floodplain, the post-project channel is re-located to the meadow surface elevation. The pre-project incised channel is obliterated by constructing a series of earth plugs. Import of enough material to completely fill in the gully is extremely costly. Instead, the pond-and-plug treatment uses on-site material to obliterate the channel. The gully is widened both upstream and downstream of each plug to provide the borrow material. The first upstream plug raises and diverts stream flow into the new channel, which is most often a historic channel that is a remnant of the days when the stream and meadow were connected. When the base level of the stream is raised, the meadow water table rises and the widened gully areas fill with ground water, resulting in a series of ponds that are as deep as the original gully (Figure 1).

Figure 1: Post-project aerial photo of Last Chance Creek (2005). The series of ponds and plugs mark the location of the pre-project gully. The widths of constructed plugs indicate pre-project gully width. Historic remnant channels are used for the base flow channel of the restored system. (Photo: Jim Wilcox)

The term “pond-and-plug,” though catchy, is a poor moniker for the treatment because the treatment’s primary restorative element is not the series of ponds and plugs but the re-connection of the stream channel with its floodplain. Pond and plug features, though potentially significant to project performance and ecological resources, are simply the method employed for economically filling the existing incised stream channel. This technique was pioneered and demonstrated to PNF and the CRM in the early 1990s by Dave Rosgen, an innovative stream restoration expert who is well-known to federal land management agencies. Rosgen describes this technique of re-establishing the channel on the historic floodplain as “Priority 1,” his primary technique to be pursued and evaluated for improvement of incised stream channels because, successfully completed, it would result in hydrologic conditions that more closely resemble historic function than treating within the gully. (Rosgen 1997).

Pond-and-plug or Priority 1 projects can be constructed without any ponds or plugs if the existing channel entrenchment is not large and a large enough borrow site is available nearby to economically fill the old channel completely and allow for re-connection of the stream and floodplain. This method was used on the Humbug-Charles project. However, excavation and haul of dirt is very expensive and, depending upon the size of the gully, import of material from a borrow source that is even just one mile away from the project can increase project costs by several times. One interesting alternative has been utilized on the Stanislaus National Forest whereby the original, vast meadow surface is scraped and used as material to fill the gully. This method would result in a restored floodplain that is lower than the historic floodplain. Also, since the entire restored floodplain will have been excavated and disturbed, quick establishment of floodplain vegetation would be critical.

A Brief Aside: The Project Planning Process

This paper is focused on technical aspects of the pond-and-plug treatment and not the process by which the treatment would become a proposed action. However, several reviewers raised a few important planning considerations associated with pond-and-plug and those considerations are discussed briefly here.

General “dos and don’ts” associated with stream restoration projects apply also to projects in which pond-and-plug is an alternative. For any stream restoration project, it is important to develop an understanding of the current condition and the factors, both natural and anthropogenic, that have shaped that condition. Natural stream channels, even those considered to be “stable” or “in equilibrium,” are dynamic and evolving, constantly depositing and eroding sediment in response to forces such as climate, basin geology, and upland condition and activities - at degrees that vary widely from watershed to watershed. In many cases, a reasonable cause and effect relationship exists between an incised, eroding stream channel and past or present land management actions. However, downcutting and rebuilding of meadows is a natural process in the Sierras and, prior to initiating a restoration project, it should be clear why the project meadow has degraded more quickly than what would occur naturally.

Further, the pond-and-plug technique is not a template treatment that should be automatically considered as the preferred alternative for all broad, alluvial valley situations. Rosgen identifies the pond-and-plug type of treatment (re-connection with historic floodplain) as being the first priority for improvement of incised stream channels due to the reduced risk and multitude of benefits associated with the treatment. But Rosgen, and all qualified stream restoration practitioners, advocate that sufficient fluvial geomorphology, hydrologic and sediment analysis be performed for each unique project site to determine the viability of applying a pond-and-plug treatment.

Stream restoration actions need to be determined to be appropriate for each situation. For example, treatments which Rosgen has implemented successfully in the Rocky Mountains may respond very differently in Sierra basins that experience rain-on-snow runoff events and are more geomorphically active. Physical (e.g., roads, homes) or biological constraints (e.g. amphibian life history needs) may exist which influence how or if a pond-and-plug project could be applied.

Ideally, restoration projects should be part of a strategy to improve the watershed beyond the project site. Fencing to exclude livestock from stream channels has also been effective in restoring hydrologic function for meadows which are not extremely incised. Ecological benefits due to stream and meadow restoration are difficult to achieve beyond the scale of the project area. However, a strategic combination of several cost-effective restoration projects such as pond-and-plug, livestock exclosure fencing, and management changes could result in extension of benefits to the landscape or watershed scale.

Stream and meadow systems are critically important landscape features for a multitude of ecological resources. For any restoration project, it is imperative that the specific project objectives be clearly communicated and that an inter-disciplinary review team be fully engaged in the development and analysis of those objectives. The term “meadow restoration" means different things to different resource experts. In the case of pond-and-plug, the chief project elements involve restoration of physical properties, namely re-connection of the meadow stream with its historic floodplain and return of the meadow water table to its historic level. These two elements result in establishment of several ecological conditions that are similar or identical to past conditions. However, to cite one example, while areas of impounded water may have occurred historically on a meadow for periods of time, the introduction of a series of large ponds on the landscape is generally not re-creation of a historic condition. While these ponds may function similarly to the historic floodplain during flood flows and may have several positive effects for non-hydrologic resources, the ponds do have effects for wildlife resources that are not similar to past conditions. The implications of introducing ponds on the landscape will likely vary substantially for different project locations. This example is presented only to illustrate the importance of involving an interdisciplinary team of specialists in project development and analysis.

Finally, planning for any stream or meadow restoration project should include an appropriate monitoring program to assess whether the specific objectives stated for the project were achieved. This monitoring can also be designed and implemented to target specific data gaps in our current understanding of the treatment's effects. Some of these data needs can be ascertained from the effects discussion below. A helpful future Appendix to this paper would list a series of monitoring questions which specialists have identified to target questions about the treatment.

Treatment Benefits and Impacts, both Theoretical and Demonstrated

Properly designed and implemented, the pond-and-plug technique effectively restores much of the natural hydrologic function of the meadow. Ecologically, montane meadows are very important landscape features, particularly in the Sierra Nevada. All of the restoration benefits described below result directly from the stream and meadow hydrologic system flowing much as it did historically. As stated above, the primary objective of the treatment is to reconnect a stream system with a functioning floodplain. Several of the potential benefits described below stem from the effect of raising the ground water elevation. Ground disturbance and the introduction of ponds could result in adverse ecological impacts.

Reduced streambank erosion

As described above, the re-location of a channel out of its existing gully and re-connecting it with the floodplain results in much less erosive force during higher flows. Reduced streambank erosion reduces turbidity and the transport and deposition of fine sediments in downstream channels. Rapidly eroding streambanks associated with incised stream channels can result in significant loss of productive land and may impact archaeological sites. Treatment benefits are apparent in photos of pre- and post-project streambank condition for several projects, including the 2006 Red Clover - McReynolds project (Figure 2).

As described above, a historic remnant channel is typically utilized for the post-project channel. Such remnant channels typically have well vegetated banks and appropriate channel dimensions to resist flow stresses. The capacity of these remnant channels is often such that the typical annual peak flood (1 year return interval) will overfill the channel and access the floodplain. If an appropriate remnant channel exists on the meadow, utilization of that channel by the project designer will generally be favored over constructing a new channel to convey low flows. The remnant channels typically evolve to a stable geometry in response to the flow and sediment regime delivered from the upper watershed (Figure 2).

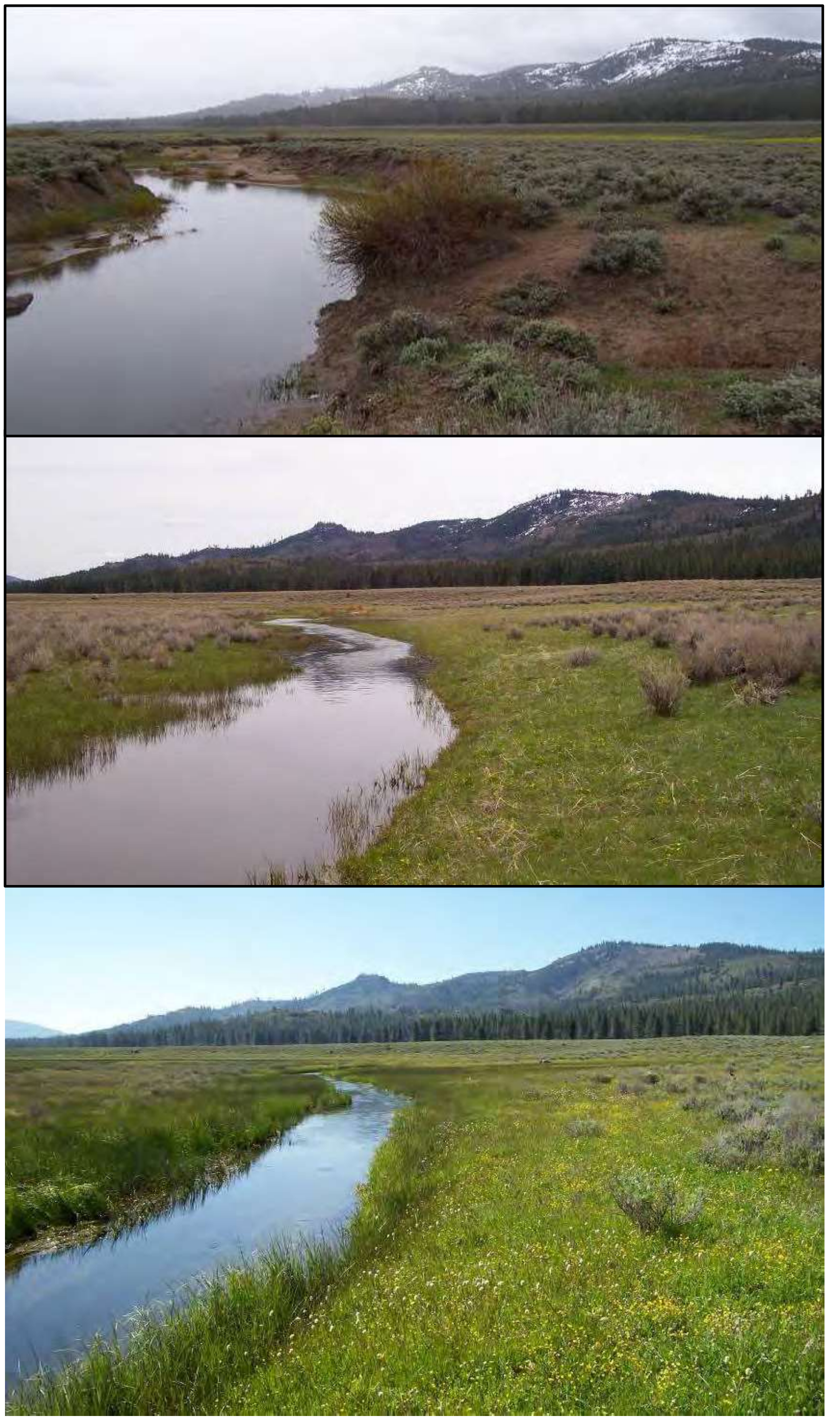


Figure 2: Pre- and post-project photos of the 2006 Red Clover–McReynolds Project (2006, 2007 and 2008). The pre-project gully is more than 10 feet deep and 90 feet wide. The steep gully banks are actively eroding. Erosive flood flows for the post-project channel easily access the meadow's broad floodplain, drastically reducing shear stress and resulting in stable stream banks (middle photo, 2007). The bright green vegetation line in the pre-project photo (upper right) is the location of the post-project base flow channel. The bottom photo (2008) shows vigorous riparian vegetation recovery on the channel banks and a narrowing of the channel due to capture of fine sediments. The narrower and deeper channel should result in cooler stream temperatures. (Photos: Jim Wilcox)

In many cases, a remnant channel or a defined base flow channel is not a requirement for application of the treatment. Assessment and observation of meadow floodplains in the Upper Feather River basin indicate that, historically, much of the sediment load from upper watershed streams deposited in alluvial fans with a distributor system of channels that spread onto the meadow surface below. Little or no coarse load material was historically transported to meadow outlets, although fine sediment transport may be an important factor for current or historic meadow channels. When the stream system is re-connected with its historic floodplain, a channel will form (or not) in response to the flow and sediment load that is delivered.

At times, where a usable remnant channel does not exist, it is desirable to pioneer a new channel (e.g. if fishery improvement within the meadow is a project objective). Such channels are designed to have geomorphic characteristics (such as sinuosity, bedload competency and capacity, width / depth ratio, riffle and pool depth, pool spacing) that mimic those of natural channels typical in comparable landscapes. It is important to utilize native vegetation transplants, such as willow stakes and meadow sod mats, to protect the new channel and facilitate the establishment of riparian vegetation.

Improved forage and riparian vegetation

By raising the stream base level to the historic floodplain elevation, the ground water table is restored. This re-watering of the meadow results in the re-establishment of riparian herbs and woody vegetation. Comparisons of pre- and post-project photos for pond-and-plug projects demonstrate the conversion of acres of meadow vegetation from dry land species, like sagebrush, to riparian species (Figure 3).

pre-project June 2001

August 2002

July 2003

Figure 3: The improved riparian grass community and improved livestock forage are evident in this series of photos from the Clarks Creek project. When the meadow is re-watered, the sagebrush quickly dies off.

This conversion has resulted in improved aquatic and terrestrial wildlife habitat and vastly improved forage for livestock grazing. For projects implemented on PNF grazing allotments, typical practice to date has been to provide fencing that excludes grazing for 2-3 years along the restored channel and the obliterated gully. For more sensitive sites, longer-term or permanent fencing may be necessary. For example, if a primary project objective is overhanging banks for fish habitat, then permanent fencing may be required. Fencing protects the restored stream channel and the project plugs while riparian vegetation is re-established. Restored stream channels which utilize historic remnant channels typically see a return of vigorous riparian vegetation within 1-2 years (Figure 2), but the banks of these channels remain sensitive to the types of excessive hoof traffic that may have initiated or widened the meadow gully. Since plugs are newly constructed features with no initial vegetation apart from project transplants, those features usually need more time to establish dense vegetation than remnant channels, particularly plugs with a finished grade that is one foot or more above the water table.

Rather than relying on a general rule for how long livestock should be excluded (e.g. 2 or 3 years), site specific analysis of vegetation along a stream channel's "greenline" (most often, at or slightly below bankfull stage) would likely give a better indication of whether vegetation is adequate to hold stream banks together (Winward 2000). Winward has developed "stability classes" for riparian plants (a rating from 1 to 10 with 10 being as stable as a stream bank composed of anchored rock) and a method for surveying a channel's greenline and calculating its stability rating based on the greenline's composition of species.

Raising the water table could affect some Forest Service-designated "sensitive" plants that have thrived under the drier pre-project condition. Historically, many meadows on the eastside of the Plumas likely had a mix of wet meadow areas and higher dry sites (mounds) that could have supported species such as *Ivesia sericoleuca* and *Pyrrocoma lucida*. These species can be found in drier sites, but most often are associated with habitats that have seasonally wet and dry conditions such as likely occurred historically throughout eastside meadows and flats. Any restoration project that affects the water table and results in long-term saturation of areas that were drier under the pre-project condition could restrict habitat for one or more sensitive plant species, regardless of whether those plants were present historically or not. Site-specific project analysis would determine whether those habitat effects would result in significant impacts to sensitive plant species.

Timing of stream flow

By raising the stream base level to floodplain elevation, the meadow's historic function of acting as a "sponge" and reservoir for runoff is restored. For the pre-project entrenchment, response to large flows is unfavorable because most floods greater than bankfull are not spread over a floodplain and do not soak into meadow soils. When floodplain function is restored, a portion of winter and spring runoff is stored in meadow soils where it is available for release later in the spring and summer. This restored meadow function results in some level of improvement of flow timing, including augmentation of some seasonal flows, potentially resulting in benefits for aquatic species and downstream irrigators. The primary flow augmentation effect would typically occur in late spring as stored groundwater from winter and spring runoff flows out of meadow soils to the stream channel. The channel flow augmentation effect often extends into summer months but this effect is variable from site to site. Increased post-project evapotranspiration could result in reduced base flow within the project reach during late summer.

The potential stream flow timing benefit is indicated by CRM monitoring results for completed projects. Stream flow was measured in 2006 above and below the Big Flat project on Cottonwood Creek (completed in 1995) (Figure 4). The flow gages are located less than half a mile apart and no significant tributary channels exist between the gages. The data indicates reduced flow peaks below the pond and plug reach. A more detailed look at flood flow recession in May - June 2006 demonstrates that flow downstream of the project, which was lower during flood peaks, is higher than flow upstream of the project as seasonal flow approaches base flow. A similar flow data comparison for the pre-project, degraded meadow is not available. Researchers in the Lake Tahoe Basin used a similar, two-gage approach to study flow timing effects (Tague 2008). The Trout Creek project was constructed in 2001, with one objective being to reestablish hydrologic connectivity between the degraded stream channel and its former floodplain. Comparisons of USGS gages located just upstream and downstream of the project indicated statistically significant increases in flow during snowmelt recession months and a 24% increase for the month of July. For the Trout Creek study, this effect of groundwater storage supporting base flow diminished through the late summer and early fall months but still appeared to be enough to cancel increased evapotranspiration from riparian vegetation along the channel and on the floodplain.

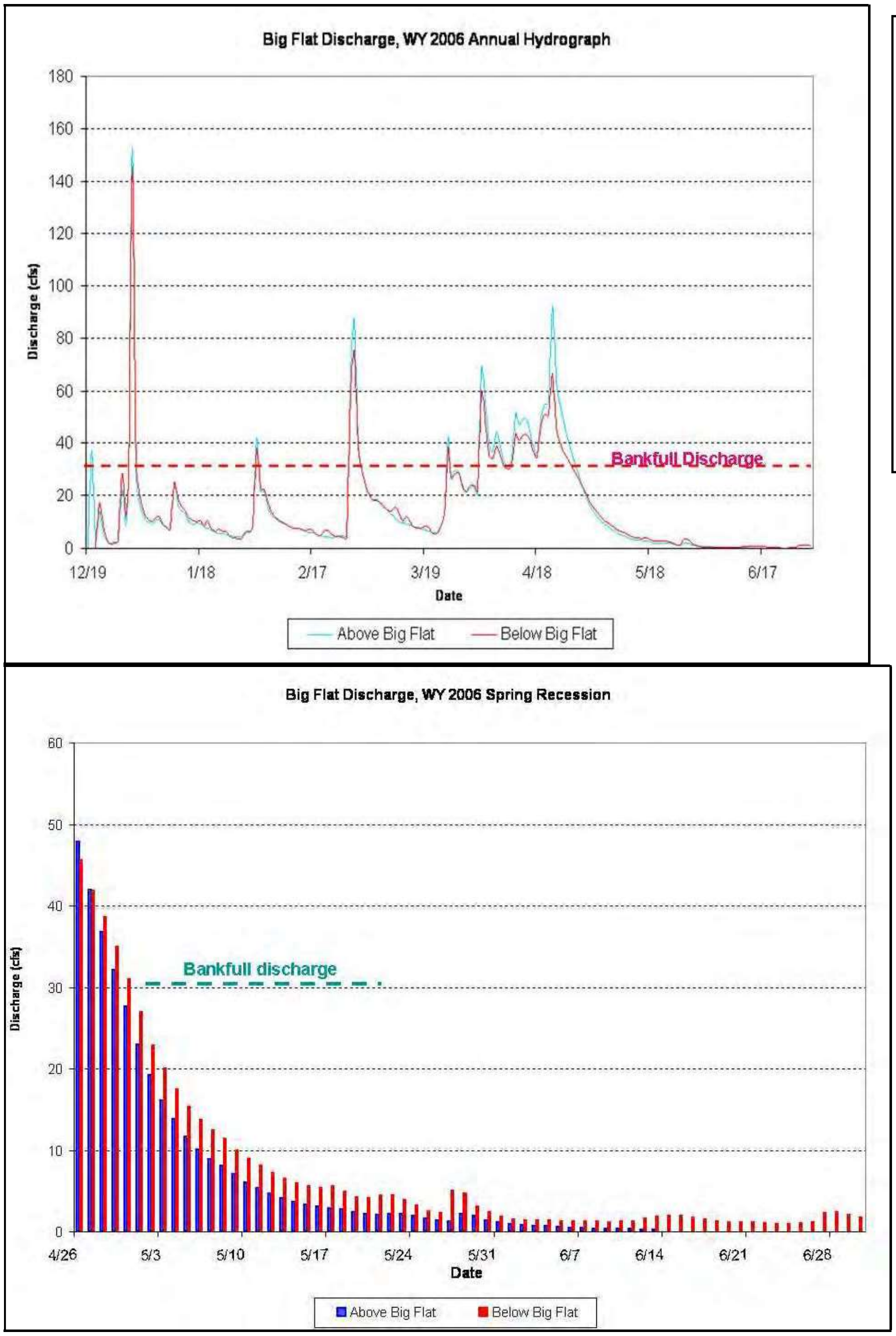


Figure 4: Stream flow measurements taken simultaneously above and below the Big Flat project demonstrate reduced flood flow peaks. The lower chart is a closer look at the spring runoff recession and demonstrates that flow downstream of the project is higher through the early part of baseflow season.

For the Clarks Creek project, water table elevations recorded from a ground water monitoring well located within the restored meadow demonstrate that runoff is stored in the meadow. The pre-project water table elevation maximized within 1 foot of the meadow surface but drained to the gully quickly, dropping to less than 2 feet below meadow surface within about 2 months (Figure 5). Post-project data for three different runoff seasons demonstrate that the ground water table elevation remains within 4 inches of the surface for over 5 months each year, even during years that had less than 80% of average precipitation. Further, the drop in water table elevation through the summer months (like Cottonwood Creek, Clarks Creek is not a perennial stream within the project reach) indicates that this stored water is being released downstream during months when, pre-project, it had been unavailable for irrigators and aquatic species.

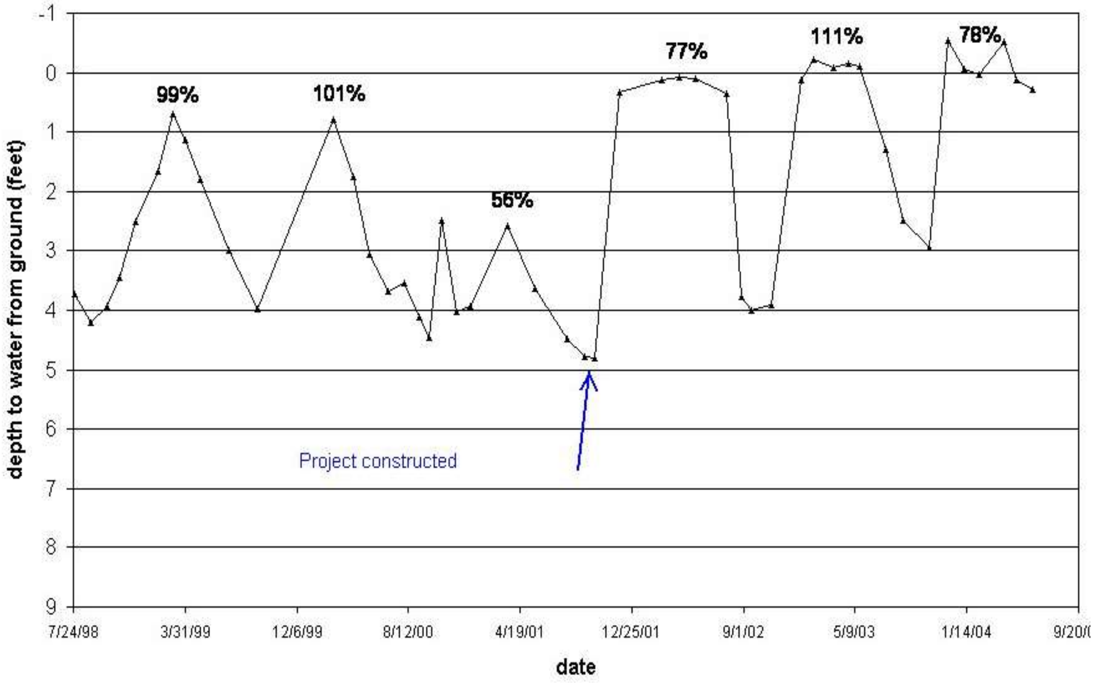


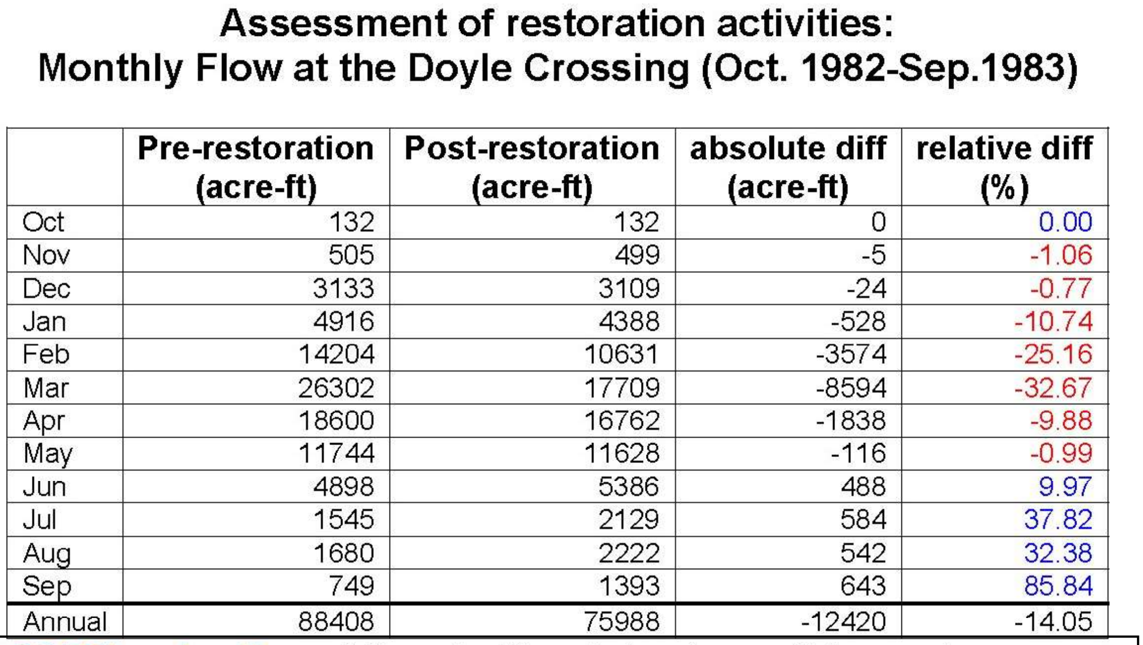
Figure 5: Water table levels at Clarks Creek project. Stated percentages represent the amount of precipitation received that year in relation to the annual average.

Sacramento State researchers estimated that, for the 116-acre Clarks Creek meadow, groundwater storage decreased by approximately 65% through summer 2007 (from 218 acre-ft to 76 acre-ft), primarily due to groundwater flowing to the incised, unrestored channel at the downstream end of the meadow (Cornwell, 2008a). The Forest Service Regional Office has secured a grant with National Fish and Wildlife Foundation to estimate improvements in groundwater storage that could be achieved through a region-wide meadow restoration initiative for National Forests in the Sierra Nevada. Those estimates will be completed by 2012.

Using the Last Chance Creek project area as his model site, a UC-Davis professor developed the Watershed Environmental Hydrology (WEHY) model to account for the various hydrologic processes associated with natural landscapes (Kavvas 2004). This model was applied to Last Chance Creek above Doyle Crossing by inputting precipitation data for October 1982 – September 1983 (Figure 6) (Kavvas 2005). The scale of this modeling effort (a watershed area of roughly 100 sq. mi.) is much larger than the scale of the other project-level monitoring or modeling presented in this section. Total predicted runoff for March 1983 for a modeled landscape that was completely restored above Doyle Crossing was 33% less than for the existing, un-restored landscape. The model results presented in Figure 6 represent changes in groundwater storage and flow volumes for the first year after restoration. In modeling flows for a dry month, total predicted flow for September 1983 for the restored stream systems was 86% greater than for the existing, un-restored landscape. These model results include evapotranspiration effects and indicate significant flow timing benefits for pond-and-plug restoration projects in the form of attenuated spring runoff and improved summer base flows.

In assessing potential benefits for stream flow timing, it is important to consider and analyze evaporation and transpiration effects. Restoration of meadow function should result in increased transpiration of groundwater since the landscape is converted from dry land species like sagebrush to historic riparian species. Potential for evaporation of ground water is increased by the installation of ponded water in the restored meadow. Stanford University professors developed an evapotranspiration (ET) mapping algorithm and showed that daily ET for two reaches of restored Last Chance Creek was approximately twice the daily ET for similar degraded reaches that had not been restored (Loheide 2005). CRM flow monitoring data for the 2006 Red Clover / McReynolds Project indicates marked reductions in late season flow at the immediate downstream terminus of the project when compared with flow measured upstream of the project (Feather River CRM, 2010). Pre-project monitoring measured flows of 1.1 and 1.6 cfs at the downstream end of the project reach in August and September 2005, reduced from 1.4 and 1.8 cfs (respectively) measured above the reach. Monitoring for August and September 2008 and 2009 indicated similar flow at the upstream location (a mean of 1.4 cfs) but practically zero flow at the downstream project terminus. The 2009 project monitoring report states that the project's effect on late season base flow cannot yet be fully evaluated because 2007-2009 were droughty years and the meadow's groundwater storage capacity is still filling. However, the report also identifies that at least part of the late season flow reduction within the project reach is due to increased evapotranspiration. As more years of post-project streamflow data is collected, this effect will be better characterized.

Researchers at UC-Davis applied a hydrologic model to a pond-and-plug project in northern California and predicted that summer baseflow duration was actually reduced following the project, with roughly half of that decrease due to an increase in evapotranspiration (Hammersmark 2008). The Bear Creek project was constructed in 1999 on a 2.2-mile-long tributary of the Fall River, approximately 60 miles northeast of Redding, CA. Model simulations demonstrated that the pond-and-plug project decidedly met the project goal of restoring connectivity between Bear Creek and its floodplain. Floodwater storage on the floodplain acted to attenuate peak flood flows (see section D below). However, anticipated improvements in aquatic habitat due to increases in baseflow were not predicted by the model. Model results indicated a decrease in the total amount of runoff of 1-2% and a shortening of the baseflow season (Bear Creek is not a perennial stream) by 13 days. In addition to ET effects, the baseflow decrease was attributed to an increased loss of stored runoff as groundwater that would have drained to the incised channel pre-project stayed as groundwater in the post-project condition and flowed out of the meadow downstream as either shallow groundwater or overland flow.



Assessment of restoration activities:
Monthly Flow at the Doyle Crossing (Oct. 1982-Sep.1983)

	Pre-restoration (acre-ft)	Post-restoration (acre-ft)	absolute diff (acre-ft)	relative diff (%)
Oct	132	132	0	0.00
Nov	505	499	-5	-1.06
Dec	3133	3109	-24	-0.77
Jan	4916	4388	-528	-10.74
Feb	14204	10631	-3574	-25.16
Mar	26302	17709	-8594	-32.67
Apr	18600	16762	-1838	-9.88
May	11744	11628	-116	-0.99
Jun	4898	5386	488	9.97
Jul	1545	2129	584	37.82
Aug	1680	2222	542	32.38
Sep	749	1393	643	85.84
Annual	88408	75988	-12420	-14.05

Figure 6: Monthly total flow estimates as predicted by the WEHY model, comparing the Last Chance Creek watershed under restored and non-restored condition. Total predicted runoff for March is 33% less with restoration. Improved base flow conditions following restoration are indicated by substantially higher modeled runoff for summer months (July – September).

The Hammersmark study illustrates that, for all pond-and-plug projects, base flow increases are more likely to be observed downstream of the project area than within the restored reach. Much of the stratigraphy of the Bear Creek meadow consists of a high-permeability layer of alluvial sand and gravel, which Hammersmark modeled as having a permeability of 0.045 m / sec. Apart from ET effects, the shortening of base flow season is also attributable to this exceptionally rapid flow rate of groundwater through the meadow soils. This effect, though less pronounced in typical meadow soils of lower permeability, has been observed qualitatively by CRM staff at several completed projects. The pond-and-plug treatment results in substantial storage of runoff as groundwater in the restored reach. This groundwater is either utilized by meadow plants (transpiration) or released down gradient throughout the spring and summer months but the released groundwater may flow subsurface for hundreds or thousands of feet below the project before interacting with a surface water channel.

More monitoring and investigation is necessary to better predict the effects of evapotranspiration and meadow storage of water in relation to stream flow timing. Flow timing effects will vary from project to project, depending upon several site-specific attributes. Flow timing effects due to pond-and-plug could represent a benefit or impact, depending upon the season and the beneficial use identified (e.g. augmented low flows in late spring may benefit irrigators, potentially lower baseflow within the project reach in late summer could impact fisheries). Perhaps the effect should be primarily characterized as establishment of a flow timing regime that is much closer to the historic regime than the pre-project condition, with meadow and riparian vegetation communities that are also much more similar to historic condition.

Flood Attenuation

At first glance, potential benefits to the timing of stream flow, as described above, would seem to logically lead to the premise that the pond-and-plug treatment could reduce peak flood flows via the same natural “sponge” function of meadows, since post-project flood flows could soak into meadow soils and would not be left to race down the pre-project gully.

In fact, flood flow at a pond-and-plug project is affected more by the spreading of flow across the floodplain than by the soaking of water into pore spaces of meadow soils. By re-connecting the floodplain, runoff would certainly be attenuated if meadow soil pore spaces were dry. However, large peak flows would most likely occur at a time when the floodplain landscape would have been saturated under both the pre- and post-project conditions. In such cases, since water is not stored within the meadow, the post-project peak flow and the pre-project peak flow would theoretically be identical because the flow into the system must equal the flow out of the system (the “continuity” equation). Post-project flow would be more shallow and slow (due to the roughness of the floodplain) but would occupy more cross-sectional area across the broad floodplain than the fast flow confined to a gully in the pre-project condition.

However, flow rate out of the project area would be identical to pre-project flood flow only after the water that is spread across the floodplain fully regains its downstream momentum. As a result of the pond-and-plug project, flow is spread in a direction away from the more direct, down-valley vector of the pre-project entrenchment, delaying delivery of the flow to the downstream end of the meadow, and resulting in a flood attenuation benefit. For severely incised pre-project channels, the deep gully would not be present post-project to laterally drain meadow soils, which may also reduce flood peaks downstream. Realize that these are highly simplified descriptions of the primary peak flood effects associated with the pond-and-plug treatment. Effects are significantly influenced by several other complex, site-specific factors for projects on the ground.

The flood spreading effect is reflected in the reduced 2006 flood peaks at Big Flat, as presented in Figure 4. The Bear Creek project researchers (see section C above) also modeled a significant flood attenuation effect at the base of the restored meadow (Hammersmark 2008). For the largest flood events simulated (between 2- and 5-year return interval flood flows), peak flow values were reduced by up to 25% due to floodwater storage on the floodplain. Such delays in flood timing, if put into effect over a large scale by several projects such as pond and plug and exclosure fencing that would restore floodplain connectivity, could result in a measurable flood control benefit. Flood-peak reductions for very large, infrequent floods are likely to be less dramatic than for higher-frequency, lower-magnitude flood flows (Hammersmark 2008). Sacramento State researchers described the flood attenuation properties of the Clarks Creek meadow but did not quantitatively predict effects (Cornwell 2008b).

Flood flow effects for a project are dependent upon several site-specific characteristics. For instance, several severely incised channels in the Upper Feather watershed still maintain floodplain connectivity at extremely high flows. For such a channel, extreme flows would be spread across the floodplain in both the pre- and post-project condition so the flood attenuation effect, while still beneficial for smaller floods, may not be as pronounced for extreme flows. Further, once a flow leaves its channel, flood timing and peak are certainly influenced by valley form such as how much the valley outlet constricts flows on the floodplain for both the pre- and post-project conditions.

The pond-and-plug treatment will affect the peaks of most flood flows at the project level, which could cumulatively result in a flood control benefit for downstream landowners and municipalities. However, given inherent variations in precipitation and flow timing characteristics that exist over large watersheds, general predictions of the degree at which flood timing and peak magnitude are affected at this larger scale are difficult to make. Re-connection of a stream channel with a broad floodplain would, however, result in flood response that is much closer to the historic condition.

Temperature Effects

Most pre-project stream channels are classified under the Rosgen system as “F” channels (Rosgen 1994). These channels have evolved in an incision that has finished down-cutting (often in response to anthropogenic activities) to a stream that is now widening into soft meadow soils to re-gain the valley width necessary to hold a stable channel. Essentially, flow processes are pushing these channels to build a functioning floodplain within the gully floor at an elevation that is 3-10 feet below the historic meadow elevation. Livestock grazing and watering along such channels can further accelerate bank erosion and channel widening.

Figure 7: Pre- and post- project photos of Ward Creek (1999 and 2005) indicate stream temperature benefits associated with improved riparian vegetation and shading. (Photos: Jim Wilcox)

Such widening “F” channels have high width / depth ratios. During the low flows that typically exist most of the year, such channels are overly wide and shallow, possessing relatively large flow surface area that subjects the stream to more solar radiation and higher stream temperatures (particularly, of course, during summer months when coldwater aquatic species are most stressed). The lack of shade from streamside vegetation on eroding banks further exacerbates stream temperature impacts.

Post-project stream channels, whether historic remnant channels or constructed pioneer channels, are designed to have width / depth ratios that are consistent with the natural geomorphology of the landscape. Channels are narrower and deeper, contributing to cooler