration cannot be characterized as entirely positive or entirely negative, but vary depending on water use interests and priorities.

Findings in this briefing are not presented in order of perceived priority or importance. Rather, findings have been organized by seasonal flow response. Early season effects are presented first. Meadow improvement projects reduce flood peaks by spreading more water over the reconnected floodplain. Some of this water is stored in meadow soils, and results in higher surface flows in late spring and early summer. Late season effects are discussed last. Changes to these flows are less certain, due to their low volume and difficulties in measuring the low flows. As a result of increased evapotranspiration, total annual runoff is reduced slightly.

Readers are cautioned that flow effects observed at project sites differ due to substantial variations in subsurface geology, soil types, meadow area and slope, precipitation, and surface flow regimes amongst watersheds in the upper Feather River basin.

Finally, it should be noted that effects to surface water flow are just one aspect of meadow improvement projects. Substantial positive effects have resulted for other aspects, such as streambank erosion control, forage, and bird and terrestrial wildlife habitat, Other effects, such as for aquatic habitat, are still subject to debate. These effects could be further discussed in future briefing papers.

Context for Expected Flow Regime Changes due to Restoring Meadow Floodplain Connection and Water Table in the Upper Feather River watershed

- Changes to late season flow due to restoration projects have garnered the most interest. Even a small change in surface water available to downstream irrigators (e.g. 0.1 cfs) is important and valuable, especially during the late irrigation season.
- Unfortunately, trends in late season flow are inherently difficult to determine due to annual variations in precipitation, small magnitudes of late season flow, and the uncertain nature of stream and groundwater interaction along the lengths of Red Clover and Last Chance Creeks from the upper meadows to the confluences with Indian Creek. Also, changes to late season flows are very difficult to measure accurately.
- Post-restoration surface and groundwater flows have probably not yet reached equilibrium. It may take decades for sub-surface flow paths to become fully functional, Therefore, monitoring the first several years after restoration improvements may not accurately depict the long-term flow regime. The reason is that the deeply incised channel dramatically changes the ground water flow regime, and it can take a long time to return to the original regime once the channel has been restored. A current study administered by the Forest Service's Pacific Southwest Regional Office (scheduled for completion in summer 2013) is expected to provide further data on expected long-term effects of meadow improvements.
- Irrigators in the Upper Feather River Basin have likely faced increasing late season challenges in recent years. A recent PG&E study (Freeman 2010) found an average annual decrease in flow on East Branch North Fork Feather River of 23% (179,000 acre-feet) for the period of 1976-2009 when compared with the 1950-1975 period, with climatic changes and decreased snowpack cited as the causes for this decrease.

Concepts of Meadow Hydrology

- In general, flow regimes on pond-and-plug reaches are much closer to the historic condition (pre-1850) than the incised channel condition (a brief description of available information pertinent to historic condition of these meadows is presented in the main body of the paper). Restoration of the floodplain and water table restores most of the natural hydrologic function of these meadows and eliminates the accelerated drainage of meadow soils caused by incised stream channels.
- All surface and ground water flowing into a meadow, regardless of whether or not improvements have occurred, will eventually flow out of the meadow – except for water consumed by evaporation and transpiration (ET). Raised ground water tables in restored meadows result in more riparian vegetation and more water to transpiration. If restoration increases water surface area (ponds) then evaporation is also a source of increased water consumption. Increased ET is an inevitable net loss to the total annual water balance in a restored channel.
- Surface flows are also affected by conditions in the meadow below the rooting depth. Ground water that drained relatively quickly to an incised channel prior to restoration flows much more slowly down valley through saturated soils after restoration. As a result, some water that appeared as late season stream flow prior to restoration remains as subsurface flow after restoration. Groundwater flow velocities vary widely depending upon soil type and meadow characteristics, with flow speeds ranging from several feet to several miles per

year. In contrast, measured stream channel flow velocities are one mile or more per day, during the late season. Nevertheless, despite very slow sub-surface velocities, these subsurface flows (unaffected by ET) eventually reach a downstream channel. This may occur within the restored meadow or several miles downstream.

- Due to differences in watershed characteristics and geology between different meadow sites, it is clear that flow regime effects will not be the same for all meadow improvement projects. It should not be assumed that effects observed at one project site will occur or have occurred at another site.

Existing Monitoring Data

- Continuous, year-round streamflow measurement data downstream of meadow restoration sites exist for one station on Red Clover Creek (at Notson Bridge) and one station on Last Chance Creek (at Doyle Crossing). These stations began collecting flow measurements in 2000 and measurements have continued to present time. The Red Clover Creek station is located approximately 6 miles downstream of 7 miles of pond-and-plug treatments (constructed between 2006 and 2010). The Last Chance Creek station is located approximately 8 miles downstream of 9 miles of pond-and-plug treatments (constructed between 2002 and 2007) (see Figures ES-3 and ES-4).
- Flow measurements were taken above and below the “McReynolds” project on Red Clover Creek for one season before pond-and-plug construction (2005) and several seasons after construction (2007-2012). Pre-project data (2005) are limited to measurements made on one single day in each of 4 calendar months of the spring and summer low flow season (June to September). Post-project measurement sets are generally of similar size, although larger data sets exist for 2008 and 2009.
- “Seepage Run” flow data were collected from Red Clover Creek to assess the results of pond-and-plug projects, with monitoring on two dates in 2011 and five dates in 2012. Each day included measurements of flow above and below five stream reaches varying in length from 0.4 to 0.9 mile in length (see Figure ES-4). Two of the seepage run reaches were located on pond-and-plug projects and the remaining three were located upstream of any pond-and-plug treatment.
- A list of potential future monitoring work is presented in Appendix B. Excellent summaries of existing flow monitoring data are posted on the Feather River CRM website.

Key Findings from Monitoring Data and Pertinent Research

- For early season effects of restoration, a study on Trout Creek, a tributary to Lake Tahoe, demonstrated a significant increase in streamflow after meadow restoration during spring and early summer (Tague 2008). After restoration, flood flows stored in meadow soils appeared to be released later in the season. Analysis of streamflow data taken above and below the Big Flat project on a tributary to Last Chance Creek (Cawley 2011) also found an increase in streamflow during this snowmelt recession period.
- In retrospect, it appears that it was mistakenly assumed that an increase in spring flows would extend into the late season for all projects. Project effects observed on Red Clover

and Long Valley Creeks indicate that some pond-and-plug projects can cause decreases in late season flow within and immediately downstream of treated reaches, at least for the first few years after restoration. This is a significant finding because the working assumption for the first decade-plus of planning and construction of these projects in the upper Feather River watershed has been that late season flows would increase at all project sites.

- Considerable caution should be exercised in analyzing data collected in the near term after project construction because the meadow soils may not have had enough time to “fill” and the ground and surface water flow systems may not have reached a long-term equilibrium. Heede (1975) indicated that a likely equilibrium was achieved for one project 7 years after restoration.
- For the near-term time frame of 1-6 years after project construction, data indicate that the Red Clover Creek pond-and-plug projects have caused substantial decreases in late season surface water flow within and immediately downstream of the treatments (Figure ES-1). The 2005 data indicates that Red Clover Creek was losing surface flow to ground water in the McReynolds reach prior to the restoration project. However, the 2011 and 2012 Seepage Run results indicates the rate of loss of streamflow per mile to be roughly double (or more) the pre-project rate (Appendix A). The four flow measurements taken on Red Clover Creek in summer 2005 (pre-project) at the bottom of the McReynolds Project exceeded 1.0 cfs. Streamflow at this same location after project construction was zero to 0.1 cfs for periods of a month or more in the summers of 2007, 2008, 2009, and 2010 (Figure ES-1). Likely causes for these apparent decreases in surface flow are enhanced ET within the treated reaches, conversion of some surface flow to slower groundwater flow, and widespread beaver activity, which further spreads surface flow across the meadow.
- While late season stream flow decreases after project construction have been indicated within and immediately downstream of the Red Clover Creek projects, that effect has not been detected further downstream. A statistical analysis (Cawley 2011) of 11 years of continuous streamflow data taken at Notson Bridge (Red Clover Creek) and Doyle Crossing (Last Chance Creek) indicated no apparent statistical trend in streamflow during the late season (no increase or decrease in flow) (Figure ES-2). The nearest downstream irrigators from the projects on Red Clover Creek are in Genesee Valley, diverting water from Red Clover Creek (5 miles downstream of the Notson Bridge station) and Indian Creek (20 miles downstream of the Doyle Crossing station; no irrigation water is diverted directly from Last Chance downstream of Doyle Crossing) (See Figures ES-3 and ES-4).
- 2012 Seepage Run data along un-restored reaches of Last Chance Creek (one event in September) indicate losing reaches in the upper meadows and gaining reaches further downstream as the stream enters the canyon above Genesee Valley. These data further emphasize an important concept to be understood when studying stream flow data: late season surface flows are strongly influenced by subsurface soil conditions and geology.
- Last Chance Creek flows quite slowly during the late season (generally < 0.1 ft/s). Surface water at Doyle Crossing would likely require more than 10 days to travel the 20 miles to Indian Creek. Water lost to evaporation over this time period may be a substantial fraction of the flow that exists at Doyle Crossing.

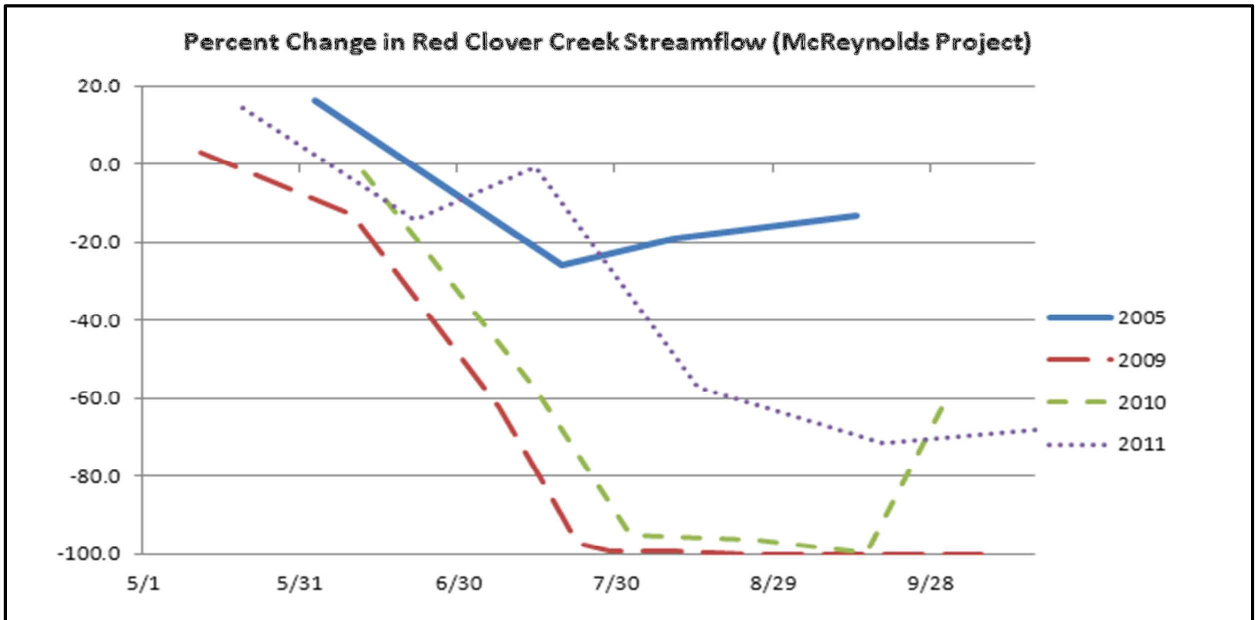

Figure ES-1: Percent change in streamflow occurring between top and bottom of McReynolds project. 2005 is pre-project. For the post-project period (2009 – 2011), rates of surface flow loss are substantially higher. 2005 and 2010 had near-normal annual precipitation. 2009 was below normal. 2011 was above normal.

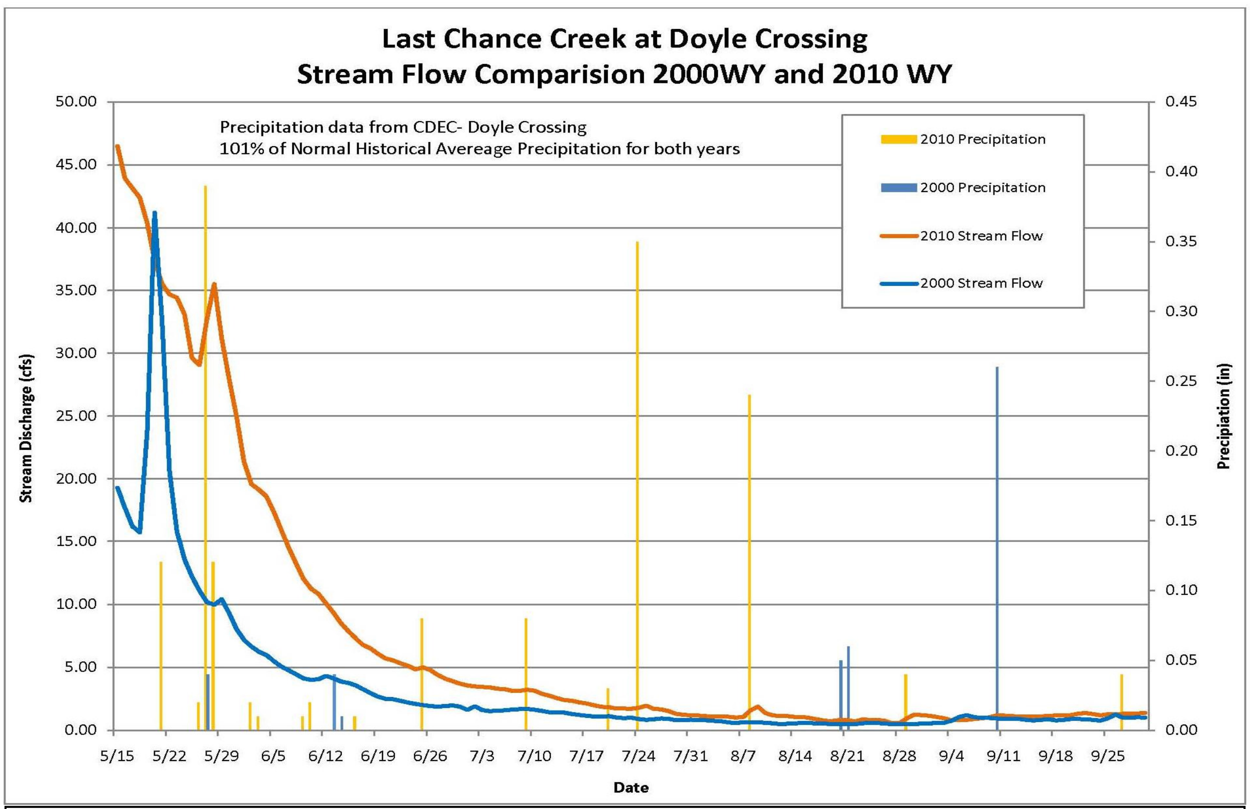

Figure ES-2: Last Chance Creek summer stream flow measurements for near-normal water years at Doyle Crossing, 2000 and 2010. Approximately 9 miles of pond-and-plug restoration was implemented upstream of this gage from 2003 through 2007 (see Figure ES-3). There is no statistical trend in late season flow amounts at Doyle Crossing.

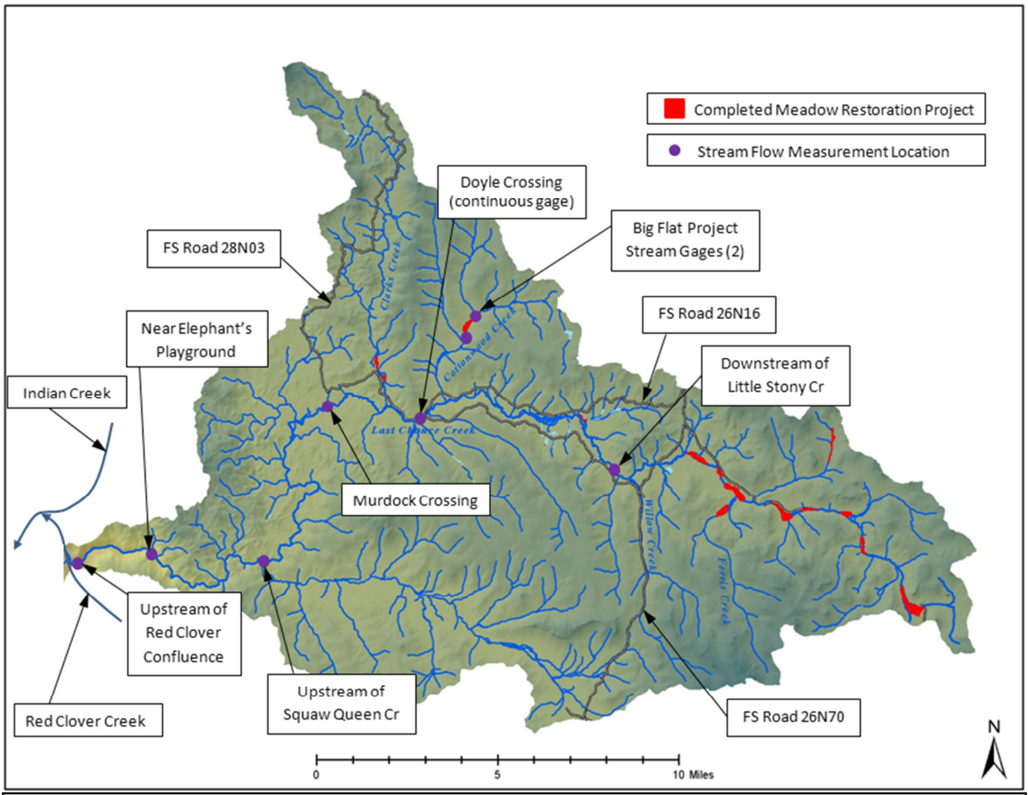

Figure ES-3: Stream flow measurement locations, Last Chance Creek watershed

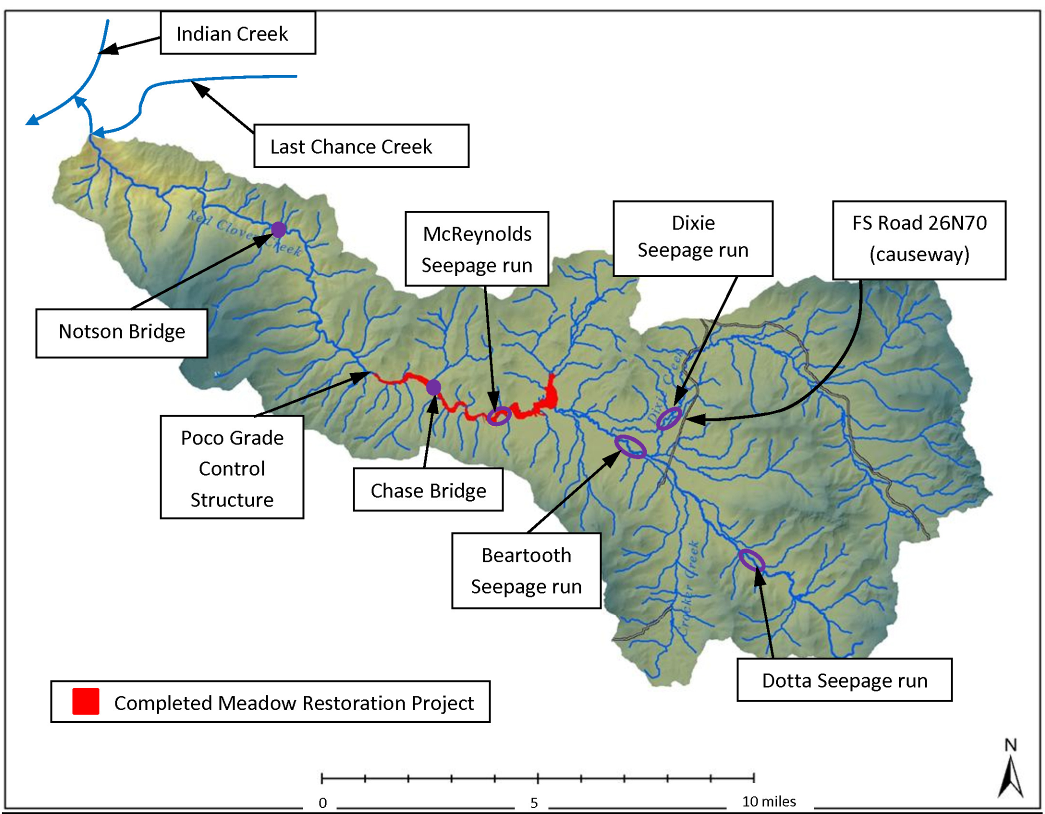

Figure ES-4: Stream flow measurement locations, Red Clover Creek watershed.

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Introduction

The impetus for meadow restoration projects, such as “pond-and-plug” treatments, in North Fork Feather River watersheds came from a desire to reduce sediment delivery. The primary sources of erosion identified are stream channels that are deeply downcut below meadow elevation and roads with poor location or design. Erosion from meadow channels is substantially reduced by effectively restoring flows at meadow elevation. In addition to increased erosion, channel down-cutting results in faster and more extensive draining of meadows. As a result, restoration of the water table in project areas results in changes to the timing and volume of water delivered.

The purpose of this summary is to briefly describe the nature of expected changes to flow due to meadow improvements such as pond-and-plug projects, and results of flow monitoring conducted to date. In addition to monitoring data, this summary draws extensively from two studies of meadow improvement treatments. These studies are from Trout Creek in the Lake Tahoe Basin, where flows before and after a channel realignment were compared (Tague, et al, 2008); and from Bear Creek in the Fall River watershed, where modeling was used to assess changes in flow resulting from a pond-and-plug project (Hammersmark, et al, 2008).

Changes to hydrology resulting from meadow restoration are listed in Table 1. Some of these changes (e.g. groundwater levels, subsurface storage, and increased evapotranspiration) occur in the meadows (rather than the channels). These changes in turn affect the flow volume and flow timing downstream of the meadow. These factors are the focus of this brief.

Hydrologic Effect	Cause
Raised groundwater levels	Channel no longer downcut
Increased subsurface storage	Channel no longer downcut
Increased frequency of floodplain inundation	Channel capacity reduced, channel and floodplain reconnected
Decreased magnitude of flood peaks	Floodplain inundation and temporary storage
Increased floodplain storage	Increased channel-floodplain connection, channel no longer downcut
Decrease in baseflow	Higher ET, and channel drains less groundwater
Decreased total annual runoff	Increased subsurface storage, higher ET from vegetation and ponds

Table 1 - Hydrological effects and their causes due to pond and plug stream restoration (from Hammersmark, et al 2008).

Meadow improvement projects in the upper Feather River watershed were originally pursued to control erosion of incised stream channels. It was envisioned that re-establishment of the water table at meadow elevation would also benefit riparian and seasonally wet meadow vegetation communities, which in turn would positively affect forage production and wildlife habitat for birds and terrestrial species. The projects have, in most cases, been quite successful at meeting the objectives of reducing stream bank erosion and improving the extent and quality of riparian and meadow vegetation. Other presumed benefits, such as for aquatic species habitat and stream flow regimes, are less clear. Effects for each of the resources described above could be topics for future briefing papers.

Concepts of Meadow Hydrology

The following discussion presents a conceptual model of meadow hydrology. The basic concepts are outlined in three schematic sketches (Figures 1A, 1B, 1C). Additionally, a summary of historic condition information (pre-European settlement) of upper Feather River meadows, particularly the Red Clover Creek and Last Chance Creek drainages, is provided.

Historic Condition (pre-1850)

Understanding the historic condition of meadows and their streams in the North Fork Feather River is limited, because we have no records, surveys or photographs of the system prior to arrival of Europeans. Following that, records are very scarce until about the 1940s, when the first aerial photographs were taken. While our assessment is not based on hard data, it is more than anecdotal. We have utilized information about the use of the land by native peoples, pertinent research on other Sierra meadow systems, and the earliest available records to piece together a description of historic meadow form and function. We also note that while the earliest dates for some of this information go back 10,000 years, that is a very short period (practically an instant) in geologic and hydrologic time.

Archaeological evidence within the northeastern Sierra Nevada indicates humans were present at least 8,000 to 9,000 years ago. Over the last 30-40 years, archaeological surveys on the east side of Plumas National Forest have noted a distinct pattern of prehistoric occupation along the margins of the broad meadows in valley bottoms. Mountain meadows offered an abundant mix of seasonal resources for early people but, if these meadows were wet, would not have been conducive for residential occupation. Thus, this pattern strongly suggests that people would reside adjacent to, but not typically within, the meadows. This settlement pattern is evident on the landscape and appears to have persisted for thousands of years.

While some meadows undoubtedly experienced down-cutting naturally, the widespread occurrence of meadows with incised channels in the Feather River watershed does not represent their pre-European settlement condition. Wood (1975) discussed meadow formation and evolution in the southern Sierra Nevada. Based on radio carbon dating of materials from numerous meadow profiles, he estimated most meadows formed on the landscape about 2300-2500 years ago, with some as recently as 750 years ago. This followed a period when the meadow bottoms were forested, about 10,000 years ago. He found evidence of cutting and filling of meadow materials during the formative meadow “filling” stage, but found no evidence of wet meadow gullying prior to about 1900. Similar carbon dating of meadow soil profiles has been performed at Last Chance and Red Clover Creeks, with data indicating the meadows have been continuously depositional (newer sediments deposited on top of older sediments) since approximately 7,000 years ago (Collins 2002). The most recent soil layer, 2 feet below meadow surface, is carbon dated as being deposited approximately 900 years ago.

Soil characteristics along downcut and incised channels in the upper Last Chance and Red Clover valleys suggest that periods of prolonged saturation once occurred in these areas (USDA 1989). Subsequent studies in Dotta Canyon, Red Clover-Poco project area, McReynolds Canyon, Last Chance Phase II project area, Big Flat, and Clarks Creek (Churchill, 2008) revealed indicators of hydric soils throughout. These indicators are formed predominately by the accumulation or loss of iron, manganese, sulfur, or carbon compounds in a saturated and anaerobic environment. Of particular importance was the identification of relic features (morphological features that reflect past hydrologic conditions of saturation) present in areas that are currently incised or severely eroded, even though facultative and obligate upland plants have existed in these areas for decades.

Hughes (1934) reported on meadow erosion control projects on the east side of the Plumas National Forest. He described historic conditions: "Originally the meadows were well watered by meandering streams whose courses were often concealed by rank vegetation. The streams ran through frequent deep pools covered by lily pads, and in the spring water stood over practically the entire area of many meadows, while the water table was high, even in summer, because the drainage channels were shallow. This abundance of water produced and excellent crop of forage and hay, and the country was prosperous. Most of the meadow land was patented in the early days". Hughes also stated that meadow erosion control efforts had been ongoing in the area for more than twenty years, suggesting that meadows had already down-cut by early in the 20th century.

Federal Government Land Office (GLO) survey maps for the upper Last Chance and Red Clover meadows date to the 1870s and can be found at the Plumas County Planning Department. These maps note substantial "swamp and overflow lands" along the mainstems of these creeks and also provide stream channel widths ranging from approximately 20 feet to 50 feet, considerably less than the current width of the current stream channel incisions (which can be as high as 150 feet).

Most researchers (e.g. Kinney, 1996, McKelvey and Johnson, 1992) attribute degradation of meadow conditions in the late 19th and early twentieth century to overgrazing, mostly by sheep, but also cattle. On the Plumas NF, grazing to produce dairy products for mining communities was the earliest concentrated use of meadows. An extreme 1860s drought in the Central Valley led to heavy use of range in the Sierra Nevada. Sudworth (1900) reported that sheep use on the forests of the Sierra numbered in the millions, though this use proved unsustainable and had dropped to 200,000 by 1900 (Vankat, 1970). The intensity of grazing removed forage and ground cover, and resulted in significant soil erosion and incision of meadow channels. Modern-day grazing practices have significantly improved protection of stream channels and riparian areas in the Last Chance and Red Clover watersheds. Early logging and associated road and railroad construction also impacted erosion rates and flow regimes and undoubtedly negatively impacted meadow condition in the watershed.

Meadow Hydrology

Upland meadows are located where alluvial material has been deposited in bedrock basins. All surface and ground water flowing into the meadow will eventually flow out of the meadow – except for water consumed by evapotranspiration (ET).

In a natural meadow, for any given time span (month, year, decade), the volume of water transferred is:

$$V_{out} = V_{in} - V_{et} + V_{SW} + V_{GW}$$

where V_{out} is outflow (downstream), V_{in} is inflow (upstream), and V_{et} is water used by evapotranspiration. V_{SW} is surface water stored temporarily in the floodplain. V_{GW}, is ground water stored temporarily in the floodplain aquifer (underground). Storage volumes are negative (-) when the water is stored and positive (+) when water is released from storage.

Ground water is stored in the floodplain aquifer in three ways:

a) Most water enters the aquifer through downward seepage when the floodplain is inundated by flood events.
b) A smaller volume enters by horizontal seepage through the channel banks.
c) Ground water discharge to aquifer soils from the underlying bedrock.

The amount of ground water stored in a meadow in any year depends on how much the ground water table has receded ("dropped") since the preceding year, the aerial extent of the aquifer, and the effective porosity (specific yield). The amount of water drained every year in order to make room for next year's stored water depends on the aquifer's hydraulic conductivity (which depends upon grain size).

For similar aquifer dimensions and similar ranges between minimum and maximum ground water levels, annual baseflow volumes are larger from coarse grained than fine-grained aquifer materials. Movement of water from the floodplain aquifer to a channel can take days in gravel, weeks to years in sand and silt, and decades in clay (Whiting and Pomeranets, 1997).

In a degraded meadow, a natural stream channel with a depth of 1 to 3 feet may be eroded to a depth of more than 10 ft (see Figure 1B). As a result:

1. The flood storage volume V_{SW} decreases and most floods are contained in the enlarged channel. This leads to increased flood peaks, especially for higher frequency events.
2. The floodplain aquifer is drained by the deeper channel. The ground water table drops and the roots of most riparian vegetation lose contact with a ground water source. Most riparian vegetation dies and is replaced by dryland vegetation. As a result, evapotranspiration (ET) decreases.

The objective of plug-and-pond improvement projects is to re-establish the original hydrologic function of a meadow by raising the stream channel to its original elevation on the meadow surface and routing flow into a newly constructed channel or existing, stable remnant channels (see Figure 1C).

However, before the floodplain aquifer's seasonal storage and release function is reestablished, the floodplain aquifer needs to be filled by surface water up to the raised channel elevation. This is the restored volume $V_{RESTORED}$ (the green area in Figure 1C). This may take several years, or even decades. As a result (and important to the flow discussion in this briefing), trends observed in flow measurements during this period may not be representative of the long-term, equilibrated condition. During this "filling period", outflow can be significantly less than inflow:

$$V_{out} = V_{in} - V_{et} - V_{RESTORED}$$

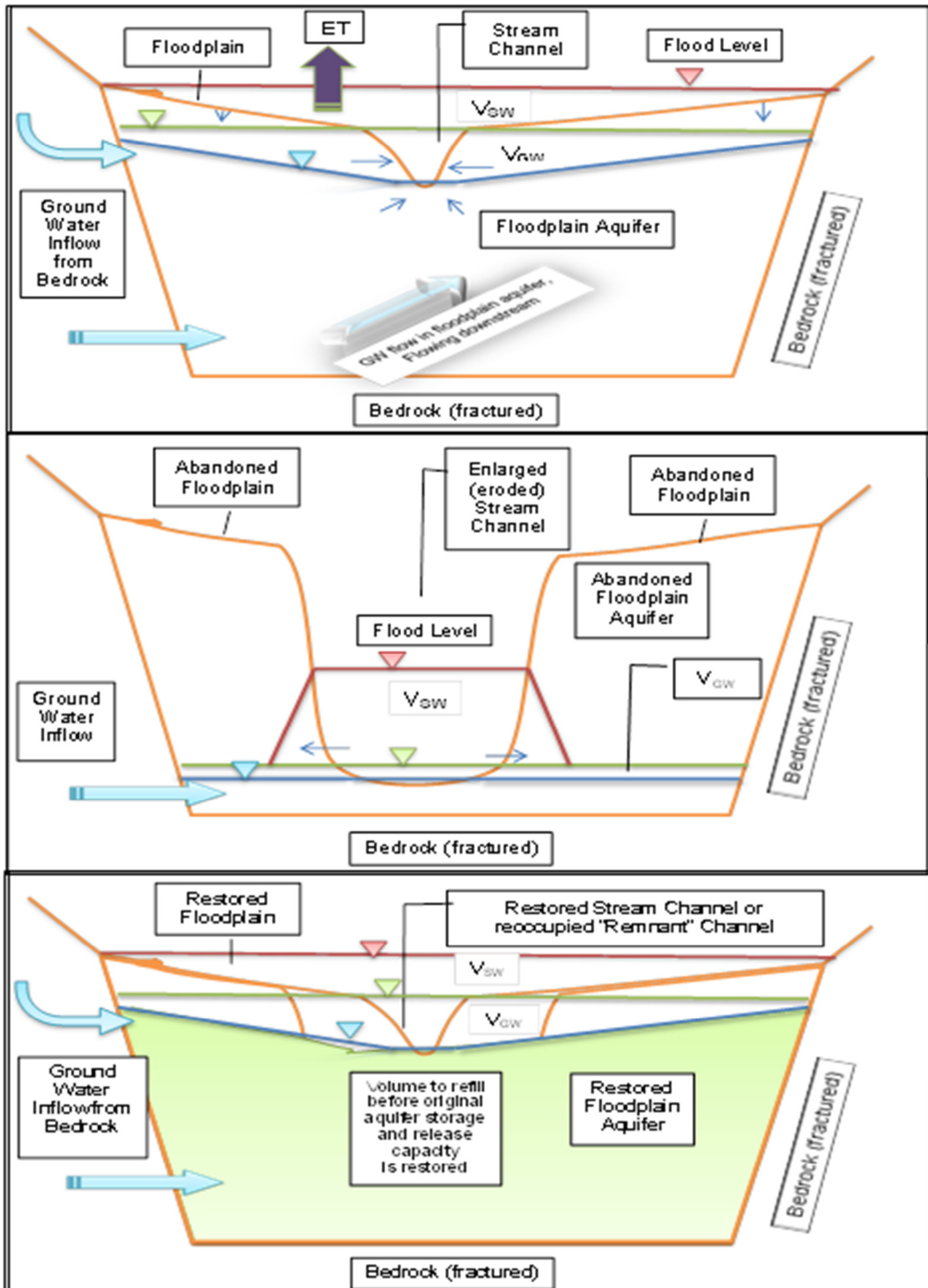

Figure 1A: Meadow hydrology under natural conditions.

Figure 1B: Meadow hydrology under degraded (eroded) channel conditions.

Figure 1C: Meadow hydrology with restored water table and floodplain.

Figure 1: Meadow hydrology under natural, eroded, and restored condition**.** Shown are valley cross-sections, looking downstream with flow moving into the page. **1A**: orange lines indicate the boundary of meadow soil (alluvium). Seasonal water levels are indicted by triangles: red, the highest seasonal flood level (typically occurs in winter); green, the groundwater table after the flood has receded and the channel is full (spring); blue, the ground water table after the floodplain aquifer has drained (typical of late fall). The amount of ground water that is annually stored and released from the floodplain aquifer is between the green and blue lines. **1B**: the stream channel has been widened and deepened by erosion. Floods are confined entirely in the channel and the floodplain is abandoned. The floodplain aquifer is not recharged by vertical infiltration (as in 1A) but by horizontal seepage from the channel. **1C**: before the original water storage and release capacity of 1A is re-established, the aquifer volume that was formerly drained by the deepened channel (the green area), needs to be saturated again. This can take years or even decades.

Once the formerly drained floodplain aquifer volume is "filled", the magnitude of ground water storage and release depends on the restored channel's range of seasonal water level fluctuations. The wider the range of seasonally high and low ground water level and the larger the specific yield of the floodplain aquifer materials (more coarse grained), the more the aquifer can contribute to baseflow later in the year. The mass balance equation applies to a restored meadow, as much as it applies to a natural system:

$$V_{out} = V_{in} - V_{et} + V_{SW} + V_{GW}$$

On an annual basis the volume of ground water stored is eventually released (flood water stored on the floodplain drains within a few hours). In other words, whatever surface and ground water flows in, flows out and both terms V_{SW} and V_{GW} become zero. Both on the scale of a particular meadow and on the scale of a watershed, the only water consumption is ET (unless there is a diversion).

Therefore the entire annual mass balance boils down to one simple equation:

$$V_{outflow} = V_{inflow} - V_{ET}$$

Interaction with the underlying bedrock aquifer

It is a common observation that stream flow in upland watersheds increases with distance from the source. This is because bedrock aquifers are recharged at higher elevations and discharge into streams at lower elevations (Freeze and Witherspoon, 1967). Most ground water flow in bedrock is concentrated in fracture zones associated with geologic faults. Therefore, stream flow probably only increases measurably in discrete zones, wherever a stream or meadow intersects a fault. In stream reaches with significant interaction with the underlying bedrock aquifer, the water balance equation for a natural or restored meadow is:

$$V_{out} = V_{in} - V_{et} + V_{GW\text{-}bedrock}$$

Again, on an annual basis:

1) When in a certain stream reach ground water flows from bedrock into the meadow aquifer, the last term in the equation is positive ("+"), and outflow is greater than inflow (resulting in a "gaining" stream).
2) When in a stream reach the bedrock ground water level is lower than in the floodplain aquifer, then ground water is "lost" into the fractured bedrock aquifer. The last term in the equation is negative ("-") and outflow is less than inflow (resulting in a "losing" stream).

Any water discharged from the stream into the underlying bedrock aquifer will remain in the larger surface-and-groundwater flow system – and is therefore not "lost" from the watershed. It will eventually resurface at some point further downstream since stream channels are the ultimate sink for shallow ground water. This demonstrates that the terms 'surface water' compared to 'ground water' have little meaning in this context (Winter et al., 1998). In the upper Feather River basin, most baseflow is derived from ground water.

Within the upper Feather River basin, the Big Flat meadow on Cottonwood Creek is an example where the downstream meadow aquifer receives flow from underlying bedrock. On the other hand, Red Clover Creek at the McReynolds project is probably an example of a losing stream where channel flow is lost due to seepage into fractured bedrock at some point in the lower reach.

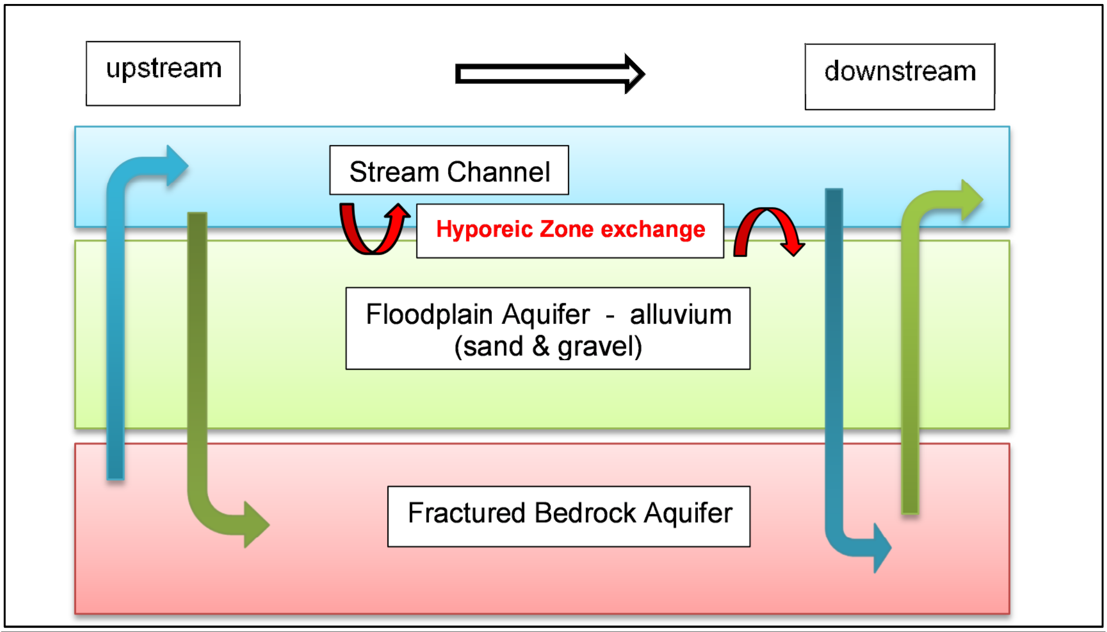

Figure 1D: The interaction between stream, floodplain aquifer, and bedrock. Gaining and losing stream reaches are affected by flow from channel to bedrock and vice versa. A losing stream reach is indicated by the large blue arrows: this occurs when the upstream channel area receives water from underlying bedrock and/or the downstream channel area drains water into underlying bedrock. Gaining stream reaches (large green arrows) can occur when those flow directions from channel to bedrock are reversed.

Implications for stream restoration

Determination of the impacts of meadow restoration projects on streamflow requires more than just comparing upstream and downstream streamflow data. It needs to include ground water flow and ET, and a careful analysis of how the geologic setting affects both local and regional ground water flow.

Description of Existing Surface Flow Monitoring Data: Upper Feather River

The list below provides brief descriptions of different stream flow monitoring efforts that have occurred relative to meadow improvement projects in the upper Feather River watershed. An excellent summary of the data for Red Clover and Last Chance Creeks, as well as files of stream flow data for other sites in the watershed, are posted on the Feather River CRM website: http://www.feather-river-crm.org/index.php?option=com_content&view=article&id=66&Itemid=66

When looking at these monitoring data, it is important to consider the accuracy of the measurements. Regardless of the level of care taken while making measurements (which is itself a variable), each measurement has some error associated with it, and is likely some percentage different from the actual stream flow. This is particularly true for indirect measurements. For example, a current meter is used to measure velocity in several locations across a stream. Each of those points of velocity is assumed to represent the average velocity for that section of stream, and the total flow is calculated by summing the flows from all sections. Each of the measurements (the velocities and widths and depths of sections) has some measurement error. Data from the Red Clover project and during “seepage run” monitoring discussed in this briefing were collected in this way.

For continuous recording stream gages, an indirect method is used whereby stage (stream surface elevation) is recorded continuously, and that stage is converted to a flow rate by using a chart of measured stage/flow relationships for that stream site. Data from the Notson Bridge and Doyle Crossing sites reported in this briefing were collected in this way.

In general, stream flow practitioners assume that the level of accuracy associated with such methods is plus or minus 10 to 15 percent. Various factors contribute to this range of accuracy, including the accuracy of the assumption for converting point velocities to average velocities, accuracy of the velocity meter, precision of stream area measurements, the quality of the site’s stage/discharge relationship, and the inherent dynamics and velocity variations associated with flowing water. This amount of error may be even higher (i.e. greater than 15%) for measurements taken during the late season, due to difficulty in achieving precise measures of low flow velocities (which are often less than 0.05 feet/sec on these streams). This means that when comparing differences in flow, changes need to be on the order of 30% or more (assuming an error of 15% in each of the compared measurements) to be greater than the measurement error.

- Continuously recorded, year-round streamflow measurement data several miles below meadow improvement sites have been collected at one station on Red Clover Creek (Notson Bridge) and one station on Last Chance Creek (Doyle Crossing). These data records start in 2000 and measurements continue to present time. The Notson Bridge station is located approximately 6 miles downstream of 7 miles of pond-and-plug treatments (constructed between 2006 and 2010). The Doyle Crossing station is located approximately 8 miles downstream of 9 miles of pond-and-plug treatments (constructed between 2003 and 2007) (see Figures 8 and 9).
- From 1998 through present, continuous recorded streamflow measurements have been made at two stations located above and below the Big Flat pond-and-plug project on Cottonwood Creek, a tributary to Last Chance Creek (Figure 8).
- Flow measurements were made above and below the “McReynolds” project on Red Clover Creek for one season before pond-and-plug construction (2005) and several seasons after construction (2007-2011). In 2005 (pre-project), measurements were made on one single day in each of 4 calendar months of the spring and summer season (June to September). A similar number of measurements were made in 2007, 2010, and 2011 with more extensive monitoring done in 2008 and 2009 (a total of 15-20 days monitored for each of those two seasons).
- “Seepage Run” flow data were collected from Red Clover Creek to assess the results of pond-and-plug projects, with two monitoring events in 2011 and five monitoring events in 2012. These events involved single-day measurements of flow above and below five stream reaches between 0.4 to 0.9 miles long (see Figure 5). Two of the seepage run reaches were located on pond-and-plug projects and the remaining three were located upstream of any pond-and-plug treatment. Measurements were made at the top and

bottom of each of the 5 reaches to determine whether surface flow was gained or lost through the reach at that time of day. Observed streamflow gain or loss can be compared between restored and un-restored reaches and between different months of the flow season.

- Seepage run data similar to that described above was collected from Last Chance Creek in September 2012.

Volume and Timing of Flow: Field Evidence and Modeling Results:

No quantitative analysis of total flow volume (ground water and surface water) resulting from restoration work on Feather River meadows has been made to date, due to lack of funding and the difficulty of accurately quantifying changes in these complex hydro-geologic systems. Instead, qualitative analysis is based on comparing results from studies in watersheds outside the upper Feather River basin with changes observed at local meadow restoration projects. One outside study (Hammersmark et al., 2008) found that, due to increased evaporation and transpiration (ET), total annual outflow from a meadow system was reduced by about 1-2% of pre-project annual flow.

Although total annual volume of flow was found to be diminished slightly, restored meadow structure has been found to significantly alter the timing and distribution of flow. These changes are illustrated in Figures 2 through 4. Several changes are noteworthy. The volume of water released during the post-restoration winter and early spring months is reduced. During this period, functioning meadows store more water than degraded meadows. Cross-sectional areas in degraded channels are larger, thereby accommodating larger flows. Natural (non-degraded) channels are smaller and flood flows are spread and stored (at least temporarily) on the floodplain. Part of this flood flow infiltrates into the meadow aquifer and most of this water is slowly discharged into the channel over the following months. This effect is illustrated by the May-July post-restoration flow increases in Trout Creek (Figures 2 and 3). A similar pattern was predicted by modeling conducted by UC-Davis during the Phase I Last Chance project (Figure 4) (Kavvas 2005).

Late Spring-Early Summer Flows

Results from the Trout Creek study show an increase in spring and early summer surface flows. Data for this study were collected from flow gages located both upstream and downstream of the project. A similar response was found at Big Flat on Cottonwood Creek, a tributary to Last Chance Creek, and a Feather River CRM project. Cawley's analysis (2011) of Big Flat's similarly paired, upstream and downstream gages found a statistically significant increase of June and July flows following implementation of the pond-and-plug project there.

Additionally, 2011 and 2012 seepage run measurements, taken just after the snowmelt recession period had ended in late spring, demonstrate that the restored reach on Red Clover-McReynolds had a substantially higher rate of streamflow gain per mile (as much as 8 times higher) than the unrestored reaches (the measured change in 2011 was greater than the assumed 10-15% level of accuracy for flow measurement; the measured change in May 2012 was just 5.7%). See seepage run measurement locations in Figure 5 and a summary of seepage run data in Appendix A.

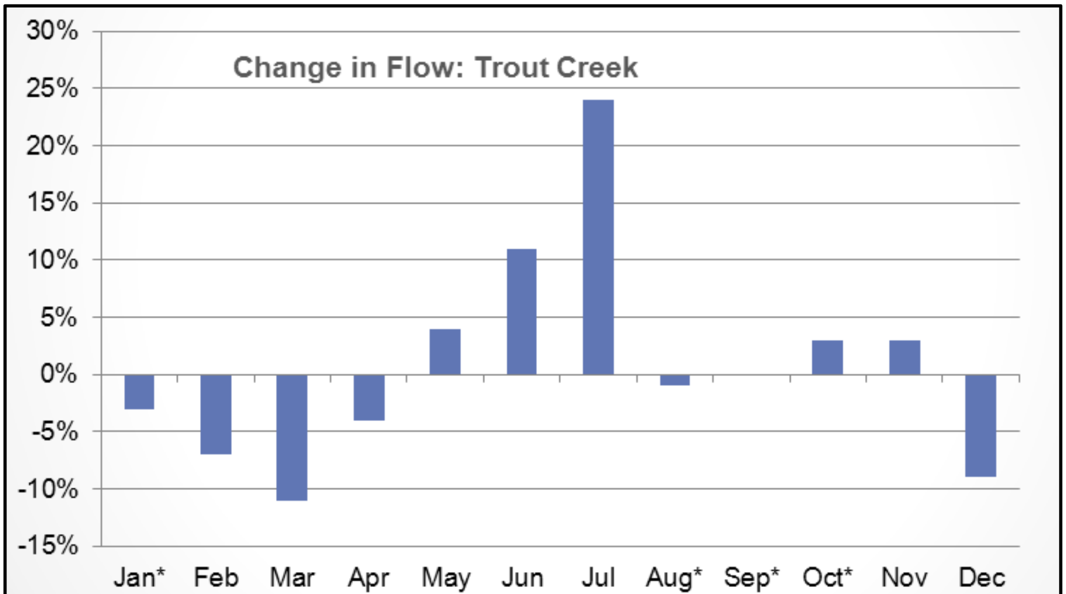

Figure 2- Monthly changes in flow from Trout Creek (from Tague, et al). Asterisks are added for January, August, September, and October because the observed changes between pre- and post-project flows were not statistically different.

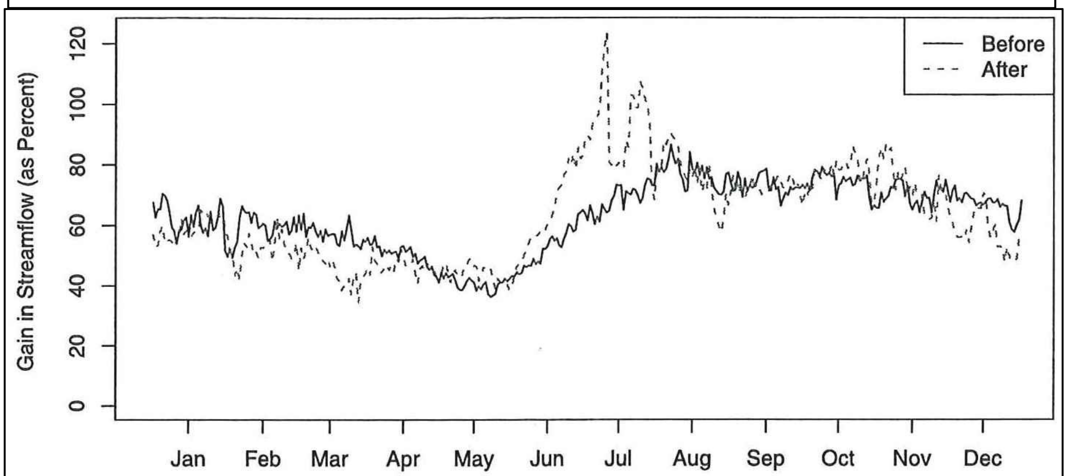

Figure 3- Pre and post- project annual hydrograph from Trout Creek (Tague, et al)

While the amount of data is limited, Feather River meadow improvement projects appear to modify annual hydrographs in a manner similar to that shown for Trout Creek in Figure 3. That is, wet season flow (and floods) are reduced, and surface flow during the late wet season and snow-melt recession period are increased. Located in the Lake Tahoe Basin, Trout Creek receives considerably more snow than the Feather River Basin and the higher elevation of this watershed causes a later snowmelt period. Therefore, it is likely that increases in spring flows following meadow restoration are larger and delivered later for Trout Creek than for the Feather River Basin.

Late Summer Flows

In this briefing, late season stream flow is termed either “baseflow” or “late season flow.” Baseflow is a term used in hydrology to describe stream flows that exist in a channel after tributary stream flows due to snowmelt have ceased. Thus, baseflow is the level of stream flow that exists due to a stream channel's interaction (either positive or negative) with groundwater sources. This section of the briefing discusses late summer and early fall stream flows that typically could be termed "baseflow" because, in the upper Feather River Basin, ephemeral and intermittent streams that flow in response to snowmelt and spring runoff have usually stopped flowing by late summer. However, in some years (such as 2011), snowpack may persist in areas of the upper watershed throughout the summer. Therefore, the more generic "late season flow" term is commonly used in this briefing because effects of meadow improvement projects on late summer flows are of interest regardless of whether those flows fit the criteria for "baseflow."

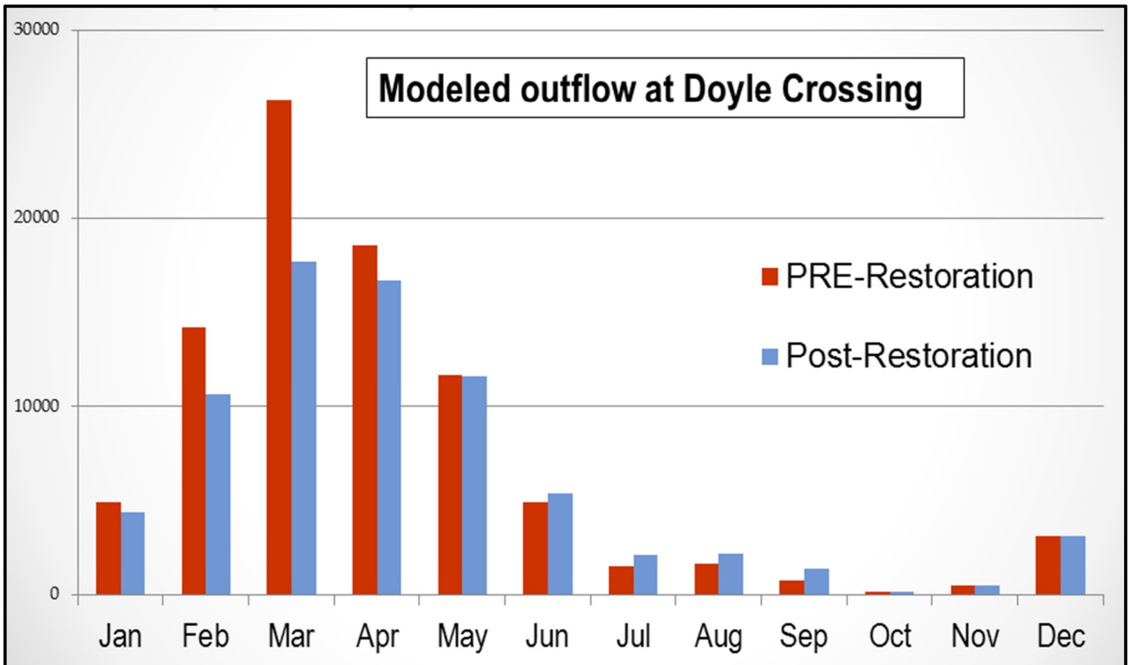

Figure 4- 2005 Model Results from Kavvas (UC-Davis) WEHY Model. The model compared expected flow at Doyle Crossing for the same water year (1983) for two scenarios: 1) with restoration of the water table in all meadows above Doyle Crossing and 2) without meadow restoration. Note the 1983 water year is one of the highest on record for Plumas County. Model results for total annual flow predict 14% less total flow for the post- restoration condition, when compared with the pre-restoration condition. However, this result is just for the first year after restoration, when the effect of filling of meadow soils would be highest. Subsequent years were not modeled.

This late season aspect of flow response to meadow improvement projects in the upper Feather River Basin has garnered the most attention, due to interest from downstream water users. Even a small change in surface water available to downstream irrigators (e.g. 0.1 cfs) is very important and valuable during the late irrigation season. Irrigators in the Upper Feather River Basin have likely faced increasing late season challenges in recent years. A recent PG&E study (Freeman 2010) found an average annual decrease in flow on the East Branch North Fork Feather River of 23% (179,000 acre-feet) for the period of 1976-2009 when compared with the 1950-1975 period, with climatic changes and decreased snowpack cited as the causes for this decrease. Unfortunately, with respect to land management actions, late season base flows are the most difficult hydrologic change to assess, due to their low magnitude, annual variations in precipitation, variation in ET, and the uncertain nature of meadow-groundwater interactions.

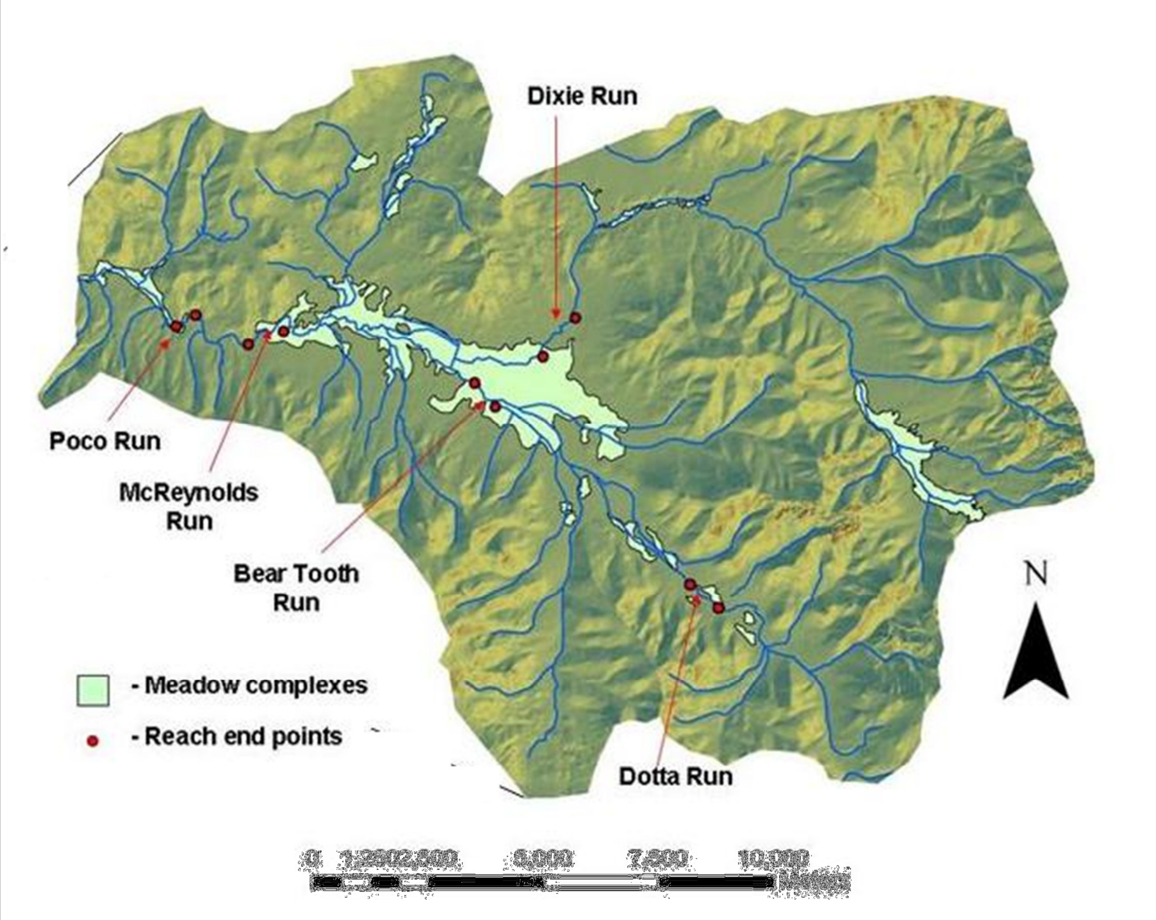

Figure 5- 2011 and 2012 Seepage Run flow measurement reaches on Red Clover and Dixie Creeks.

A further complication for assessing the impact of meadow restoration projects in terms of effects to late season stream flow exists because re-establishment of the water table triggers an adjustment of the interaction between ground and surface water along the restored reach. It may take years, or even decades, after restoration for subsurface flow paths to become fully functional. Heede (1975) indicated that a likely equilibrium was achieved for one project 7 years after restoration. Therefore, monitoring results from the first few years after restoration probably do not accurately depict the long-term flow regime. In the longer term, additional delivery of water downstream through subsurface paths would be expected, although the size of this additional delivery may be small. Also, whether or not additional delivery would ever occur for a particular site is unknown. An ongoing study (scheduled for completion in summer 2013) administered by the Forest Service's Pacific Southwest Regional Office will provide more information on expected long-term effects of meadow improvements.

Modeling at the restored meadow at Bear Creek (Hammersmark 2008) predicted a slight reduction in the duration of baseflow within the site of the pond and plug project, due primarily to estimated maximum ET increases of 3.6 mm (0.15 inches) per day. On the other hand, Hammersmark reported an increase of baseflow downstream of the restoration project, due to increased meadow groundwater storage being delivered via flow paths beneath the restored reach.

The vegetative changes responsible for increased ET within the project area are beneficial for on-site riparian grazing, wildlife habitat, and stability of meadow soils. Evaporation from pond surfaces is somewhat higher than transpiration. Using the averages from the closest sites with long-term evaporation data (Vinton and Tahoe City), a rough estimate of 0.25 inches/day for pond evaporation (June through August) can be applied to the upper Feather River area.

Monitoring results (Figure 6, Table 2) for Red Clover Creek generally indicate responses similar to those predicted at Bear Creek. The four flow measurements taken on Red Clover Creek at the bottom of the McReynolds project throughout summer 2005 (pre-project) all exceeded 1.0 cfs. Streamflow at this same location after project construction was zero or less than 0.1 cfs for periods of a month or more in the summers of 2007, 2008, 2009, and 2010. 2007 – 2009 were dry years. 2010 had near-normal annual precipitation, but below average snowpack. The pre-project 2005 data for the McReynolds project indicates a loss of surface flow through the reach during summer months but the post-project rate of loss in streamflow per mile appears to be roughly double (or more) the pre-project rate.

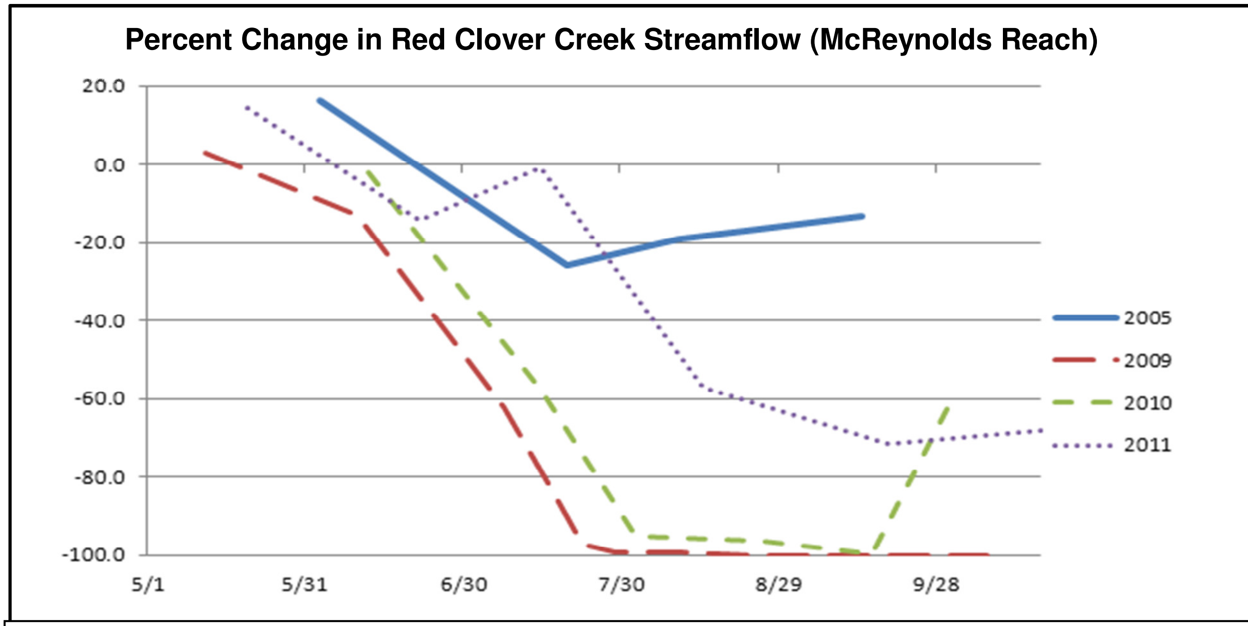

Figure 6- Percent change in streamflow occurring between top and bottom of McReynolds project. 2005 is pre-project. For the post-project period (2009 – 2011), rates of surface flow loss are substantially higher. 2005 and 2010 had near-normal annual precipitation. 2009 was below normal. 2011 was above normal.

This result is mimicked by the rates of loss observed along the McReynolds seepage run reaches of 2011 and 2012 (Appendix A). Likely causes for these apparent decreases are enhanced ET within the treated reaches, conversion of surface water flow to much slower ground water flow, and widespread beaver activity, which further spreads surface flow across the meadow. One concern for the low-flow season seepage run data is measurement error. Flow velocities measured in the field are often below the velocity meter manufacturer’s stated precision (measured velocities are often less than 0.07 feet/sec). Also, it is difficult to find measurement points with solid channel bottoms at some of the sample locations.

The value of these comparisons is further limited because they are based on data from just one pre-project year, and a few post-project years, when the restored system has probably not reached a steady state. Therefore the effect of wet and dry years and other factors on flows cannot be assessed.

It should be noted that, due to differences in watershed characteristics and geology between different meadow sites and differences in project designs, flow responses will not be the same for all meadow improvement projects. It should not be assumed that effects observed at one project site will occur or have occurred at another site.

Month	2005	2007	2008	2009	2010	2011
June (3rd)	2.5	-1.2	-1.2	-0.9	-0.3	-0.3
July (20th)	-0.4	-1.1	-1.6	-1.8	-1.8	-0.1
August (10th)	-0.3	-1.1	-1.4	-1.5	-1	-1.5
September (14th)	-0.2	-0.01	-1.5	-1.3	-2.8	-2.8

Table 2- Approximate changes in flow (cfs) above and below the McReynolds meadow improvement project. 2005 is pre-project, 2007-2011 are post project. All data are from single dates, with post-project measurements from the date closest to the pre-project measurement date.

Late season flow changes within project reaches for Last Chance Phase I have not been detected because pre-project flow measurements were not collected within and near the treated reaches. Seepage run data for Last Chance Creek was collected once during September 2012. Results indicate reduction of surface flow in reaches in the upper meadows (from Little Stoney Creek to Doyle Crossing and from Doyle Crossing to Murdock Crossing) and gaining reaches further downstream (from Murdock Crossing to Squaw Queen Creek and in the upper portion of Last Chance Creek canyon) (Figure 7). None of the tributary streams along this stretch of Last Chance Creek had flowing surface water on that date, except for a small amount of flow (< 0.04 cfs) in Squaw Queen Creek at its confluence with Last Chance Creek. All of these measurements were taken downstream of the 9 miles of pond-and-plug restoration constructed between 2003 and 2007 (restoration project reach locations are shown in Figure 8). These data demonstrate the concept that late season surface flows are strongly influenced by subsurface soil conditions and geology.

Downstream Changes in Late Season Flows

The following discussion includes analysis of flow data collected from above and below the McReynolds meadow improvement project in Red Clover Valley, at Notson Bridge on Red Clover Creek, at Doyle Crossing on Last Chance Creek, and at Flournoy Bridge on Indian Creek. The locations of these sites are depicted in Figures 8 and 9.

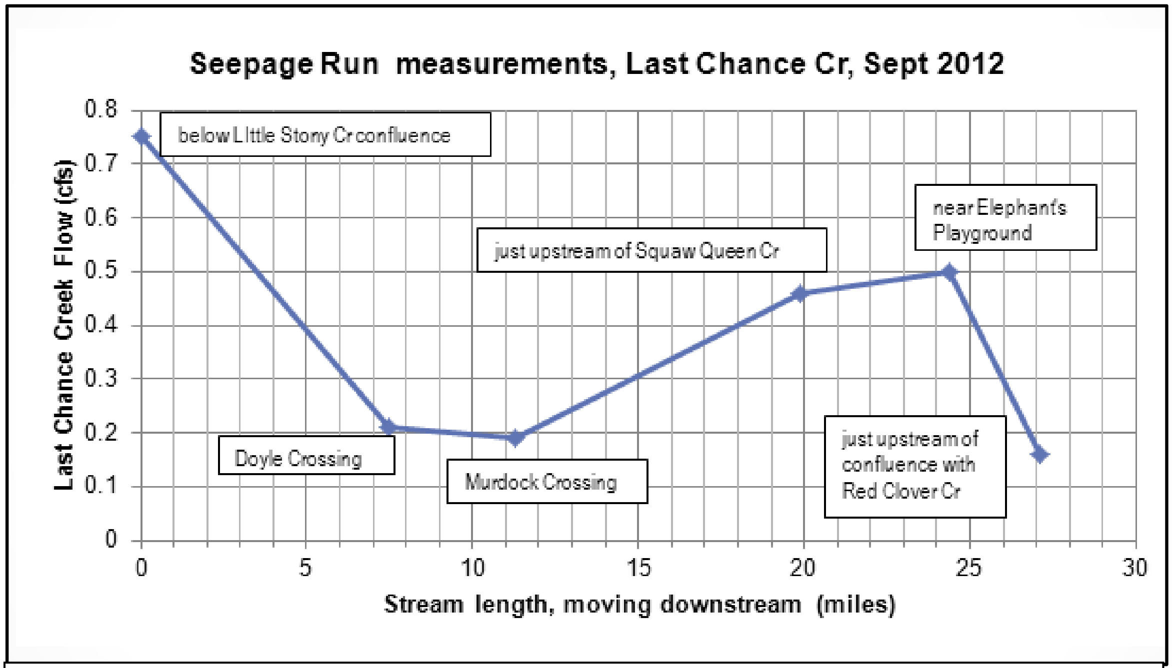

Figure 7 – Seepage run stream flow measurement taken on Last Chance Creek on September 13, 2012. Surface flow decreased through the upper meadow reaches but increased as Last Chance Creek flowed into the canyon reach above Genesee Valley.

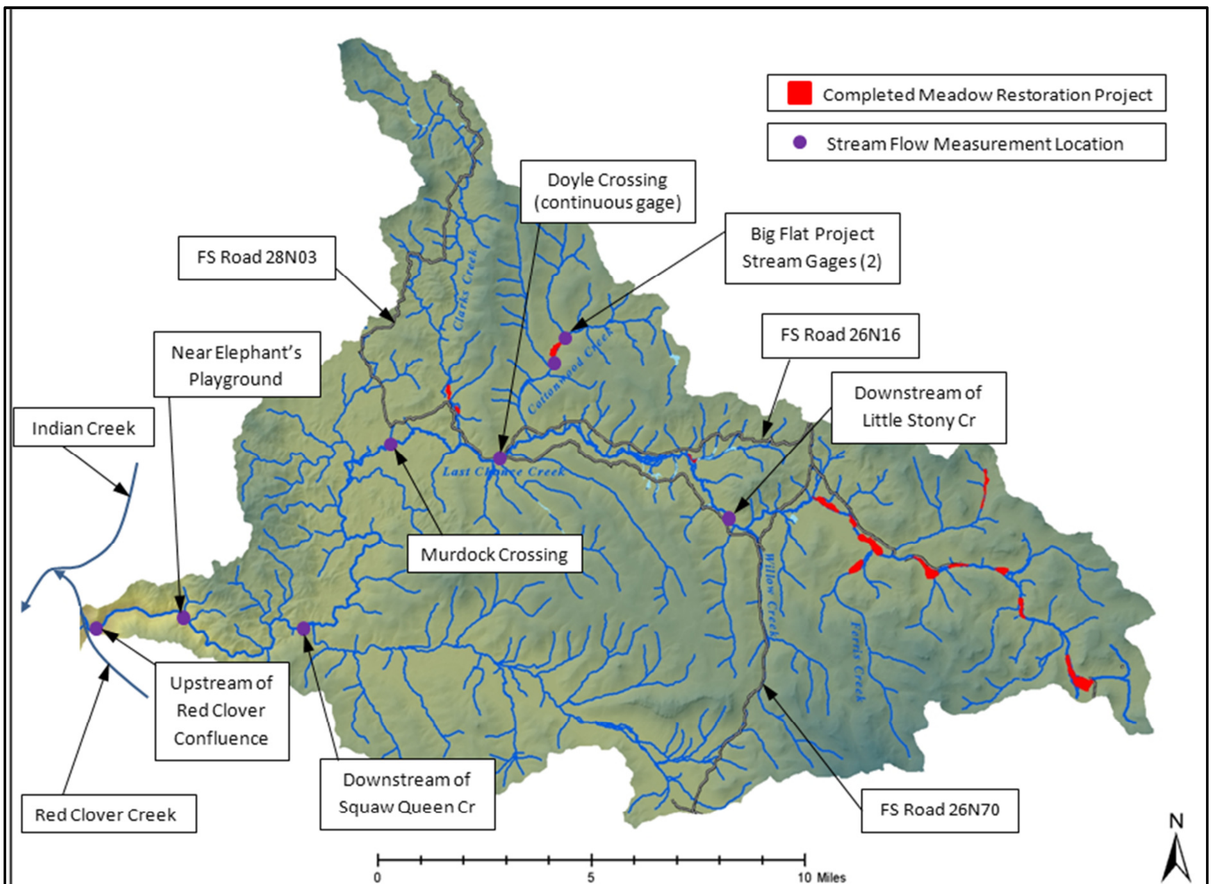

Figure 8 - Stream flow measurement locations in the Last Chance Creek watershed.

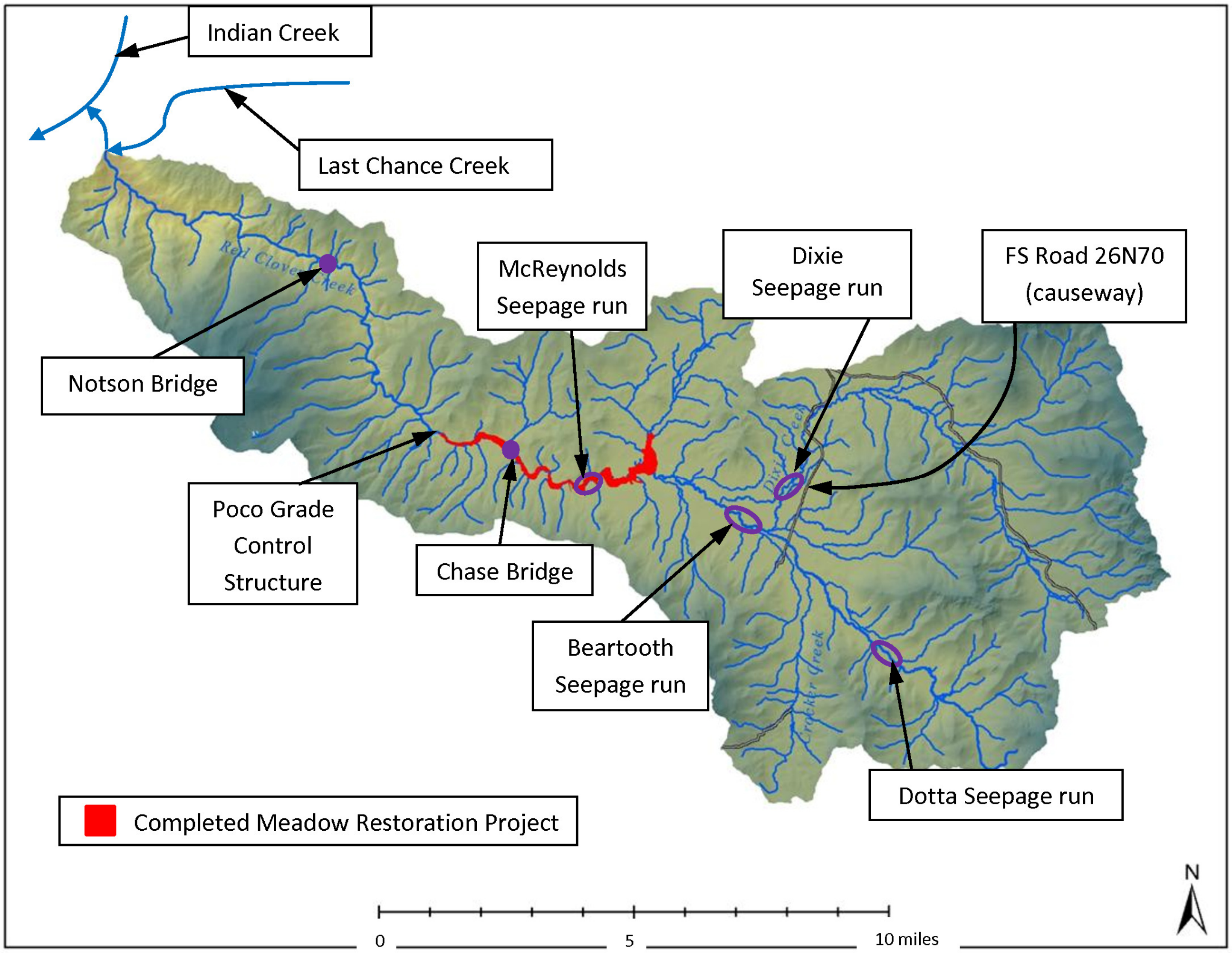

Figure 9 - Stream flow measurement and Seepage Run locations in the Red Clover Creek watershed

A statistical analysis (Cawley 2011) of 11 years of continuous streamflow data on Last Chance and Red Clover Creeks found no differences between pre- and post-project late season flows (neither an increase or decrease in flow). The analysis found that variation in normalized flow data from year to year appears to be more associated with precipitation and snowmelt patterns dominant in any given year than the extent of stream restoration accomplishments in the watershed. The Last Chance Creek gage at Doyle Crossing is located 8 miles downstream of large-scale pond-and-plug restoration, and the Notson Bridge gage is located 6 miles downstream of pond-and-plug restoration in Red Clover Valley. The nearest downstream irrigator diverts from Red Clover Creek near its confluence with Indian Creek, 5 miles downstream of Notson Bridge. No irrigation diversions from Last Chance Creek currently occur downstream of Doyle Crossing; the nearest diversion for water which flows in Last Chance Creek is from Indian Creek, near its confluence with Red Clover and Last Chance Creeks, 20 miles downstream of Doyle Crossing.

Cawley's findings are consistent with data from Trout Creek, which showed no significant difference in base flows at a gauge located about 1000 meters (0.6 mile) downstream of the meadow improvement project. Further analysis of this data by others (Aylward and Merrill, 2012) suggested that late season flows may have increased during dry years, and decreased slightly in wet years following project implementation. As discussed above, the Bear Creek modeling study predicted a reduction in the duration of late season flow, but the authors also postulated that some increased meadow groundwater storage would be delivered downstream of projects by flow paths beneath the meadow channel.

When differences in flow above and below the McReynolds project are compared with mean daily flows at Notson Bridge from the same day, it appears that the volume of water added from Red Clover tributaries between the project areas and Notson Bridge is low. As stated above, both the pre-project (2005) and post-project flow measurements demonstrate that the McReynolds reach of Red Clover Creek is a reach that loses surface flow. Similar post-project data and seepage run data indicate post-project reduction of flow rates are double (or more) the pre-project rate.

These reductions in flow were compared with flows recorded on the same date downstream at Notson Bridge. For example, for July 20 2005, a 0.36 cfs reduction in flow was measured between the top and bottom of the McReynolds reach. On that same date, stream flow at Notson Bridge measured 5.3 cfs. Table 3 expresses the reduction in flow through the McReynolds reach as a percentage of the flow at Notson. For the July 20 2005 example, the reduction of 0.36 cfs is 6.8% of the flow that existed at Notson Bridge (5.3 cfs). In Table 3, the flow decreases through the McReynolds reach during late season months range from 4.3% to 6.8% pre-project (2005), and from 1.1% to 57.6% for post-project seasons (2010 and 2011).

A number of cautions should be observed when analyzing the data in Table 3. For simplicity sake, the data shown compare flow from the same date. In reality, it can take several days for flow to reach Notson Bridge from the McReynolds reach; seepage run data indicate that both Red Clover Creek and Last Chance Creek flow quite slowly during the late season (< 0.1 ft/s). Additionally, the 2010 and 2011 upstream data were taken from a different measurement station than the 2005 data. The station was moved approximately 1/3 of a mile upstream of the 2005 station because beaver activity had made the 2005 station untenable for measuring surface flow.

Also, the Table 3 analysis is limited by the scarcity of pre-project data (based on just 4 measurements in 2005). The 2011 Cawley analysis includes six years of pre-project data and better represents natural variability of flows. And again, it may take years (or decades) for sub-surface flow paths to become fully functional in improved meadow systems. For this reason, post-project data from the 2007-2009 seasons are not presented in Table 3 because it is likely that surface flow through the project during those first three years after construction was affected by “re-filling” of the meadow aquifers (see Figures 1B and 1C). It is certainly possible that this effect persisted through the 2010 and 2011 seasons, so those data may not represent the long-term, equilibrated condition that will occur after area aquifers have filled to a steady state.

Regardless of whether or not pond-and-plug improvements have been constructed, surface flow from upper headwater meadows is reduced substantially by evaporation as it flows to Indian Creek. Seepage run measurements in 2011 and 2012 indicate that both Last Chance and Red Clover Creeks flow quite slowly during the late season (< 0.1 ft/s or less than 1.6 miles per day).

Given that Doyle Crossing is located approximately 20 miles upstream of Genesee Valley, flow from Doyle Crossing would likely require more than 10 days to reach Indian Creek. Using an evaporation rate of 0.25 inch per day and a rough assumption for channel width of 8 to 12 feet, evaporation loss for 20 miles is about 0.5 acre-feet for the 10 days (or about 0.25 cfs of the flow that exists at Doyle Crossing). Relative evaporative losses for Red Clover Creek flow from its upper meadows would be less because the meadows are located closer to Genesee Valley, but those reductions are still a considerable portion of surface flow present in the upper meadows.

The Trout Creek study (gage located about 0.5 miles downstream of the meadow project) detected no significant change in late season stream flows (illustrated in Figure 2). Differences in project design may contribute to late season flow trends. The Trout Creek project included a new channel, sized to bankfull dimensions to carry flow through the meadow. Meadows in the Red Clover-McReynolds project are drained by shallower, braided channels. It is likely this channel system is more inefficient in passing flow through the meadow than a larger and deeper channel such as that constructed at Trout Creek.

The next logical question regards percentage change to flows in Indian Creek in Genesee Valley, located about 7 miles downstream of Notson Bridge. In addition to evaporative loss, and accretion of flows from groundwater sources and inputs from tributaries originating on Mount Ingalls, flow at this point is supplemented by the Upper Indian Creek and Last Chance Creek watersheds. As might be expected, flow at Flournoy Bridge is substantially greater than at Notson Bridge, and any reduction in surface flow in Red Clover Valley, when expressed as a percentage of the Flournoy flow rate, is correspondingly less.

Date	Flow at top of McReynolds reach (cfs)	Flow at bottom of McReynolds reach (cfs)	Change in flow through McReynolds reach (cfs)	Flow at Notson Bridge (cfs)	Change in McReynolds flow, as percentage of Notson Flow	Flow at Flournoy (Indian Creek) (cfs)	Change in McReynolds flow, as percentage of Flournoy flow
6/3/2005	15.3	17.8	2.5	45.4	5.4%	179.2	1.4%
7/20/2005	1.4	1.0	-0.4	5.3	-6.8%	28.3	-1.3%
8/10/2005	1.4	1.1	-0.3	3.6	-7.5%	24.9	-1.1%
9/14/2005	1.8	1.6	-0.2	5.6	-4.3%	24.4	-1.0%
6/12/2010	16.5	16.1	-0.3	28.1	-1.1%	148.2	-0.2%
7/15/2010	3.2	1.4	-1.8	3.6	-51.1%	46.5	-4.0%
8/15/2011	2.5	1.1	-1.4	4.5	-32.2%	21.8	-6.7%
9/19/2011	2.3	0.7	-1.7	2.9	-57.6%	20.1	-8.3%

Table 3- Measured changes in flow through the McReynolds project, expressed as a percentage of flow that existed that date at downstream gages on Red Clover Creek (Notson Bridge) and (Indian Creek) Flournoy Bridge.

Additional Reading: Meadow Restoration and Hydrologic Changes

Barry Hill, Regional Hydrologist for the Forest Service Pacific Southwest Region, has prepared an annotated bibliography of publications related to hydrologic effect of meadow restoration in the Sierra Nevada. That literature summary is available at http://www.fs.usda.gov/detailfull/plumas/landmanagement/?cid=stelprdb5363125&width=full.

Summary

Models and studies from the mid- 2000s and earlier indicated that pond-and-plug would slightly reduce overall flow volume and reduce flood flows. Stored flood flow reductions would be released later in the year, resulting in higher flows in the late spring and early summer. Increases in late-spring and early-summer flows have been observed and verified to some extent by monitoring at Trout Creek and Big Flat. The 2005 Kavvas model predicted that the post-project increase in surface flow would also occur throughout the late season on Last Chance Creek.

In retrospect, it appears that it was mistakenly assumed that the increase in spring flows would extend late into the season and increase baseflow at all project sites. Early-term monitoring (within 5 years of project construction) at Red Clover and Long Valley Creek project sites indicate that pond-and-plug projects caused decreases in late season flow within and immediately downstream of treated reaches.

Measurements conducted on site (McReynolds project) indicate loss of surface flow following the project, but statistical analysis of pre- and post-project flows farther downstream did not detect a change. In this analysis (Cawley 2011) of 11 years of continuous streamflow data on Last Chance and Red Clover Creeks, no differences were found between pre- and post-project late season flows (neither an increase or decrease in flow) 8 and 6 miles (respectively) downstream of large-scale pond-and-plug treatments. Given the measurement error associated with flow measurements, the variation in surface flow as influenced by numerous natural factors, the short period of pre-project data, and the recent implementation of the meadow improvement projects, it is not surprising that there is still uncertainty about the magnitude and trend in post-project flow characteristics. Continued flow monitoring, as well as applying alternate methodologies (like environmental tracers) is warranted to gain a clearer understanding of effects. Additionally, an ongoing study (scheduled for completion in summer 2013) administered by the Forest Service's Pacific Southwest Regional Office will provide information on long-term effects of meadow improvements.

Given the assumption that meadow improvement projects would increase summer flows, project designs included features which promoted retention of surface flows (braided versus bankfull channels) in the meadows rather than delivery through them. Future project designs should fully consider the impact of alternative channel designs on stream flow effects.

While stream flow is the focus of this report, we should note that the meadow improvement projects have fully met the primary objective for which they were designed, as the vast majority of projects have substantially reduced the production and delivery of sediment downstream.

Other project benefits include improvements to riparian and meadow habitat and livestock forage.

Finally, relative to flow, it should be noted that post project flow regimes are much closer to the historic condition than that characterized by degraded meadows that are artificially drained by deep, incised channels. This includes hydrologic processes in the meadow such as maintenance of water table elevation and saturation of soils, as well as the nature of flows leaving the meadow, including enhanced attenuation of flood flows, increased flow during spring and early summer snowmelt periods, and potentially less surface flow in the late season.

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Appendix A: Summary of Seepage Run Results

June 28, 2011

Reach	Q (cfs) downstream	delta Q	percent change Q	length of reach (ft)	length of reach (mi)	delta Q per mi	GW elev	AM-PM	GW elev - stream elev
Dotta	2.25	0.65	40.6%	2,820	0.53	1.22	91.68	0.50	7.2
Dixie	5.29	0.45	9.3%	3,475	0.66	0.68	86.73	0.26	0.8
Beartooth	5.77	1.48	34.5%	4,505	0.85	1.73	91.41	-0.43	0.86
McReynolds	10.2	3.48	51.8%	3,298	0.62	5.57	94.58	1.07	1.7
Poco	15.4	1.2	8.5%	2,183	0.41	2.90	94.31	-0.30	

Sept. 7, 2011

Reach	Q (cfs) downstream	delta Q	percent change Q	length of reach (ft)	length of reach (mi)	delta Q per mi	GW elev	AM-PM	GW elev - stream elev
Dotta	0.57	0.1	21.3%	2,820	0.53	0.19	88.2		3.9
Dixie	0.11	0.09	450.0%	3,475	0.66	0.14	86.59		1.0
Beartooth	1.3	0.33	34.0%	4,505	0.85	0.39	90.02		-0.14
McReynolds	0.73	-0.16	-18.0%	3,298	0.62	-0.26	94.99		3.9

Oct 3-4, 2011

Reach	Q (cfs) downstream	delta Q	percent change Q	length of reach (ft)	length of reach (mi)	delta Q per mi	GW elev	AM-PM	GW elev - stream elev
Dixie							85.48		-0.12
Beartooth	1.03	0.15	17.0%	4,505	0.85	0.18	90.81		-0.65
McReynolds	1.48	-0.28	-15.9%				95.25		4.07

Notes:

1. Assumed streamflow (Q) measurement error is 10% to 15%
2. delta Q is the change in flow rate through the reach (downstream Q - upstream Q)
3. "GW elev" is the elevation of the water table, measured at the upstream end of the reach
   GW elevations provided are not tied from reach to reach, but are provided to show the trend in each well through the flow season
4. "GW elev - stream elev" provides the difference between the water table and the stream surface elevations
   A positive difference means the GW table is higher than the stream surface
5. "AM-PM" equals Q in morning minus Q in afternoon (a measure of ET)

May 16, 2012

Reach	Q (cfs) downstream	delta Q	percent change Q	length of reach (ft)	length of reach (mi)	delta Q per mi	GW elev	AM-PM	GW elev - stream elev
Dotta	1.08	0.35	47.9%	2,820	0.53	0.66	91.96		7.51
Dixie	1.97	-0.26	-11.7%	3,475	0.66	-0.40	86.08		0.21
Beartooth	3.99	0.05	1.3%	4,505	0.85	0.06	93.35		2.89
McReynolds - u/s							95.39		4.02
McReynolds - d/s	8.51	0.46	5.7%	3,298	0.62	0.74	93.34		
Poco	8.45	-0.09	-1.1%						

June 13, 2012 - AM

Reach	Q (cfs) downstream	delta Q	percent change Q	length of reach (ft)	length of reach (mi)	delta Q per mi	GW elev	AM-PM	GW elev - stream elev
Dotta	0.57	0.17	42.5%	2,820	0.53	0.32	90.91	0.06	6.56
Dixie	1.06	0.15	16.5%	3,475	0.66	0.23	86.04	0.12	0.28
Beartooth	0.98	0.41	71.9%	4,505	0.85	0.48	90.85	0.01	0.67
McReynolds - u/s							95.21		3.93
McReynolds - d/s	1.44	-0.41	-22.2%	3,298	0.62	-0.66	93.11	0.36	0.20
Poco	1.64	0.58	54.7%				92.92	-0.05	1.66

July 11, 2012 - AM

Reach	Q (cfs) downstream	delta Q	percent change Q	length of reach (ft)	length of reach (mi)	delta Q per mi	GW elev	AM-PM	GW elev - stream elev
Dotta	0.34	0.09	36.0%	2,820	0.53	0.17	dry	-0.01	-----
Dixie	0.16	0.13	433.3%	3,475	0.66	0.20	85.75	0.03	0.15
Beartooth	0.81	0.11	15.7%	4,505	0.85	0.13	90.17	0.18	0.10
McReynolds - u/s							94.82		3.59
McReynolds - d/s	0.22	-0.13	-37.1%	3,298	0.62	-0.21	92.84	0.01	0.22
Poco	0.15	Flow measured at plug #29; zero flow at Chase Bridge					dry	-0.04	-----

August 15, 2012 - AM

Reach	Q (cfs) downstream	delta Q	percent change Q	length of reach (ft)	length of reach (mi)	delta Q per mi	GW elev	AM-PM	GW elev - stream elev
Dotta	0.16	0	0.0%	2,820	0.53	0.00	dry		-----
Dixie	0.04	0.04	-----	3,475	0.66	0.06	85.71		0.24
Beartooth	0.87	0.31	55.4%	4,505	0.85	0.36	89.79		-0.27
McReynolds - u/s	can't measure: little or no surface flow at this location						94.32		3.97
McReynolds - d/s	0	0	-----	3,298	0.62	0.00	92.55		0.17
Poco	0.05	Flow measured at grade control; zero flow at Chase Bridge					dry		-----

October 10, 2012 - AM

Reach	Q (cfs) downstream	delta Q	percent change Q	length of reach (ft)	length of reach (mi)	delta Q per mi	GW elev	AM-PM	GW elev - stream elev
Dotta	0.06	-0.08	-57.1%	2,820	0.53	-0.15	dry		-----
Dixie	0.05	0.04	400.0%	3,475	0.66	0.06	85.6		0.2
Beartooth	0.74	-0.63	-46.0%	4,505	0.85	-0.74	89.86		-0.12
McReynolds - u/s							95.08		3.95
McReynolds - d/s	0.54	-0.33	-37.9%	3,298	0.62	-0.53	92.99		0.19
Poco	0.05	Flow measured 1000 ft d/s of GCS; zero flow at Chase Bridge					dry		-----

Notes:

1. Assumed streamflow (Q) measurement error is 10% to 15%
2. delta Q is the change in flow rate through the reach (downstream Q - upstream Q)
3. "GW elev" is the elevation of the water table, measured at the upstream end of the reach
The McReynolds reach has a well at both ends of the reach
GW elevations provided are not tied from reach to reach, but are provided to show monthly trend
4. "GW elev - stream elev" provides the difference between the water table and the stream surface elevations
A positive difference means the GW table is higher than the stream surface
5. "AM-PM" equals Q in morning minus Q in afternoon (a measure of ET)

Appendix B: Additional Stream Flow Monitoring and Analysis Needs

- The briefing illustrates the value of long term stream flow data in assessing changes resulting from meadow improvement work. First priority for monitoring should be to continue collection of streamflow data.
- Expand the comparison of pre- and post-project flows at Notson Bridge and Doyle Crossing gages to include late winter-spring snow melt recession.
- In 2016, after 5 more years of flow data are available, repeat the statistical analysis of pre- and post-project flows at the Notson and Doyle Crossing gages.
- CA Department of Water Resources and Plumas National Forest have begun a project to develop a full water budget, including both groundwater and surface water flows, for a site on Thompson Creek (a tributary to Red Clover Creek). This project would include several years of both pre-and post-project data so that the full effect of a meadow restoration project on water availability can be assessed. Data collection includes continuous recording of stream flow, groundwater levels, and climatology.
- To better understand groundwater-surface water response and interactions in restored meadows, conduct isotope tracer monitoring in Red Clover and Last Chance Creek. Ideally, monitoring would be conducted before and after project implementation, but there is also value in using the technique to track the path of water in reaches that are currently restored.
- Additional analysis of meadow soils and soil stratigraphy to better understand historic meadow and meadow stream conditions. For example, the age of redox amorphic concretions observed in meadow soil profiles (commonly used to help define wetland areas) could potentially be established through carbon dating.
- Additional replicated low flow measurements to better quantify measurement error.
- For future projects, include longer periods (more than one season) of pre-project flow measurements within and adjacent to project sites
- Further investigate potential changes for surface flow timing and availability that have occurred naturally over the past few decades due to potential climate changes